MAYFIELD DAM DOWNSTREAM MIGRANT
SMOLT SURVIVAL STUDY USING ACOUSTIC TAG
METHODOLOGIES IN 2014

Final Report

Prepared for

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EXECUTIVE SUMMARY

The 2014 juvenile bypass survival study at Mayfield Dam released 252 live coho, 248 steelhead and 252 Chinook smolts implanted with operating acoustic tags. These numbers of released tagged fish met the pre-determined, recommended sample size requirements of 250 tagged fish per species group, as defined in the study plan. The peak number of tagged fish released per study month in 2014 generally corresponded to the historic peak passage month of each species at Mayfield Dam over the preceding 10 year period. The 2014 coho smolt outmigration occurred during May-July, with the largest proportion of this species passing in June (66%). The percentage of coho smolt tagged and released in June 2014 was very similar (60%). Steelhead smolt run-timing was distributed over April-June with the largest proportion passing in May (68%). The percentage of tagged steelhead smolt released that month was moderately higher, at 80%, of the total steelhead smolts tagged in 2014. The 2014 Chinook smolt run-timing was spread over June-December with the largest proportion passing in September (27%). In 2014, Chinook smolt tagging was confined to the months of October and November, with 78% of the tagged smolts occurring in October.

Tagged forebay smolts (treatment fish) were released in the north and south louver bay apex downwells, which precluded the possibility of fish not traveling downstream through the juvenile bypass channel, into the secondary separator, and ultimately through to the counting house below the dam. Therefore, there was no concern for tagged treatment fish being lost from the study (i.e. by migrating upstream to the forebay) in 2014.

During the fall outmigration, a large proportion of Chinook smolts were found to be unhealthy. The majority of the unhealthy Chinook smolts were infested with internal parasites. All of the Chinook smolts may have had compromised immune systems. For this reason, an attempt was made to tag and mark the healthier Chinook smolts. The 2014 study results were most likely affected by the unhealthy Chinook smolts.

Dead fish releases conducted on 10 April 2014 detected no dead fish passing the new hydrophone array deployed at the Upper Barrier site, or the existing hydrophone arrays at the Barrier Dam, or the Trout Hatchery. The Cowlitz River flow rate was approximately 9,000 cfs during the dead fish releases. Therefore, there was little concern that any fish mortalities that occurred during juvenile bypass system passage would positively bias the JBS passage survival estimates.

Bias attributed to fish tagger effects in the 2013 study, were not a consideration during the 2014 acoustic tag study, as all fish tagging was conducted by a single tagger.

The mean monthly Cowlitz River flow rate at Mayfield Dam ranged from a low of 3,271 cfs to a high of 12,573 cfs. The mean monthly river flow rates decreased from the beginning of sampling in May through July, before steadily increasing through into December. The low summer flow rates may have been a contributing factor in the slower downstream migration for the coho and Chinook observed in late summer and fall.

It was anticipated that the majority of steelhead, coho, and Chinook smolts released in the louver bay downwells would pass through the juvenile bypass system through to the counting house relatively quickly. Average coho smolt travel times, from release to the final detection at the Trout Hatchery was 4.8 days for tailrace-released fish, and 8.1 days for bypass-released fish passing through the bypass system. Average coho holding times were relatively long at the Barrier Dam and ranged from 6.0 days for bypass passage fish, and 6.7 days for tailrace-released fish.

Mean steelhead smolt travel times, from release to the final detection at the Trout Hatchery were 2.0 days for tailrace released fish and 5.2 days for fish released in the louver bay downwells. Average steelhead smolt holding times for louver bay released fish were relatively short for all sampling locations, ranging from 0.02 days at the Trout Hatchery to 1.14 days at the Upper Barrier site. For the tailrace released steelhead smolts, the longest period of holding was observed at the Barrier Dam at 0.85 days.

Chinook smolt travel times, from release to the final detection at the Trout Hatchery, averaged 0.29 days for tailrace-released fish and 9.3 days for louver bay downwell released fish. Mean Chinook holding times were relatively long at the secondary separator, requiring an average of 9.7 days before exiting the secondary separator.

Chinook smolts encountered significant delays in passing from the secondary separator through the bypass to the counting house, in comparison to the steelhead smolt travel and holding time results. Similar delays in passage of coho smolts was also observed at the Barrier Dam detection site, relative to the steelhead and Chinook smolt travel and holding time results at this location. The delays in Chinook smolt passage through the secondary separator observed in this study, were also observed in the 2013 study. Similar delays in passage of coho smolts, was also observed at the Barrier Dam detection site, relative to the steelhead and Chinook smolt travel and holding time results at this location.

During preliminary analysis of the VIE tagged steelhead and coho results, discrepancies were observed in the detection rates at sequential downstream observation sites. The preliminary results suggested survival rates decreased as the tagged fish releases approached the recollection site located at the counting house. As a result of this analysis, TPU conducted a study to evaluate the tag retention and visual detection rates of the VIE tagged fish. These results showed that the VIE tagged fish were identifiable by all three VIE taggers, but a color bias in VIE tag identification was apparent for one of the three taggers. This finding precluded quantitative analysis of the VIE tagged steelhead and coho salmon study data due to potential tag misidentification or omission. Based on these findings, the two taggers that successfully identified correctly all of the passing VIE color-coded tagged fish were used for the VIE Chinook tagging portion of the study. Subsequently, only the results of the VIE tagged Chinook salmon are presented.

The VIE tagging study to estimate smolt survival between the louver bay downwells and the secondary separator downwells S_{LB-SS} was calculated using the relative recovery model of Ricker (1958). The louver bay downwell releases were separated into north and south release locations. A chi-squared test of homogeneity found no difference in recovery rates of Chinook live smolts between north and south locations and, hence, the data were pooled for subsequent analyses $(P(\chi_1^2 \geq 0.0442) = 0.8334)$. For Chinook salmon smolts, the estimate of survival between louver bay downwells and downstream of the secondary separator was found to be S_{LB-SS}=0.6654, with a standard error of $\widehat{\mathrm{SE}}(\hat{S}_{LB-SS})$ = 0.0360.

Paired release-recapture studies were used to estimate survival between the louver bay and tailrace (i.e., bypass passage survival). Bypass passage survival was estimated the lowest for Chinook salmon ($S_{Bypass=}0.2793, SE = 0.0476$) and highest for steelhead ($S_{Bypass=}0.9839, SE = 0.0168$). Coho salmon had an intermediate estimate of dam passage survival ($S_{Bypass=}0.7979, SE = 0.0338$).

Estimates of transport tank to tailrace survival ranged from a high of 0.9891 ($\widehat{\mathrm{SE}}$ = 0.0161) for steelhead to a low of 0.5490 ($\widehat{\mathrm{SE}}$ = 0.1058) for Chinook salmon. The transport tank to tailrace survival for steelhead was just 0.0052 points above the estimate of overall dam passage survival. For coho salmon, the survival of the transport tank to tailrace was estimated to be 0.8296 ($\widehat{\mathrm{SE}}$ = 0.0376).

Acoustic tag detection probabilities were high (>0.93) at the secondary separator, Upper Barrier array, and the Barrier Dam across all three fish stocks. Detection probabilities in the transport tank varied considerably between fish stocks with a range of 0.7769–0.9384. The joint probability of survival between the Barrier Dam and the Trout Hatchery and being detected at the Trout Hatchery (i.e., $\lambda = S \cdot p$) ranged from 0.3390–0.9084 between fish stocks.

Reach survivals by Chinook salmon were estimated at 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches. However, reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace to Upper Barrier arrays were very low with values of 0.5175 ($\widehat{SE}$ = 0.0608), 0.6531 ($\widehat{SE}$ = 0.0876), and 0.7628 ($\widehat{SE}$ = 0.0934), respectively, for Chinook salmon.

Reach survivals by steelhead smolts were virtually 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches. The reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace - Upper Barrier arrays were also very high with values of 0.9939 ($\widehat{SE}$ = 0.0068), 0.9945 ($\widehat{SE}$ = 0.0073), and 0.9858 ($\widehat{SE}$ = 0.0103), respectively, for steelhead.

Reach survivals for coho salmon smolts were nearly 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches. The reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace - Upper Barrier arrays decreased through the bypass with values of 0.9398 ($\widehat{SE}$ = 0.0235), 0.9297 ($\widehat{SE}$ = 0.0283), and 0.9127 ($\widehat{SE}$ = 0.0269), respectively, for coho smolts.

The individual reach survivals can be multiplied together to estimate a cumulative survival. Cumulative survival from release at the louver bay to the Barrier Dam was estimated at 0.2627 ($\widehat{SE}$ = 0.0443), 0.9697 ($\widehat{SE}$ = 0.0150), and 0.7851 ($\widehat{SE}$ = 0.0342) for Chinook salmon, steelhead, and coho, respectively.

The low acoustic tag survival estimates for Chinook salmon correspond to the low values observed in the VIE tag study. The location of the low survival estimates was similar for both the VIE and acoustic tag study. The VIE tag study estimated Chinook salmon survival between louver bay and downstream of the secondary separator at 0.6654 ($\widehat{SE}$ = 0.0360). Similarly, the acoustic tag study estimated low survival between the secondary separator and the transport tank ($\hat{S}$ = 0.5175, $\widehat{SE}$ = 0.0608). In addition, the acoustic tag Chinook survival was low between the transport tank and the tailrace ($\hat{S}$ = 0.6531, $\widehat{SE}$ = 0.0876). The 2014 study has identified a survival problem with Chinook salmon, and it points to the bypass system from upstream of the secondary separator through the transfer tank.

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1.0 INTRODUCTION

1.1 Background

Improving protection of anadromous fish migrating downstream at Mayfield Dam has been identified as a priority by the City of Tacoma, Department of Public Utilities, Light Division (Tacoma). To that end, License Article 415, the Anadromous Fish Passage Plan was submitted to Federal Energy Regulatory Commission (FERC) in compliance with requirements of the amended license for the Cowlitz River Project No. 2016. The plan, filed in February 2006 was developed in consultation with the Fisheries Technical Committee (FTC) and included a description of the Mayfield Dam downstream fish facility improvements to be completed (City of Tacoma, 2006).

Built in 1963, Mayfield Dam is located in southwest Washington State and is one of four dams on the Cowlitz River, a tributary to the Columbia River (Figure 1). Mayfield Dam at river mile (RM) 52, is one of three hydroelectric dams in the Cowlitz River Project (Barrier Dam (RM 49.5), constructed in 1968, does not generate electricity). Mayfield Dam is a concrete arch and gravity dam approximately 250 ft tall, with a gravity fed powerhouse capable of generating 162 megawatts (MW). The powerhouse draws water from the reservoir through two intake channels.

The two intakes are oriented to the north and to the south upstream of the power tunnel entrance. The downstream fish guidance and collection system is an integrated function of the water intake system for power generation at Mayfield Dam. Each intake has a series of L-shaped louver vanes that divert migrant fish to a vertical slot at the apex of the louver bay. Upon entering the vertical slots, fish enter the secondary separator, a screened holding pool with outflow into the transport pipe that runs through Mayfield Dam to the counting house facilities. Fish exit the transport pipe and are held in raceways until they are examined and counted in the counting house. Fish exit the counting house and are re-released into the transport pipe. Fish travel down the pipeline to its terminus at the Mayfield powerhouse tailrace (City of Tacoma 2006).

Prior to implementation of the plan, several evaluations were conducted to measure the efficiency of the fish guidance and collection system, and identify areas of special concern. Results of a study conducted in 1967 evaluating fish guidance efficiency (FGE) in the louver system indicated 66.4% of coho salmon, 81.4% of spring Chinook, and 73.6% of steelhead arriving at Mayfield Dam enter the juvenile bypass (louver) system (Thompson and Paulik 1967). Those fish that were not guided, passed through the three vertical Francis turbines with average discharge of approximately 9,000 cfs through the powerhouse. Since this evaluation, a fourth vertical Francis turbine was installed and total plant discharge has increased.

In 2001, an evaluation at one of the two guidance louvers measured the effectiveness of the louver system in diverting downstream migrating juvenile salmonids away from the power tunnel. This evaluation measured where non-guided fish passed through the louvers and developed a computational fluid dynamics (CFD) model to verify flow lines. In addition, the three-dimensional behavior of guided and non-guided fish was monitored using an acoustic tag tracking system. CFD modeling of velocity vector fields was correlated with the acoustic tag results. These results indicated 81.3% of fish (all coho) entered the juvenile bypass (louver) system. However, tagged fish were observed approaching the bypass entrance then swimming back upstream possibly due to debris or unacceptable acceleration of the velocity field. It was suggested that minor changes to the bypass entrance such as lighting and/or painting of the bypass slot may improve efficiency (Zapel et al. 2002). In 2002, additional velocity measurements were collected and limited CFD simulations were completed. Based on field observations from 2001 and 2002, regular cleaning of the louver vanes and entrance trashracks was recommended.

Based on previous recommendations, additional studies were conducted. A 2003 study placed lights in the bypass slot entrance of the south louver bay. Recoveries of marked fish were low compared to historic collection efficiencies and results indicated that there was little difference between lights on and off conditions (Tacoma Public Utilities 2003). Measurements of sound levels within the louvers were completed in 2002 (Wicke and Coutant 2002) and 2007 (Olson 2007). These results indicated that the louver bypass system is very noisy underwater, largely from the louvers and pump noise. In 2002, an evaluation of a louver operational change was completed. Previously the Mayfield Dam louver bypass system secondary separator pumps were shut down when downstream migrant numbers dropped off. In this study, the separator pumps operated continuously. Results indicated that with pumps left on, collection efficiency of the louver bypass system was improved (Tacoma Public Utilities 2003).

Turbine survival was evaluated in 2002. Comparison of estimated survival rates of juvenile coho salmon, and steelhead in passage through an old Francis turbine (Unit 44) and a new Francis turbine (Unit 41) were completed. Turbine passage survival at Unit 41 was lower than that of Unit 44. The survival rates of juvenile salmonids at Mayfield Dam was shown to be turbine type specific, rather than species specific (Normandeau 2003).

Incorporating recommendations from previous studies, the Anadromous Fish Passage Plan identified several modifications to the downstream juvenile fish bypass and fish collection facilities. The modifications completed in 2009-2011 included: improvements at the louver and fish screen panels and the addition of an automated brush system; improvements to the secondary separator and pump operations; modified raceways with an exclusionary bird netting system; a replacement counting house; re-routing and upgrading the transport pipeline outfall and debris management (City of Tacoma, 2012). Once these improvements were completed the next step was an evaluation of downstream fish passage survival at Mayfield Dam.

In 2013, an acoustic tag study was conducted at Mayfield Dam as the first year of a stepwise approach to evaluating survival across multiple seasons. The primary objective in 2013 was to measure dam passage survival, with resolution of bulk turbine and bypass survival, of juvenile coho and Chinook salmon, and steelhead (Steig et al 2014). A secondary objective of the 2013 acoustic tag study was to determine the rate of passage and routes of passage for the acoustic tagged juvenile coho and Chinook salmon, and steelhead. Acoustic tags were also used to monitor the movement of tagged fish as they migrated from the forebay and tailrace release sites at Mayfield Dam, downstream to the two detection sites located at the Barrier Dam and the Cowlitz Trout Hatchery, and provided information regarding the relative rate of travel downstream of the release sites.

The 2013 study indicated that a large proportion of tagged fish (89% of coho; 84% of steelhead; and 58% of Chinook) released into the forebay above the louvers, entered the juvenile bypass system (Steig et al 2014). However, dam passage survival for all three species was lower than anticipated, and coho and Chinook smolts exhibited significant delays in passing through the bypass system, from the secondary separator to the bypass tunnel. Coho and Chinook smolt also exhibited delays in migration past the first tag detection array, located approximately two and a half miles downstream at the Barrier Dam.

In consideration of the 2013 Mayfield downstream migrant study results, the scope of work for the 2014 study was adapted to focus primarily on the investigation of fish survival and delay of passage through the fish bypass system, and downstream migration past Barrier Dam.

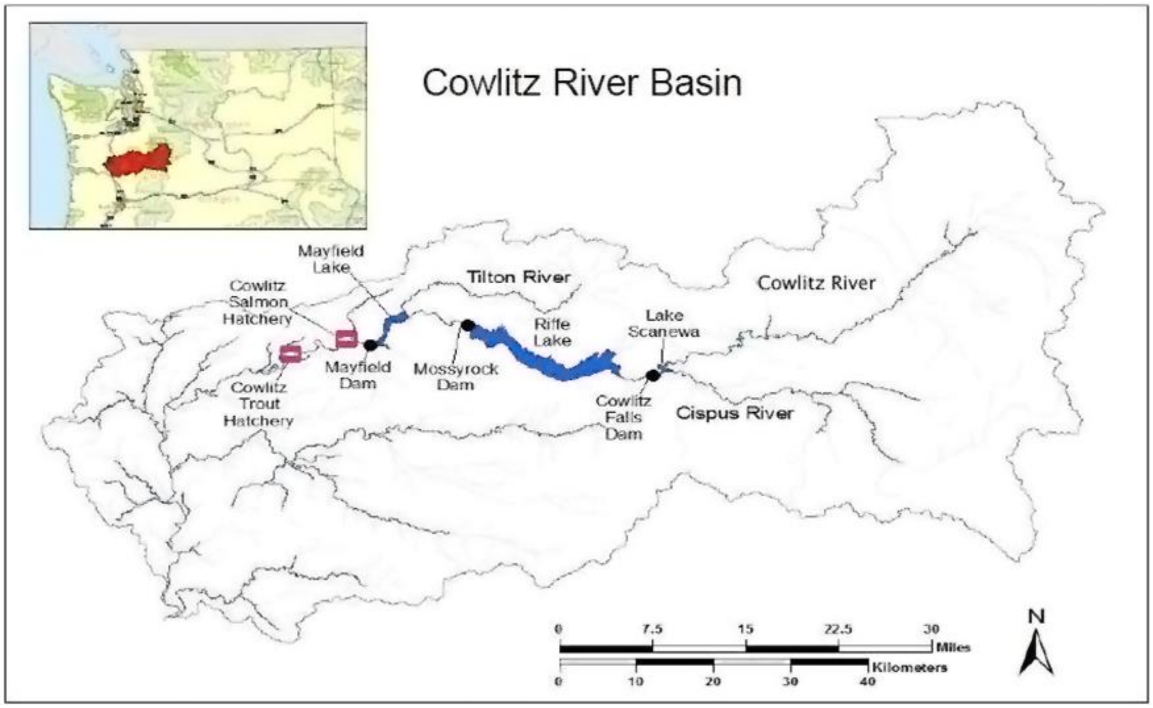


Figure 1. Map of the Cowlitz River Basin, showing the location of Mayfield Dam, the Cowlitz Salmon Hatchery (Barrier Dam) and the Cowlitz Trout Hatchery. (Graphic courtesy of City of Tacoma, Department of Public Utilities, Light Division (TPU)).

1.2 Site Description

The acoustic telemetry system installed at Mayfield Dam in 2013 to monitor juvenile fish passage, was modified to accommodate the differing study objectives at Mayfield Dam in 2014. The primary hydrophone array for the 2014 study included a hydrophone deployed in the secondary separator, and two hydrophones located at the downstream migrant fish collection facility (counting house; Figure 2). One additional hydrophone, also located at the counting house, was used for the conduct of the tag-life tests.

The release location of the acoustic tagged juvenile salmonids was also modified for the 2014 study (Figure 2). Since the 2014 study objectives did not include fish passage through the power intake channel, tagged fish for the 'test' releases (R_t) were released into the north and south louver bay apex downwells, not upstream of the V-shaped fish guidance louvers as in 2013. Control releases (R_c) were made in the tailrace region below the powerhouse, as in 2013.

The two in-river acoustic telemetry detection sites deployed for the 2013 study, located downstream of Mayfield Dam at Barrier Dam (Cowlitz Salmon Hatchery; approx. RM 49.6), and at the Cowlitz Trout Hatchery (approx. RM 42.2), were also used in 2014 to record tagged fish outmigration (Figure 3).

In order to gain a better understanding of the tagged fish outmigration, two additional in-river detection sites were added to the Mayfield Dam study deployment in 2014. A single hydrophone deployed in the Mayfield Dam tailrace, was used to detect tagged fish as they exited the fish bypass system into the tailrace, and a two hydrophone array deployed approximately 1.7 miles downstream (and approximately 0.5 miles upstream of the Barrier Dam; approx. RM 50.1) of the tailrace as an additional survival detection site.

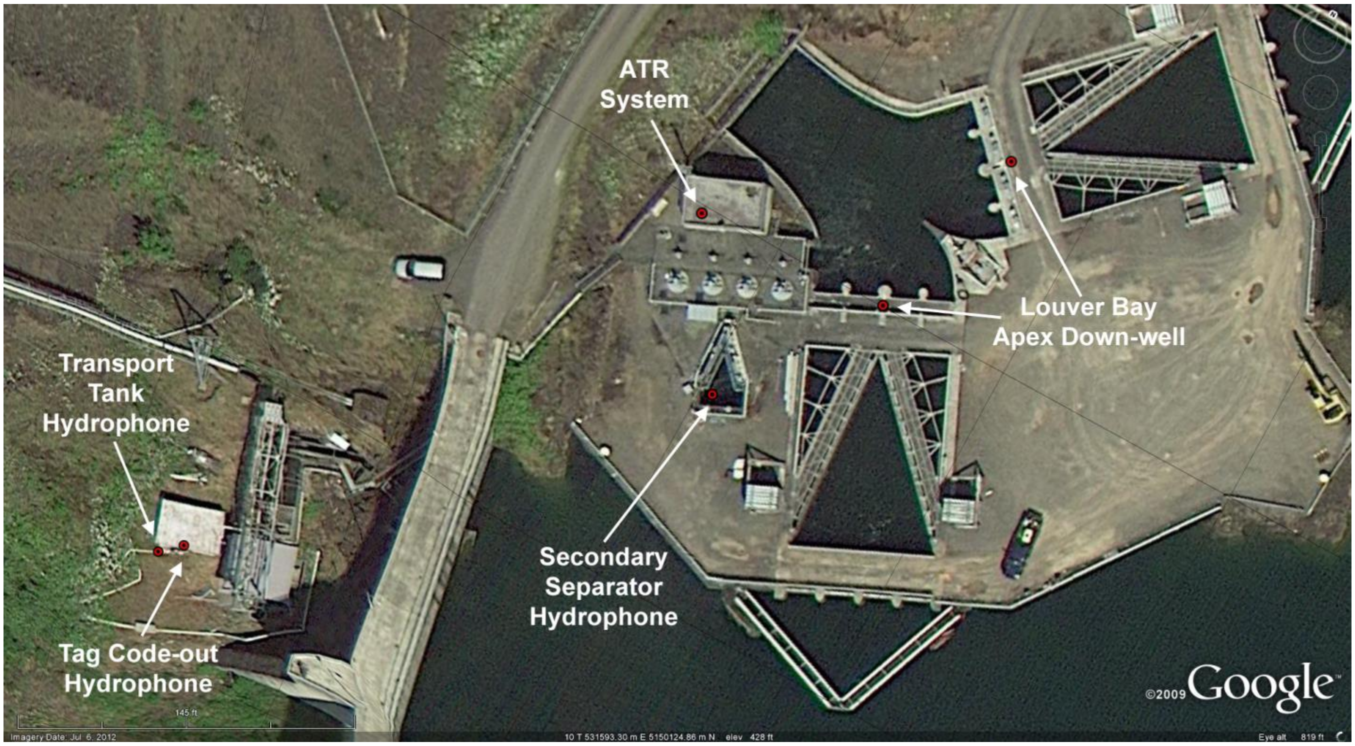


Figure 2. Location of the ATR system and of the primary acoustic hydrophone array at the Mayfield Dam project in 2014. Tagged smolts for the test releases (R_t) were released in the north and south louver bay apex downwells. Hydrophones were located at the secondary separator, and at the counting house below the dam for tag code-out, and for recollected fish in the transport tank. An additional hydrophone at the counting house was used for the tag life tests.

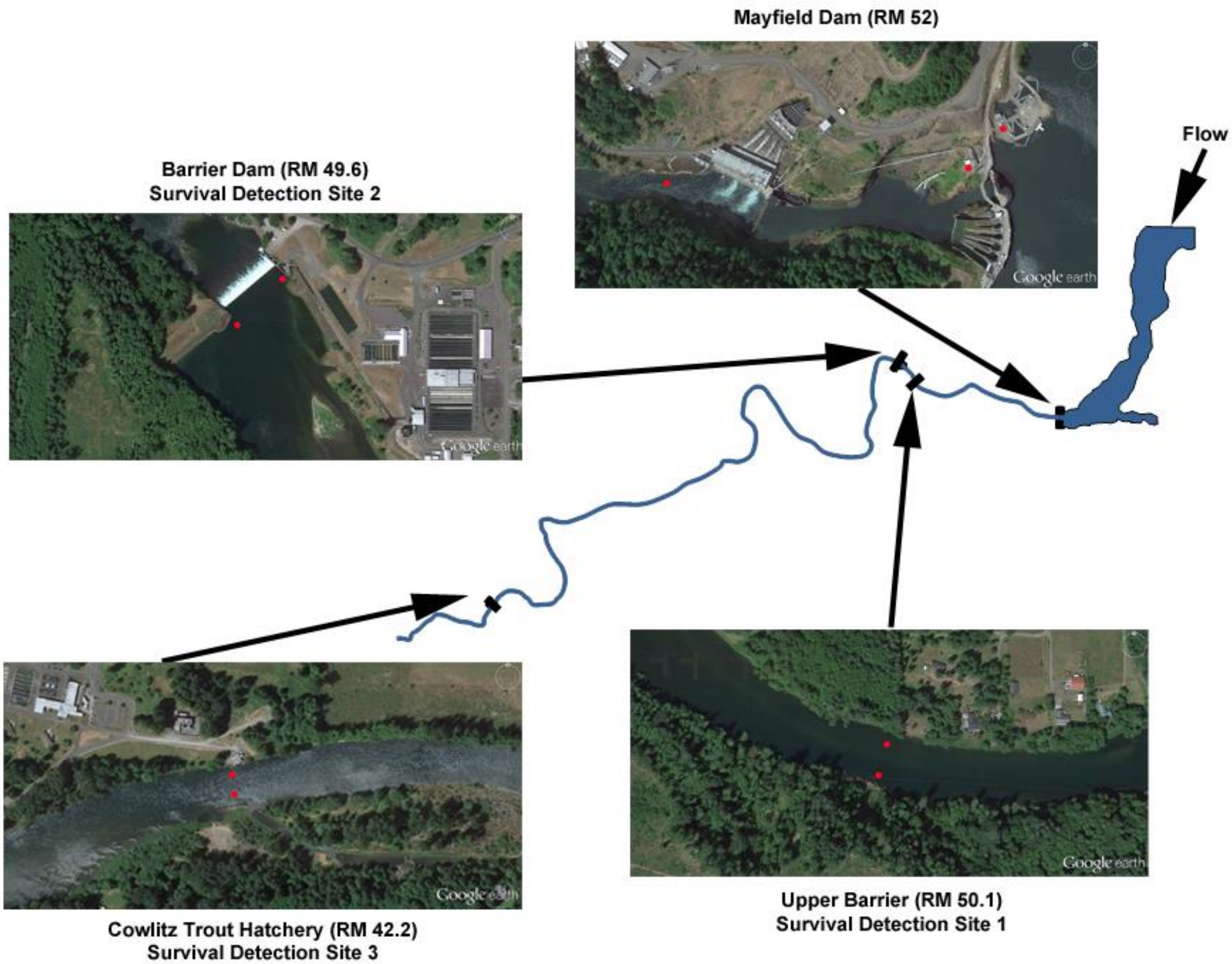


Figure 3. Aerial view of the Mayfield Dam, location of the ATR system and primary hydrophone array, and the three downstream detection sites (Upper Barrier, Barrier Dam and the Cowlitz Trout Hatchery) used in 2014.

2.0 STUDY OBJECTIVES

Downstream fish facility improvements at Mayfield Dam have been guided by requirements of the Anadromous Fish Passage plan for the Cowlitz River Project (FERC No. 2016, License Article 415). Beginning in 2009, these improvements have included modifications to the louver facilities, juvenile fish bypass and fish collection facilities. With these modifications complete, the City of Tacoma, Department of Public Utilities, Light Division began the evaluation of downstream fish passage survival at Mayfield Dam beginning in 2013. The primary objective of the 2013 study, the first year of a multiyear evaluation, was to conduct an evaluation of fish passage survival at the Mayfield Dam (Steig, et al. 2014).

In 2014, the Mayfield Dam study effort focused on smolt migration through the Juvenile Bypass System (JBS). The primary objective in 2014 was to investigate, and attempt to determine the cause(s) of the low survival through the JBS of steelhead, coho, and Chinook smolts observed in the 2013 acoustic tag survival study. Specifically, the study was to examine each stage of fish passage through the juvenile bypass system (JBS); from the entrance at the louver bay apex downwell, through the bypass pipe to the secondary separator; and from the secondary separator through the bypass pipe to the raceway above the counting house; and finally through the counting house itself. A secondary objective was to investigate the delay in tagged smolt migration, between the release sites at Mayfield Dam and the first downstream detection array located at the Barrier Dam, observed in 2013.

To accomplish these objectives, combinations of two separate studies were conducted at Mayfield Dam in 2014, one using acoustic tags, and the other using Visible Implant Elastomer marking. This document describes the methodology and results of the assessment of the JBS, and downstream migrant smolt survival at Mayfield Dam, on the Cowlitz River in 2014.

3.0 MATERIALS AND METHODS

3.1 Project Scope

The scope of the 2014 study efforts were based on the 2013 Mayfield Dam study results, and focused on two elements of fish passage:

1) Evaluating the Juvenile Bypass System (JBS), and the effect(s) it has in delaying smolt migration, and impacts on general fish health and condition;

2) Investigate the delay in fish passage within the study area.

The 2014 juvenile salmon study at Mayfield Dam utilized a combination of Visible Implant Elastomer (VIE) marking, and acoustic tags in the evaluation of the Juvenile Bypass System. The VIE releases provided the primary metrics for estimating smolt survival and assessing the general physical condition of smolts through the JBS; i.e. from release at the apex of the louver bay downwells to the secondary separator, and from the secondary separator on through to the counting house. The acoustically tagged smolts, released at the apex of the louver bay downwells and the powerhouse tailrace, provided an estimate of overall smolt survival and timing through the juvenile bypass system.

The statistical plan for the 2014 Mayfield study, estimating the VIE and acoustic tagged fish sample sizes, and contributing to the study design is included in Appendix A - Statistical Plan for the Juvenile Salmonid Survival Studies at Mayfield Dam in 2014.

3.2 Acoustic Tags

The HTI *Model 795Lm Micro Acoustic Tag,* used in the 2013 study, were also used for the investigations at Mayfield Dam in 2014. The *Model 795Lm* tags were approximately 6.8 mm in diameter by 16.5 mm long and averaged 0.67 g in air. The tags were encapsulated with a non-reactive, inert, low toxicity resin compound. Transmit power level for the tags, was approximately 147 dB uPa @ 1 m.

Ping rate, pulse width, and individual tag ID were programmed in the field, approximately 1 day prior to implantation. The tag transmission rate (i.e., ping rate) was set at 1 ping every 4.0-5.0 sec, with a broadcast pulse width of 1.0 msec. A total of 764 tags were used to tag juvenile steelhead trout, and coho and Chinook salmon, for the Mayfield Dam study in 2014.

3.2.1 Tag Life Test

In 2013, the observed delay in migration of juvenile salmon smolts through the JBS downstream to the Barrier Dam and Trout Hatchery detection sites, may have resulted in fish passing through the detection zones undetected due to expired battery life in some of the acoustic tags. In order to gain a better understanding of the effects of tag life on the overall survival estimates, a tag life test was conducted in 2014. Tag life tests are conducted to accurately determine the longevity of battery life in the acoustic tags used in the survival study, and can provide a correction factor for tagged fish that were not seen downstream as a result of tag life expiration due to battery failure.

In 2014, a total of 17 acoustic tags were selected from each release group (i.e., steelhead, Chinook, and coho) and were programmed with similar tag periods and pulse widths as the releases for the tag life tests. These tags were kept in a controlled environment (at the counting house), subject to the same river water temperatures as the tagged release fish. The functional duration of each tag was recorded for each test group. Tag life corrections are implemented by comparing the tag life death timing curve versus the tagged fish travel time to the various detection sites.

3.3 Acoustic Tag Tracking Systems

The primary acoustic telemetry system used for the Mayfield Dam study in 2014 was the HTI *Model 291 Acoustic Tag Tracking System*. The Acoustic Tag Receiver (ATR) system can determine the presence or absence of tagged fish. The ATR operates at 307 kHz, which has been found to be an optimum frequency with respect to detection ranges and resolution at the numerous hydropower dams where the system has been used to date (HTI 1997). The *Model 291* ATR system supports up to 4 individual hydrophones. All hydrophones used in this study had omni-directional detection beams.

Seven HTI *Model 395 Acoustic Tag Data Loggers* (ATDL) were used as downstream detection arrays at four locations downstream of the dam. The ATDL also operate at 307 kHz and utilize an individual hydrophone. Each of the ATDL's was used for simple tag detection (presence or absence).

The ATR and ATDL's continuously receive and store all tag transmit pulses detected by each hydrophone simultaneously. The specifications for the acoustic tag receiver and ADTL are provided in Appendix A of the 2013 Mayfield Dam report (Steig, et al. 2014).

3.3.1 Mayfield Dam Acoustic Tag System

The acoustic tag system deployment from the 2013 study, with minor modification, was used in the 2014 study. The *Model 291 Portable Acoustic Tag Receiver,* deployed in the small building located adjacent to the secondary separator pumps, sampled the hydrophone deployed in the secondary separator, and three hydrophones located at the counting house below the dam (see Figure 2). The secondary separator hydrophone was used to establish tagged fish entrance and exit times as they passed through the secondary separator, into the bypass pipe through the dam, and down to the counting house. One of the hydrophones located at the counting house was used for initial tag testing and verification (called code-out), and one functioned in the detection/verification of recollected tagged fish, i.e., tagged fish that had moved through the bypass and were recovered in the counting house (Table 1). Recollected tagged fish were sampled in the transport tank (as part of the virtual releases), recording the time of last detection prior to reintroduction into the bypass system. The third hydrophone at the counting house was used for the conduct of the tag life tests.

The 2014 hydrophone deployment positively established the timing of acoustic tagged fish passage from the secondary separator, through to the counting house downstream, and back into the bypass pipe. Since no tagged fish were released in front of the louvers, and therefore available to pass through the power intake canal, the hydrophone deployed in the intake canal in 2013 was not utilized in 2014.

3.3.2 Downstream Detection Array Acoustic Tag Systems

Seven HTI *Model 395 Acoustic Tag Data Loggers* (ATDL) were used as tag detection arrays downstream of Mayfield Dam. The 2014 study utilized the two ATDL's installed at the Barrier Dam, located approximately 2.4 river miles downstream of Mayfield Dam, and the two ATDL's deployed at the Cowlitz Trout Hatchery approximately seven river miles (RM 42.2) downstream of the Barrier Dam, as in the 2013 survival study (see Steig et al. 2014 for complete description).

Table 1. Release and detection locations of the acoustic tags for the 2014 Mayfield Dam study.

Location	Type of Site
Mayfield Dam (RM 52)	Release
Secondary Separator	Detection
Counting House	Code-out
Counting House (Transport Tank)	Detection
Counting House	Tag Life Tests
Mayfield Dam Tailrace (RM 51.9)	Detection
Upper Barrier (RM 50.1)	Detection
Barrier Dam (RM 49.6)	Detection
Trout Hatchery (RM 42.2)	Detection

Two additional in-river tag detection sites were deployed downstream of Mayfield Dam for the 2014 study. One ADTL was installed in the tailrace of Mayfield Dam, approximately 300 feet downstream of the turbine outfall (Figure 4). This hydrophone was used primarily to determine the travel time of tagged smolts between the transport tank at the counting house, through the bypass pipe, and into the Mayfield Dam tailrace. A two ADTL array (called Upper Barrier), was deployed at a site approximately one half mile above the Barrier Dam site, and approximately 1.7 miles downstream of Mayfield Dam (Figure 5). This detection array was used as the most upstream survival gate, and to gain a better understanding of the mechanisms of increased travel time and holding time of coho and Chinook smolts between Mayfield Dam and Barrier Dam, as observed in 2013.

Each of the ATDL's utilized one hydrophone and were housed in small construction boxes. The ATDL's at the Mayfield Dam tailrace, Barrier Dam, and the Trout Hatchery operated off of 110 VAC 'line' power. The Upper Barrier ATDL's operated off of three 12 VDC batteries (in parallel), and a solar panel. All of the ATDL's monitored the presence or absence of tagged fish as they passed downstream through the detection sites. Each of the units included remote cell phone modems to allow full control, monitoring, and data downloading from each location.

3.4 Hydrophone Deployments

3.4.1 In-River Hydrophone Deployment

The Barrier Dam and Trout Hatchery downstream detection sites were deployed in 2013. A complete description of the mount construction, and deployment for each of these locations was described in the 2013 Mayfield Dam study report (see Steig et al. 2014). New hydrophones deployed at the Mayfield Dam tailrace, and at the Upper Barrier detection site were deployed on April 29, 2014, using the same bottom mount design used for the south Barrier Dam hydrophone.

All hydrophone cables were paired with ¼" galvanized steel cables to hold them in place on the river substrate and to aid in mount retrieval at the study's conclusion. The hydrophone/retrieval cables were routed back to the north bank by boat, to the data collection construction boxes housing the ATDL's.

Figure 4. A single hydrophone was deployed in the tailrace region of Mayfield Dam in 2014, the first tag detection site downstream of the dam.

Figure 5. Two additional hydrophones were deployed at the Upper Barrier tag detection site, located approximately 1.7 miles downstream of Mayfield Dam, in 2014. The ADTL's were housed in a construction box on the north bank.

3.4.2 Mayfield Dam Hydrophone Deployment

The hydrophone configuration at the Mayfield Dam detection sites was modified from the configuration used in 2013, to accommodate the change in objectives of the 2014 study. The hydrophone monitoring the secondary separator unit in 2013, was used as deployed for the 2014 study.

The powerhouse intake canal hydrophone, no longer required for the 2014 study, was moved to the counting house below the dam and used to detect the recollected fish in the transport tank. Each day, when all smolts in the counting house had been processed and put into the transport tank (see Section 3.6.1 below), the hydrophone was placed into the tank to detect the tagged smolts that had passed from the secondary separator through to the counting house (i.e., recollected fish), just prior to their reintroduction into the JBS (Figure 6).

3.5 Juvenile Salmonid Handling

3.5.1 Juvenile Salmonid Collection

All juvenile salmonids used for the acoustic tag and VIE marking studies during 2014 were of natural origin (NOR) fish collected at the Mayfield Dam downstream fish migrant facility (counting house). On each tagging/marking day, juvenile salmon and steelhead were moved from the raceway into holding tanks at the counting house for processing, and individuals of suitable tagging size were selected and segregated for tag implantation and marking.

During the fall outmigration, a large proportion of Chinook smolts were found to be unhealthy. The majority of the unhealthy Chinook smolts were infested with internal parasites. All of the Chinook smolts may have had compromised immune systems. For this reason, an attempt was made to tag and mark the healthier Chinook smolts.

3.5.2 Juvenile Salmonid Tagging and Post-Tag Holding

Tag programming generally occurred in the morning prior to fish collection and tagging. After programming, tag functionality was verified and monitored through at least three transmission cycles. At least 3 attempts were made to program each tag.

During each tagging session, fish were surgically implanted with HTI *Model 795 Lm micro* acoustic tags. Prior to transmitter implantation, fish were anesthetized in 70 mg/L tricane methanesulfonate (MS-222) buffered with an equal concentration of sodium bicarbonate until they lost equilibrium. Fish were removed from anesthesia, the fork length (FL) measured to the nearest mm, and weighed to the nearest 0.1 g. The surgical tagging protocol document used for this study was described in 2013 Mayfield Dam study report (Steig et al. 2014), and follows the implantation procedures outlined in Adams et al. (1998) and Martinelli et al. (1998). Typical surgery times were less than 2 min.

Tagged fish were then placed into perforated 19 L buckets to recover from anesthesia effects. Buckets were perforated to allow for water exchange and were covered with a ‘snap-on’ lid. The tagged fish in the perforated buckets were then transferred to a holding tank with circulating river water, and held for approximately 24 hours until release. Tagged fish were monitored by the code-out hydrophone at the counting house during the holding period to confirm the operational status of each tag.

Figure 6. The transport tank was sampled for recollected fish at the Mayfield Dam counting house, using a hydrophone held by hand in the tank, prior to processed fish being returned to the bypass pipe.

3.5.3 Tagged Juvenile Salmonid Releases

Acoustically tagged juvenile salmon smolts (steelhead, coho and Chinook) were utilized at Mayfield Dam in 2014, in a paired release recapture study design, to estimate survival through the entire Juvenile Bypass System. Figure 7 shows a schematic representation of the acoustic tag release recapture study. Acoustically tagged fish were released at two (2) locations. Treatment tagged fish (R_1) were divided equally, and released in the north and south louver bay apex downwells. Control tagged fish (R_2) releases were made downstream of the powerhouse, in the Mayfield Dam tailrace, where there was the potential for mixing between the treatment and control fish releases to occur.

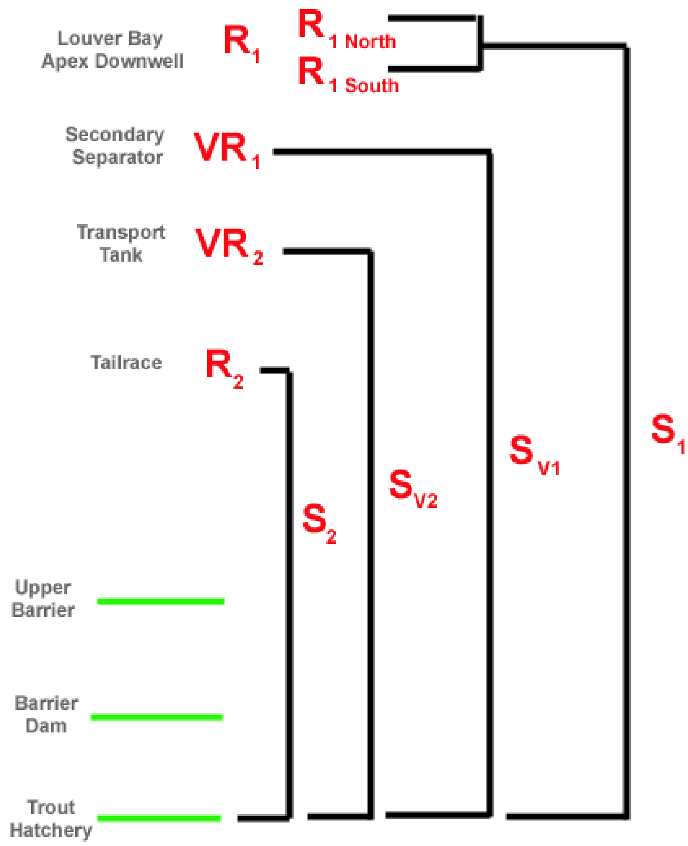


Figure 7. Schematic representation of the acoustic tag release recapture study at Mayfield Dam 2014.

The acoustic tag release design allowed for 'virtual' release recapture survival estimates downstream of the secondary separator and in the transport tank (downstream of the counting house) to be derived. The virtual release locations (VR_1 and VR_2) utilized tag detections at the secondary separator, and the transport tank, and were compared with the tailrace releases (R_2) to provide survival estimates from each point (i.e., S_1, S_{v1}, S_{v2}, and S_2) of the virtual release locations.

A total of 752 tagged juvenile steelhead, coho and Chinook salmon smolts were released at Mayfield Dam between May 7 and November 11, in 30 release groups consisting of 17-37 juvenile steelhead and salmon smolts per release (Table 2). All groups of acoustically tagged fish were checked for mortalities prior to release.

3.6 Visible Implant Elastomer (VIE) Marked Fish

3.6.1 VIE Marked Fish Releases

Visible Implant Elastomer (VIE) marking was used to evaluate the JBS in an attempt to determine the cause(s) of low survival and the delay in migration of juvenile salmon smolts (steelhead, coho and Chinook) through the JBS, observed in 2013.

Table 2. Summary of the steelhead, coho and Chinook releases including number of releases, first and last release date, and number of fish tagged for the forebay and tailrace releases at Mayfield Dam in 2014.

Species	Release Location	Number of Releases	First Release Date	Last Release Date	Number Tagged Fish Released
Steelhead	Forebay	5	5/7/2014	6/4/2014	148
Steelhead	Tailrace	5	5/9/2014	6/6/2014	100
Coho	Forebay	5	6/11/2014	7/9/2014	152
Coho	Tailrace	5	6/13/2014	7/11/2014	100
Chinook	Forebay	5	10/8/2014	11/5/2014	151
Chinook	Tailrace	5	10/10/2014	11/6/2014	101
				Totals	752

To examine the effects of each section of the JBS, VIE marked fish were released at three locations: 1) the louver bay apex downwells (North and South; R_1); 2) the secondary separator downwell (R_2); and 3) the raceway entrance to the counting house (R_3). Figure 8 shows a schematic representation of the VIE release recapture study, and the release locations for VIE marked fish are shown graphically in Figure 9.

All fish used in the evaluation were collected and marked at the counting house. Each release group was marked with a unique color and/or location of VIE mark, and all marked fish were recollected at the counting house for evaluation.

The 2014 study plan called for the release of 250 VIE marked fish at each release location, for each of the three species of smolts. VIE releases generally occurred during the peak migration months for each species; steelhead in May and June, and coho in June and July, except Chinook which occurred in October and November (Table 3).

3.7 Study Design and Statistical Methods

The primary objective of the 2014 tagging studies at Mayfield Dam was to estimate juvenile bypass system (JBS) passage survival and partition passage survival in the JBS for steelhead, coho salmon, and Chinook salmon smolts. Ancillary information on travel times was also collected.

3.7.1. Acoustic Tag Release-Recapture Design

A paired release-recapture design was used to estimate JBS passage survival at the Mayfield Dam (Figure 10). For the acoustic tag study, treatment fish (i.e., upstream fish) were released into the north and south louver bay apex downwells, and control fish (i.e., downstream fish) were released into the tailrace. In 2014, hydrophone detection sites were located in the JBS at the secondary separator, and in the transportation tank. For each of the steelhead, coho salmon, and Chinook salmon stocks, release sizes were approximately 150 tagged smolts at the louver bay apex downwells, and 100 tagged smolts in the tailrace. This release-recapture design allowed for both paired- and single-release estimates of survival.

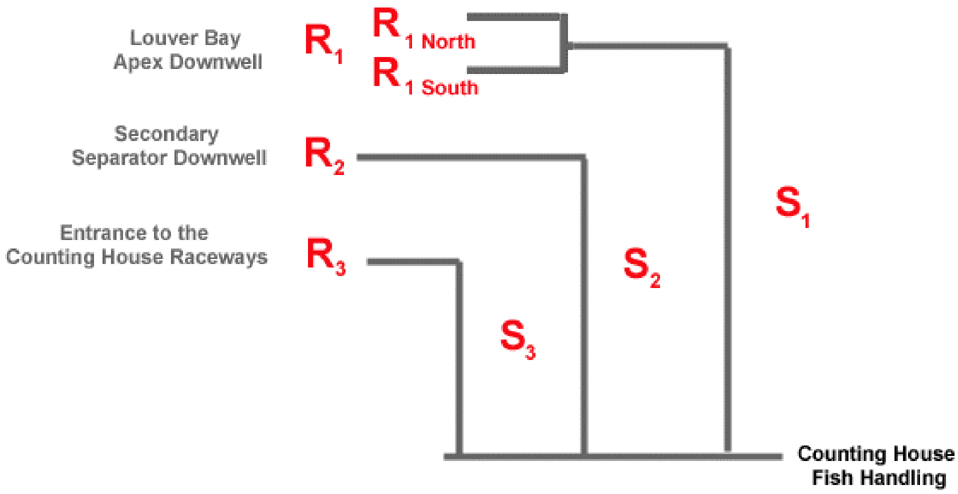


Figure 8. Schematic representation of the VIE marked release recapture study at Mayfield Dam 2014.

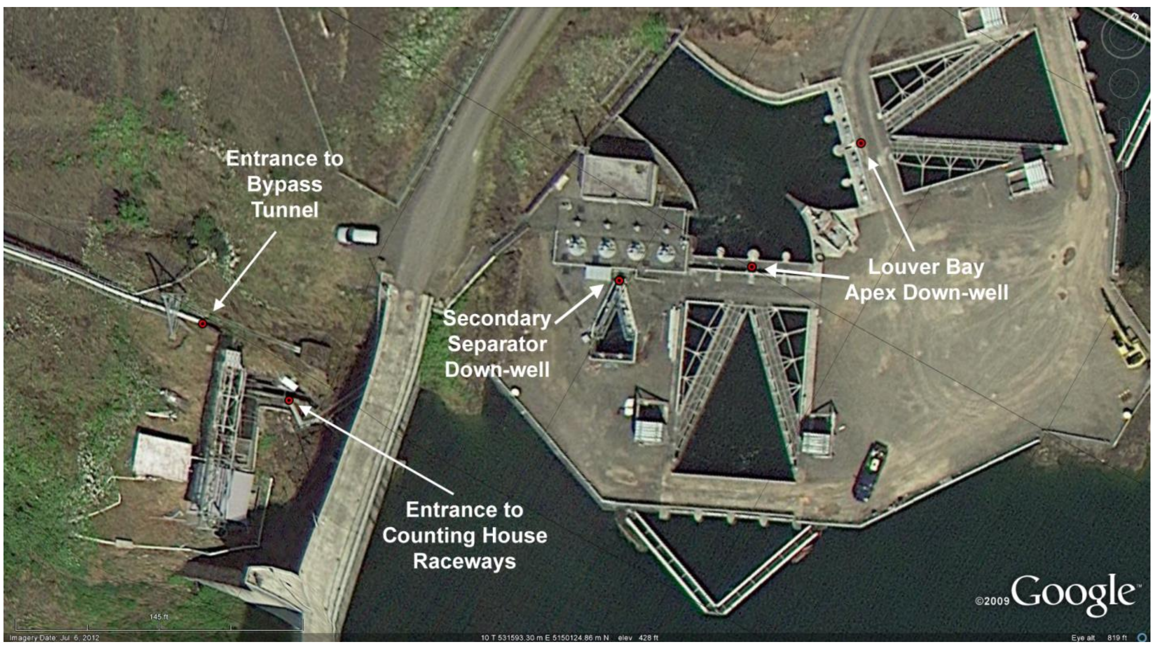


Figure 9. Upstream VIE treatment (R_t) release locations at Mayfield Dam, 2014. VIE marked fish were released at the louver bay apex downwells of the north and south louvers, the secondary separator downwell, and the raceway above the counting house. Marked fish were recollected and evaluated at the counting house.

Table 3. Total number of VIE marked fish by species, release location, and study month at Mayfield Dam, 2014.

	Marked Steelhead Numbers			Marked Coho Numbers			Marked Chinook Numbers			
	R_1	R_2	R_3	R_1	R_2	R_3	R_1	R_2	R_3	Total
January										
February										
March										
April										
May	200	200	200							600
June	50	50	50	150	150	150				600
July				100	100	100				300
August										
September										
October							83	83	83	249
November							167	167	167	501
December										
Total										2,250

Below Mayfield Dam, there were three primary detection arrays, comprised of two hydrophones each. These arrays provided the downstream detection histories used in the release-recapture analysis (Figure 10). The first downstream array, the Upper Barrier array, was new for the 2014 study and located approximately 1.7 miles downstream of the tailrace at RM 50.1. The last two detection arrays, utilized in the 2013 study, were located at Barrier Dam (RM 49.6) and at the Cowlitz Trout Hatchery (RM 42.2). An additional hydrophone was deployed in the tailrace region in 2014, near the tailrace release site, primarily to gather ancillary information on the travel times of recollected fish between the transport tank and the tailrace.

3.7.2. Visible Implant Elastomer (VIE) Tags

There were three releases of visible implant elastomer (VIE) marked smolts for each species within the Mayfield Dam in 2014. VIE marked fish were released at the louver bay apex downwells, the secondary separator downwell, and the entrance to the counting house raceways. All tag recoveries occurred during the daily juvenile fish processing at the counting house. Release sizes were approximately 250 fish per release location, per fish stock (i.e., steelhead, coho salmon, and Chinook salmon). The release-recapture design used to estimate JBS passage survival at Mayfield Dam using the VIE marked fish is given in Figure 11.

3.7.3 Acoustic Tag Release Schedule and Sizes

The steelhead, and coho and Chinook salmon were released over the course of their respective outmigrations. The releases were distributed over time, generally in proportion to the historical distributions of the outmigrations. The nominal release sizes were 150 fish in the louver bay apex downwells, and 100 fish at the tailrace location, for each fish species (Table 4).

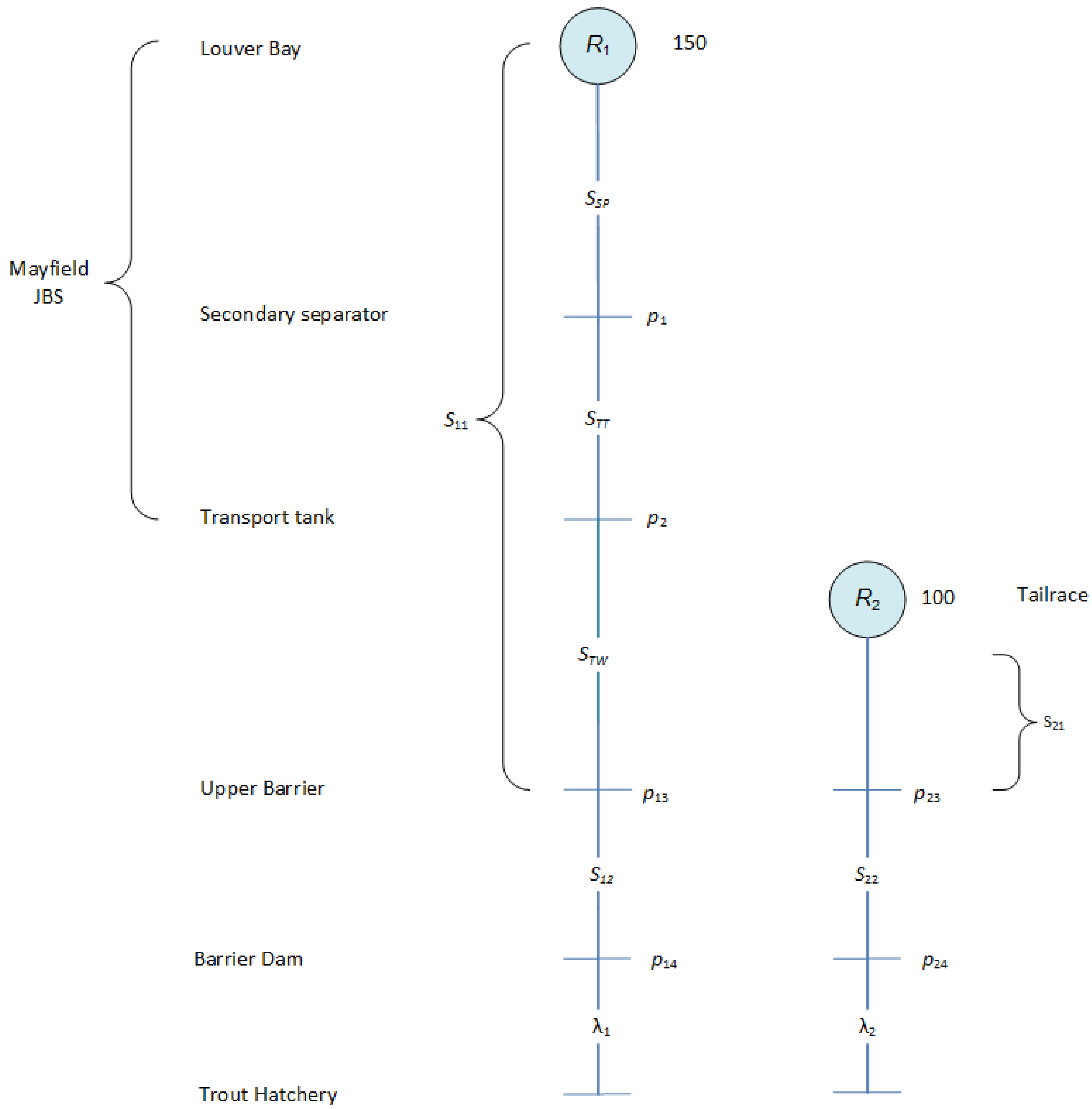


Figure 10. Schematic of the acoustic tag, release-recapture design at Mayfield Dam in 2014, along with releases (R), reach survivals (S), detection probabilities (p), and joint survival and detection (λ) parameters that will be estimated.

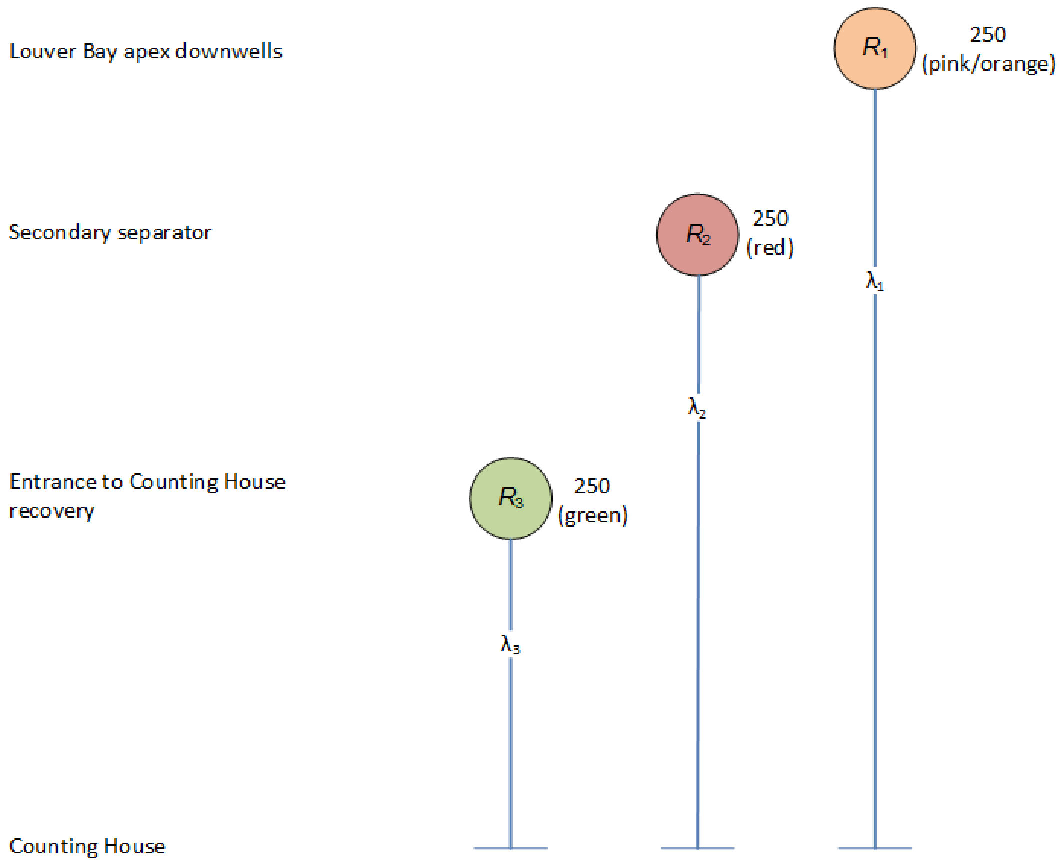


Figure 11. Schematic of VIE tag, release-recapture design with releases (R), and joint probabilities of survival and detection (λ) which are directly estimable. Tag colors are indicated by location.

Table 4. Release sizes for steelhead, and coho and Chinook salmon used in estimating juvenile bypass survival at Mayfield Dam in 2014.

Release Location	Steelhead	Coho Salmon	Chinook Salmon
Downwells (*Rt*)	148	152	151
Tailrace (*Rc*)	100	100	101

3.7.4 Tagger Effort

In 2013, the first year of the Mayfield Dam studies, three individuals (taggers) tagged all the coho smolts, although most fish (75.4%) were tagged by a single individual tagger (Steig et al. 2014). However, tagger effort was found to not be evenly distributed across each of the release locations, and fish tagged by different individuals had different downstream reach survival potentially resulting in a bias of the survival estimates. Consequently, some tagged fish had to be removed from the analysis.

In 2014, all tag insertion surgery (for both the upstream (R_T) and downstream (R_C) releases) was completed by an individual tagger, thereby eliminating any between taggers effect on the estimates of juvenile bypass passage survival. However, it was not possible to identify any tagger effects.

3.8 Data Analysis

3.8.1 Tests of Assumptions – Downstream Mixing

Evaluation of homogeneous arrival of release groups at downriver detection sites (i.e., tailwater, Barrier Dam, Trout Hatchery) were based on graphs of arrival distributions. The graphs were used to identify any systematic and meaningful departures from mixing. Ideally, the arrival distributions should overlap one another with similarly timed modes.

3.8.2 Survival Analysis

The analysis of the acoustic tag study was a combination of single and paired release-recapture methods.

3.8.2.1 Single Release-Recapture Methods

The single release-recapture method (Skalski et al. 1998) was used to estimate survival within the JBS using the R_1 release group (Figure 10). Survival within the JBS was estimated for the following reaches:

S_{SP}	Louver Bay downwells– Secondary separator downwell
S_{TT}	Secondary separator downwell – Transport tank
S_{TW}	Transport tank – Tailwater array

Survival through the JBS was estimated by the product

$$S_{SP} \cdot S_{TT} \cdot S_{TW}.$$

Program ATLAS (http://www.cbr.washington.edu/analysis/apps/atlas) was used to provide tag-life-adjusted survival estimates for these reaches.

It should be noted that these estimates may be negatively biased if there are any post-release handling or tag effects.

3.8.2.2 Paired Release-Recapture Methods

The paired-release design for complete capture histories (Burnham et al. 1987:112-145) was used to estimate survival between the louver bay and tailrace (Figure 10). Using the four downstream detection arrays, there were sixteen possible capture histories for each release group (i.e., R_1 and R_2, Figure 10). Program ATLAS was used to provide tag-life-adjusted survival estimates. Survival through the JBS was estimated by the quotient

$$\hat{S}_{\mathrm{JBS}} = \frac{\hat{S}_{11}}{\hat{S}_{21}}. \quad (4)$$

A fully parameterized model was used to estimate the release-recapture parameters for the model depictured in Figure 10. With the high detection probabilities ($p \geq 0.95$), there was no precision benefit in using a more parsimonious model. In so doing, both the precision and model robustness were retained.

3.8.2.3 Survival Analysis – VIE Tags

For the VIE tagging study (Figure 11), survival within the JBS was estimated using the paired-release design for relative recovery methods (Burnham et al. 1987:78-100). Using the VIE-tag releases, two estimates of survival could be calculated:

1. Survival between louver bay and the secondary separator, i.e.,

$$\hat{S}_{LB-SS} = \frac{\hat{\lambda}_1}{\hat{\lambda}_2} \tag{5}$$

with associated variance estimator

$$\widehat{\mathrm{Var}}\left(\hat{S}_{LB-SS}\right) = S^2_{LB-SS}\left[\frac{1}{r_2} - \frac{1}{R_2} + \frac{1}{r_3} - \frac{1}{R_3}\right]. \tag{6}$$

2. Survival between the secondary separator and the entrance to Counting House raceway, i.e.,

$$\hat{S}_{SS-CH} = \frac{\hat{\lambda}_2}{\hat{\lambda}_3} \tag{7}$$

with associated variance estimator

$$\widehat{\mathrm{Var}}\left(\hat{S}_{SS-CH}\right) = S^2_{SS-CH}\left[\frac{1}{r_2} - \frac{1}{R_2} + \frac{1}{r_3} - \frac{1}{R_3}\right]. \tag{8}$$

The separate estimates could be combined to estimate the probability of surviving between louver bay and the Counting House entrance, i.e.,

$$\hat{S}_{LB-CH} = \hat{S}_{LB-SS} \cdot \hat{S}_{SS-CH} = \frac{\hat{\lambda}_1}{\hat{\lambda}_2} \cdot \frac{\hat{\lambda}_2}{\hat{\lambda}_3} = \frac{\hat{\lambda}_1}{\hat{\lambda}_3} \tag{9}$$

with associated variance estimator

$$\widehat{\mathrm{Var}}\left(\hat{S}_{LB-CH}\right) = S^2_{LB-CH}\left[\frac{1}{r_1} - \frac{1}{R_1} + \frac{1}{r_3} - \frac{1}{R_3}\right], \tag{10}$$

where $R_i (i = 1, \ldots, 3)$ are release sizes and $r_i (i = 1, \ldots, 3)$ are recovery numbers per release group. The key assumption of this method is that the probability of recovery is the same across the three release groups. This assumption cannot be directly tested. However, homogeneous passage over time of the three releases at the Counting House would be indirect evidence of such homogeneity.

3.8.2 Ancillary Analyses

Travel times were calculated for the various release groups between detection or release-and-detection locations for acoustic-tagged fish. Mean and median travel times were directly calculated for the following reaches:

Tag Type	Reach
Acoustic	Louver Bay downwells– Secondary separator
	Secondary separator – Transport tank
	Transport tank – Tailrace
	Tailrace – Upper Barrier
	Upper Barrier – Barrier Dam
	Barrier Dam – Trout hatchery

4.0 RESULTS

4.1 Acoustic System Operations

The *Model 291 Acoustic Tag Receiver* deployed at Mayfield Dam and the seven *Model 395 Acoustic Tag Data Loggers* (ATDL) deployed at the four in-river sites operated 24 h/d, 7 d/w from April 27, 2014 through the end of the study on December 2, 2014. Only minor interruptions occurred during this time period that resulted in any loss of data.

4.2 Acoustic Tag Fish Releases

Pre-season dead fish releases were conducted on 10 April 2014. Ten dead fish were released in the Mayfield Dam tailrace and none of the dead fish were detected at the Upper Barrier site, the Barrier Dam, or the Trout Hatchery. The Cowlitz River flow rate was approximately 9,000 cfs during the dead fish releases. Therefore, there was little concern that any fish mortalities that occurred during juvenile bypass system passage would positively bias the JBS passage survival estimates.

As previously mentioned, a large proportion of Chinook smolts were found to be unhealthy. The majority of the unhealthy Chinook smolts were infested with external and internal parasites. Figure 12 shows a picture of a Chinook smolt with parasites in its gills. Evidence of internal parasites in a Chinook smolt are shown in Figure 13. All of the Chinook smolts may have had compromised immune systems. For this reason, an attempt was made to tag and mark the healthier Chinook smolts. The 2014 study results were most likely affected by the unhealthy Chinook smolts.

Summaries of all the tagged fish releases during the 2014 Mayfield Dam survival study are presented in Table 5, for steelhead, coho and Chinook salmon in the louver bay downwells releases, and in Table 6 for the corresponding steelhead, coho and Chinook tailrace releases. A total of 752 tags were utilized for the coho, steelhead and Chinook releases. Once tagged, fish were held up to 24 h prior to release to assess fish mortality and tag failure. Both these conditions occurred over the study period, resulting in slightly fewer fish being released than the total tagged (Tables 5 and 6). There were 248 tagged steelhead smolts released over the study period, with 148 tagged smolts released in the louver bay downwells, and 100 tagged steelhead released in the tailrace. Of the 252 tagged coho smolts released, 152 were released at the louver bay downwells, and 100 tagged coho smolts released in the tailrace. Total tagged Chinook smolts released was 252, with 151 released in the louver bay downwells and 100 Chinook smolts released in tailrace.

Figure 12. Chinook salmon smolt showing signs of external parasites in its gills during the 2014 survival study.

Figure 13. Chinook salmon smolt showing signs of internal parasites during the 2014 survival study.

Table 5. Summary of the acoustic tagged steelhead, coho and Chinook salmon forebay releases during the 2014 Mayfield survival study.

Release Number	Species	Release Date-Time	Number Fish Tagged	Non-operational Tags	Tagged Fish Mortalities	Forebay Released Fish
MFS01	Steelhead	5/7/14 1:23 PM	30	0	0	30
MFS02	Steelhead	5/14/14 1:15 PM	30	0	0	30
MFS03	Steelhead	5/21/14 1:56 PM	30	1	0	29
MFS04	Steelhead	5/28/14 12:00 PM	30	0	1	29
MFS05	Steelhead	6/4/14 1:20 PM	32	2	0	30
		Sub-Totals	**152**	**3**	**1**	**148**
MFO01	Coho	6/11/14 1:30 PM	30	1	0	29
MFO02	Coho	6/18/14 1:00 PM	31	1	0	30
MFO03	Coho	6/25/14 1:15 PM	33	0	0	33
MFO04	Coho	7/2/14 11:45 AM	30	0	0	30
MFO05	Coho	7/9/14 1:46 PM	30	0	0	30
		Sub-Totals	**154**	**2**	**0**	**152**
MFC01	Chinook	10/8/14 12:15 PM	30	0	0	30
MFC02	Chinook	10/15/14 1:55 PM	30	0	2	28
MFC03	Chinook	10/22/14 12:55 PM	34	1	2	31
MFC04	Chinook	10/29/14 1:05 PM	33	1	3	29
MFC05	Chinook	11/5/14 12:45 PM	39	4	2	33
		Sub-Totals	**166**	**6**	**9**	**151**

Table 6. Summary of the acoustic tagged steelhead, coho and Chinook salmon tailrace releases during the 2014 Mayfield survival study.

Release Number	Species	Release Date-Time	Number Fish Tagged	Non-operational Tags	Tagged Fish Mortalities	Tailrace Released Fish
MTS01	Steelhead	5/9/14 12:29 PM	20	0	1	19
MTS02	Steelhead	5/16/14 12:30 PM	20	0	0	20
MTS03	Steelhead	5/23/14 12:20 PM	21	0	0	21
MTS04	Steelhead	5/30/14 1:20 PM	20	0	0	20
MTS05	Steelhead	6/6/14 1:48 PM	21	1	0	20
		Sub-Totals	**102**	**1**	**1**	**100**
MTO01	Coho	6/13/14 12:18 PM	20	0	0	20
MTO02	Coho	6/20/14 2:20 PM	20	0	0	20
MTO03	Coho	6/27/14 12:10 PM	20	0	0	20
MTO04	Coho	7/3/14 12:50 PM	20	0	0	20
MTO05	Coho	7/11/14 12:40 PM	20	0	0	20
		Sub-Totals	**100**	**0**	**0**	**100**
MTC01	Chinook	10/9/14 11:55 AM	20	1	3	16
MTC02	Chinook	10/16/14 2:20 PM	21	0	2	19
MTC03	Chinook	10/23/14 1:30 PM	25	1	3	21
MTC04	Chinook	10/30/14 2:15 PM	24	0	1	23
MTC05	Chinook	11/6/14 1:40 PM	23	0	1	22
		Sub-Totals	**113**	**2**	**10**	**101**

4.3 Fish Length and Weight Distributions

Length frequency distributions for the acoustically tagged coho smolts released at Mayfield Dam are presented in Figure 14. Tagged coho smolts ranged in size from 137-219 mm, with an average length of 161 mm for the louver bay downwell released fish, and an average length of 160 mm for the tailrace released fish. The coho size distributions were moderately skewed toward small fish, and were similar between the louver bay downwells and tailrace releases.

Length frequency distributions for the acoustically tagged steelhead smolts released at Mayfield Dam are presented in Figure 15. The tagged steelhead smolts ranged in size from 160-280 mm, with an average length of 210 mm for the fish released in the louver bay downwells and an average length of 211 mm for the tailrace released fish. Steelhead smolt size distributions were more normally distributed, and were similar between the louver bay downwells and tailrace releases.

Length frequency distributions for the acoustically tagged Chinook smolts released at Mayfield Dam are presented in Figure 16. Tagged Chinook smolts ranged in size from 132-183 mm, with an average length of 154 mm for the fish released in the louver bay downwells and an average length of 155 mm for the tailrace released fish. Chinook size distributions for tagged smolts were normally distributed, and were similar between the louver bay downwell and tailrace releases.

Weight frequency distributions for the acoustically tagged coho smolts released at Mayfield Dam are presented in Figure 17. The tagged coho smolts ranged in weight from 0.023-0.097 kg, with an average weight of 0.046 kg for the louver bay downwell released fish and an average weight of 0.047 kg for the tailrace released fish. As with the coho length frequency distributions, coho weight distributions were also moderately skewed toward smaller fish lengths, and were similar between the downwell and tailrace releases.

Weight frequency distributions for the acoustically tagged steelhead smolts released at Mayfield Dam are presented in Figure 18. The tagged steelhead smolts ranged in weight from 0.041-0.203 kg, with an average weight of 0.089 kg for the louver bay downwell released fish and an average weight of 0.088 kg for the tailrace released fish. The steelhead weight distributions were also slightly skewed toward small fish, and were similar between the louver bay downwell and tailrace releases.

Weight frequency distributions for the acoustically tagged Chinook smolts released at Mayfield Dam are presented in Figure 19. The tagged Chinook smolts ranged in weight from 0.014-0.069 kg, with an average weight of 0.046 kg for the louver bay downwell released fish and an average weight of 0.045 kg for the tailrace released fish. The Chinook weight distributions were normally distributed and were similar between the downwell and tailrace releases.

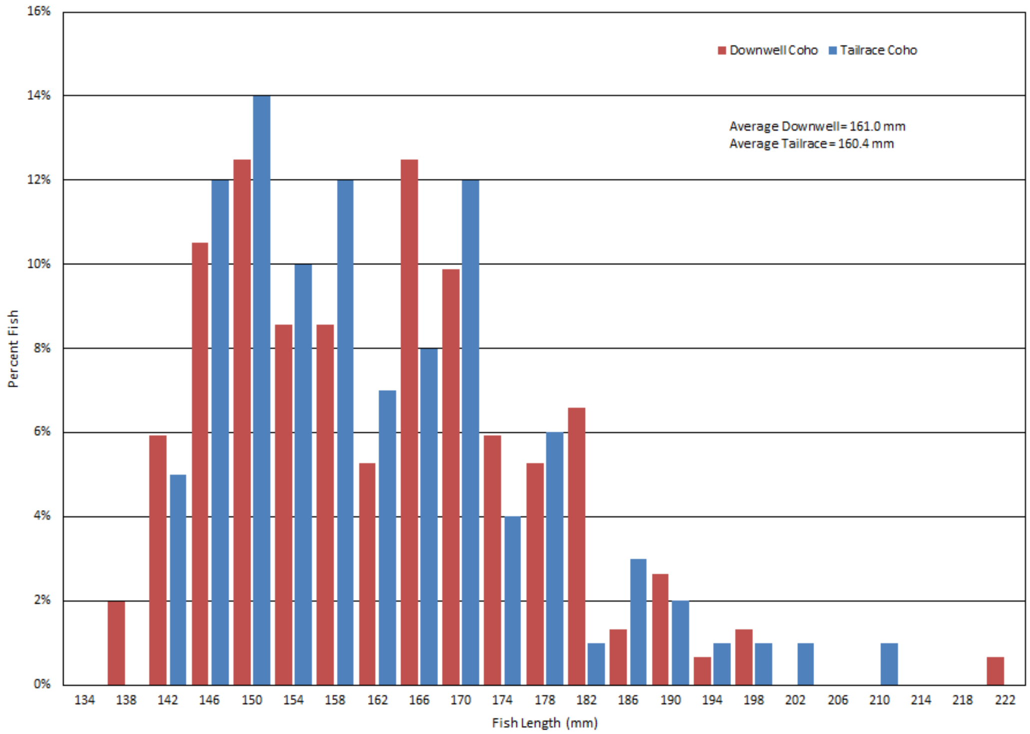


Figure 14. Fish length distribution of acoustically tagged coho smolts at Mayfield Dam in 2014.

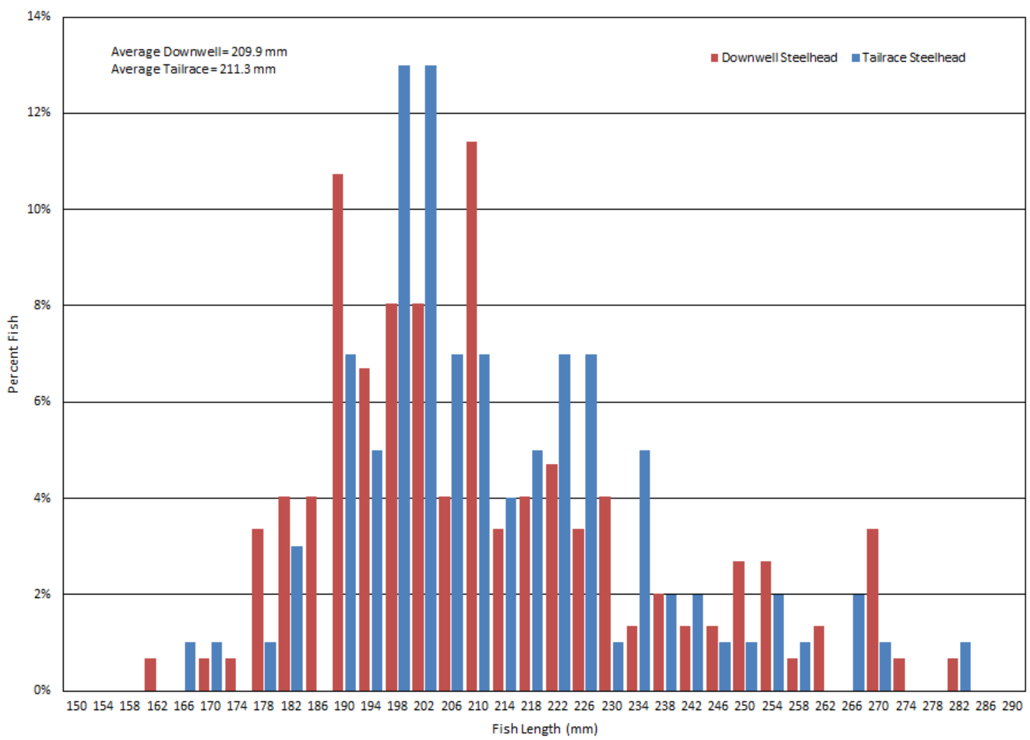


Figure 15. Fish length distribution of acoustically tagged steelhead smolts at Mayfield Dam in 2014.

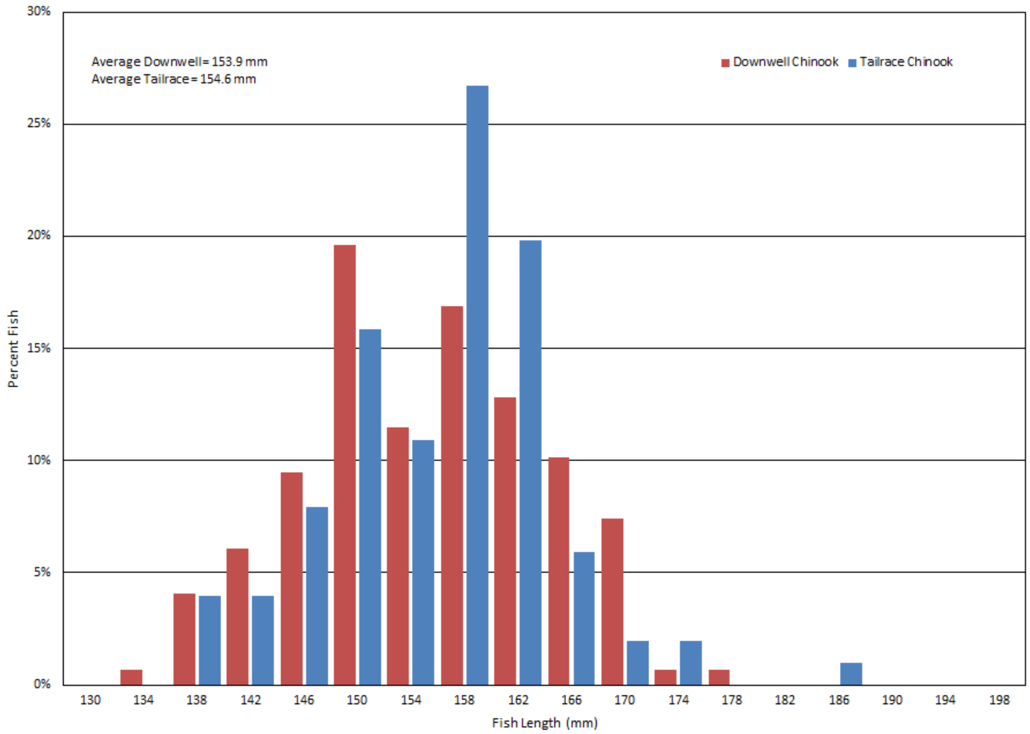


Figure 16. Fish length distribution of acoustically tagged Chinook smolts at Mayfield Dam in 2014.

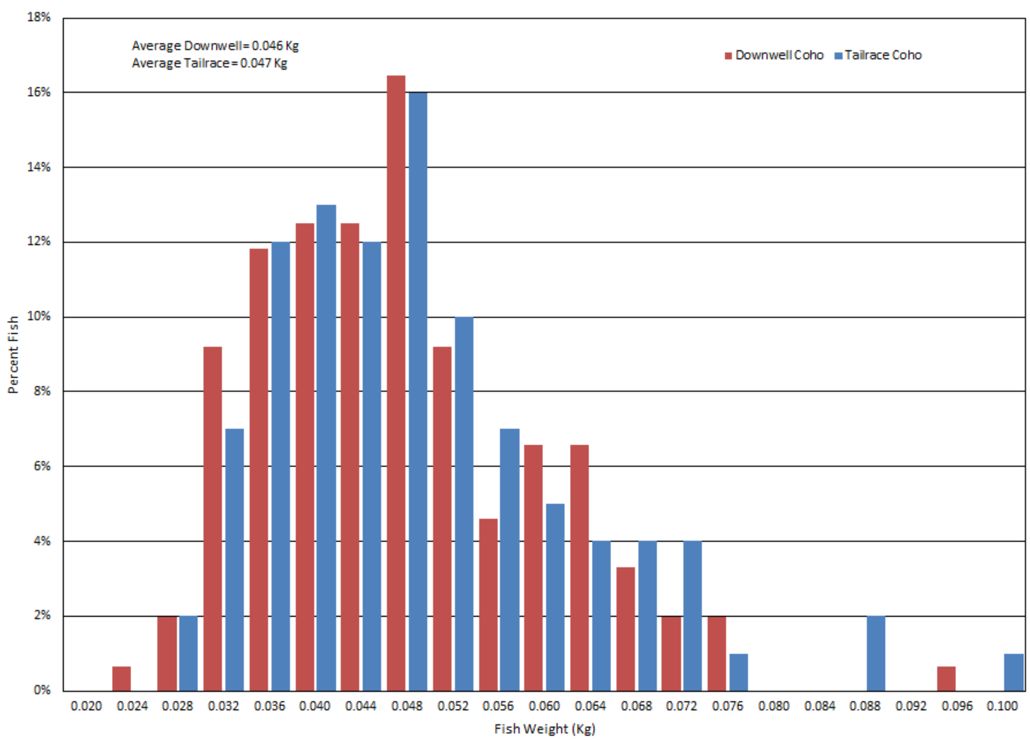


Figure 17. Fish weight distribution of acoustically tagged coho smolts at Mayfield Dam in 2014.

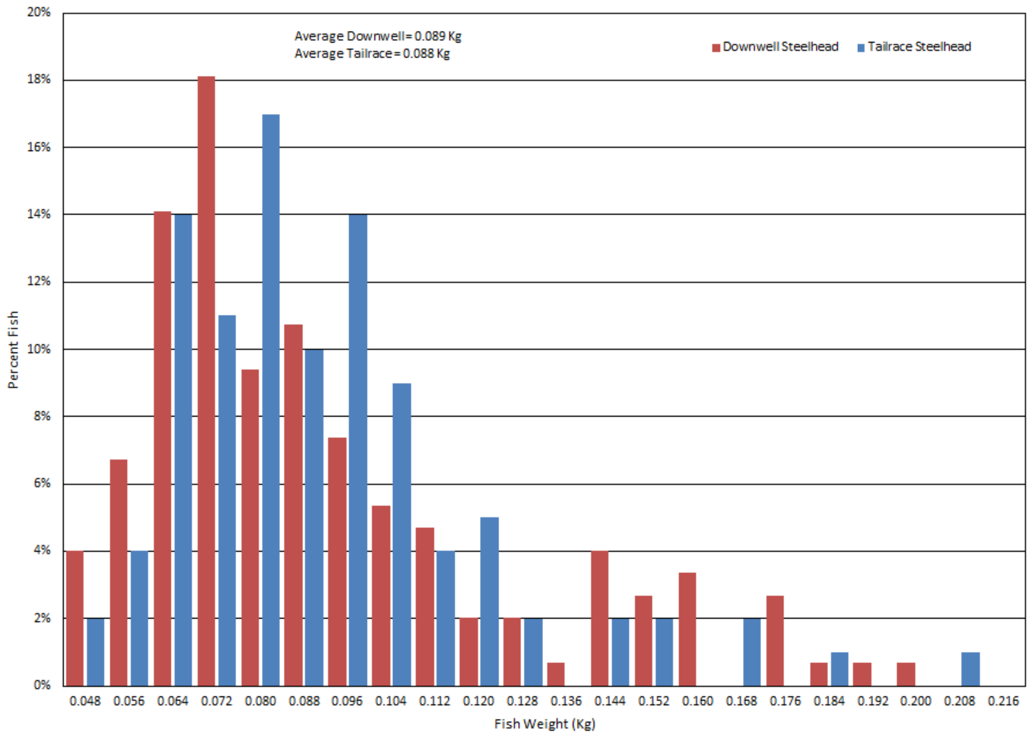


Figure 18. Fish weight distribution of acoustically tagged steelhead smolts at Mayfield Dam in 2014.

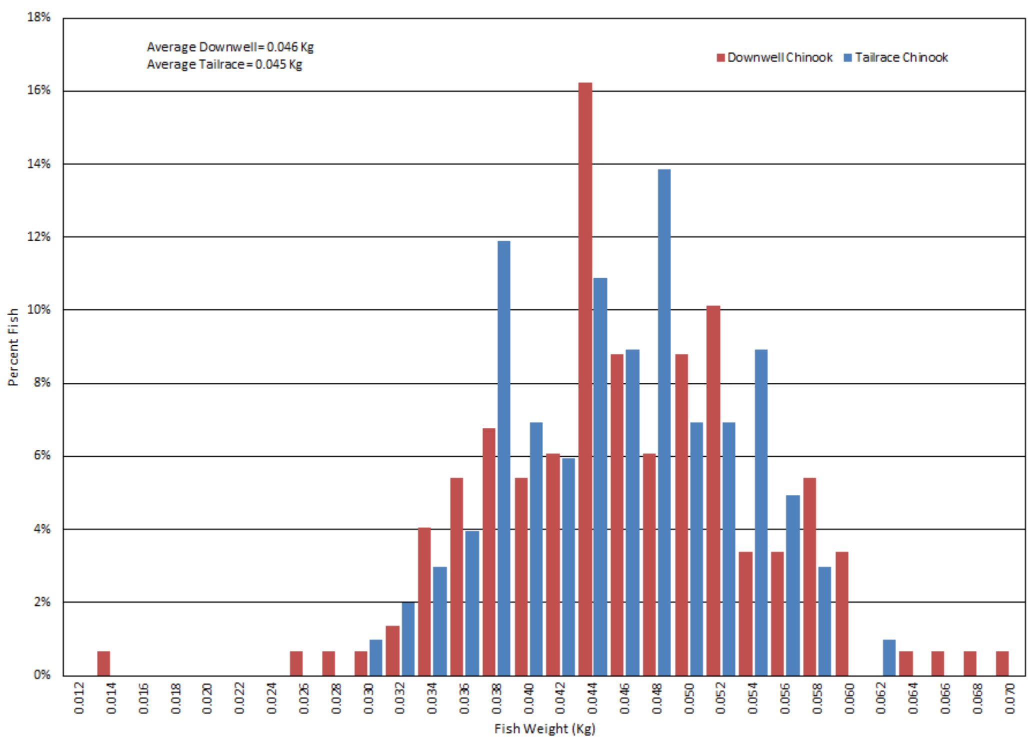


Figure 19. Fish weight distribution of acoustically tagged Chinook smolts at Mayfield Dam in 2014.

4.4 Project Flow Rates

River flow data for the 2014 Mayfield Dam survival study were summarized on a daily and weekly basis from May 1, 2014 through December 31, 2014. The Cowlitz River flow data passing though Mayfield Dam was acquired from the USGS website (http://waterdata.usgs.gov/usa/nwis/uv?14238000). The average daily flow rates in cubic feet per second (cfs) are presented in Figure 20. There was a wide range of daily flow rates ranging from a minimum of 2,470 cfs from July 3 through 8, 2014 to a maximum of 14,350 cfs on November 25 and 28, 2014. The average flow rate in the Cowlitz River over the study time period was 6,613 cfs.

The monthly average flow rates are presented in Figure 21. There was a wide range in monthly flow rates ranging from a high of 12,573 cfs in December 2014, to a low of 3,271 cfs in July 2014.

4.5 Fish Passage Run Timing

The Mayfield Dam survival study design incorporated tagging of fish during the peak month of the natural migration. The proportions of fish to be tagged each month was based on the average of the previous 11 years of run-timing results of coho and steelhead smolts as counted at the Mayfield Dam bypass counting station.

The 2014 run-timing of coho, steelhead and Chinook smolts at Mayfield Dam based on the counts at the counting station are presented in Figure 22. The coho smolt run-timing was primarily spread over 3 months (May-July) with the peak passage month of June when 66% of the smolts passed Mayfield Dam. The steelhead smolt run-timing was also primarily spread over 3 months (April-June) with the peak passage month of May when 68% of the smolts passed Mayfield Dam. The Chinook smolt run-timing was spread over 8 months (May-December) with the peak passage month of September when 27% of the smolts passed Mayfield Dam.

The proportion of coho, steelhead and Chinook smolts tagged each month is presented in Figure 23. In general, the coho, steelhead and Chinook smolts monthly tagging proportions approximated the major peaks of the smolt run-timing results, with the peak tagging month for coho of June (60%), for steelhead of May (80%) and for Chinook of October (78%).

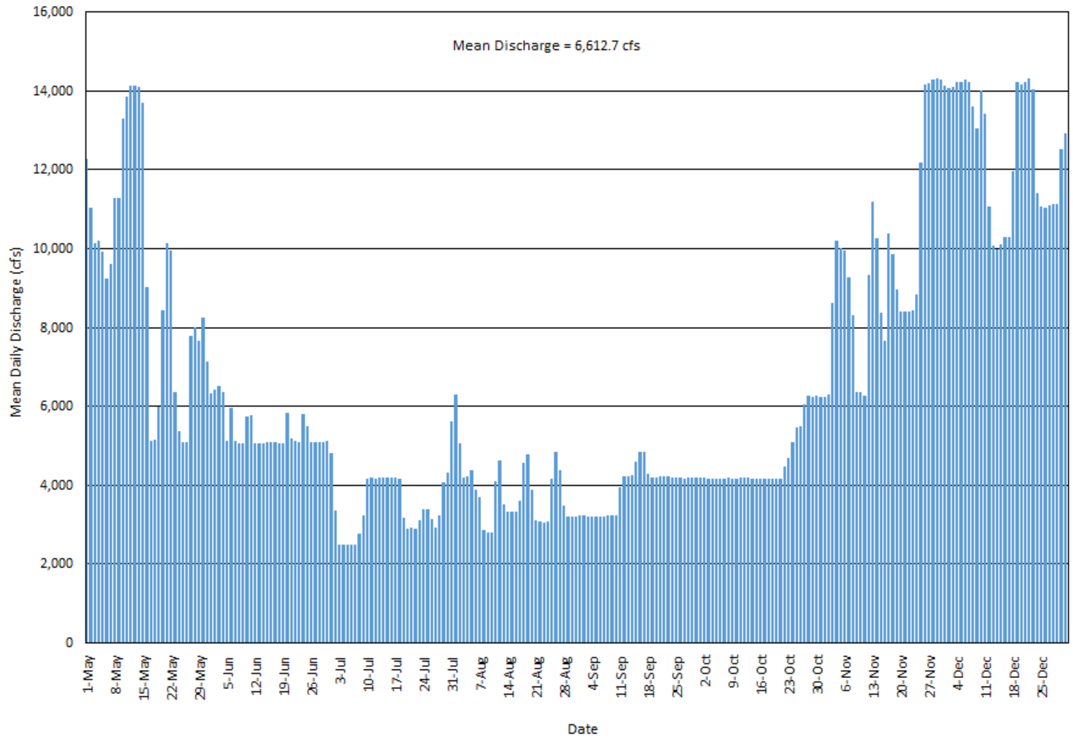


Figure 20. Cowlitz River daily average flow rates (cfs) at Mayfield Dam in 2014.

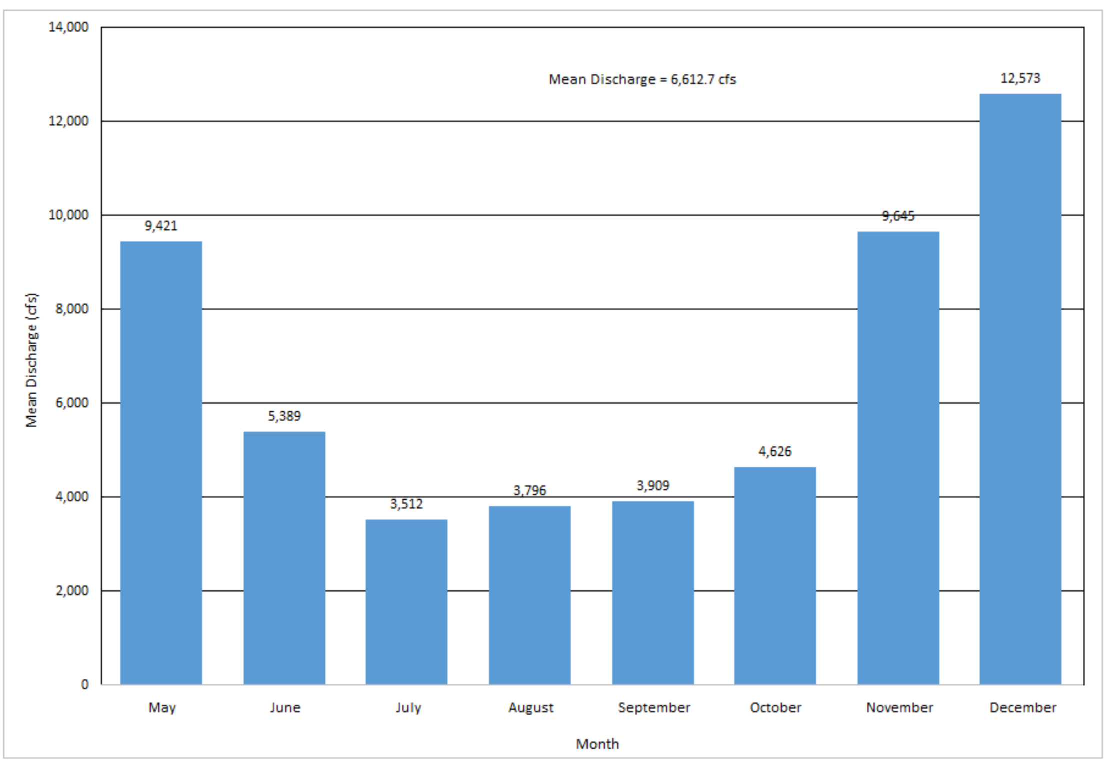


Figure 21. Cowlitz River monthly average flow rates (cfs) at Mayfield Dam in 2014.

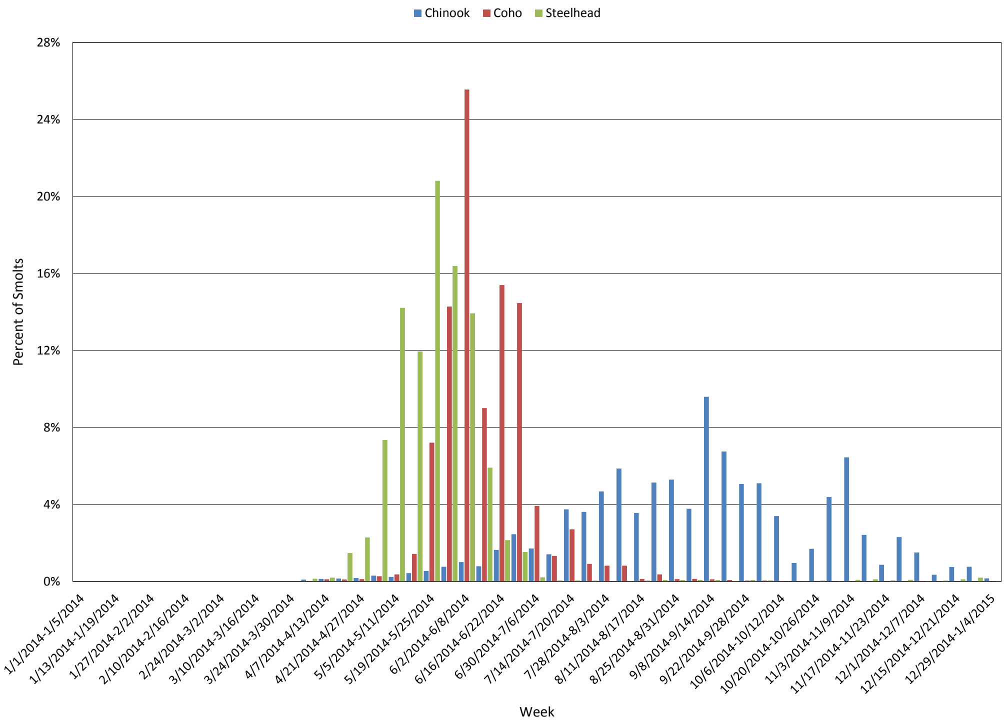


Figure 22. Monthly percent of smolts passing through the bypass channel at Mayfield Dam in 2014. The results are from Mayfield Dam Counting Station, part of the bypass system.

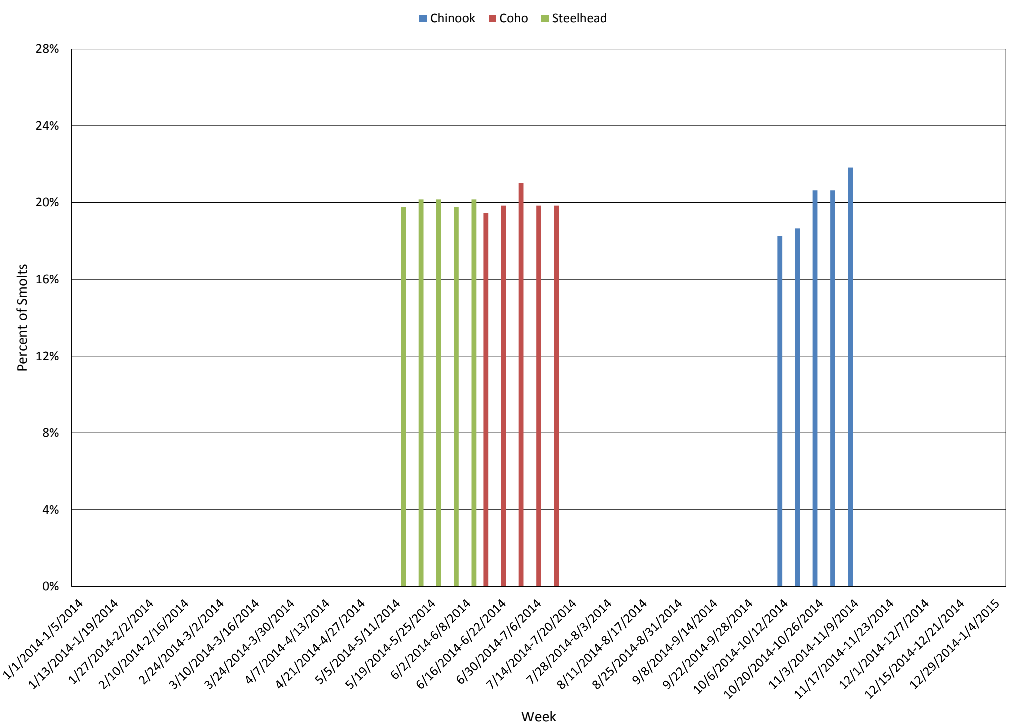


Figure 23. Monthly percent of smolts tagged for the survival study at Mayfield Dam in 2014.

4.6 Fish Passage Travel and Holding Times

Fish travel time is defined as the average amount of time from release, until the tagged smolts are detected at the various downstream detection sites. Fish holding time is defined by the time difference between the first and last detection of a given fish at the various detection sites. The results have been grouped by louver bay bypass (forebay) and tailrace smolts. The travel and holding times are presented in Table 7 for all tagged smolts species.

Juvenile bypass passage travel and holding times for the three species of smolts released in the north and south louver bay downwells, are presented in Figure 24. Steelhead smolts released into the north and south louver bay downwells, were first detected at the secondary separator, on average approximately 0.02 days after release and had an average holding time in the separator of 1.7 days. Steelhead smolts averaged 3.07 days from time of release to being detected at the transport tank. On average, the first detection in the Mayfield Dam tailrace of steelhead smolts was approximately 4.0 days after release, with an average holding time of 0.03 days in the tailrace. This suggests that steelhead smolts, on average, held in the bypass pipe approximately 1 day. The first detection of tagged steelhead smolts at the Upper Barrier detection site was on average 4.18 days after release, with an average holding time of 1.1 days in this region of the river. Steelhead smolts averaged 4.3 days to travel to the Barrier Dam detection site, and held at the Barrier Dam on average 0.04 days with no discernible holding. Bypass passage steelhead arrived at the Trout Hatchery on average in 5.2 days, and passed the Trout Hatchery in 0.02 days, again with no discernible holding.

Juvenile bypass passage coho smolts were first detected in the secondary separator, on average approximately 0.004 days after release, and averaged another 1.9 days in the separator before travelling into the bypass pipe, downstream to the collection facility. On average, the first detection in the transport tank of tagged coho smolts was approximately 3.1 days after release. The first detection of coho smolts at the Mayfield tailrace detection site was approximately 5.5 days after release, with a negligible average holding time of 0.2 days in the tailrace. This suggests that coho smolts, on average, held in the bypass pipe approximately 2.4 days. Mean travel time of coho smolts from time of release to the Upper Barrier detection site was 5.8 days, with a holding time of 1.2 days at this detection site. Mean travel time to the Barrier Dam was 6.1 days for coho smolts, with a holding time of another approximately 6.0 days (Table 7a). Bypass passage coho arrived at the Trout Hatchery on average, in 8.1 days, and passed the Trout Hatchery in 0.02 days with no discernible holding. The Barrier Dam coho arrival and holding overlap the Trout Hatchery detection and holding. This is primarily due to the fact that of the 118 coho smolts detected at the Barrier Dam, only 40 were subsequently detected at the Trout Hatchery.

Chinook smolts released in the downwells, were first detected in the secondary separator, on average approximately 0.56 days after release and averaged another 9.65 days holding in the separator before travelling into the bypass pipe to the raceways above the counting house. The first detection in the transport tank of Chinook smolts was approximately 8.0 days after release. Mean travel time through the bypass system to the Mayfield tailrace for Chinook smolts was 9.02 days, and Chinook smolts held in the tailrace region for approximately 0.17 days. This suggests that Chinook smolts, on average, held in the bypass pipe approximately 1 day. On average, the first detection at the Upper Barrier site of Chinook smolts was approximately 8.86 days after release, with a negligible mean holding time of 0.003 days. This apparent contradiction in travel time is a result of not all of the tagged fish reaching the Upper Barrier site due to either mortality and/or expiration of the tag batteries. Travel time for Chinook smolts released into the louver bay downwells to the Barrier Dam detection array averaged 8.55 days, with a minimal holding time of 0.003 days.

Table 7. Steelhead, coho and Chinook salmon smolt travel times (a), and holding times (b), from release at the louver bay apex downwells and the tailrace, to the various downstream detections sites for the 2014 Mayfield Dam survival study.

a)

Travel Time (days)	Secondary Separator	Transport Tank	Mayfield Tailrace	Upper Barrier	Barrier Dam	Trout Hatchery
Steelhead Forebay Releases	0.024	3.069	4.009	4.182	4.251	5.206
Steelhead Tailrace Releases				0.382	0.372	2.003
Coho Forebay Releases	0.004	3.107	5.504	5.762	6.094	8.096
Coho Tailrace Releases				1.874	2.139	4.765
Chinook Forebay Releases	0.557	7.965	9.015	8.475	8.549	9.322
Chinook Tailrace Releases				0.117	0.124	0.288

b)

Holding Time (days)	Secondary Separator	Transport Tank	Mayfield Tailrace	Upper Barrier	Barrier Dam	Trout Hatchery
Steelhead Forebay Releases	1.666	0.010	0.032	1.140	0.044	0.023
Steelhead Tailrace Releases				0.003	0.854	0.079
Coho Forebay Releases	1.932	0.006	0.198	1.243	5.993	0.021
Coho Tailrace Releases				1.386	6.653	0.004
Chinook Forebay Releases	9.652	0.006	0.171	0.003	0.003	0.001
Chinook Tailrace Releases				0.002	0.031	0.004

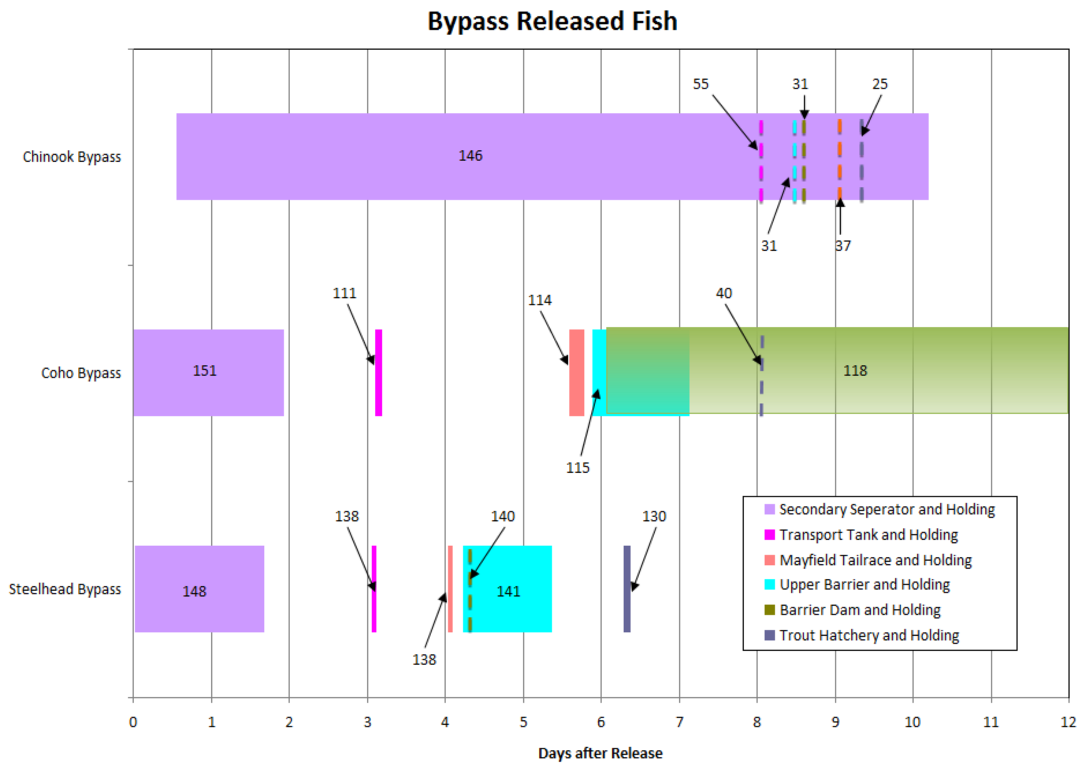


Figure 24. Travel and holding times for the three species, released in the north and south louver bay down-wells, at the various detection sites for the 2014 survival study. Numbers on the figure correspond to the sample size at that detection site.

Louver bay released Chinook smolts arrived at the Trout Hatchery in an average of 9.32 days, and passed the Trout Hatchery in 0.001 days with no discernible holding. The secondary separator Chinook arrival and holding overlap both the Barrier Dam and Trout Hatchery detection and holding. This was primarily due to the fact that of the 146 Chinook smolts entered the secondary separator, only 31 were detected at the Barrier Dam and only 25 were detected at the Trout Hatchery.

Travel and holding times, for each of the three species of smolts released in the tailrace of Mayfield Dam, are presented in Figure 25 and Table 8b. Tailrace released steelhead smolts were first detected at the Upper Barrier detection site, on average approximately 0.38 days after release, with a negligible mean holding time of 0.003 days. Tailrace released steelhead smolts averaged 0.37 days to travel to the Barrier Dam, with a mean holding time 0.85 days at the Barrier Dam. On average, the first detection at the Trout Hatchery of steelhead smolts was approximately 2.0 days post-release, and passed the Trout Hatchery in 0.08 days with no discernible holding.

Tailrace released coho smolts were first detected at the Upper Barrier detection site, on average approximately 1.87 days after release, with a holding time of 1.39 days in this region of the river. Mean travel time of coho smolts to the Barrier Dam was 2.14 days from time of release, and averaged another 6.65 days holding in the Barrier Dam detection zone. The first detection at the Trout Hatchery of tailrace released coho smolts was approximately 4.77 days and passed the Trout Hatchery in 0.004 days, with no discernible holding. Again, this apparent contradiction between holding times at the Barrier Dam, and mean travel time to the Trout Hatchery site, was a result of all the tagged fish observed at the Barrier Dam not making it to the Trout Hatchery site.

Tailrace released Chinook smolts were first detected at the Upper Barrier location, on average approximately 0.12 days after release and averaged 0.002 days holding in the vicinity of the detection array. Tailrace released Chinook averaged 0.124 days from time of release to travel to the Barrier Dam. Holding time at the Barrier Dam site for tailrace Chinook averaged 0.031 days. Mean travel time of tailrace released Chinook to the Trout Hatchery detection site was 0.288 days and passed the Trout Hatchery in 0.004 days, with no discernible holding.

Chinook smolts encountered significant delays in passing from the secondary separator through the bypass to the counting house, in comparison to the steelhead smolt travel and holding time results. Similar delays in passage of coho smolts were also observed at the Barrier Dam detection site, relative to the steelhead and Chinook smolt travel and holding time results at this location. The Chinook delays in smolt passage through the secondary separator and the coho delays at the Barrier Dam observed in this study, were also observed in the 2013 study.

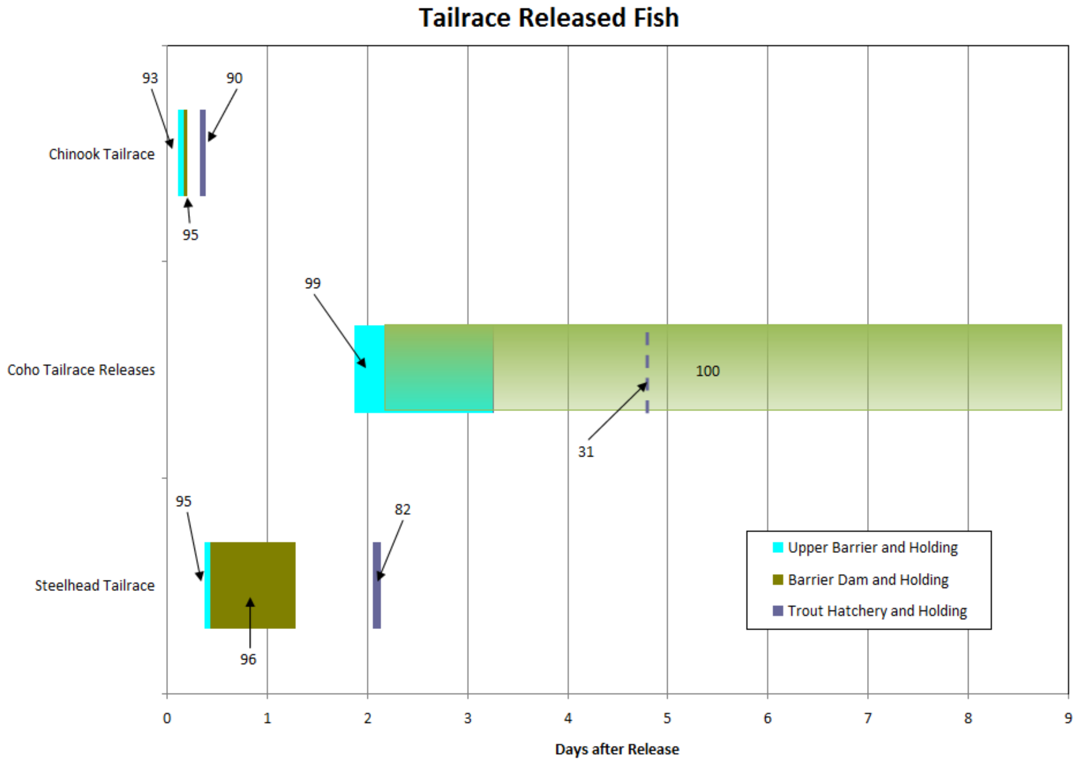


Figure 25. Travel and holding times, for the three species released in the tailrace, at the various detection sites for the 2014 survival study. Numbers on the figure correspond to the sample size at that detection site.

4.7 VIE-Tag Recovery Study

During preliminary analysis of the VIE tagged steelhead and coho results, discrepancies were observed in the detection rates at sequential downstream observation sites. The preliminary results suggested survival rates decreased as the tagged fish releases approached the recollection site located at the counting house. As a result of this analysis, TPU conducted a study to evaluate the tag retention and visual detection rates of the VIE tagged fish. These results showed that the VIE tagged fish were identifiable by all three VIE taggers, but a color bias in VIE tag identification was apparent for one of the three taggers. This finding precluded quantitative analysis of the VIE tagged steelhead and coho salmon study data due to potential tag misidentification or omission. Based on these findings, the two taggers that successfully identified correctly all of the passing VIE color-coded tagged fish were used for the VIE Chinook tagging portion of the study. Subsequently, only the results of the VIE tagged Chinook salmon are presented in the 2015 report.

The intent of the VIE-tagging study was to estimate smolt survival between the louver bay downwells and the secondary separator downwells S_{LB-SS} and between the secondary separator downwells and the Counting House S_{SS-CH} using the relative recovery model of Ricker (1958). The louver bay downwell releases were separated into north and south release locations. A chi-squared test of homogeneity found no difference in recovery rates of live Chinook smolts between north and south locations and, hence, the data were combined for subsequent analyses$(P(\chi_1^2 \geq 0.0442) = 0.8334)$. Observed discrepancies in the VIE colored tags results for the Chinook released at the entrance to the counting house raceways suggested a problem with detecting these VIE tagged fish and precluded the analysis and subsequent estimation of S_{SS-CH}. There were 61.13% recovery of the louver bay downwell releases, and 91.87% recovery of the secondary separator downwell releases, yet only 86.00% recovery of the releases at the entrance to the counting house.

For Chinook salmon smolts, the estimate of survival between louver bay downwells and downstream of the secondary separator was found to be

$$\hat{S}_{LB-SS} = \frac{\left(\frac{151}{247}\right)}{\left(\frac{226}{246}\right)} = \frac{0.6113}{0.9187} = 0.6654$$

with a standard error of $\widehat{SE}(\hat{S}_{LB-SS})$ = 0.0360.

4.8 Acoustic Tag Release-Redetection Study

4.8.1 Downstream Mixing Plots

One way the paired release-redetection study can meet model assumptions is if the release groups mix before arriving at downstream detection facilities. The arrival distributions of the louver bay (R_1) and tailrace (R_2) tag releases at the Trout Hatchery were visually compared (Figure 26). The Chinook salmon arrival pattern shows distinct forebay and tailrace release groups intermingled over the course of the study. The arrival distributions of coho salmon and steelhead show a greater degree of intermixing on both a daily basis and across the season.

4.8.2 Tag Life

Two tag-life studies were performed: one for the tags used on steelhead and coho salmon, and another for the tags used on Chinook salmon. Sample sizes were 33 and 65, respectively. The failure-time data for both tag groups were fit to a two-parameter Weibull distribution (Figure 27). Average tag life for the steelhead and coho salmon tags was estimated to be 29.35 days ($\widehat{SE}$ = 0.56). For the tags used on Chinook salmon, average tag life was estimated to be 17.29 days ($\widehat{SE}$ = 0.50).

The tag life reduction seen for the Chinook survival study as compared to the steelhead and coho survival studies was most likely due to when the tags were manufactured compared to when they were used in the study. The tags used in for the Chinook survival study were manufactured in late May and the Chinook smolts were tagged in October and November.

To determine if the studies had adequate tag life, the cumulative arrival distributions of the louver bay (R_1) releases to the Trout Hatchery detection array were superimposed on the tag-life curves (Figure 28). Inspection of the figures indicates both the steelhead and coho studies had adequate tag life for the fish to exit the study before tag failure became a serious issue. For Chinook salmon, some fish were still in play when tag life was near complete. This could negatively bias the results of the Chinook salmon study to some unknown but likely small degree.

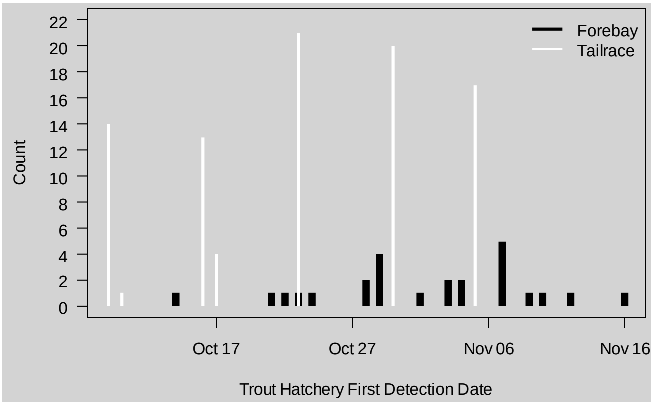
4.8.3 Paired-Release Survival Estimates

Paired release-recapture studies were used to estimate survival between the louver bay and tailrace (i.e., bypass passage survival). Approximately 150 acoustic tagged fish were released at the louver bay and 100 acoustic tagged fish at the tailrace for each of the three fish stocks (Table 8). A secondary analysis formed virtual release groups at the transport tank to estimate survival in the tailrace (i.e., transport tank to tailrace) using, again, the paired release-recapture model adjusted for tag life. Sizes of the virtual releases ranged from 55 for Chinook salmon to 138 for coho salmon (Table 8).

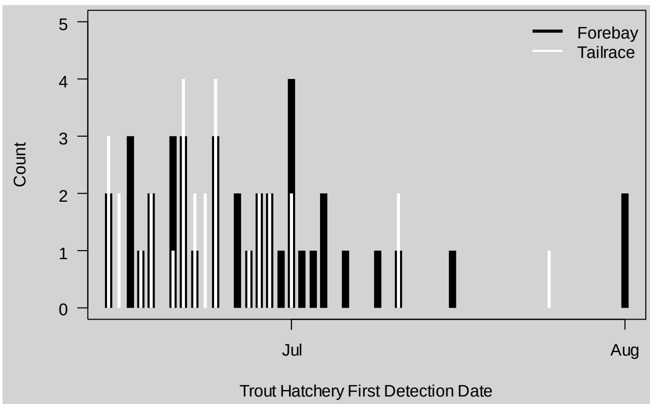
Paired release-recapture studies were used to estimate survival between the louver bay and tailrace (i.e., bypass passage survival). Bypass passage survival was estimated the lowest for Chinook salmon ($S_{Bypass=}0.2793, SE = 0.0476$) and highest for steelhead ($S_{Bypass=}0.9839, \quad SE = 0.0168$). Coho salmon had an intermediate estimate of dam passage survival ($S_{Bypass=}0.7979, SE = 0.0338$) (Table 9).

Estimates of transport tank to tailrace survival ranged from a high of 0.9891 ($\widehat{SE}$ = 0.0161) for steelhead to a low of 0.5490 ($\widehat{SE}$ = 0.1058) for Chinook salmon. The transport tank to tailrace survival for steelhead was just 0.0052 points above the estimate of overall dam passage survival. For coho salmon, the survival for the transport tank to tailrace was estimated to be 0.8296 ($\widehat{SE}$ = 0.0376) (Table 9).

a. Chinook salmon



b. Coho salmon



c. Steelhead

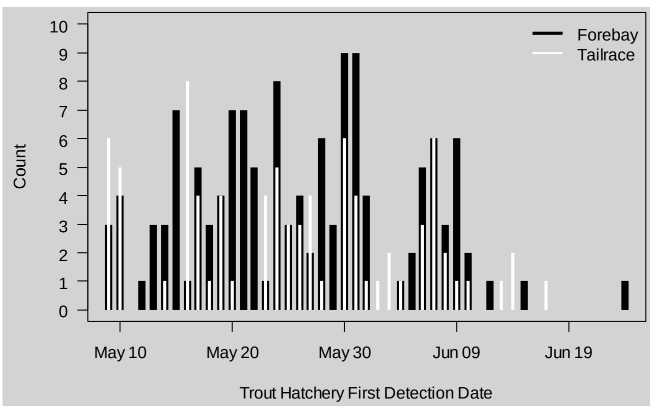
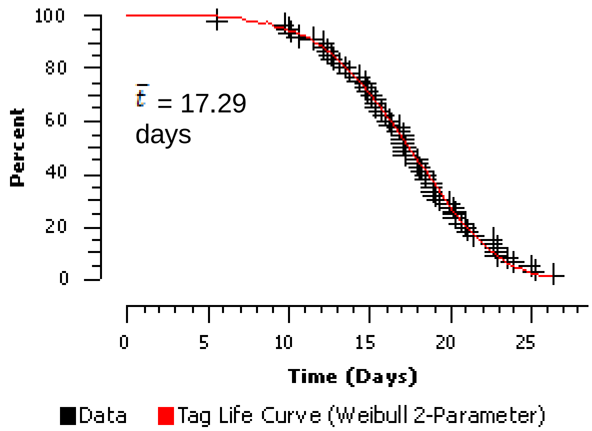


Figure 26. Arrival distributions of a) Chinook salmon, b) coho salmon, and c) steelhead at the Trout Hatchery array, based on first detections at the Trout Hatchery hydrophone array.

a. Chinook salmon tag



b. Steelhead/coho salmon tag

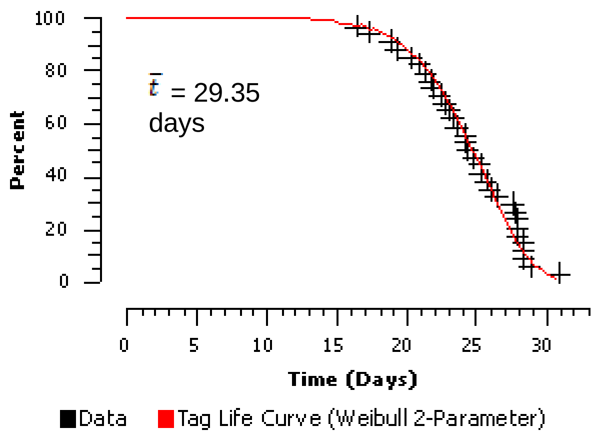
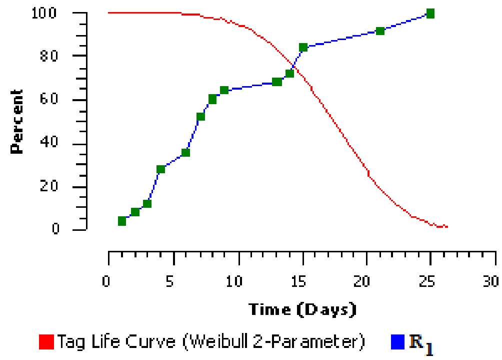
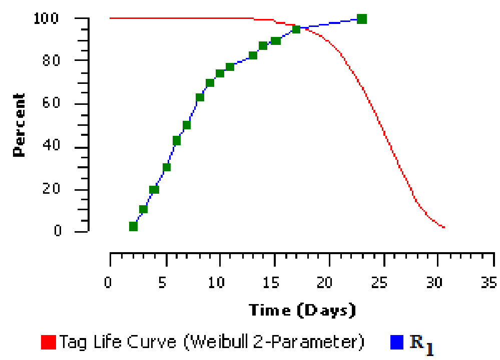


Figure 27. Fitted tag-life curves to the tag lots used in the a) Chinook salmon and b) steelhead/coho salmon acoustic tag studies and associated mean tag lives. Each + represents a failure time of a tag.

a. Chinook salmon



b. Coho salmon



c. Steelhead

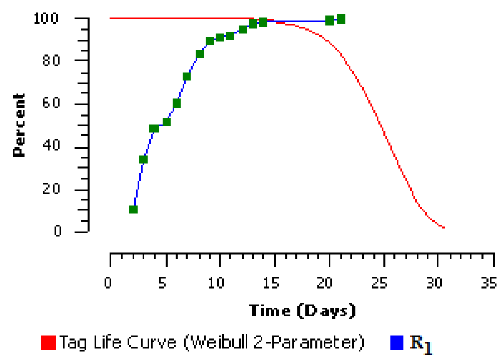


Figure 28. Plots of arrival distributions for the acoustic tag releases at the louver bay (R_1) to the Trout Hatchery versus lag-life curves for a) Chinook salmon, b) coho salmon, and c) steelhead.

Table 8. Acoustic tag release sizes used in estimating bypass passage survival and transport tank to tailrace survival at Mayfield Dam in 2014 by fish stock.

Species	Site	Release size
Chinook salmon	Forebay	151
	Tailrace	101
	Transport tank	55*
Coho salmon	Forebay	152
	Tailrace	100
	Transport tank	111*
Steelhead	Forebay	148
	Tailrace	100
	Transport tank	138*

*Virtual release

Table 9. Results of acoustic tagged paired release-recapture studies to estimate bypass passage survival and transport tank to tailrace survival for Chinook salmon, coho salmon, and steelhead at Mayfield Dam in 2014.

	Bypass survival		Tailrace survival	
Survivals	*S*	SE(*S*)	*S*	SE(*S*)
Chinook salmon	0.2793	0.0476	0.5490	0.1058
Coho salmon	0.7979	0.0338	0.8296	0.0376
Steelhead	0.9839	0.0168	0.9891	0.0161

4.8.4 Reach Survival Estimate

The louver bay acoustic tag release (R_1) was used to estimate reach survival through the Mayfield Dam and below to the Barrier Dam. The tailrace release (R_2) was used to estimate survival between the tailrace and the Upper Barrier.

Acoustic tag detection probabilities were high (>0.93) at the secondary separator, Upper Barrier array, and the Barrier Dam across all three fish stocks (Table 10). Detection probabilities in the transport tank varied considerably between fish stocks with a range of 0.7769–0.9384. The joint probability of survival between the Barrier Dam and the Trout Hatchery and being detected at the Trout Hatchery (i.e., $\lambda = S \cdot p$) ranged from 0.3390–0.9084 between fish stocks (Table 10).

Reach survivals by Chinook salmon were estimated at 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches (Table 11). However, reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace to Upper Barrier arrays were very low with values of 0.5175 ($\widehat{SE}$ = 0.0608), 0.6531 ($\widehat{SE}$ = 0.0876), and 0.7628 ($\widehat{SE}$ = 0.0934), respectively, for Chinook salmon.

Reach survivals by steelhead smolts were virtually 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches (Table 12). The reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace - Upper Barrier arrays were also very high with values of 0.9939 ($\widehat{SE}$ = 0.0068), 0.9945 ($\widehat{SE}$ = 0.0073), and 0.9858 ($\widehat{SE}$ = 0.0103), respectively, for steelhead.

Reach survivals for coho salmon smolts were nearly 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches (Table 13). The reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace - Upper Barrier arrays decreased through the bypass with values of 0.9398 ($\widehat{SE}$ = 0.0235), 0.9297 ($\widehat{SE}$ = 0.0283), and 0.9127 ($\widehat{SE}$ = 0.0269), respectively, for coho smolts.

Cumulative survival from release at the louver bay to the Barrier Dam was estimated at 0.2627 ($\widehat{SE}$ = 0.0443), 0.9697 ($\widehat{SE}$ = 0.0150), and 0.7851 ($\widehat{SE}$ = 0.0342) for Chinook salmon, steelhead, and coho, respectively (Table 14).

The reduced tag life for the Chinook study most likely had little effect on the reach survivals through the secondary separator and transfer tank. The reach survivals and cumulative survivals to the downstream in river detections sites may have been negatively biased to some unknown but likely small degree.

The low acoustic tag survival estimates for Chinook salmon correspond to the low values observed in the VIE tag study (see Section 4.7). The location of the low survival estimates was similar for both the VIE and acoustic tag study. The VIE tag study estimated Chinook salmon survival between louver bay and downstream of the secondary separator at 0.6654 ($\widehat{SE}$ = 0.0360). Similarly, the acoustic tag study estimated low survival between the secondary separator and the transport tank ($\hat{S}$ = 0.5175, $\widehat{SE}$ = 0.0608). In addition, the acoustic tag Chinook survival was low between the transport tank and the tailrace ($\hat{S}$ = 0.6531, $\widehat{SE}$ = 0.0876). The 2014 study has identified a survival problem with Chinook salmon, and it points to the bypass system from upstream of the secondary separator through the transfer tank.

4.8.5 Travel Time

Travel times (mean and median) were calculated for all available reaches within and below the Mayfield Dam using acoustic tag detections. Median travel times were generally shorter than average travel time because of the right-skewed distribution of the travel times.

Travel times between the louver bay and the secondary separator were among the shortest with a range of 0.002–0.021 d median time, depending on fish stock (Table 15). In general, the longest travel times were between the secondary separator and the transport tank with a range of 0.941–1.744 d median time, depending on species.

Table 10. Acoustic tag detection probabilities for the R_1 release group by array location and fish stock.

	Chinook salmon		Steelhead		Coho salmon	
Array location	$\hat{p}$	$\widehat{\mathrm{SE}}(\hat{p})$	$\hat{p}$	$\widehat{\mathrm{SE}}(\hat{p})$	$\hat{p}$	$\widehat{\mathrm{SE}}(\hat{p})$
Secondary separator	0.9516	0.0273	1.0	0.0	0.9929	0.0071
Transport tank	0.8293	0.0588	0.9384	0.0199	0.7769	0.0365
Tailrace	0.8788	0.0568	0.9444	0.0191	0.8667	0.0310
Upper Barrier	0.9394	0.0416	0.9790	0.0120	0.9576	0.0185
Barrier Dam	0.9200	0.0543	0.9769	0.0132	1.0	0.0
Trout Hatchery*	0.7919	0.0786	0.9084	0.0246	0.3390	0.0436

$*\lambda = S \cdot p$

Table 11. Reach survival estimates for Chinook salmon using the single release-recapture model and either the louver bay (R_1) or tailrace (R_2) acoustic tag releases.

	R_1		R_2	
Reach	$\hat{S}$	$\widehat{\mathrm{SE}}(\hat{S})$	$\hat{S}$	$\widehat{\mathrm{SE}}(\hat{S})$
Louver Bay –Secondary separator	1.0190	0.0201	N/A	
Secondary separator – Transport tank	0.5175	0.0608	N/A	
Transport tank – Tailrace	0.6531	0.0876	N/A	
Tailrace – Upper Barrier	0.7628	0.0934	0.9406	0.0235
Upper Barrier – Barrier Dam	1.0	0.0	1.0	0.0

Table 12. Reach survival estimates for steelhead using the single release-recapture model and either the louver bay (R_1) or tailrace (R_2) acoustic tag releases.

Reach	R_1		R_2	
	$\hat{S}$	$\widehat{\mathrm{SE}}\left(\hat{S}\right)$	$\hat{S}$	$\widehat{\mathrm{SE}}\left(\hat{S}\right)$
Louver Bay – Secondary separator	1.0	0.0	N/A	
Secondary separator – Transport tank	0.9939	0.0068	N/A	
Transport tank – Tailrace	0.9945	0.0073	N/A	
Tailrace – Upper Barrier	0.9858	0.0103	0.9904	0.0100
Upper Barrier – Barrier Dam	0.9951	0.0074	0.9935	0.0109

Table 13. Reach survival estimates for coho salmon using the single release-recapture model and either the louver bay (R_1) or tailrace (R_2) acoustic tag releases.

Reach	R_1		R_2	
	$\hat{S}$	$\widehat{\mathrm{SE}}\left(\hat{S}\right)$	$\hat{S}$	$\widehat{\mathrm{SE}}\left(\hat{S}\right)$
Louver Bay – Secondary separator	1.0006	0.0006	N/A	
Secondary separator – Transport tank	0.9398	0.0235	N/A	
Transport tank – Tailrace	0.9297	0.0283	N/A	
Tailrace – Upper Barrier	0.9127	0.0269	1.0025	0.0009
Upper Barrier – Barrier Dam	0.9839	0.0130	1.0001	0.0017

Table 14. Cumulative survival estimates through Mayfield Dam, and downriver by fish stock using the louver bay (R_1) acoustic tag releases.

Array location	Chinook salmon $\hat{S}$	Chinook salmon $\widehat{SE}(\hat{S})$	Steelhead $\hat{S}$	Steelhead $\widehat{SE}(\hat{S})$	Coho salmon $\hat{S}$	Coho salmon $\widehat{SE}(\hat{S})$
Release	1.0		1.0		1.0	
Secondary separator	1.0190	0.0201	1.0000	< 0.0001	1.0006	0.0006
Transport tank	0.5273	0.0606	0.9939	0.0068	0.9403	0.0234
Tailrace	0.3435	0.0511	0.9883	0.0095	0.8697	0.0294
Upper Barrier	0.2627	0.0442	0.9744	0.0136	0.7979	0.0335
Barrier Dam	0.2627	0.0443	0.9697	0.0150	0.7851	0.0342

Table 15. Mean $(\bar{x})$ and median travel times for Chinook salmon, steelhead, and coho salmon based on acoustic tag detections. Time expressed in days (d).

a.

Reach	Chinook salmon Mean $(\bar{x})$	Chinook salmon SE $(\bar{x})$	Chinook salmon Median	Steelhead Mean $(\bar{x})$	Steelhead SE $(\bar{x})$	Steelhead Median	Coho salmon Mean $(\bar{x})$	Coho salmon SE $(\bar{x})$	Coho salmon Median
Louver Bay – Secondary separator[a]	0.558	0.131	0.021	0.024	0.010	0.002	0.004	<0.001	0.003
Secondary separator – Transportation tank[a]	1.783	0.157	1.743	1.448	0.110	0.941	1.594	0.123	0.955
Transportation tank – Tailrace[a]	1.288	0.349	0.571	1.005	0.099	0.590	2.484	0.297	1.296
Tailrace – Upper Barrier[b]	0.117	0.011	0.064	0.382	0.081	0.099	1.875	0.358	0.391
Upper Barrier – Barrier Dam[c]	0.006	<0.001	0.006	0.024	0.005	0.008	0.160	0.062	0.028
Barrier Dam – Trout Hatchery[c]	0.120	0.011	0.093	1.295	0.154	0.345	2.029	0.333	0.878

b. Based on louver bay release (R_1)
c. Based on tailrace release (R_2)
d. Based on pooled R_1 and R_2 releases

4.9 Summary

The 2014 juvenile bypass survival study at Mayfield Dam released 252 live coho, 248 steelhead and 252 Chinook smolts implanted with operating acoustic tags. These numbers of released tagged fish met the pre-determined, recommended sample size requirements of 250 tagged fish per species group, as defined in the study plan. The peak number of tagged fish released per study month in 2014 generally corresponded to the historic peak passage month of each species at Mayfield Dam over the preceding 10 year period. The 2014 coho smolt outmigration occurred during May-July, with the largest proportion of this species passing in June (66%). Steelhead smolt run-timing was distributed over April-June with the largest proportion passing in May (68%). The 2014 Chinook smolt run-timing was spread over 8 months (May-December) with the largest proportion passing in September (27%). The study design goal, to time the releases of tagged smolts to match the natural outmigration timing of each species at Mayfield Dam was generally met for steelhead and coho in 2014. The Chinook releases occurred after the peak of the outmigration.

The tagged forebay smolts were released in the north and south louver bay apex downwells, which precluded the possibility of treatment fish not travelling downstream through the juvenile bypass channel, into the secondary separator, and ultimately through to the counting house below the dam. Therefore, there was no concern for tagged treatment fish being lost from the study (i.e. by migrating upstream to the forebay).

During the fall outmigration, a large proportion of Chinook smolts were found to be unhealthy. The majority of the unhealthy Chinook smolts were infested with internal parasites. All of the Chinook smolts may have had compromised immune systems. For this reason, an attempt was made to tag and mark the healthier Chinook smolts. The 2014 study results were most likely affected by the unhealthy Chinook smolts.

Dead fish releases conducted on 10 April 2014 detected no dead fish passing the new hydrophone array deployed at the Upper Barrier site, or the existing hydrophone arrays at the Barrier Dam, or the Trout Hatchery. The Cowlitz River flow rate was approximately 9,000 cfs during the dead fish releases. Therefore, there was little concern that any fish mortalities that occurred during juvenile bypass system passage would positively bias the JBS passage survival estimates.

Bias attributed to fish tagger effects in the 2013 study, were not a consideration during the 2014 acoustic tag study, as all fish tagging was conducted by a single tagger.

The mean monthly Cowlitz River flow rate at Mayfield Dam ranged from a low of 3,271 cfs to a high of 12,573 cfs. The mean monthly river flow rates decreased from the beginning of sampling in May through October, before steadily increasing through to December. The low summer flow rates may have contributed to the slower downstream migration rates of coho smolts in late summer.

It was anticipated that the majority of steelhead, coho, and Chinook smolts released in the louver bay downwells would pass through the juvenile bypass system through to the counting house relatively quickly. Average coho smolt travel times, from release to the final detection at the Trout Hatchery was 4.8 days for tailrace-released fish, and 8.1 days for bypass-released fish passing through the bypass system. Average coho holding times were relatively long at the Barrier Dam and ranged from 6.0 days for bypass passage fish, and 6.7 days for tailrace-released fish.

Average steelhead smolt travel times, from release to the final detection at the Trout Hatchery was 2.0 days for tailrace released fish, and 5.2 days for louver bay-released fish passing through the bypass system. Average steelhead smolt holding times were relatively short for all of the sampling locations.

The average Chinook smolt travel times, from release to the final detection at the Trout Hatchery was 0.3 days for tailrace-released fish, and 9.3 days for louver bay-released fish passing through the bypass system. Mean Chinook holding times were relatively long at the secondary separator, requiring an average of 9.7 days before exiting the secondary separator.

Chinook smolts encountered significant delays in passing from the secondary separator through the bypass to the counting house, in comparison to the steelhead smolt travel and holding time results. The delays in Chinook smolt passage through the secondary separator observed in this study, were also observed in the 2013 study. Similar delays in passage of coho smolts, was also observed at the Barrier Dam detection site, relative to the steelhead and Chinook smolt travel and holding time results at this location.

During preliminary analysis of the VIE tagged steelhead and coho results, discrepancies were observed in the detection rates at sequential downstream observation sites. The preliminary results suggested survival rates decreased as the tagged fish releases approached the recollection site located at the counting house. As a result of this analysis, TPU conducted a study to evaluate the tag retention and visual detection rates of the VIE tagged fish. These results showed that the VIE tagged fish were identifiable by all three VIE taggers, but a color bias in VIE tag identification was apparent for one of the three taggers. This finding precluded quantitative analysis of the VIE tagged steelhead and coho salmon study data due to potential tag misidentification or omission. Based on these findings, the two taggers that successfully identified correctly all of the passing VIE color-coded tagged fish were used for the VIE Chinook tagging portion of the study. Subsequently, only the results of the VIE tagged Chinook salmon are presented.

The VIE tagging study to estimate smolt survival between the louver bay downwells and the secondary separator downwells S_{LB-SS} was calculated using the relative recovery model of Ricker (1958). The louver bay downwell releases were separated into north and south release locations. A chi-squared test of homogeneity found no difference in recovery rates of live Chinook smolts between north and south locations and, hence, the data were pooled for subsequent analyses $(P(\chi_1^2 \geq 0.0442) = 0.8334)$. For Chinook salmon smolts, the estimate of survival between louver bay downwells and downstream of the secondary separator was found to be S_{LB-SS}=0.6654, with a standard error of $\widehat{\mathrm{SE}}(\hat{S}_{LB-SS})$ = 0.0360.

Paired release-recapture studies were used to estimate survival between the louver bay and tailrace (i.e., bypass passage survival). Bypass passage survival was estimated the lowest for Chinook salmon ($S_{Bypass=}0.2793, SE = 0.0476$) and highest for steelhead ($S_{Bypass=}0.9839$, $SE = 0.0168$). Coho salmon had an intermediate estimate of dam passage survival ($S_{Bypass=}0.7979, SE = 0.0338$).

Estimates of transport tank to tailrace survival ranged from a high of 0.9891 ($\widehat{\mathrm{SE}}$ = 0.0161) for steelhead to a low of 0.5490 ($\widehat{\mathrm{SE}}$ = 0.1058) for Chinook salmon. The transport tank to tailrace survival for steelhead was just 0.0052 points above the estimate of overall dam passage survival. For coho salmon, the survival of the transport tank to tailrace was estimated to be 0.8296 ($\widehat{\mathrm{SE}}$ = 0.0376).

Acoustic tag detection probabilities were high (>0.93) at the secondary separator, Upper Barrier array, and the Barrier Dam across all three fish stocks. Detection probabilities in the transport tank varied considerably between fish stocks with a range of 0.7769–0.9384. The joint probability of survival between the Barrier Dam and the Trout Hatchery and being detected at the Trout Hatchery (i.e., $\lambda = S \cdot p$) ranged from 0.3390–0.9084 between fish stocks.

Reach survivals by Chinook salmon were estimated at 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches. However, reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace to Upper Barrier arrays were very low with values of 0.5175 ($\widehat{SE}$ = 0.0608), 0.6531 ($\widehat{SE}$ = 0.0876), and 0.7628 ($\widehat{SE}$ = 0.0934), respectively, for Chinook salmon.

Reach survivals by steelhead smolts were virtually 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches. The reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace - Upper Barrier arrays were also very high with values of 0.9939 ($\widehat{SE}$ = 0.0068), 0.9945 ($\widehat{SE}$ = 0.0073), and 0.9858 ($\widehat{SE}$ = 0.0103), respectively, for steelhead.

Reach survivals for coho salmon smolts were nearly 1.0 for the louver bay – secondary separator and Upper Barrier – Barrier Dam reaches. The reach survivals between the secondary separator and transport tank, between the transport tank – tailrace, and tailrace - Upper Barrier arrays decreased through the bypass with values of 0.9398 ($\widehat{SE}$ = 0.0235), 0.9297 ($\widehat{SE}$ = 0.0283), and 0.9127 ($\widehat{SE}$ = 0.0269), respectively, for coho smolts.

The individual reach survivals can be multiplied together to estimate a cumulative survival. Cumulative survival from release at the louver bay to the Barrier Dam was estimated at 0.2627 ($\widehat{SE}$ = 0.0443), 0.9697 ($\widehat{SE}$ = 0.0150), and 0.7851 ($\widehat{SE}$ = 0.0342) for Chinook salmon, steelhead, and coho, respectively.

The low acoustic tag survival estimates for Chinook salmon correspond to the low values observed in the VIE tag study. The location of the low survival estimates was similar for both the VIE and acoustic tag study. The VIE tag study estimated Chinook salmon survival between louver bay and downstream of the secondary separator at 0.6654 ($\widehat{SE}$ = 0.0360). Similarly, the acoustic tag study estimated low survival between the secondary separator and the transport tank ($\hat{S}$ = 0.5175, $\widehat{SE}$ = 0.0608). In addition, the acoustic tag Chinook survival was low between the transport tank and the tailrace ($\hat{S}$ = 0.6531, $\widehat{SE}$ = 0.0876). The 2014 study has identified a survival problem with Chinook salmon, and it points to the bypass system from upstream of the secondary separator through the transfer tank.

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APPENDIX A. Statistical Plan for Mayfield Dam Survival Studies in 2014

Statistical Plan for the
Juvenile Salmonid Survival Studies at Mayfield Dam in 2014

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9 April 2014

Contents

Introduction

The objective of the 2014 tagging studies at Mayfield Dam is to estimate juvenile bypass system (JBS) passage survival and partition passage survival in the JBS for steelhead, coho salmon, and Chinook salmon smolts. Ancillary information on travel times will also be collected.

Study Design

Acoustic-Tag Release-Recapture Designs

A paired release-recapture design will be used to estimate JBS passage survival at the Mayfield Dam. Treatment fish (i.e., upstream fish) will be released into the Louver Bay Apex Downwells; control fish (i.e., downstream fish) will be released into the tailrace. Unlike 2013, additional hydrophone detection arrays will be located in the JBS at the secondary separator and transportation tank. There will also be three below-dam detection arrays (Figure 1). For each of the steelhead, coho salmon, and Chinook salmon stocks, release sizes will be 150 at the Louver Bay Apex Downwells and 100 in the tailrace. This release-recapture design will permit both paired- and single-release estimates of survival (Figure 1).

In addition, dead tagged fish releases will be performed to assure the first below-dam detection array is sufficiently far to avoid false-positive detections due to fish that died during dam passage with still active tags. Furthermore, 50 acoustic tags will be used to estimate tag life in order to produce tag-life-corrected estimates of fish survival.

Visible Implant Elastomer (VIE) Tags

There will be three releases of visible implant elastomer (VIE) tags within the Mayfield Dam in 2014. Release locations will be at the Louver Bay Apex Downwells, Secondary Separator, and Entrance to the Counting House Raceway. All tag recoveries will occur at the Counting House. Release sizes will be 250 fish per release location per fish stock (steelhead, coho salmon, and Chinook salmon) (Figure 2).

Tag Release Schedule

The tagging studies will occur during the middle of the outmigration for each fish stock. For steelhead, releases are planned roughly weekly between 6 May – 6 June 2014. For coho salmon, releases are planned roughly weekly between 10 June – 11 July 2014. For Chinook salmon, weekly releases are planned between 23 September – 31 October. For each fish stock, even numbers of fish will be released weekly at the respective release locations for both acoustic- and VIE-tagged fish.

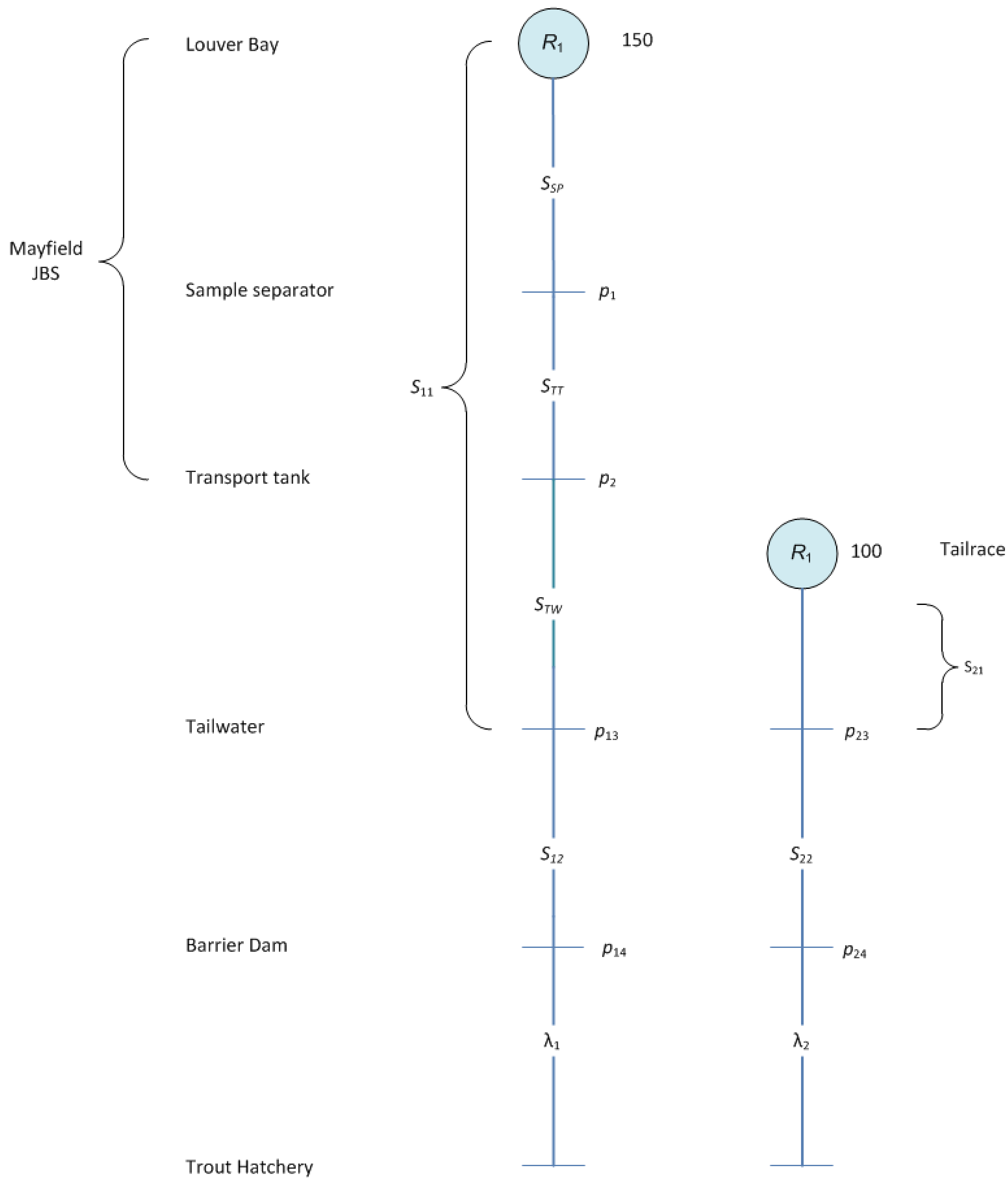

Figure A1. Schematic of the acoustic-tag, release-recapture design at Mayfield Dam in 2014, along with releases (R), reach survivals (S), detection probabilities (p), and joint survival and detection (λ) parameters that will be estimated.

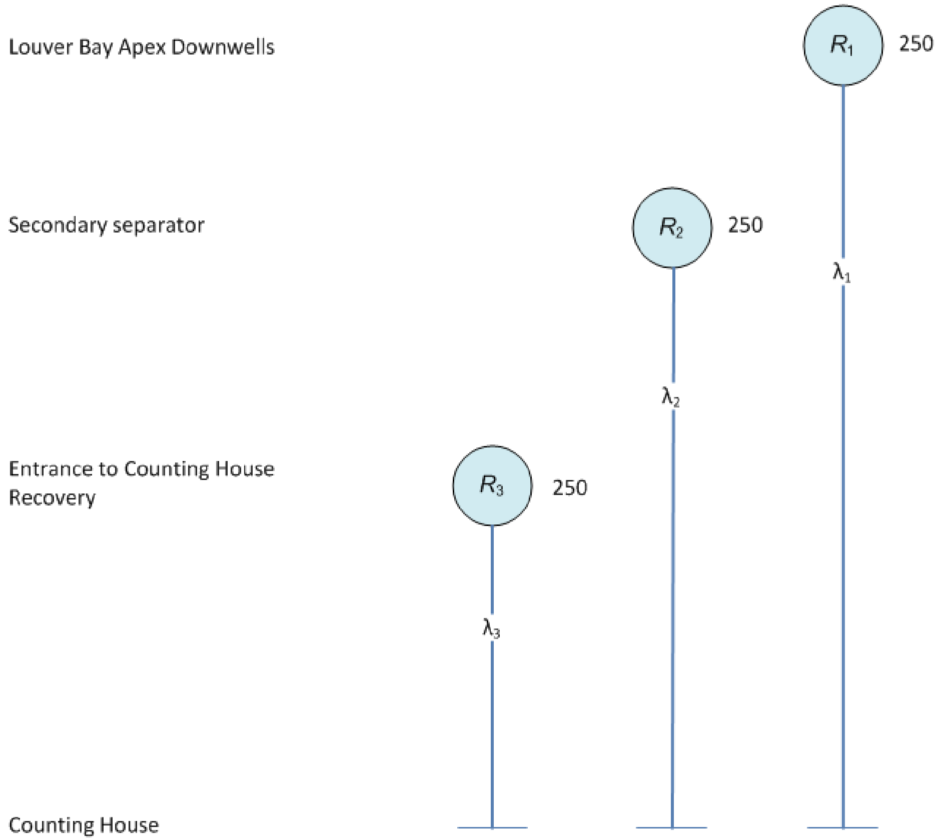

Figure A2. Schematic of VIE-tag, release-recapture design with releases (R), and joint probabilities of survival and detection (λ) which are directly estimable.

Tagger Effort

In order to minimize tagger effects on the estimates of dam passage survival, the multiple taggers should tag the same proportion of fish in both the upstream (R_1) and downstream (R_2) releases (Figure 1). Individual taggers can tag different numbers of fish, but the proportions should be the same in the R_1 and R_2 releases.

Also, in order to detect tagger effects, the tagger effort should also be evenly distributed over time. For example, some taggers should not tag fish only early in the outmigration and the other staff tag fish only later in the study. Such a disproportionate distribution of effort will make detection of deleterious tagger effects difficult.

Data Analysis

Tests of Assumptions

Downstream Mixing

Evaluation of homogeneous arrival of release groups at downriver detection sites (i.e., tailwater, Barrier Dam, trout hatchery) will be based on graphs of arrival distributions. The graphs will be used to identify any systematic and meaningful departures from mixing. Ideally, the arrival distributions should overlap one another with similarly timed modes.

Tagger Effects

Subtle differences in handling and tagging techniques can have an effect on the survival of acoustically tagged smolts used in the estimation of dam passage survival. For this reason, tagger effects will be evaluated. The single release-recapture model will be used to estimate reach survivals for fish tagged by different individuals. The analysis will evaluate whether any consistent pattern of reduced reach survivals exists for fish tagged by any of the tagging staff.

For independent reach survival estimates from k different taggers, a test of equal survival will be performed using the F-test

$$F_{k-1,\infty} = \frac{s_{\hat{S}}^2}{\left(\frac{\sum_{i=1}^{k} \operatorname{Var}\left(\hat{S}_i \middle| S_i\right)}{k}\right)} \tag{1}$$

where

$$s_{\hat{S}}^2 = \frac{\sum_{i=1}^{k}\left(\hat{S}_i - \hat{\bar{S}}\right)^2}{k-1} \tag{2}$$

and

$$\hat{\bar{S}} = \frac{\sum_{i=1}^{k}\hat{S}_i}{k}. \tag{3}$$

This F-test will be used in evaluating tagger effects.

Survival Analysis – Acoustic Tags

The analysis of the acoustic-tag study will be a combination of single and paired release-recapture methods.

Single Release-Recapture Methods

The single release-recapture method (Skalski et al. 1998) will be used to estimate survival within the JBS using the R_1 release group (Figure 1). Survival within the JBS will be estimated for the following reaches:

S_{SP}	Louver Bay – Sample separator
S_{TT}	Sample separator – Transport tank
S_{TW}	Transport tank – Tailwater array

Survival through the JBS can be estimated by the product

$$S_{SP} \cdot S_{TT} \cdot S_{TW} \, .$$

Program ATLAS (http://www.cbr.washington.edu/analysis/apps/atlas) will be used to provide tag-life-adjusted survival estimates for these reaches.

It should be noted that these estimates may be negatively biased if there are any post-release handling or tag effects.

Paired Release-Recapture Methods

The paired-release design for complete capture histories (Burnham et al. 1987:112-145) will be used to estimate survival between the Louver Bay and tailrace (Figure 1). Using the three downstream detection arrays, there will be eight possible capture histories of reach release group (i.e., R_1 and R_2, Figure 1) (Table 1). Program ATLAS will be used to provide tag-life-adjusted survival estimates. Survival through the JBS will be estimated by the quotient

$$\hat{S}_{\mathrm{JBs}} = \frac{\hat{S}_{11}}{\hat{S}_{21}} \, . \qquad (4)$$

A fully parameterized model will be used to estimate the release-recapture parameters for the model depictured in Figure 1. With the anticipated high detection probabilities ($p \geq 0.95$), there is no precision benefit in using a more parsimonious model. In so doing, both the precision and model robustness are retained.

Table A1. Possible capture histories and associated probabilities of occurrence used in modeling the paired release-recapture study at Mayfield Dam. "1" denotes detection, and "0" denotes no detection.

Release Group	Capture History	Probability of Occurrence
R_1	111	$S_{11}p_{13}S_{12}p_{14}\lambda_1$
	011	$S_{11}(1-p_{13})S_{12}p_{14}\lambda_1$
	101	$S_{11}p_{13}S_{12}(1-p_{14})\lambda_1$
	001	$S_{11}(1-p_{13})S_{12}(1-p_{14})\lambda_1$
	110	$S_{11}p_{13}S_{12}p_{14}(1-\lambda_1)$
	010	$S_{11}(1-p_{13})S_{12}p_{14}(1-\lambda_1)$
	100	$S_{11}p_{13}[(1-S_{12})+S_{12}(1-p_{14})(1-\lambda_1)]$
	000	$(1-S_{11})+S_{11}(1-p_{13})[(1-S_{12})+S_{12}(1-p_{14})(1-\lambda_1)]$
R_2	111	$S_{21}p_{23}S_{22}p_{24}\lambda_2$
	011	$S_{21}(1-p_{23})S_{22}p_{24}\lambda_2$
	101	$S_{21}p_{23}S_{22}(1-p_{24})\lambda_2$
	001	$S_{21}(1-p_{23})S_{22}(1-p_{24})\lambda_2$
	110	$S_{21}p_{23}S_{22}p_{24}(1-\lambda_2)$
	010	$S_{21}(1-p_{23})S_{22}p_{24}(1-\lambda_2)$
	100	$S_{21}p_{23}[(1-S_{22})+S_{22}(1-p_{24})(1-\lambda_2)]$
	000	$(1-S_{21})+S_{21}(1-p_{23})[(1-S_{22})+S_{22}(1-p_{24})(1-\lambda_2)]$

Survival Analysis – VIE Tags

For the VIE tagging study, survival within the JBS will be estimated using the paired-release design for relative recovery methods (Burnham et al. 1987:78-100). Using the VIE-tag releases, two estimates of survival can be calculated:

3. Survival between Louver Bay and the Secondary Separator, i.e.,

$$\hat{S}_{SS} = \frac{\hat{\lambda}_1}{\hat{\lambda}_2} \quad (5)$$

with associated variance estimator

$$\widehat{\mathrm{Var}}\left(\hat{S}_{SS}\right) = S_{SS}^2\left[\frac{1}{r_2} - \frac{1}{R_2} + \frac{1}{r_3} - \frac{1}{R_3}\right]. \quad (6)$$

4. Survival between the Secondary Separator and the entrance to Counting House Raceway, i.e.,

$$\hat{S}_{CH} = \frac{\hat{\lambda}_2}{\hat{\lambda}_3} \quad (7)$$

with associated variance estimator

$$\widehat{\mathrm{Var}}\left(\hat{S}_{CH}\right) = S_{CH}^2\left[\frac{1}{r_2} - \frac{1}{R_2} + \frac{1}{r_3} - \frac{1}{R_3}\right]. \quad (8)$$

The separate estimates can also be combined to estimate the probability of surviving between Louver Bay and the Counting House entrance, i.e.,

$$\hat{S}_{LB-CH} = \hat{S}_{SS} \cdot \hat{S}_{CH} = \frac{\hat{\lambda}_1}{\hat{\lambda}_2} \cdot \frac{\hat{\lambda}_2}{\hat{\lambda}_3} = \frac{\hat{\lambda}_1}{\hat{\lambda}_3} \quad (9)$$

with associated variance estimator

$$\widehat{\text{Var}}\left(\hat{S}_{LB-CH}\right) = S^2_{LB-CH}\left[\frac{1}{r_1} - \frac{1}{R_1} + \frac{1}{r_3} - \frac{1}{R_3}\right], \quad (10)$$

where $R_i(i = 1, \ldots, 3)$ are release sizes and $r_i(i = 1, \ldots, 3)$ are recovery numbers per release group. The key assumption of this method is that the probability of recovery is the same across the three release groups. This assumption cannot be directly tested. However, homogeneous passage over time of the three releases at the Counting House would be indirect evidence of such homogeneity.

Ancillary Analyses

Travel times will be calculated for the various release groups between detection or release-and-detection locations. Mean and median travel times will be directly calculated for the following reaches:

Tag Type	Reach
Acoustic	• Louver Bay – Sample separator
	• Sample separator – Transport tank
	• Transport tank – Tailwater array
	• Tailrace – Tailwater array
	• Tailwater array – Barrier Dam
	• Barrier Dam – Trout hatchery
VIE	• Louver Bay – Counting House
	• Secondary separator – Counting House
	• Entrance Counting House raceway – Counting House

Literature Cited

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