Passage Evaluation of Spring Creek Hatchery Subyearling Chinook Salmon at Bonneville Dam Second Powerhouse, 2013

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Report of research for

Environmental Resources Branch, Planning and Engineering Division
Portland District, U.S. Army Corps of Engineers
Robert Duncan Plaza
333 S.W. 1st Avenue
Portland, Oregon 97208-2946
Contract W66QKZ30370929

July 2014

Executive Summary

Smolt monitoring observations in 2007 and tests conducted by NOAA Fisheries in 2008-2009 confirmed that tule stock subyearling Chinook salmon *Oncorhynchus tshawytscha* passing through Bonneville Dam Second Powerhouse bypass system were subject to higher mortality rates during turbine operation at the upper end of the 1% peak efficiency range than at lower operational levels within the range. Gatewell flow patterns were investigated using computational fluid dynamics modeling in 2010-2011, and results indicated that gatewell hydraulics could be improved by filling the vertical spaces above both sides of a submersible traveling screen with turbulence reduction devices (TRDs).

This modification was subsequently endorsed by the U.S. Army Corps of Engineers Post-construction Evaluation Program as a viable alternative to reduce passage mortality during upper 1% turbine operation. Prototype TRDs were fabricated and installed in Gatewell 14A prior to the 2013 juvenile fish-passage season. In late March and early April 2013, Harbor Consulting Engineers[†] and Alden Research Laboratory collected and analyzed detailed flow measurements to determine how TRDs affected gatewell flow patterns. Immediately following the collection of flow data, NOAA Fisheries conducted test releases of juvenile Chinook salmon to determine if the TRDs reduced passage mortality during upper 1% turbine operation. This report details the results of these biological tests.

The study design for biological testing called for releases of subyearling Chinook salmon into the 14A Turbine Intake under three turbine operating conditions:

1) upper 1% operation with no TRDs installed,
2) upper 1% operation with TRDs installed
3) lower 1% operation with no TRDs

Specified flows for testing in Turbine Unit 14 were 12.0-12.5 kcfs for lower 1% operation and 17.5-18.0 kcfs for upper 1% operation. The research summary for this study (BPS-P-13-1) called for a test with sufficient statistical power to detect a 3% difference in additive mortality between treatments, with $\alpha = 0.05$ and $\beta = 0.2$ and for comparisons to be made between the lower 1% treatment and each of the upper 1% treatment groups.

[†] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

We obtained subyearling Chinook salmon from Spring Creek Hatchery and PIT-tagged these fish in lots of 193-300 individuals for daily treatment groups. Releases were made via fish hose into the 14A Turbine Intake. We also released a group of 50-67 fish into the bypass system collection channel once during each weekly release series to quantify baseline timing, tag loss, and mortality not associated with the gatewell environment.

Four replicate release series were conducted between 8 April and 1 May 2013 using a total of 3,712 fish. Average fork lengths and weights of fish in replicate groups ranged 70-77 mm and 4.2-5.8 g. Test fish were recaptured at the downstream end of the juvenile bypass system using the PIT-tag separation-by-code capability at the Second Powerhouse Juvenile Fish Monitoring Facility. For each treatment condition, examination of recaptured study fish with PIT tags in situ showed the following mortality rates:

1) 23.6% for fish released at upper 1% operation with no TRDs
2) 17.0% for fish released at upper 1% operation with TRDs installed
3) 2.1% for fish released at lower 1% operation with no TRDs

No mortality was observed for fish released into the bypass system collection channel.

Differences in mortality between both upper 1% treatments and the lower 1% treatment were large and highly significant (P <0.01; ANOVA). We concluded that installation of TRDs did not adequately mitigate for the mortality increase associated with operation of Second Powerhouse turbines at the upper end of the 1% peak efficiency range. We note that inferences from these test results may be limited because while many stocks of juvenile salmon pass Bonneville Dam, our replicate release groups consisted of only Spring Creek Hatchery subyearling Chinook. Furthermore, study fish were released at a single location within the intake, and "A" gatewells are known to have higher flows that "B" or "C" gatewells. Therefore, these results may not be applicable to other stocks and may overestimate the overall passage mortality of tule stock subyearling Chinook salmon at the Second Powerhouse.

Timing data for fish recaptured live showed more rapid median passage times for the treatment groups released during upper 1% operation than during lower 1% operation. In most test situations, more rapid gatewell egress would correspond with lower mortality rates, since fish would be exposed to potentially adverse gatewell hydraulics for a shorter period of time. In this study, however, more rapid passage times were associated with higher mortality and lower recapture rates. Comparison of timing distributions between treatment groups released at upper and lower 1% operations suggests that relatively few fish released at upper 1% operation were able to withstand gatewell conditions for more than a few hours. These data indicate that for upper 1% releases, the observed passage distributions were truncated, resulting in non-representative passage times.

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Introduction

Fall Chinook salmon reared at Spring Creek Hatchery are an indicator stock for the Pacific Salmon Treaty between the U.S. and Canada, are included in treaty obligations to Native Americans, provide mitigation for habitat lost due to dam construction, and contribute to ocean and Columbia River sport and commercial fisheries (USFWS 2014). The objective of this study was to determine efficacy of prototype gatewell Turbulence Reduction Devices in reducing bypass system passage mortality of Spring Creek stock fall Chinook salmon. On a broader scale, the work represented a step toward the continuing goal of improving Second Powerhouse passage conditions for juvenile migrants.

In March and April 2007, data from the Smolt Monitoring Program (SMP) at Bonneville Dam Second Powerhouse indicated that substantial mortality had occurred during passage of Spring Creek Hatchery tule subyearling Chinook salmon *Oncorhynchus tshawytscha* (D. Ballinger, PSMFC, personal communication). Daily mortality rates at the sampling facility ranged from 1.6 to 11.7% during the passage of Spring Creek Hatchery fish released from 7 through 13 March 2007. Fish released on 13 April 2007 began arriving at the smolt monitoring facility at about 0545 PDT, and from that time until 0800, the mortality rate was 10.1%. In contrast, data from previous SMP daily samples (≥100 fish) of Spring Creek Hatchery fish had shown that mortality exceeded 1% on only four occasions during March and April of prior years (2000-2006): 16 March 2002 and 1, 17, and 18 April 2004.

Inspection of Second Powerhouse passage facilities in 2007 did not identify mechanical or operational problems, and necropsy of passage mortalities did not show evidence of external injury or disease. After regional consultation, the U.S. Army Corps of Engineers (Corps) reduced turbine operation to lower levels within the 1% peak efficiency range, an action which resulted in greatly decreased mortality rates in subsequent SMP samples. In addition, because of the passage mortality sustained by Spring Creek Hatchery Chinook salmon in 2007 and the apparent association between mortality and turbine operation at the upper end of the 1% peak efficiency range, NOAA Fisheries conducted additional biological evaluations of fish passage in 2008-2009 (Gilbreath et al. 2012).

Results from these evaluations showed that gatewell passage mortality of Spring Creek Hatchery stocks increased in a stepwise manner as Second Powerhouse turbines were operated at higher levels within the 1% peak efficiency range. Observed mortality increases were typically associated with lower recapture rates, and unexpectedly, more rapid passage times. In 2008, partial failure of horizontal seals between vertical barrier screen (VBS) sections on two occasions resulted in dramatically lowered recapture rates, emphasizing the importance of seal integrity in maintaining gatewell containment.

In 2009, all test fish were measured to the nearest millimeter fork length. Length-frequency data were evaluated using logistic regression to produce estimated mortality curves for lower-middle and middle 1% treatment groups. For fish within the 62-82 mm length range, mortality decreased as fish size increased, and estimated mortality curves tended to converge as fish size increased. That is, the difference in absolute mortality between operating conditions decreased as fish size increased. Also in 2009, we held recaptured fish for 10 d to determine delayed mortality. Less than 1.0% of the fish died during the 10-day holding period, suggesting minimal latent mortality.

Following completion of biological tests in 2008-2009, the gatewell environments were evaluated by the Corps using computational fluid dynamics modeling. Modeling results showed that gatewell flow conditions were less than optimum, with notable increases in turbulence at flows representative of the upper end of the 1% peak efficiency range (USACE 2013). Model results suggested that using turbulence reduction devices (TRDs) to block the vertical spaces above the side structural members of the submersible traveling screen (STSs) would minimize flow expansion at these locations. Flow minimization would thereby reduce or eliminate the large circulation cells at each end of the gatewell and would streamline gatewell flow patterns. In spring 2013, prototype removable TRDs were designed, fabricated, and installed in Gatewell 14A for hydraulic and biological testing.

Hydraulic measurements were taken by Harbor Consulting Engineers[‡] and Alden Research Laboratory between 29 March and 5 April 2013 (HCE and ARL 2013). Water velocity measurements were collected in Gatewells 14A, 15A, and 14C. Unit flows tested were 12, 15, and 17 kcfs in Gatewells 14A and 15A, and 17 kcfs in 14C. Turbulence reduction devices were tested in 14A only. Results showed that gatewell flow patterns were generally similar among gatewells, with upward (vertical), sweeping flows along the vertical barrier screens (VBSs).

The upward flow velocity was higher at the center than sides of VBSs, which resulted in lower through-screen velocities at center panels of each VBS. Through-screen velocities increased as gatewell flow levels increased, particularly at the top two rows of the VBSs porosity panels. Effectiveness of the TRDs in altering flow patterns or reducing gatewell turbulence was not apparent from these test data. Flow measurements showed persistent recirculation cells on the south sides of test gatewells, including

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Gatewell 14A with TRDs installed, whereas computational fluid dynamics modeling had shown that the TRDs could potentially eliminate these recirculation cells.

For biological tests in 2013, we used subyearling tule stock Chinook salmon obtained directly from Spring Creek Hatchery. Tests began on 8 April and concluded on 1 May. The decision to proceed with biological testing was based on the anticipated favorable outcome of the hydraulic testing. Significant improvements in flow patterns were expected after placement of TRDs. However, results of hydraulic tests were not available by the required start date for biological testing. Therefore, we proceeded with releases of Spring Creek Hatchery test fish and planned subsequent tests using run-of-river yearling and subyearling Chinook salmon in May and July, respectively. These tests were eventually canceled due to ineffectiveness of the TRDs in sufficiently reducing mortality rates for Spring Creek Hatchery fish during upper 1% operations.

Methods

We compared post-recapture mortality for treatment groups of PIT-tagged subyearling Chinook salmon released at lower (12.0-12.5 kcfs unit inflow) and upper (17.5-18.0 kcfs unit inflow) turbine operational settings within the 1% peak efficiency operating range. Treatment groups for the study were released during the following operational conditions:

1) upper 1% operation with no TRDs installed,
2) upper 1% operation with TRDs installed
3) lower 1% operation with no TRDs.

We also released test fish into the bypass system collection channel adjacent to the 14A north orifice to identify mortality and passage time not associated with turbine intake and gatewell passage.

The research summary for study BPS-P-13-1 called for statistical power sufficient to detect a difference of 3% in additive mortality between both upper 1% treatment groups and the lower 1% treatment group at $\alpha = 0.05$ and $\beta = 0.20$. Direct comparisons between the two upper 1% treatment groups were not specified because the objective of TRD deployment was to reduce mortality to within 3% of the baseline lower 1% operation level, not to identify smaller, incremental improvements. Thus, the null and alternate hypotheses for mortality were as follows:

Null hypothesis: There is no true difference in mortality rates between fish groups passing at upper 1% operations with TRDs and those passing at lower 1% operation without TRDs and no difference between those passing at upper or lower 1% operations without TRDs.

Alternate hypothesis: Mortality rates differ between fish groups passing at upper 1% operations with the TRD installed vs. those passing at lower 1% operation without TRDs and mortality rates differ between upper and lower 1% operations without TRDs.

These were expressed as:

H_0: $M_{upper1\%, TRD+} = M_{lower1\% ,TRD-}$ and $M_{upper1\%, TRD-} = M_{lower1\% TRD-}$

H_1: $M_{upper1\%, TRD+} \neq M_{lower1\% TRD-}$ and $M_{upper1\%, TRD-} \neq M_{lower1\%, TRD-}$

Where M is mortality rate, upper and lower1% are turbine operational levels within the 1% peak efficiency range, and TRD+ and TRD- are test conditions with and without turbulence reduction devices installed.

Treatment group sizes were calculated using the following equation from Zar (1999):

$$n \approx \frac{(t_{\alpha/2} + t_{\beta})^2 [p_1(1-p_1) + (p_1+d)(1-p_1-d)]}{d^2} \approx \frac{8[p_1(1-p_1) + (p_1+d)(1-p_1-d)]}{d^2}$$

where d is the specified additive difference, p_1 is the expected background or control effect, and $t_{\alpha/2}$ and t_{β} are the t-values corresponding to $\alpha = 0.05$ and $\beta = 0.20$. We estimated p_1, the expected lower 1% mortality rate at 0.03 (3%), based on results from our 2008-2009 studies. The additive difference between the two upper 1% vs. the lower 1% treatments, d, was specified as 3% by the research summary for study BPS-P-13-1.

Based on these values, we calculated that 817 fish per treatment group were needed. We expanded this number to account for an expected 90% recapture rate, and this increased treatment group size to 908 fish. With three treatment groups, the study would therefore require 2,724 fish. In addition, we planned to release about 200 fish into the bypass system collection channel, bringing the total estimated number of test fish needed to 2,924.

Biological testing was constrained by a number of factors, including the completion date of hydraulic testing (5 April). In addition, upper 1% turbine operation was proscribed from 11 to 15 April for the passage of production fish released from Spring Creek Hatchery on 11 April and again for a second production release on 2 May. Also, placement and removal of TRDs could be scheduled only during the Monday-Thursday work week for project staff. Additional study constraints included the availability of only one gatewell for testing and the need for a 24-h period of uninterrupted operational conditions after each release to ensure that study fish passed under the conditions being tested.

Although the study period was constrained for the reasons stated above, we conducted replicate releases in case of unforeseen problems and to capture the size range of test fish. Individual test releases are detailed in Appendix Table 1 and operational conditions are shown in Appendix Table 2.

Average fork lengths and weights of fish in replicate groups ranged 70-77 mm and 4.2-5.8 g. Test fish were collected by grab sample from Spring Creek Hatchery ponds, weighed to estimate number, and then transported to the Second Powerhouse juvenile facility in 75-L oxygenated containers. Duration of transport was about 45 min. Water temperatures ranged 9.1-11.0°C in the Columbia River and 8.4-9.6°C at the hatchery ponds during tests. At the juvenile facility, fish were transferred water-to-water into 720-L rectangular tanks supplied with flow-through river water. Fish were held undisturbed for 16-24 h for temperature acclimation and stress reduction before tagging.

Prior to tagging, fish were anesthetized using tricaine methane sulfonate (Argent Labs, Redmond, Washington) at a concentration of about 50 mg/L. We used 134.2-kHz FDXB ISO PIT tags (12.5 mm long by 2.0 mm diameter). Tags were preloaded into single-use needles and injected with an MK-25 rapid-implant gun (Biomark Inc., Boise, Idaho). Successful implantation was confirmed by scanning tag codes into a computer file using P3 tagging software developed by the Pacific States Marine Fisheries Commission. We also recorded weight in grams and fork length in millimeters for each fish tagged.

Tagged fish were placed into 75-L containers and held for release the following day. On the morning of release, holding containers were checked for shed tags and mortalities, and live fish were transferred into 720-L truck-mounted tanks for releases into turbine intakes or placed in a 720-L tank in the bypass system collection channel gallery for release into the collection channel adjacent to the 14A North Orifice discharge.

Fish were directed to the submerged turbine intake release point via a 10.2-cm-diameter PVC hose. The release hose support mechanism was identical to that used in our studies during 2008-2009 (Gilbreath et al. 2012). Figure 1 shows a side view of the turbine with approximate release locations and gatewell structures relevant to the study. Test fish passing through the bypass system were recaptured using the programmable separation-by-code (SbyC) system at the juvenile fish facility. Figure 2 shows plan views of Bonneville Dam Second Powerhouse and its Juvenile Fish Monitoring Facility with locations of the SbyC system and PIT-tag monitors.

Recaptured test fish and bycatch were scanned for presence of tags, and data were entered into P3 files for upload to the PTAGIS database. Tagging and recapture file data were later imported into spreadsheet and relational database programs for summary and analysis. Statistical significance of results was determined by ANOVA.

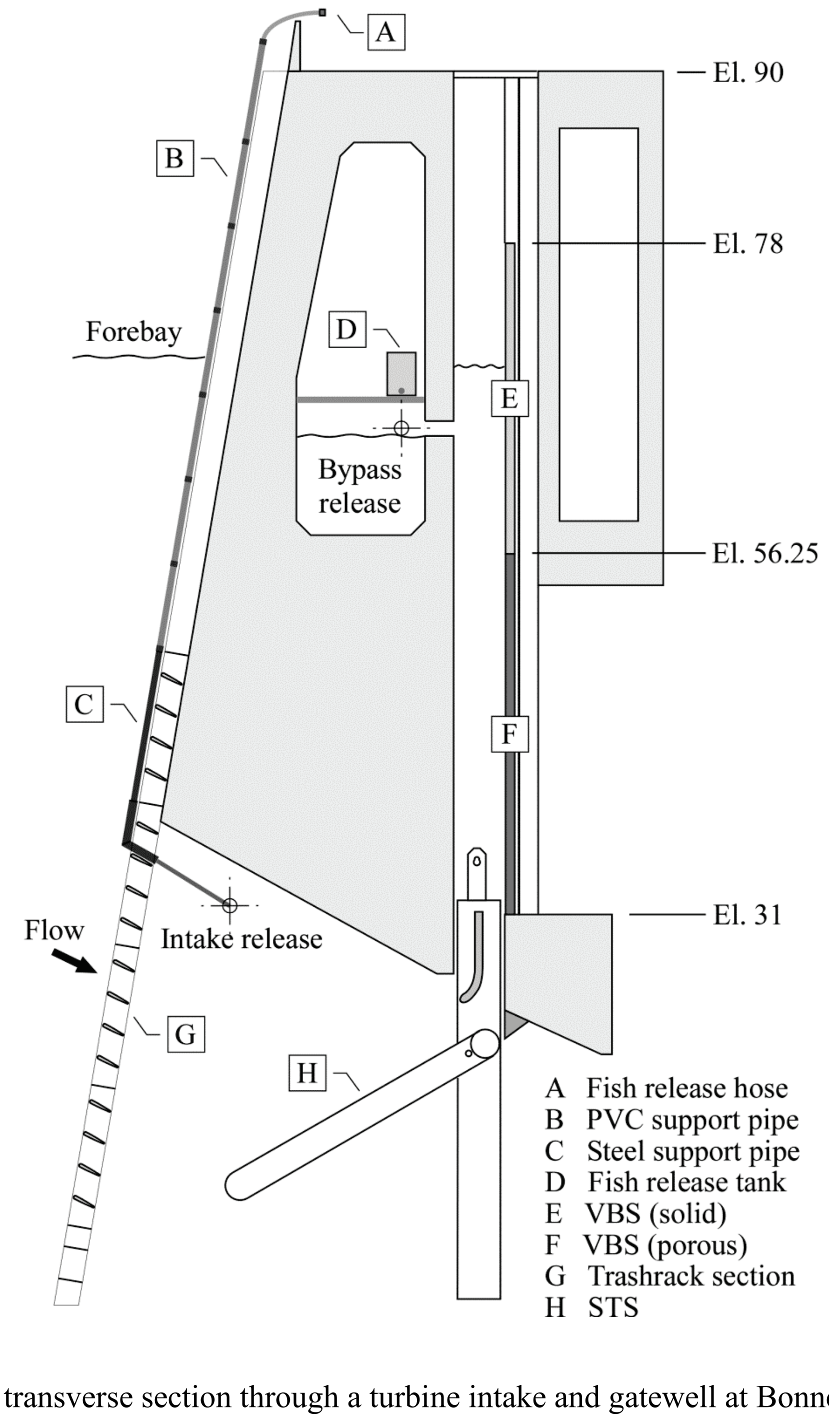


Figure 1. Partial transverse section through a turbine intake and gatewell at Bonneville Dam Second Powerhouse. Standard fish guidance structures and release locations used by NOAA Fisheries in 2013 are labeled. Elevations are in feet msl. Crosshair symbols denote release locations. Abbreviations: VBS, vertical barrier screen; STS, submersible traveling screen.

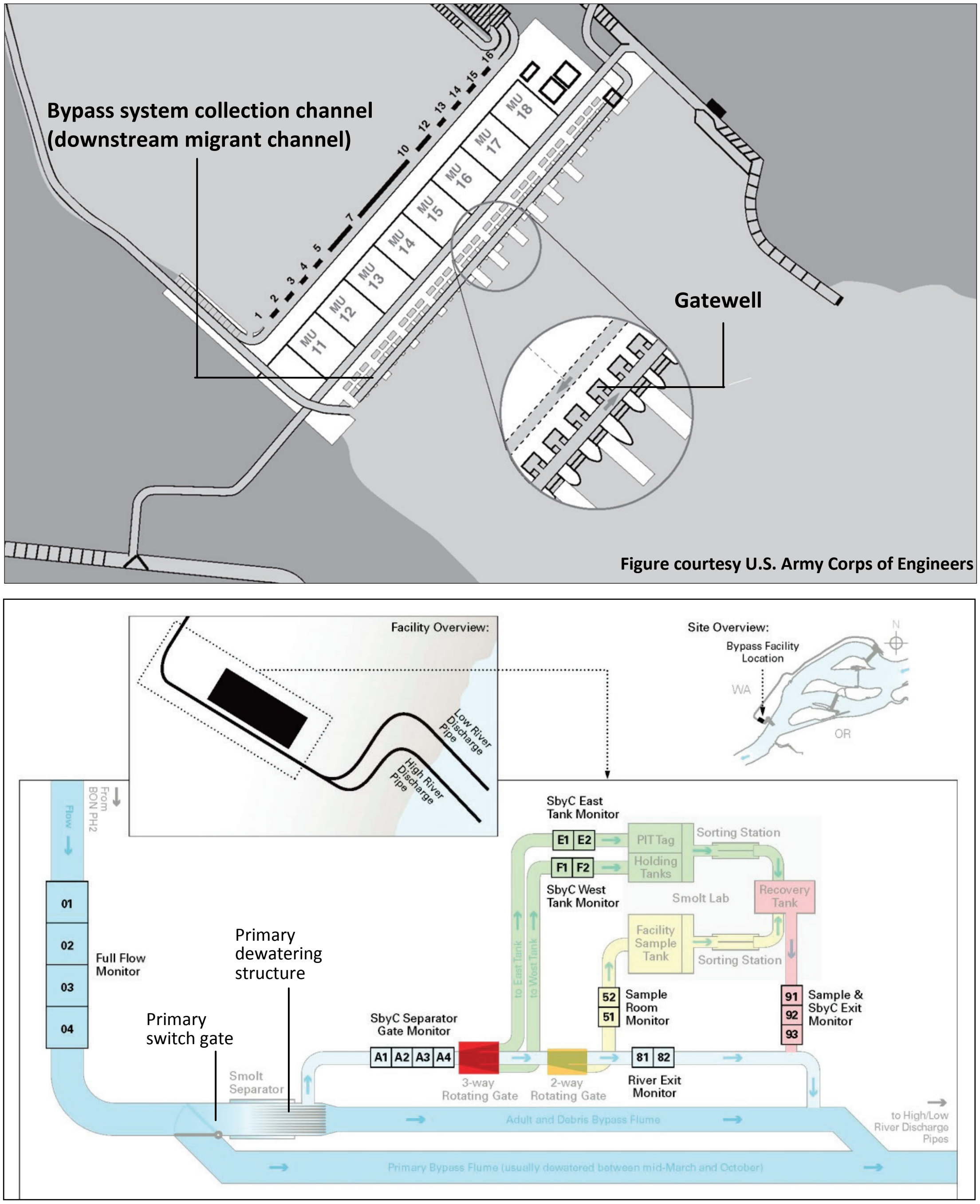


Figure courtesy of Pacific States Marine Fisheries Commission

Figure 2. Upper panel shows plan view of Bonneville Dam Second Powerhouse with locations of Turbine Unit 14 gatewell and juvenile migrant channel. Lower panel shows plan view of the Juvenile Fish Monitoring Facility with location of full flow monitor, primary switch gate, and SbyC monitors.

Results

Biological tests were scheduled to minimize impacts to Bonneville Project operations while completing the study within the limited period available. Tests were also scheduled to avoid periods of heavy passage from Spring Creek Hatchery production releases in April and May. This schedule helped to minimize exposure of production fish to the upper 1% turbine operating condition and also helped to avoid excessive numbers of bycatch. The effectiveness of TRDs in reducing mortality at upper 1% turbine operation was evaluated according to specifications in the research summary for study BPS-P-13-1.

As observed during studies in 2008-2009, test fish obtained from Spring Creek Hatchery in 2013 showed no indication of condition problems during pre-release handling. The timing of our handling procedures, from acquisition at the hatchery to release, was about 48 h. This approximated the time spent in the river for most fish between release at Spring Creek Hatchery and arrival at Bonneville Dam. Acclimation to river temperature was not a factor of concern, since hatchery and river temperatures were similar.

The incidence of tag loss between tagging and release was negligible (2 of 3,712 tagged), and very few untagged live fish with fresh needle wounds were observed during processing of recaptures. Of live fish recaptured, four were partially descaled and seven descaled based on the criteria of Ceballos et al. (1993). Injuries such as abrasions, lacerations, and other flesh wounds were not observed in the catch.

Results in this section are reported in the following sequence.

1) Detection and recapture outcomes observed in the study.
2) Observed mortality rates based on fish recaptured with tags in situ—the primary measure of results.
3) An alternate method of evaluation—observed survival based on the percentage of fish released which were recaptured live.
4) Timing data for morning and evening releases.
5) Recovery of bare tags from the system.[§]
6) Observations from introductions of tags at bypass system locations.

[§] We used the term "bare tag" to denote a tag which likely dropped from a fish post-mortem as opposed to tags lost or shed from live fish.

Detection and Recapture Outcomes

We identified five outcome categories from releases of Spring Creek Hatchery subyearling Chinook salmon at the Second Powerhouse. Study fish in the two primary categories were those recaptured either alive or dead with tags in situ. Query of the PTAGIS database identified three additional categories: detections for which we recovered a tag but no fish, detections for which we recovered neither a tagged fish nor a tag, and study fish that were never detected after release.

The detection and recapture outcome categories for treatment groups are shown in Figure 3. Percentages in column segments are based on overall counts, rather than averages of replicates. Almost 96% of fish released at lower 1% operation were recaptured with tags in situ. The recapture rate dropped to about 71% for upper 1% releases with TRDs installed and to 54% for upper 1% releases with no TRDs.

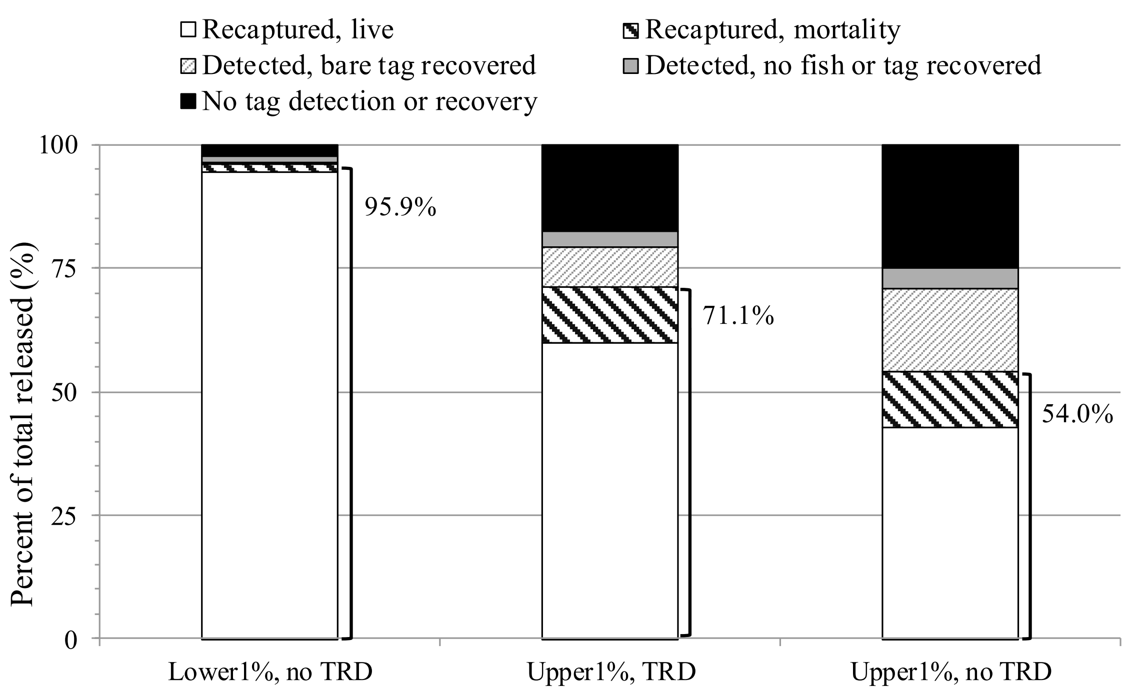


Figure 3. Recapture and detection outcomes for treatment groups of PIT-tagged Spring Creek Hatchery subyearling Chinook salmon released into the 14A Turbine Intake at Bonneville Dam Second Powerhouse in 2013. Lower and Upper 1% are turbine operational levels within the 1% peak efficiency range. Turbulence reduction devices (TRDs) were installed or removed during releases. Brackets identify fish recaptured with tags in situ.

Records in PTAGIS indicated that a significant number of tags were last detected on the full-flow monitor. On 25 July and 15 October, we recovered bare tags from study fish in the area between the juvenile facility primary switch gate and the primary dewatering structure (Figure 2). Comparison of these tag codes with our tagging records showed that proportions of fish last detected on the full-flow monitor were less than 1% from the lower 1% releases, about 8% from the upper 1% releases with TRDs installed, and about 17% from the upper 1% releases with TRDs removed.

Relatively small percentages from each treatment group (2-4%) fell into the category of detections for which no fish or bare tag was recovered. As shown by examination of last detection monitor data, some fish in this category were misdirected back to the river by the SbyC 3-way rotational gate. Others were likely bare tags that we did not recover from the holding raceway or from the flume between the head wall and the primary dewatering structure.

Percentages of tagged fish not accounted for by recapture, tag recovery, or detection varied: these percentages were about 2% in the lower 1% treatment group, about 18% in the group released at upper 1% with TRDs installed, and 25% in the group released at upper 1% operation with TRDs removed. Fish in this category may have passed through the gap area at the top of the STSs, escaped gatewell containment, or may represent unrecovered mortalities.

Observed Mortality at Recapture

Table 1 summarizes total numbers released in each group, as well as the average recapture and observed mortality rates. As expected, the baseline group released into the bypass system collection channel adjacent to the 14A North Orifice discharge had the highest recapture rate (98.6%) and lowest mortality rate (0.0%). The treatment group released at lower 1% turbine operation represented the standard by which effectiveness of gatewell passage improvement was to be assessed. Results from this group showed a 95.1% recapture rate and 2.1% mortality rate. In comparison, turbine operation at the upper 1% of the peak efficiency range resulted in diminished recapture and elevated mortality rates, both with and without TRDs.

Observed mortality rates were similar between the two upper 1% treatments, at 19.1% with TRDs installed and 23.6% with TRDs removed. However, the 68.2% recapture rate with TRDs installed was noticeably higher than the 51.3% rate with TRDs removed. Statistical treatment of the test results showed that mortality for both upper 1% groups was significantly higher than mortality during lower 1% operation ($P < 0.01$).

Table 1. Observed mortality as a percentage of test fish recaptured. Spring Creek Hatchery subyearling Chinook salmon were PIT-tagged and released at Bonneville Dam Second Powerhouse from 8 April to 1 May 2013. Percentages are grand averages for release groups. Specified turbine unit flow during tests was 12.0-12.5 kcfs for lower 1% operation and 17.5-18.0 kcfs for upper 1% operation. Test fish ranged 55-95 mm fork length.

Release location	Turbine operation[a]	TRD installed	Released (number)	Recaptured (%)	Mortality (%)
Collection channel	n/a	n/a	218	98.6	0.0
Intake 14A	lower 1%	no	1,147	95.1	2.1
Intake 14A	upper 1%	yes	1,202	68.2	19.1
Intake 14A	upper 1%	no	1,145	51.3	23.6

[a] Relative to the 1% peak efficiency range.

Live Recaptures as a Percentage of Number Released

To partially adjust for the wide variation in recapture rates among treatments, we calculated survival as the percentages from each treatment release group that were recaptured alive (based on number released rather than number recaptured). This approach allowed us to obtain minimum observed values for survival in each treatment group, regardless of whether the fish not recaptured were live or mortalities. We believe this analysis provided a more accurate overall reflection of the true difference between upper 1% treatment groups. Results from this analysis are shown in Table 2.

Table 2. Observed number of test fish recaptured live as a percentage of the total number released. Spring Creek Hatchery subyearling Chinook salmon were PIT-tagged and released at Bonneville Dam Second Powerhouse from 8 April to 1 May 2013. Specified turbine unit flow during tests was 12.0-12.5 kcfs for lower 1% operation and 17.5-18.0 kcfs for upper 1% operation. Percentages are grand averages for releases.

Release location	Turbine operation[a]	TRD installed	Released (number)	Recaptured live (%)
Collection channel	n/a	n/a	218	98.6
Intake 14A	lower 1%	no	1,147	93.2
Intake 14A	upper 1%	yes	1,202	56.1
Intake 14A	upper 1%	no	1,145	39.7

[a] Relative to the 1% peak efficiency range.

Average live recaptures for the upper 1% groups were 39.7% for releases with no TRDs and 56.1% for releases with TRDs installed, a difference 16.4%. In comparison, based on observed mortalities in the catch at the juvenile facility, the difference between upper 1% treatments with and without TRDs was relatively small, at only 4.5% (Table 1).

Bypass System Passage Timing

Morning Releases: 8 April-1 May

Figure 4 shows median passage time from release to arrival in the juvenile fish facility for Spring Creek Hatchery subyearling Chinook salmon. Releases were into the bypass system collection channel or into the "A" intake of Turbine Unit 14 (whisker bars show 10th and 90th percentiles) at upper 1% operation with and without TRDs and at lower 1% operation. Data are for releases during morning hours only. Passage time for evening releases are shown in following sections. Passage mortalities were excluded from all analyses of timing data.

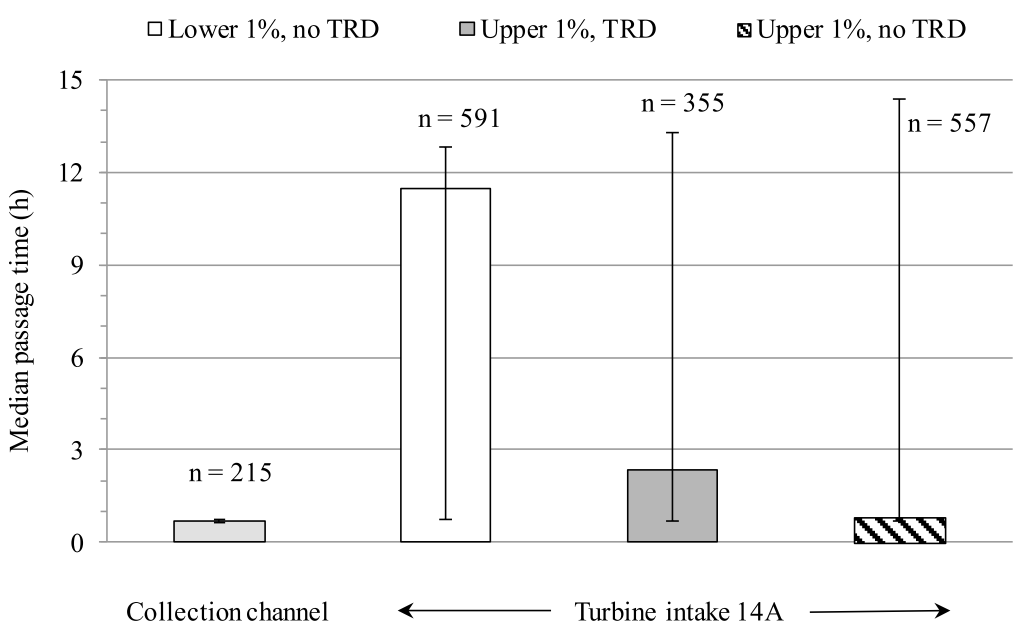


Figure 4. Median time to arrival in the juvenile fish facility for hatchery subyearling Chinook salmon released to the collection channel or turbine intake during morning hours at Bonneville Dam Second Powerhouse in 2013. Vertical bars denote 10th and 90th passage percentiles. Lower and upper 1% indicate turbine operational levels within the 1% peak efficiency range. Turbulence reduction devices were installed (TRD) or removed (no TRD) during releases.

Median passage time for test fish released into the collection channel was 41 minutes, and passage time was tightly grouped for this release, with 10^{th} and 90^{th} passage percentiles of 38 and 44 minutes, respectively. The most rapid passage time for these fish was 36 minutes and the slowest was 57 minutes.

Test fish released during lower 1% turbine operation were observed at the juvenile fish monitoring facility as soon as 40 minutes after release. For these fish, median passage time was 11.5 h, and their 10^{th} and 90^{th} passage time percentiles were at 44 minutes and 12.8 h, respectively. Nine of these fish took longer than 24 h to arrive at the juvenile facility, with the slowest passage time being 3.5 d.

Median passage times were markedly different between treatment groups released during upper and lower 1% turbine operations. For fish released at upper 1% operation with TRDs in place, median passage time was 2.4 h, and the 10^{th} and 90^{th} passage time percentiles were 42 minutes and 13.3 h, respectively. For fish released at upper 1% operation with TRDs removed, median passage time was 50 minutes, and the 10^{th} and 90^{th} percentiles for passage time were 41 minutes and 14.4 h, respectively.

In examining median passage timing data for upper 1% releases, we noticed some anomalies in the data, suggesting that further evaluation was necessary. For example, median passage time of upper 1% releases with TRDs removed was 50 minutes, compared with median passage time for collection channel releases of 41 minutes. These medians indicate that the first 50% of recaptured, live fish from the upper 1% releases had been exposed to the gatewell environment for less than 10 minutes. In comparison, for fish released during lower 1% operation, median passage time was 11.5 h, indicating that the first 50% of recaptured, live fish had remained in the gatewell for up to 11 h.

However, the more rapid passage timing of upper 1% treatments was associated with lower recapture rates and higher mortalities than observed for the slower passage time of the lower 1% treatment. We suspected that the timing distributions of upper 1% treatment groups might have been truncated due to mortality, i.e., fish became less able to withstand gatewell conditions over time during upper 1% operation. We therefore calculated hourly passage as a percentage of the total number of fish released. This allowed direct comparison of the timing distributions among treatment groups released to the turbine intake (Figure 5).

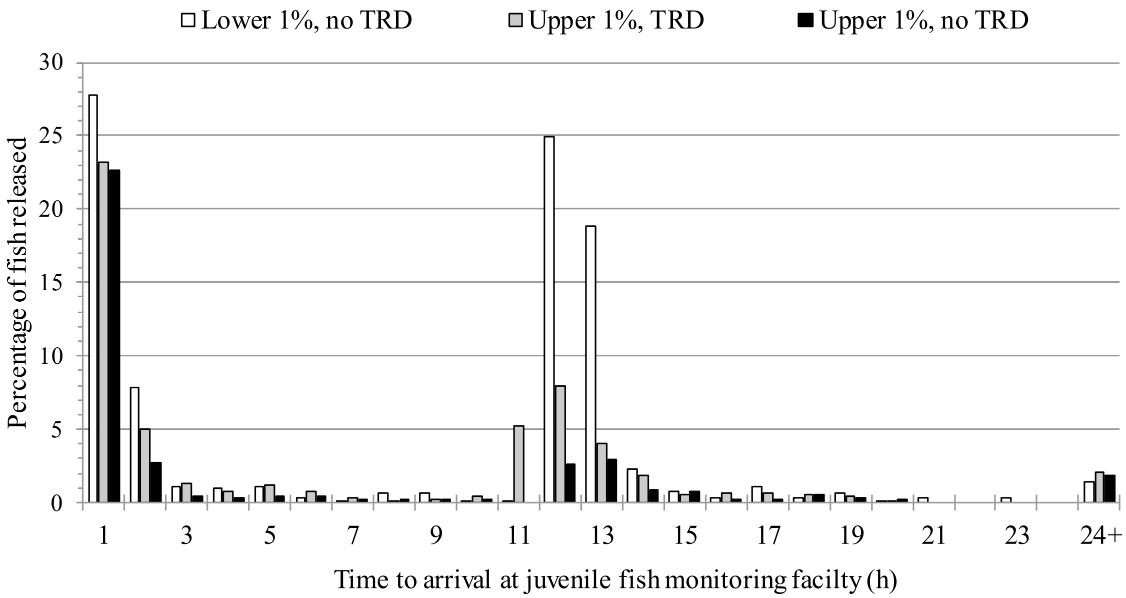


Figure 5. Passage timing distribution for three treatment groups of PIT-tagged hatchery subyearling Chinook salmon released during morning hours at Bonneville Dam Second Powerhouse, 2013. During each release, turbine operational levels were within the upper or lower 1% of peak efficiency range, and turbulence reduction devices were installed (TRD) or removed (no TRD).

Examination of the 24-h passage distributions for turbine intake groups released during morning hours showed that for all groups, the highest percentage of fish passed during the first hour after release: 28% for fish released at lower 1% operation and about 23% each for fish released at both upper 1% operations. Passage during the second hour declined to less than 10% for fish in the lower 1% group and to 5% or less for those in upper 1% groups. Minimal passage (<2% per h) occurred from the 3rd through the 10th hour after release. From the 11th through the 14th hour, coinciding with the typical evening peak of juvenile passage, increased passage was observed for all groups. This was particularly noticeable in the lower 1% group, with smaller increases in the upper 1% groups. From the 14th to the 24th hours, passage dropped to 1% per hour or less in all groups.

Thus, timing distributions between treatment groups differed mainly at the evening passage peak. For fish in the lower 1% release, fully 46.3% exited during this evening peak time block and were recaptured alive. In contrast, only 19.0% of fish in the upper 1% group with TRDs and 6.4% of fish in the upper 1% group without TRDs exited during this period. This evaluation also showed large proportions of missing fish from both upper 1% groups, and these losses were not compensated for prior to or after the evening peak. Therefore, it is likely the missing timing data represent fish that either escaped from the gatewell or died and were either not recaptured at all or not recaptured with tags in situ.

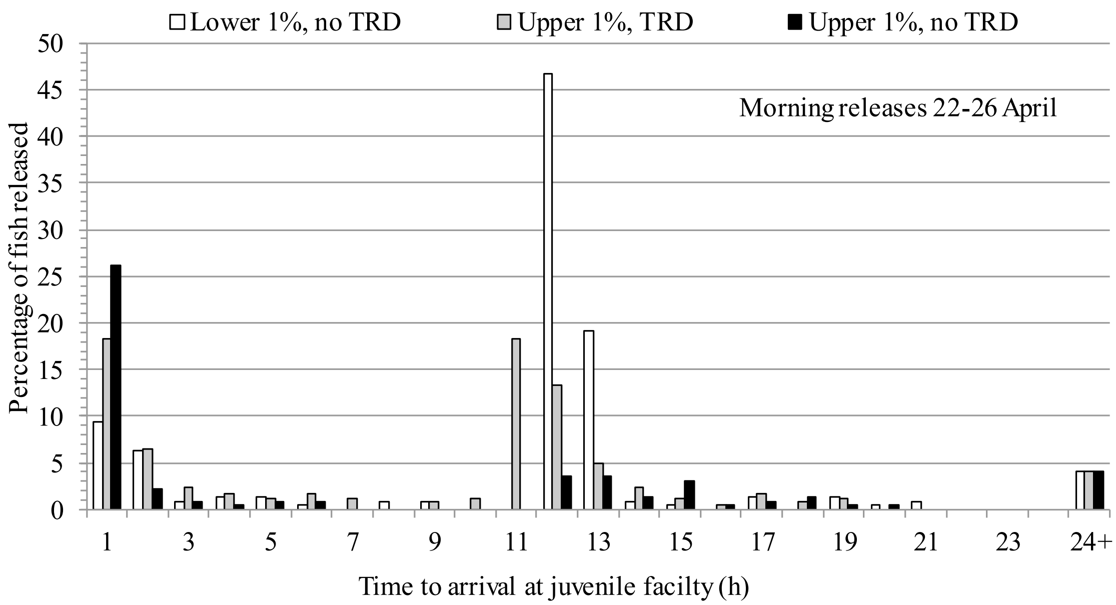
Comparison of Morning and Evening Releases: 22-26 April

We added a set of turbine intake releases to the schedule during the third week of testing to investigate whether fish released near dusk would exit the test gatewell sooner. We speculated that evening releases could potentially increase recapture rates and reduce mortality in the upper 1% treatment groups. In addition, the lower 1% release on 1 May was delayed until evening hours due to an unforeseen delay in removing the TRDs. Evening release times varied from 1900 to 1923 PST on dates when sunset occurred from 1906 to 1918 PST.

Figure 6 compares timing data for morning and evening releases during the third week of testing. In contrast to the bimodal passage pattern observed in morning releases, evening releases exited the gatewell at highest rates during the first four hours after release and nearly completed passage by the end of the 10th hour. Nevertheless, data from this one-time comparison of morning and evening releases did not provide evidence that evening release greatly improved either recapture or observed mortality rates for the upper 1% treatment groups.

For fish released at upper 1% operation with TRDs installed, recapture rates were 87.4% for morning and 82.7% for evening releases. For releases at upper 1% operation with TRDs removed, recapture rates were 62.7% for morning and 68.4% for evening releases. Mortality rates at upper 1% operation with TRDs installed were 5.1% for morning and 12.4% for evening releases. With TRDs removed, mortality rates at upper 1% were 19.1% for morning and 13.0% for evening releases. In contrast, for the group released at lower 1% operation during the third week of testing, recapture rates were greater than 96%, and mortality rates were less than 0.5%.

Results from this limited comparison suggest that factors such as turbine operational level and presence or absence of the TRDs shaped timing results. Although the effect of daily release time was not apparent in this comparison, an effect may exist and be of greater importance if differences between treatments are not as great. For future studies, we recommend that releases be conducted in evening hours to better reflect the time fish enter gatewells.



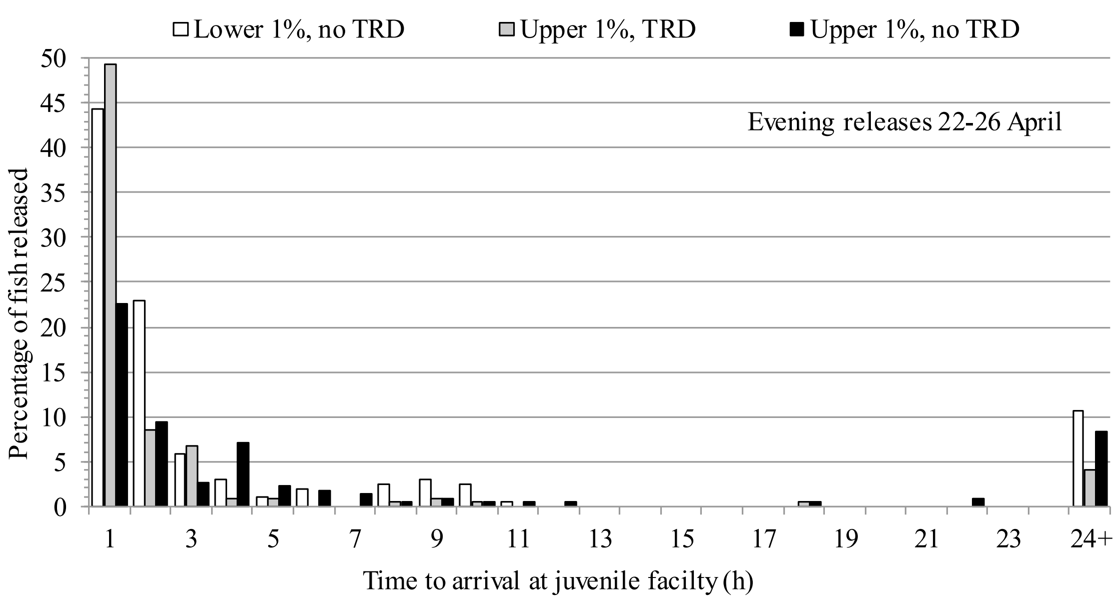


Figure 6. Comparison of passage-time distributions for morning and evening releases of -hatchery subyearling Chinook salmon from release at turbine intakes to arrival in the Bonneville Second Powerhouse juvenile fish facility, 22-26 April 2013. Turbine operational levels were at the upper or lower end of the 1% peak operating efficiency range; turbulence reduction devices were installed (TRD) or removed (no TRD) during each 24-h test.

Evening Release: 1 May

For the release at lower 1% operation in the final study week, we observed an unusually protracted timing pattern. As mentioned previously, this release was made during evening hours because TRDs installed for the previous test could not be removed by the morning of 1 May, as originally scheduled. We could not delay this test until the morning of 2 May due to the arrival of fish released that day at Spring Creek Hatchery. These hatchery production fish could have passed during the lower 1% operating conditions; however, our effort to recapture study fish would have resulted in excess bycatch if testing had coincided with the peak arrival of these fish.

Figure 7 shows passage timing results for the 1 May test release. Recapture and mortality rates were 97.7 and 0.3%, respectively. Passage timing of this group was unusual in that a large proportion of fish (37%) passed during the second 24-h period after release, a pattern not observed in previous releases. The high recapture and low observed mortality rates suggest benign gatewell conditions, since fish were recaptured live after extended periods in the gatewell.

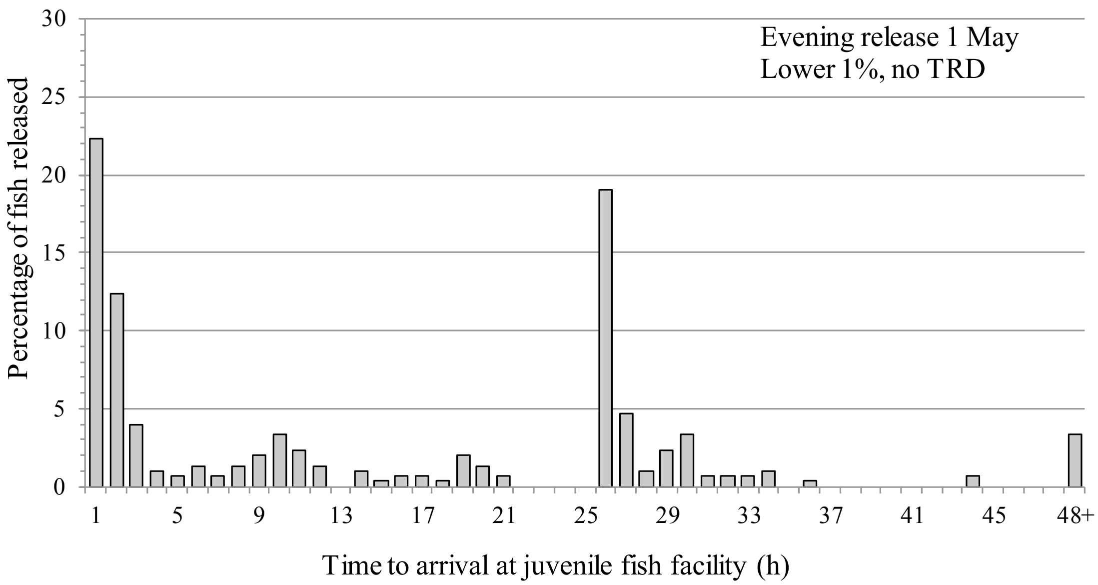


Figure 7. Passage distribution timing for hatchery subyearling Chinook from release at turbine intakes to arrival at the juvenile facility at Bonneville Dam Second Powerhouse on 1 May 2013. These fish were released with turbines operating at the lower end of the 1% peak efficiency range. No turbulence reduction devices were installed during their release.

Recovery of Tags Last Detected at the Full Flow Monitor

We queried the PTAGIS database for data from study fish releases and found that 319 of the PIT tags used in the study were detected only on the full-flow monitor. This monitor is the furthest upstream of all monitors at the Bonneville Juvenile Fish Monitoring Facility (Figure 2). Overall, detections on only the full-flow monitor accounted for 31.2% of fish not recaptured following release.

We recovered many of these detections as bare tags in the approach flume of the primary dewatering structure after it was dewatered (Table 3). Overall, 92.2% of the tags detected only on the full-flow monitor were found at this location. Tags not recovered may have been missed during this recovery effort or they may have been flushed down the bypass flume to the river after the primary switch gate was moved to bypass position (Figure 2, lower panel). This high recovery rate confirmed that tags last detected at the full-flow monitor represented bare tags rather than indicating fish with tags in situ that were lost to the bypass flume via defective seals on the primary switch gate.

Table 3. Number of PIT tags last detected at the full flow monitor and recoveries of bare tags from the primary dewatering structure approach flume. Study fish were Spring Creek Hatchery subyearling Chinook salmon released at Bonneville Dam Second Powerhouse in 2013.

Release groups	Total tagged fish released (N)	Detected only at full flow monitor (N)	Bare tags recovered at primary dewatering structure N	Bare tags recovered at primary dewatering structure (%)
Collection channel	218	0	n/a	n/a
Lower 1%, no TRD	1,147	4	4	100.0
Upper 1% with TRDs	1,202	106	95	89.6
Upper 1%, no TRD	1,145	209	195	93.3
Totals	3,712	319	294	92.2

Introduction of Tags into the Bypass System

In June and July, we introduced tags at several locations within the bypass system to determine if tags not in situ would pass through the system. Tags were introduced at four locations: into the conveyance pipe at the first access hatch upstream from the full flow monitors, at the upstream entrance to the conveyance pipe at the north end of the collection channel (or DSM—downstream migrant channel), at the upper end of the collection-channel dewatering screens, and into the collection channel adjacent to the 14A North Orifice.

Results are shown in Table 4. The first introduction of tags was dropped through the access hatch as a group, and detections were poor due to tag collision at the full-flow monitor. Thereafter, tags were dropped at 1- to 2-second intervals, resulting in 100% detection.

Table 4. Detections of bare tags introduced at locations within the Bonneville Dam Second Powerhouse Bypass System in 2013. Tag collision at the full-flow monitor reduced detection efficiency on 25 June (gray highlight). Abbreviations: SbyC, separation by code system.

		Detections by monitor (n)							
		First		Last			Time to first detection		
Location and date	Tags released (N)	Full flow	SbyC	Full flow	Sample room	River exit	Median	Min	Max
Conveyance pipe, first access hatch upstream from full-flow monitor.									
25 June	100	43	7	40	0	10	2.4 min	2.2 min	67.9 d
27 June	100	100	0	93	0	7	6.6 min	3.3 min	9.9 min
Conveyance pipe, upstream entrance at north end of collection channel									
1 July	100	100	0	85	1	14	2.5 h	2.3 h	3.6 h
Collection channel, upstream end of dewatering screens									
16 July	100	99	0	90	0	9	2.9 h	2.5 h	116.6 d
Collection channel, North 14A orifice discharge.									
2 July	100	81	0	75	0	6	91.6 d	0.8 d	238.1 d
10 July	100	81	0	81	0	0	86.0 d	4.2 d	225.9 d

Tags introduced at the inspection hatch on 27 June were detected passing the full-flow monitor within 3-10 minutes after introduction. Tags placed into the flow at the entrance to the circular conveyance pipe (north end of collection channel) were detected at the full-flow monitor 2.3-3.6 h after introduction. A high detection rate was expected for these releases, since the smooth pipe interior was engineered to provide uniform flow with minimal obstructions.

It seemed less likely that tags dropped into the collection channel at the upstream end of the channel dewatering screens would be carried up the screen incline and enter the conveyance pipe. However, detection records indicated that all but one of the 100 tags placed at this location were detected at the full-flow monitor. Median timing was 2.9 h, about 24 minutes longer than for tags placed at the entrance to the conveyance pipe. Considering the sinking rate of tags and the high water velocity at the introduction point, it is unlikely that tags contacted the full length of the dewatering screens.

We expected very few of the tags introduced at 14A, about halfway up the collection channel, to appear at the full-flow monitor. Nevertheless, our latest query of the PTAGIS database on 8 March 2014 showed that 81% of these tags had been detected. Median time for these tags to be carried through the system was about 90 d, with the latest detection logged 238 d after the introduction date. Tag movement over this period was possible because the system was left watered up almost continuously during winter 2013-2014.

The detection record also shows that not all tags remained in place after reaching the approach flume of the primary dewatering structure. The first four groups listed in Table 4 passed through the system before the primary switch gate was changed to bypass mode. Of the 400 tags in these groups, 10% were detected at river exit monitors. These tags had been carried by flow up the incline to the primary dewatering screen and had dropped through the large fish and debris separator bars down into the river-return flume. Without the knowledge that we had introduced these tags, based on query of PTAGIS, we would have assumed that these detections on the river exit monitor represented live tagged fish or passage mortalities.

Results from this test clearly suggest that a portion, perhaps a majority, of the bare tags recovered in our 2008-2009 and 2013 studies were from gatewell mortalities. In 2008-2009, we had observed weekly cleaning of the VBSs. The cleaning procedure simply hosed the screen surface clean as the screen was hoisted above water level in the gatewell, with materials rinsed from the VBSs dropping back down into the gatewell. At most cleanings, we observed remains from mortalities entangled with semi-buoyant debris. Flow patterns within the gatewell could have carried debris and tags to the orifice entrance, and thence into the bypass system collection channel. Once in the collection channel, this material could pass freely to the conveyance pipe, or if impinged on the north end dewatering screens, tags could be freed by the air-burst screen cleaning system.

Discussion

In our 2013 study, increasing turbine operation from lower to upper levels within the 1% peak efficiency range resulted in lower rates of recapture and higher rates of observed mortality. In 2008 tests using Spring Creek Hatchery stock, similar trends were noted in comparisons of lower and middle 1% vs. upper 1% operation (11.7 and 14.7 kcfs vs. 17.8 kcfs). In 2009, recapture rates were lower and mortality rates higher for fish released at middle 1% than at lower-middle 1% (13.5 kcfs) unit operation (Gilbreath et al. 2012). Similar relationships were noted for run-of-river yearling and subyearling Chinook in 2009, although for these larger fish, passage effects were typically expressed as increases in descaling rather than large increases in mortality. Thus, gatewell flow improvements benefitting Spring Creek Hatchery stock can also be expected to improve passage conditions for run-of-river juvenile Chinook salmon.

Despite promising results from studies using computational fluid dynamics models, TRDs did not adequately mitigate for the large increase in observed mortality between lower and upper 1% turbine operations. To be considered successful, installation of TRDs would have had to result in observed mortality rates less than 3% higher (by additive difference) during upper 1% than during lower 1% operation. In addition, recapture rates would have had to be equivalent, and passage distributions would have to demonstrate that fish can withstand more than a few hours of gatewell residence. In this study, threshold values for effectiveness of TRDs would have been about 5% for mortality with a 95% recapture rate. For morning releases, about 45% of the passage should have coincided with the evening passage peak. Clearly, none of these criteria were met. For fish released at upper 1% operation with TRDs installed, observed mortality was 19%, recapture rate was 68%, and only 19% of fish passed during the evening peak passage period.

The fate of test fish that were not recaptured is unknown. In our 2008-2009 study, we witnessed loss of live fish from the gatewell on several occasions due to failure of the horizontal seals between upper and lower VBSs. Loss rates were higher at upper than at lower 1% operation, presumably because flow velocity through the gaps was greater at the higher load setting. It is also possible that live fish were carried through the gap area at the top of the STSs and passed through the turbine directly to the tailrace. Percentages of fish passing through the gap area would be expected to increase at higher levels of unit inflow. Live fish may have escaped the turbine intake by swimming upstream, but this is very unlikely given the higher recapture rates observed for lower 1% releases.

Alternately, fish not recaptured may have died during passage into the gatewell or during confinement within the gatewell. This is the most likely explanation based on observations during 2008-2009 of decomposed mortalities and bare tags retained on the upper panels of the VBSs porosity section. This evidence of mortality was particularly strong when coupled with the subsequent recovery of bare tags from the approach to the primary dewatering structure and documented movement of bare tags from the collection channel to the juvenile facility.

Wide differences in recapture rates would be expected to confound conclusions if differences between treatment groups were small. However, in our study these differences were large, and observed mortality alone was adequate to confirm that TRDs did not meet effectiveness criteria at upper 1% operation. For future studies, it may be necessary to release groups of sacrificed fish in order to determine if the recapture rate for mortalities is biased low.

There is no reason to suspect that poor fish condition in this stock contributed to the observed results, either in 2008-2009 or in 2013. Fish health surveys conducted by the U.S. Fish and Wildlife Service in these years did not find disease conditions that would have predisposed these fish to passage mortality (S. Gutenberger, personal communication). Further, mortality during transport, handling, and tagging was minimal.

Fish reared in the low-velocity ponds at Spring Creek Hatchery face their first exposure to high-velocity flows during Second Powerhouse passage, most within 1-3 d after release. Small fish contained within turbulent gatewells may lack the stamina to avoid impingement on screens for more than a few hours, even at velocities that would not present a problem in other situations. This hypothesis is supported by the observation that mortality rates decrease for larger fish, as illustrated by logistic regression modeling of fork length and mortality data from our 2009 study (Gilbreath et al. 2012).

With the exception of the initial test series using fin-clipped fish in 2008, all of our testing has been done in the A intake of Turbine 14. Of the A, B, and C intakes for each turbine unit, the A intake typically has the greatest inflow and would therefore be expected to show the most severe passage effects. For example, flow computations during calibration and validation of the CFD model estimated Bay A, B, and C flows as 6.8, 6.2, and 5.0 kcfs, respectively, at 18.0 kcfs unit flow (U.S. Army Corps of Engineers 2013). At lower 1% operation (12.0 kcfs unit flow) Bay A, B, and C flows were estimated at 4.5, 4.1, and 3.4 kcfs respectively. Bay A flows at VBSs were calculated to be 219 cfs for lower 1% operation and 328 cfs for upper 1% operation.

Inclusion of the TRDs into the computational fluid dynamics model resulted in upper 1% flow increasing to 366 cfs due to the flow streamlining effect of the TRDs.

Thus, in 2013, flow at VBSs was estimated to have been about 147 cfs higher during our upper 1% releases (TRDs installed) than during the lower 1% releases. Fish passage effects at upper 1% flows have not been investigated for the B and C intakes. This should be done in future studies, particularly for C intakes, to determine whether modification of these gatewells is warranted.

We caution that the results observed here with Spring Creek Hatchery fish should not be assumed predictive of results for other juvenile migrants, such as naturally produced salmonid fry or juvenile sockeye *O. nerka*. However, it is worthwhile to consider that while problems with these stocks are seldom observed in SMP samples, a portion of mortalities may remain impinged on VBSs and may not be detected in routine monitoring.

Conclusions and Recommendations

1) Turbine operation at the upper end of the 1% peak efficiency range (18.0-18.5 kcfs unit inflow) resulted in excessive mortality for subyearling Chinook salmon originating from Spring Creek Hatchery, regardless of whether turbulence reduction devices were installed. During peak passage for the April and May production releases from Spring Creek Hatchery, we recommend that turbine units continue to be operated at the lower end of the 1% peak efficiency range (12.0-12.5 kcfs unit inflow).

2) Observed passage-timing distributions for upper 1% treatment groups were likely truncated by gatewell mortality, which appeared to increase over time. In this study, the more rapid median passage times reflect worse rather than better gatewell conditions. We recommend that passage timing data be viewed with caution in tests with low recapture and high mortality rates.

3) Results suggest that TRDs were somewhat effective in improving gatewell conditions. For example, of the totals released, the percentages recaptured live increased from 39.7% without TRDs to 56.1% with TRDs.

   In 2013, testing of the TRDs with run-of-river yearling and subyearling Chinook salmon was cancelled based on the unfavorable outcome with Spring Creek Hatchery fish. Therefore, it is not known whether TRDs can produce an incremental improvement that would benefit other species or mitigate effects in lower-flow B and C gatewells. We recommend that future tests include these species and evaluation of a C gatewell.

4) We recovered bare tags from the approach flume leading to the primary dewatering structure and documented the movement of introduced tags from the bypass system collection channel through the full-flow monitor. These findings suggest that actual mortality rates were higher than rates derived from recapture of fish with tags in situ. We noted that 10% of the tags introduced to the system worked their way up to the dewatering screen on the primary dewatering structure and were last detected at the river exit monitors. For future projects, we recommend careful examination of detection histories, keeping in mind that PIT-tag detection may not necessarily indicate passage of a fish. Detection of tags can occur with no fish present; however, this is probably a rare occurrence.

5) We reluctantly recommend that future studies include releases of sacrificed fish in order to determine the extent of bias in the recapture rate for mortalities.

6) Although we have no reason to suspect fish tagged 1 d before release were more prone to tag loss in the upper 1% releases, it might be worthwhile to tag fish 1-2 weeks in advance of release dates in order to allow the tagging wound to close.

7) The Bonneville Second Powerhouse FGE Improvements document states that the biological goal is to improve conditions for Spring Creek Hatchery fish while maintaining (or improving) fish guidance efficiency (FGE). This goal may prove difficult to achieve. Fish guidance efficiency depends on maintaining flow into the gatewells, while reducing adverse passage effects may require reducing gatewell flows. However, if the stated goal could be achieved, Spring Creek Hatchery fish would likely benefit from lowered mortality rates while other stocks of larger juvenile salmonids would likely benefit from lowered incidence of descaling.

Acknowledgments

The Bonneville Project structural crew, under the direction of Scott Burnett, provided crane service to place the release hose support assembly. The structural crew also installed and removed turbulence reduction devices and raised VBSs for inspection and cleaning. Bonneville Project operations maintained flow at the prescribed levels during test periods. Jonathan Rerecich of the U.S. Army Corps of Engineers Portland District, was the Contracting Officer's Technical Representative and Bonneville Project liaison for the project. Tammy Mackey, also of Portland District, assisted us in meeting requirements for researchers working at Bonneville Dam.

The U.S. Fish and Wildlife Service's Spring Creek Hatchery staff, led by Mark Ahrens, provided test fish for the study. Susan Gutenberger of the U.S. Fish and Wildlife Service Lower Columbia River Fish Health Center provided the fish health certification necessary to obtain a fish transport permit.

In addition to the NOAA Fisheries employees listed on the title page of this report, Ron Marr of NOAA Fisheries Pasco Research Station provided fabrication and field support throughout the project. JoAnne Butzerin from our Fish Ecology Division edited earlier report drafts, greatly improving the quality of this product. Finally, we thank Lila Charlton for assistance in tagging, examination of SbyC recaptures, and data entry. Lila's work in 2013 marked her 26th and final year of seasonal employment with NOAA Fisheries. During that time, Lila provided invaluable assistance to a wide range of studies at Bonneville Dam and other Columbia River locations. We are grateful for her service.

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Appendix

Appendix Table 1. Release and recapture data for Spring Creek Hatchery subyearling Chinook salmon PIT tagged for evaluation of fish condition at Bonneville Dam Second Powerhouse in 2013. Test fish were recaptured and examined at the Second Powerhouse Juvenile Fish Monitoring Facility. Abbreviations: TRDs = turbulence reduction devices, FL = fork length, Mort. = mortality, and Rec. = recapture.

							Recaptured and examined			
Release group	Release location[a]	Turbine operation[b]	TRDs status[c]	Released (no.)	Ave. FL (mm)	Ave. wt. (g)	Live (no.)	Mort. (no.)	Mort. (%)	Rec. (%)
Morning releases – 7:31 to 9:22 AM Pacific Standard Time										
Week 1										
8 Apr	Intake 14A	Upper 1%	Out	224	70	3.8	59	35	37.2	42.0
9 Apr	Channel	N/A	N/A	67	70	4.4	66	0	0.0	98.5
9 Apr	Intake 14A	Upper 1%	In	244	71	4.3	96	50	34.2	59.8
10 Apr	Intake 14A	Lower 1%	Out	193	71	4.3	158	12	7.1	88.1
Week 2										
16 Apr	Intake 14A	Lower 1%	Out	224	72	4.7	216	2	0.9	97.3
17 Apr	Channel	N/A	N/A	51	73	4.5	51	0	0.0	100.0
17 Apr	Intake 14A	Upper 1%	In	261	73	4.0	111	27	19.6	52.9
18 Apr	Intake 14A	Upper 1%	Out	249	72	4.7	91	22	19.5	45.4
Week 3										
22 Apr	Intake 14A	Upper 1%	In	247	75	5.2	205	11	5.1	87.4
24 Apr	Channel	N/A	N/A	50	76	5.7	50	0	0.0	100.0
24 Apr	Intake 14A	Upper 1%	Out	225	77	5.6	144	27	19.1	62.7
26 Apr	Intake 14A	Lower 1%	Out	225	75	5.6	217	0	0.0	96.4
Week 4										
29 Apr	Intake 14A	Upper 1%	Out	222	76	5.5	91	25	21.6	52.3
30 Apr	Channel	N/A	N/A	50	79	6.1	48	0	0.0	96.0
30 Apr	Intake 14A	Upper 1%	In	225	78	6.1	145	24	14.2	75.1
Evening releases - 7:01 to 7:23 PM Pacific Standard Time										
Week 3										
22 Apr	Intake 14A	Upper 1%	In	225	75	5.3	163	23	12.4	82.7
24 Apr	Intake 14A	Upper 1%	Out	225	74	5.3	134	20	13.0	68.4
26 Apr	Intake 14A	Lower 1%	Out	205	78	6.2	201	1	0.5	98.5
Week 4										
1 May	Intake 14A	Lower 1%	Out	300	78	5.9	292	1	0.3	97.7

[a] Release locations: Channel = released into the bypass system collection channel just downstream from the 14A north gatewell orifice: Intake 14A= releases into the 14A turbine intake just below the intake ceiling on the downstream side of the top trashrack.

[b] Relative to the 1% peak efficiency range. N/A = not applicable for this release location. Specified turbine unit flow during tests: Lower 1%, 12.0-12.5 kcfs; Upper 1%, 17.5-18.0 kcfs.

[c] TRDs were installed (In) or removed (Out) during tests.

Appendix Table 2. Turbine 14 operating conditions during releases of subyearling Spring Creek Hatchery Chinook salmon at Bonneville Dam Second Powerhouse in 2013. Lower 1% and upper 1% are turbine operational settings within the 1% peak efficiency range. Values for operating head are in feet msl. Data are for 24-hour time blocks after release. Start times are in Pacific Daylight Savings Time.

Date	Start time (24-h clock)	Turbine operation	Unit flow (kcfs)			Average head (ft)
			Average	Minimum	Maximum	
Morning releases						
Week 1						
8 Apr	0835	Upper 1%	17.9	17.1	18.8	53.3
9 Apr	0853	Upper 1%	17.7	16.9	18.4	50.7
10 Apr	0934	Lower 1%	12.1	11.6	12.9	50.9
Week 2						
16 Apr	0831	Lower 1%	12.0	11.6	12.5	51.5
17 Apr	0921	Upper 1%	17.7	16.6	18.1	52.6
18 Apr	0938	Upper 1%	17.8	16.8	18.4	53.9
Week 3						
22 Apr	1022	Upper 1%	17.6	16.9	18.4	53.1
24 Apr	0932	Upper 1%	17.8	17.2	18.4	55.1
26 Apr	0938	Lower 1%	12.3	12.0	12.7	56.1
Week 4						
29 Apr	0931	Upper 1%	17.8	16.9	18.6	55.3
30 Apr	0958	Upper 1%	17.7	13.2	19.5	54.2
Evening releases						
Week 3						
22 Apr	2021	Upper 1%	17.6	16.9	18.2	53.8
24 Apr	2009	Upper 1%	17.8	17.2	18.2	55.2
26 Apr	2023	Lower 1%	12.3	11.9	12.7	55.7
Week 4						
1 May	2001	Lower 1%	12.2	11.5	12.7	54.4