Passage Behavior and Survival for Radio-Tagged Yearling Chinook Salmon and Juvenile Steelhead at Lower Monumental Dam, 2009

Eric E. Hockersmith, Gordon A. Axel, Randall F. Absolon, Brian J. Burke, Kinsey E. Frick, Jesse J. Lamb, Matthew G. Nesbit, Nathan D. Dumdei, and Benjamin P. Sandford

Report of research by

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

to

Walla Walla District
Northwestern Division
U.S. Army Corps of Engineers
201 North 3rd
Walla Walla, WA 99362-1875
Contract W68SBV80438584

June 2010

EXECUTIVE SUMMARY

In 2009, we evaluated passage behavior and estimated relative survival of radio-tagged hatchery yearling Chinook salmon *Oncorhynchus tshawytscha* and juvenile steelhead *O. mykiss* at Lower Monumental Dam on the Snake River. This was the second year of evaluations related to operation of a removable spillway weir (RSW). River-run fish were PIT tagged and surgically implanted with a radio transmitter at the dam. Treatment groups were comprised of 1,157 yearling Chinook salmon and 1,173 juvenile steelhead released 7 km upstream from the dam. Reference groups were comprised of 1,045 yearling Chinook salmon and 1,027 juvenile steelhead released into the tailrace. Releases occurred during both daytime and nighttime operations for 27 d from 28 April to 24 May. Two spill pattern treatments were used (uniform and bulk spill) in a 4-d random block operating schedule, with each pattern operating for 2 d. Both treatments utilized the RSW. River flow, percent spill, and tailwater elevation averaged 99 kcfs, 37%, and 441 ft msl, respectively, during the uniform spill pattern and 102 kcfs, 26%, and 441 ft msl, respectively, during the bulk spill pattern.

Median forebay residence for yearling Chinook salmon was significantly shorter during uniform spill than during bulk spill (P = 0.004), but only by about 50 min. For yearling Chinook salmon, 7.1% more fish passed via the spillway during uniform spill than during bulk spill (P = 0.006), while 7.4% more fish passed via the juvenile bypass system (JBS) during bulk spill than during uniform spill (P = 0.003). Spill effectiveness was significantly less during uniform spill than during bulk spill for both yearling Chinook salmon (-0.595; P = 0.000) and juvenile steelhead (-0.651; P = 0.000). All other fish passage metrics estimated were similar between spill treatments for both salmonid species.

Although changes in spill volume between treatments slightly altered passage distributions, overall relative survival through all routes varied little for either yearling Chinook salmon (Table 1) or steelhead (Table 2).

With one exception, all estimates of dam survival (concrete survival in this report) met both the targeted point estimates and precision criteria in the passage performance standard of the 2008 Biological Opinion for the Federal Columbia River Power System (FCRPS). The exception was in precision for the estimate of yearling Chinook salmon passing the dam during bulk spill. Survival estimates for yearling Chinook salmon and juvenile steelhead were 1-6% and 5-11% lower, respectively, for passage through the JBS than for passage through spillways and turbines. Improved JBS passage survival at Lower Monumental Dam would increase the likelihood of meeting or exceeding the passage performance standard in the 2008 Biological Opinion for the FCRPS.

Table 1. Operating conditions, passage behavior, and relative survival for radio-tagged yearling Chinook salmon at Lower Monumental Dam, 2009 (95% confidence intervals (CI) in parentheses).

	Uniform spill	Bulk spill
Average Operating Conditions		
Project discharge (kcfs)	98.6	101.6
Spill discharge (kcfs)	36.1 (38%)	26.5 (27%)
RSW discharge (kcfs)	7.2 (7%)	7.1 (7%)
Training flow discharge (kcfs)	28.9 (29%)	19.4 (19%)
Tailwater elevation (ft msl)	440.5	440.7
Water temperature (°C)	10.7	10.9
Passage route distribution (%)		
Unknown route	3	3
Juvenile bypass	16	23
Turbine unit 1	1	1
Turbine unit 2	1	1
Turbine unit 3	0	0
Turbine unit 4	1	1
Turbine unit 5	0	0
Turbine unit 6	0	0
Turbine passage	3	3
Spillbay 8 (RSW)	59	55
Spillbay 7	2	0
Spillbay 6	4	6
Spillbay 5	4	6
Spillbay 4	3	1
Spillbay 3	2	1
Spillbay 2	3	1
Spillbay 1	1	1
Spillway passage (all bays)	78	71
Fish Passage Metrics		
Median forebay residence (h) (~0.7 km)	2.8 (2.3-3.3)	3.6 (3.0-4.3)
Fish passage efficiency (FPE)	0.967 (0.951-0.983)	0.970 (0.955-0.985)
Spill efficiency (SPE)	0.802 (0.766-0.837)	0.730 (0.692-0.769)
Spill effectiveness (SPS)	2.097 (2.017-2.202)	2.671 (2.562-2.847)
RSW efficiency (SOE)	0.605 (0.562-0.648)	0.568 (0.525-0.611)
RSW effectiveness (SOS)	7.864 (7.304-8.425)	7.741 (7.155-8.328)
Bypass efficiency (BPE)	0.165 (0.133-0.198)	0.240 (0.203-0.277)
Fish guidance efficiency (FGE)	0.833 (0.760-0.907)	0.888 (0.835-0.941)
Median tailrace egress (minutes)	5.6 (5.4-6.1)	5.4 (5.2-5.7)
Relative Survival		
Dam *(forebay BRZ (~0.7 km) to tailrace)*	0.945 (0.925-0.966)	0.949 (0.914-0.985)
Concrete *(all fish passing the dam)*	0.973 (0.951-0.996)	0.975 (0.931-1.020)
Spillway *(fish passing through spillway)*	0.976 (0.944-1.010)	0.972 (0.930-1.015)
Bypass *(fish passing through JBS)*	0.943 (0.864-1.030)	0.965 (0.885-1.052)
Turbine *(fish passing through turbines)*	0.956 (0.846-1.080)	1.021 (1.008-1.034)
Bay 8 (RSW) *(fish passing through Bay 8*	0.988 (0.956-1.021)	0.988 (0.937-1.042)

Table 2. Operating conditions, passage behavior, and relative survival for radio-tagged juvenile steelhead at Lower Monumental Dam, 2009 (95% confidence intervals (CI) in parentheses).

	Uniform spill	Bulk spill
Average Operating Conditions		
Average project discharge (kcfs)	98.6	101.6
Average spill discharge (kcfs)	36.1 (38%)	26.5 (27%)
Average RSW discharge (kcfs)	7.2 (7%)	7.1 (7%)
Average training flow discharge (kcfs)	28.9 (29%)	19.4 (19%)
Average tailwater elevation (ft msl)	440.5	440.7
Average water temperature (°C)	10.7	10.9
Passage route distribution (%)		
Unknown route	2	1
Juvenile bypass	27	30
Turbine unit 1	0	0
Turbine unit 2	0	1
Turbine unit 3	0	0
Turbine unit 4	0	0
Turbine unit 5	0	0
Turbine unit 6	0	0
Turbine passage	1	1
Spillbay 8 (RSW)	52	49
Spillbay 7	3	0
Spillbay 6	3	8
Spillbay 5	2	8
Spillbay 4	2	1
Spillbay 3	2	1
Spillbay 2	3	1
Spillbay 1	2	1
Spillway passage (all bays)	70	68
Fish Passage Metrics (95% CI)		
Median forebay residence (h) (~0.7 km)	3.1 (2.4-4.2)	3.2 (2.7-3.9)
Fish passage efficiency (FPE)	0.992 (0.984-1.000)	0.986 (0.977-0.996)
Spill efficiency (SPE)	0.713 (0.672-0.753)	0.688 (0.649-0.726)
Spill effectiveness (SPS)	1.865 (1.760-1.970)	2.515 (2.375-2.655)
RSW efficiency (SOE)	0.530 (0.485-0.574)	0.493 (0.452-0.534)
RSW effectiveness (SOS)	6.883 (6.307-7.458)	6.722 (6159-7.285)
Bypass efficiency (BPE)	0.280 (0.240-0.319)	0.299 (0.261-0.336)
Fish guidance efficiency (FGE)	0.973 (0.946-1.000)	0.956 (0.926-0.987)
Median tailrace egress (minutes)	6.1 (5.7-6.6)	5.8 (5.4-6.5)
Relative Survival (95% CI)		
Dam *(forebay BRZ (~0.7 km) to tailrace)*	0.970 (0.942-1.000)	0.977 (0.955-1.000)
Concrete *(all fish passing the dam)*	0.967 (0.939-0.996)	0.976 (0.955-0.998)
Spillway *(fish passing through spillway)*	0.982 (0.959-1.004)	0.991 (0.971-1.013)
Bypass *(fish passing through JBS)*	0.899 (0.793-1.018)	0.939 (0.878-1.005)
Turbine *(fish passing through turbines)*	1.008 (0.999-1.016)	1.009 (1.000-1.018)
Bay 8 (RSW) *(fish passing through Bay 8*	0.993 (0.971-1.017)	0.998 (0.987-1.009)

CONTENTS

EXECUTIVE SUMMARY iii

INTRODUCTION 1

METHODS 3
- Study Area 3
- Fish Collection, Tagging, and Release 3
- Telemetry Monitoring 6
- Data Processing and Analysis 6
  - Forebay Residence Time 7
  - Approach and Passage Distribution 8
  - Fish Passage Metrics 10
  - Tailrace Egress 10
  - Survival Estimates 11
  - Avian Predation 13

RESULTS 15
- Fish Collection, Tagging, and Release 15
- Project Operations 22
- Forebay Residence Time 25
- Approach and Passage-Route Distribution 29
- Fish Passage Performance Metrics 32
- Tailrace Egress 38
- Survival Estimates 43
  - Detection Probability 43
  - Relative Survival 43
- Avian Predation 47

DISCUSSION 51

RECOMMENDATIONS 55

ACKNOWLEDGMENTS 57

REFERENCES 59

APPENDIX A: Evaluation of Study Assumptions 63

APPENDIX B: Treatment and Reference Release Groups for Estimating Survival 85

APPENDIX C: Telemetry Data Processing and Reduction 95

INTRODUCTION

A primary focus of recovery efforts for depressed stocks of Pacific salmon *Oncorhynchus* spp. has been assessing and improving fish passage conditions at mainstem dams on the Columbia and Snake Rivers. The spillway has long been considered the safest passage route for migrating juvenile salmonids at these dams. Holmes (1952) reported survival estimates of 96 (weighted average) to 97% (pooled) for fish passing Bonneville Dam spillway during the 1940s. A review of 13 estimates of spillway mortality published through 1995 concluded that for fish passing via standard spillbays, mortality rates most likely range from 0 to 2% (Whitney et al. 1997).

Similarly, recent survival studies of juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that survival was highest through spillways, followed by bypass systems, then turbines (Muir et al. 2001). Pursuant to the National Marine Fisheries Service (NMFS) 2000 Biological Opinion (NMFS 2000) and subsequent Biological Opinions, project operations at Lower Monumental Dam have relied on a combination of voluntary spill and collection of fish for transport to improve hydropower system passage survival for migrating juvenile salmonids.

Juvenile anadromous salmonids in the Columbia River Basin generally migrate in the upper 3 to 6 m of the water column (Johnson et al. 2000; Beeman and Maule 2006). However, juvenile fish passage routes at dams on the lower Columbia and Snake Rivers require fish to dive to depths of 15 to 18 m in order to enter a passage route. Engineers and biologists within the U.S. Army Corps of Engineers (USACE) developed a removable spillway weir (RSW) to provide surface-oriented spillway passage. The RSW uses a traditional spillway and is attached to the upstream face of the spillbay. In the lower Snake River, RSWs were installed at Lower Granite Dam in 2001, Ice Harbor Dam in 2005, and Lower Monumental Dam in 2008. At Lower Granite and Ice Harbor Dams RSWs appear to have reduced migrational delays, improved fish passage efficiency, and provided increased passage survival (Axel et al. 2008; Plumb et al. 2003, 2004). The RSW at Lower Monumental Dam was installed in Spillbay 8 because the majority of fish first approach the dam in this area (Hockersmith et al. 2005; Johnson et al. 1998).

In 2008, passage behavior and survival at Lower Monumental Dam in conjunction with operation of the new RSW for yearling Chinook salmon *O. tshawytscha* and juvenile steelhead *O. mykiss* was examined for the first time (Hockersmith et al. 2010). In 2009 we evaluated passage behavior and survival for a second year at Lower Monumental Dam in conjunction with operation of the RSW. In addition, behavior and survival were evaluated for two spill patterns (uniform and bulk spill patterns) during 2009. The goal of this study was to evaluate passage behavior and survival associated with the new RSW

at Lower Monumental Dam compared to historical baseline data on passage behavior and survival, and determine if uniform or bulk spill patterns provided better passage conditions.

Results of this study will be used to inform management decisions for operation of the RSW at Lower Monumental Dam, and to optimize survival and passage for juvenile salmonids. This study addressed research needs outlined in SPE-W-00-1 of the Anadromous Fish Evaluation Program (USACE, Northwestern Division), and in Reasonable and Prudent Alternative Action 23 of the 2008 Biological Opinion for the Federal Columbia River Power System (FCRPS; NMFS 2008).

METHODS

Study Area

The study area included a 74-km river reach of the Snake River from 7 km upstream of Lower Monumental Dam (rkm 589) to the confluence of the Snake and Columbia River (rkm 522; Figure 1). The focus of this study was Lower Monumental Dam on the Snake River in Washington State, 67 km above the confluence of the Snake and Columbia Rivers. Lake Herbert G. West, the reservoir behind Lower Monumental Dam extends 46 km upstream. Construction of Lower Monumental Dam was completed in 1969, and the dam is 1,155 m long and 34 m high. The powerhouse contains 6 Kaplan turbines (numbered 1 to 6 from north to south) capable of producing 810 megawatts of electricity. Total hydraulic capacity of the powerhouse is about 130 kcfs.

In the powerhouse, each turbine unit intake is outfitted with standard length submersible traveling screens which divert downstream-migrating salmonids into the juvenile fish bypass system (JBS). Fish entering the powerhouse that are not diverted pass through turbines. The spillway is 156 m long and consists of 8 spillbays, numbered 1 to 8 from south to north. Spillbay flow is regulated by operation of Tainter-style radial spill gates (15 m wide by 18 m high) with the exception of the RSW bay (Spillbay 8), where flow is regulated exclusively by forebay pool elevation. The RSW was installed during winter 2007-2008, and was first operated for fish passage during spring 2008. The spillway crest is at elevation 483 ft msl for conventional spillbays and 525 ft msl for the RSW bay.

Fish Collection, Tagging, and Release

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a user-defined shut-off after 10 d, and were pulse-coded for identification of individual fish. Each radio tag measured 14.3 mm in length by 6.4 mm in diameter, had a volume of 351 mm^3, weighed 0.8 g in air, and had a 30-cm long external antenna.

River-run, hatchery yearling Chinook salmon and juvenile steelhead were collected from the smolt collection facility at Lower Monumental Dam from 26 April to 23 May. We used only hatchery-origin yearling Chinook salmon and run-of-the-river juvenile steelhead that were not previously PIT tagged, that had no visual signs of disease or injury, and that weighed more than 12 g. Fish were anesthetized with tricaine methanesulfonate (MS-222) and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were randomly selected from the daily

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

smolt-monitoring sample and transferred through a water-filled, 10.2-cm hose to a 935-L holding tank. Following collection and sorting, fish were maintained via flow-through river water and held a minimum of 18 h prior to radio tagging.

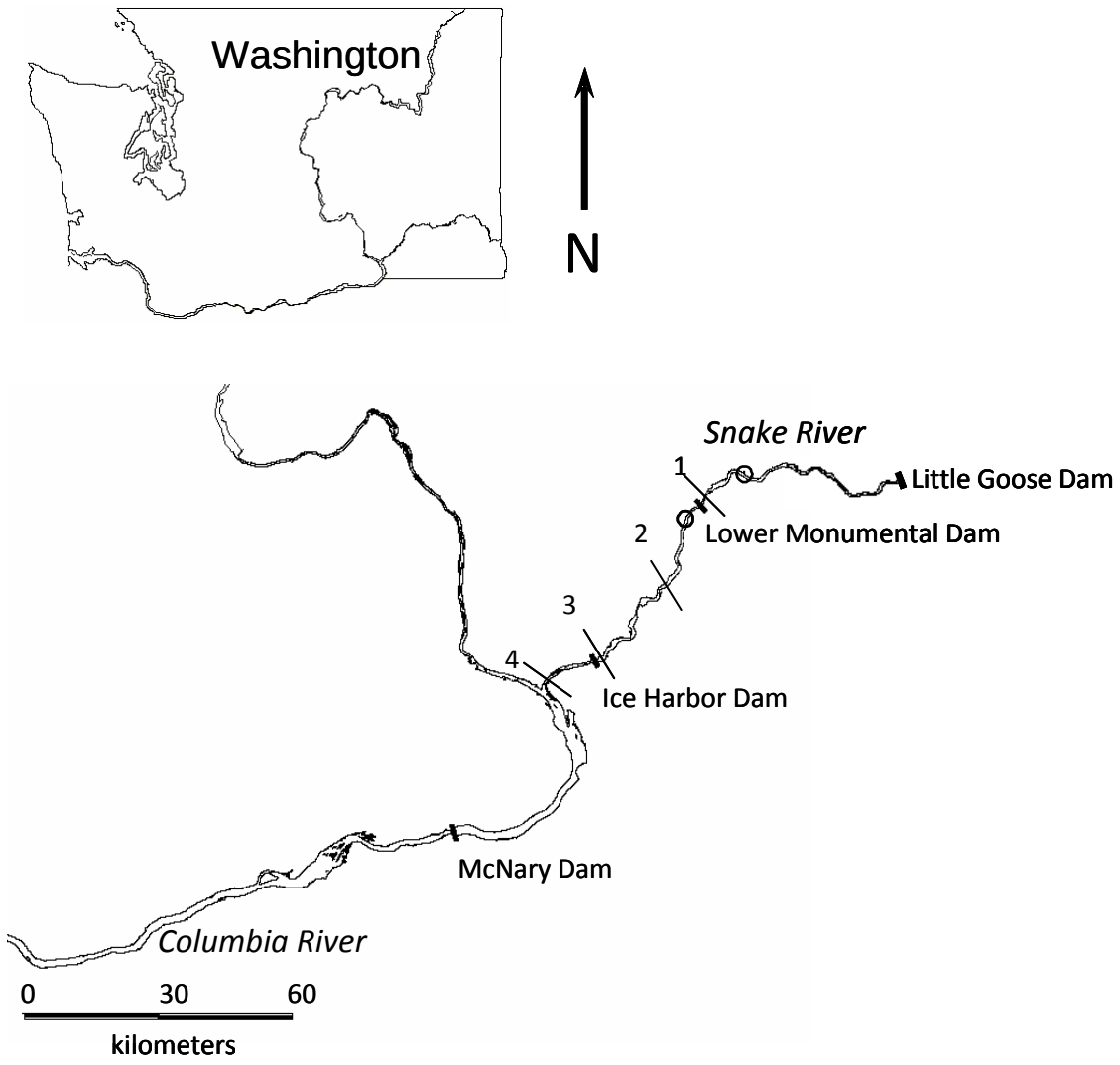


Figure 1. Detail of the study area showing release locations (O) for radio tagged fish and radio telemetry transects used for estimating survival at Lower Monumental Dam in 2009. Transects include: 1 = forebay of Lower Monumental Dam, 2 = Lower Monumental Dam primary survival transect 16 km downstream of the dam, 3 = Lower Monumental Dam secondary survival transect 50 km downstream of the dam in the forebay of Ice Harbor Dam, and 4 = transect at the mouth of the Snake River. The tailrace and all routes of passage at Lower Monumental and Ice Harbor Dams were also monitored.

Fish were surgically tagged with a radio transmitter using techniques described by Adams et al. (1998). A PIT tag was also inserted with the radio transmitter so that study fish diverted to the Lower Monumental Dam JBS could be separated by code and returned to the river (Marsh et al. 1999). Surgical tagging was conducted simultaneously at three tagging stations. During a 4-h shift, approximately 200 fish were tagged.

Immediately following tagging, fish were placed into aerated 9-L buckets until they recovered from the anesthesia (2 fish per bucket). Buckets were then closed and placed into a large holding tank (1.5-m wide, 2.5-m long, 0.5-m deep) which accommodated up to 28 buckets and which was supplied with flow-through river water during tagging and holding. Fish were held a minimum of 24 h for recovery and determination of post-tagging mortality.

Release procedures followed those used in 2007 at Lower Monumental Dam during a study to evaluate passage and survival (Hockersmith et al. 2008a). After a post-tagging recovery period, fish were transported in their recovery buckets to release locations (7 km upstream from Lower Monumental Dam or into the tailrace). Immediately prior to transport to release locations, transmitters of all tagged fish were checked for operation and to verify that codes were recorded correctly in the database. To provide mixing of treatment and reference groups, treatment groups were released all at one time twice daily (morning and afternoon periods), and reference release groups were released over a 6-h period twice daily (daytime and nighttime periods).

Treatment groups were transported upstream by truck, then transferred water-to-water from the tank to a release tank mounted on an 8.5 × 2.4-m barge while still in their recovery buckets. Treatment groups were released 7 km upstream from Lower Monumental Dam in the middle of the river channel. Reference groups were transferred in their recovery buckets to a holding tank on a truck and then driven to their release location approximately 1,300 m downstream from Lower Monumental Dam.

Upon arrival at the release site, reference fish were maintained via flow-through river water until release. Fish were released one or two at a time, with the entire group released over a 6-h period during both the daytime and nighttime release periods. Reference fish were released using a flume that extended a minimum of 7.6 m from the north shoreline out into the river. The reference group release location was based on tailrace conditions observed in the field and from a 1:55 scale model of Lower Monumental Dam at the USACE Research and Development Center, Vicksburg, MS.

Lower Monumental Dam operations utilized two spill patterns (uniform and bulk spill patterns) that followed a 4-d random block operating schedule with each pattern operated for 2 consecutive days. The RSW was operated during both treatments. In general, the maximum difference in the gate openings for spillbays 1 though 6 was less than 2 stops during the uniform spill pattern and more than 2 stops for the bulk spill pattern. Project operation data were collected every 5 min by the USACE. Treatment fish were assigned to project operations corresponding to conditions recorded at the time closest to the time of forebay entry and passage. For treatment fish that passed the dam with an undetermined passage time, project operations were assigned based on conditions closest to the time of first detection recorded in the tailrace. For treatment fish that did not pass the dam, project operations corresponded to conditions closest to the time of forebay entry. Operational conditions assigned to reference fish corresponded to conditions closest to time of release.

Telemetry Monitoring

Radio telemetry receiver arrays were positioned to determine forebay entrance, dam approach, route of passage, tailrace exit, and downstream detection (Figure 1). The locations of fixed telemetry receiver sites at Lower Monumental Dam in 2009 are summarized in Table 3 and Figure 2. Based on past experience, we did not utilize a double array (Skalski et al. 2002) for evaluating routes of passage because the proportion of fish with undetermined passage routes has been low (typically less than 3%).

Data Processing and Analysis

Telemetry data were retrieved through an automated process that downloaded networked telemetry receivers up to four times daily. Data processing and reduction are summarized in Appendix C. After downloading, individual data files were compressed by recording the first time a radio-tagged fish was detected and counting the number of detections where the time-difference between adjacent detections was less than or equal to 5 min. When the difference between adjacent detections became greater than 5 min, a new line of data was created. All compressed data were combined and loaded into a database, where automated queries and algorithms were used to remove erroneous data. On the cleaned data set, detailed detection histories were created for each radio-tagged fish. These detection histories were used to calculate arrival time in the forebay, forebay approach patterns, passage-route distribution and timing, tailrace exit timing, and timing of downstream detections for individual radio-tagged fish.

Forebay Residence Time

Forebay arrival time was based on the first time a fish was detected on the forebay entry line at the upstream end of the boat restricted zone (BRZ) at Lower Monumental Dam (approximately 675 m upstream from the face of the dam). Forebay residence was determined for fish that had been released upstream from Lower Monumental Dam and detected entering the forebay, detected in a passage route, and detected in the immediate tailrace on the stilling-basin, turbine draft tube, or tailrace-exit telemetry receivers (Figure 2). Forebay residence for individual fish was calculated as the difference between the first detection on the forebay entrance line at the upstream end of the BRZ and the time of last detection in a passage route prior to passage.

We estimated residence by species and treatment block. Data for fish that entered under one treatment block and passed under the subsequent one were "right-censored" (Hosmer et al. 2008). For censored data, the time from forebay entry until the end of the treatment block was used in the estimation, while the time spent in the subsequent treatment block was ignored. This was done to avoid bias in forebay residence estimation due to possible "edge effects" from the change between treatment operations.

To analyze forebay residence patterns, we used *survival analysis*, or "time-to-event" data (Lawless 1982, Tableman and Kim 2004). Time-to-event data track the time it takes for individuals to attain a particular event (for forebay residence it is the time to pass the dam). A benefit of this method is that it can accommodate censored individuals. The analysis includes a survivorship function (describing the timing of passage), and the hazard function (describing the rate of passage). Survival analysis is based on the survival function, $S(t)$, which describes the proportion of fish remaining through time t. In other words, if we define a random variable T that represents the distribution of forebay passage times (t) of individuals in a population, then $S(t) = P(T > t)$. Note that $S(t)$ always equals 1.0 at $t = 0.0$, and decreases to 0.0 through time.

For an assessment of the empirical passage distributions by species and treatment, we modeled the data with the non-parametric product-limit, or Kaplan-Meier method (K-M) (Lawless 1982, Hosmer et al. 2008). This method estimated the decrease in survival at each successive discrete point, i, where passage (one or more) occurred, while adjusting for censored data. The K-M survival estimate at time t was:

$$\hat{S}(t) = \prod_{i=1}^{k} \frac{n_i - d_i}{n_i}$$

where n_i was the number of individuals remaining in the forebay at the beginning of interval i, d_i was the number of fish passing at the end of interval i, and t was measured as the time between intervals k and $k + 1$. Thus, the estimated proportion remaining was

produced by multiplying together the probability of surviving through each time increment. The summary statistic we used to describe the "location" parameter of the K-M curve was the time at which 50% (median) of the fish had passed. Significant differences ($\alpha = 0.05$) between K-M survival curves by treatment (spill operation) were determined using a log-rank chi-square test (Tableman and Kim 2004), which compared the actual and expected number passing at each time.

Approach and Passage Distribution

Approach patterns were established based on the first detection at either underwater dipole spillway antennas (Beeman et al. 2004) or on stripped coax underwater antennas (Knight et al. 1977) on the standard-length traveling screens (Table 3). Preseason testing of the detection fields indicated that first approach locations were within 18 m of the dam. Route of passage through the dam was based on the last time a fish was detected on a passage-route antenna and was assigned only to fish that were subsequently detected in the tailrace on either the stilling-basin, turbine draft tube, or tailrace-exit telemetry receivers (Figure 2). Tailrace detections were used to validate passage because fish could be detected on a passage-route receiver while still in the forebay. Approach and passage behavior was compared between treatment operations (uniform vs. bulk spill patterns) and included only fish which entered the forebay and passed the dam during the same treatment block.

Spillway passage was assigned to fish that were detected in the tailrace after last being detected in the forebay on one of the eight antenna arrays deployed along each of the two pier noses on the sides of individual spillbays. RSW passage was assigned to fish that were detected in the tailrace of the dam after last being detected in the forebay on one of the antenna arrays that were deployed to monitor RSW passage. Powerhouse passage was assigned to fish last detected in a turbine intake prior to detection in the tailrace of the dam. Fish passing via the powerhouse were further partitioned into either turbine or JBS passage based on the presence or absence of a detection in the JBS (either PIT-tag or telemetry detection). Fish assigned to powerhouse passage, but with no detection in the JBS were assigned to turbine passage. For analysis of passage-route distributions, we included only fish that had been released upstream from Lower Monumental Dam and detected in the immediate tailrace either on the stilling-basin, turbine draft tube, or tailrace-exit telemetry receivers. A small number of fish could potentially pass the dam via either the unmonitored adult fish ladder or navigation lock.

Table 3. Locations of fixed-site telemetry receivers for evaluating passage behavior and survival at Lower Monumental Dam, 2009.

Location	Number of receivers	Type of monitoring	Antenna type
0.5 km above forebay	3	Entrance line and timing	3-element Yagi
Turbine units 1-6	6	Approach and passage location	Striped coax
Spillbays 1-7	7	Approach and passage location	Underwater dipole
RSW (spillbay 8)	2	Approach and passage location	Tuned loop and underwater dipole
Stilling basin	2	Project passage	Tuned loop
Juvenile bypass system	1	JBS passage	Tuned loop
Turbine unit draft tubes	3	Project passage	Underwater dipole
Tailrace exit	2	Project passage and egress	3-element Yagi
Total receivers	26		

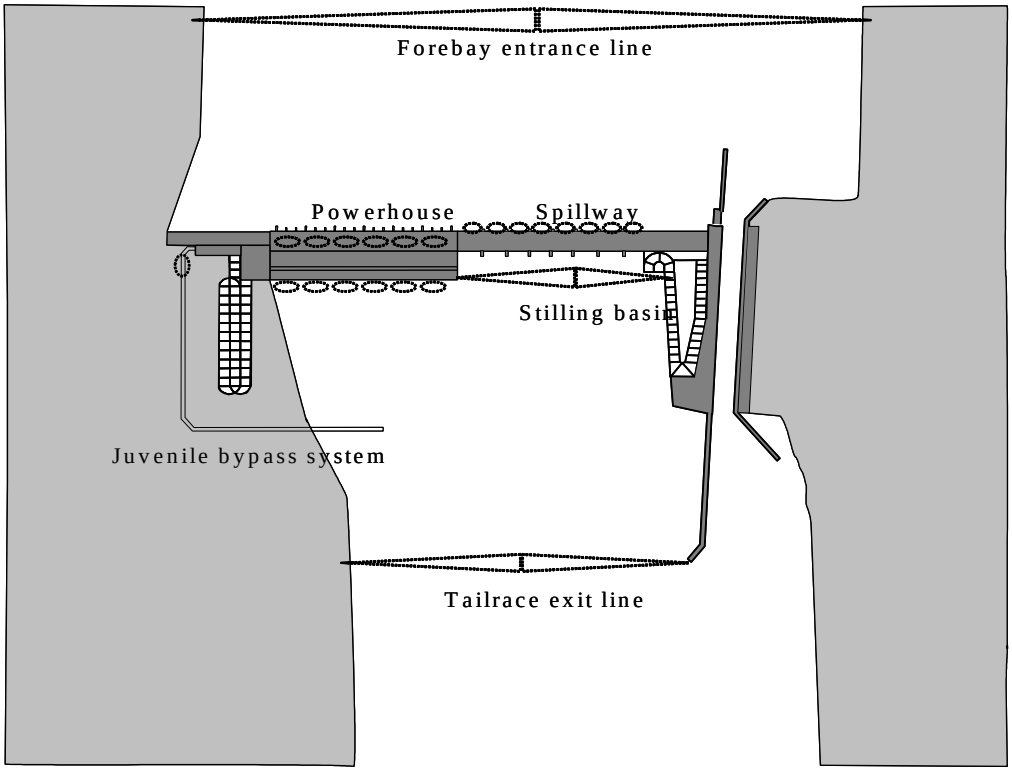


Figure 2. Lower Monumental Dam plan view showing approximate locations of detection zones for radio telemetry receivers in 2009. Oval lines represent underwater antennas, and triangular lines represent aerial antennas.

Fish Passage Metrics

Fish passage metrics included spillway passage efficiency (SPE), spillway passage effectiveness (SPS), fish passage efficiency (FPE), fish guidance efficiency (FGE), surface outlet efficiency (SOE), surface outlet effectiveness (SOS), and JBS Passage Efficiency (BPE). These metrics were estimated as follows:

SPE: Number of fish passing the dam via the spillway divided by the total number of fish passing the dam.

SPS: Proportion of fish passing the dam via the spillway divided by the proportion of water spilled.

FPE: Number of fish passing the dam through non-turbine routes divided by total number of fish passing the dam.

FGE: Number of fish passing the dam through the JBS divided by the total number of fish passing the dam through the powerhouse (turbines and JBS).

SOE: Number of fish passing through a surface flow outlet (RSW, TSW, ITS, corner collector, etc) divided by the total number of fish passing the dam.

SOS: Proportion of fish passing through a surface flow outlet (SOE) divided by the proportion of water passing through the surface flow outlet.

BPE: The number of fish passing through the JBS divided by the total number of fish passing the dam.

Differences in fish passage metrics were compared between treatment operations (uniform vs. bulk spill patterns) using paired *t*-test ($\alpha = 0.05$). Operational treatment assigned to fish for fish passage metrics analysis was based on the treatment block during passage.

Tailrace Egress

For analysis of tailrace egress, we included only fish that had been released upstream from Lower Monumental Dam, detected in a passage route, and detected again in the immediate tailrace. Tailrace egress time for individual fish was calculated as the difference between time of last detection in a passage route and time of last detection on the tailrace-exit array (approximately 500 m downstream of the dam). Tailrace egress data was analyzed using the Kaplan-Meier method, as described for analyzing forebay residence except that no data collected from these fish were censored.

Survival Estimates

Survival estimates were based on detections of individual fish at Snake River telemetry transects 16 km downstream of the dam, 50 km downstream of the dam in the forebay of Ice Harbor Dam, and 47 km downstream of the dam at the mouth of the Snake River (Figure 1). Detection histories were evaluated independently for treatment and reference groups using the single-release or CJS model (Cormack 1964; Jolly 1965; Seber 1965). Data were analyzed using *Survival with Proportional Hazards* (SURPH), a statistical software developed at the University of Washington (Smith et al. 1994).

Survival estimates followed the guidelines described by Peven et al. (2005). Lower Monumental Dam survival was defined as survival of treatment fish through all passage routes combined relative to survival of tailrace-released reference fish. The "effect zone" (Peven et al. 2005) extended from the forebay entrance array (~675 m upstream of the dam) to the tailrace control release location. The tailrace release location (reference fish) was approximately 1,300 m downstream from Lower Monumental Dam.

Concrete survival was an estimate of the treatment fish surviving through the combined passage routes of Lower Monumental Dam relative to survival of the tailrace reference fish. The effect zone extended from the exit of all passage routes to the tailrace control release location. Concrete survival did not include any losses in the forebay.

Capture histories of treatment and reference groups were partitioned into two periods for survival estimation: detection at the primary survival array (16 km downstream from Lower Monumental Dam) and detection at or below the Ice Harbor Dam forebay array 50 km downstream of the dam. Treatment groups for estimates of survival were comprised of fish released above Lower Monumental Dam and subsequently detected on the forebay entrance array approximately 675 m upstream from the dam. For estimates of dam survival, treatment groups were grouped by operational treatment block determined from the time of forebay entry. Treatment fish that passed the dam during a different operational treatment block than the one when they entered the forebay were excluded from analysis of dam survival. Reference fish groups were formed based on operational treatment block during their release.

For estimates of relative survival, treatment fish assigned to an operational treatment block *i* were paired with reference fish that were released to the tailrace during the same block (i.e., operational treatment block *i*). Relative survival was estimated as the ratio of survival estimates between treatment (numerator) and reference (denominator) fish groups for each operational treatment block. The geometric mean of the operational treatment block estimates was calculated to summarize survival for the season.

For estimates of concrete and route-specific survival, treatment groups were grouped by operational treatment block determined from the time of passage. Reference fish groups were formed based on operational treatment block during their release. For estimates of relative survival, treatment fish assigned to an operational treatment block *i* were paired with reference fish that were released to the tailrace during the same block (i.e., operational treatment block *i*). Relative survival was estimated as the ratio of survival estimates between treatment (numerator) and reference (denominator) fish groups for each operational treatment block. The geometric mean of the operational treatment block estimates was calculated to summarize survival for the season. Survival was pooled for survival estimates with too few replicates and reasonable sample sizes.

Confidence intervals for estimates of relative survival were constructed using the geometric mean of treatment block estimates of survival. Since geometric means were used, the ratios of proportions were assumed log-normally distributed (Snedecor and Cochran 1980). Thus, the geometric mean was assumed equivalent to the back-transformed arithmetic mean of the log-transformed estimates. Confidence intervals were of the form:

$$\left({}_e\log(\bar{x}) - t_{.05,n-1} \times SE \;,\; {}_e\log(\bar{x}) + t_{.05,n-1} \times SE \right)$$

where $\bar{x}$ was the geomean; *t* was the *t*-value, given $\alpha = 0.05$ and 25 degrees of freedom (i.e., approximately equal 2); and *SE* was the standard error of the geomean.

An assumption of the CJS model is that fish in all groups have equal probabilities of survival and detection downstream from the point of release (i.e., the tailrace of Lower Monumental Dam). This assumption is reasonable if release groups have similar passage distributions at downstream detection sites, in this case at the primary survival array 16 km downstream from the dam. To evaluate this assumption, we compared differences between treatment and reference groups in temporal passage distribution at the primary survival array. Treatment fish were grouped by operational treatment block and "paired" with tailrace fish grouped by the same block. Confidence intervals (95%) and *t*-tests were constructed for statistical comparison. Model assumptions and methods used to evaluate them are detailed in Appendix A. Treatment fish were assumed to have passed the dam through the location where they were last detected and their passage confirmed by detection in the immediate tailrace.

To provide continuity between analysis and interpretation of survival and passage behavior, we excluded any fish that did not meet the criteria for both passage behavior and survival analyses. In addition, fish that were transported from Lower Monumental Dam were excluded from analysis. These exclusions did not bias any of the estimated parameters, but decreased the precision of estimates, since the effect was to decrease

sample size. At present, no formal analysis of adult returns of tagged fish used in this study is anticipated.

Avian Predation

Predation by Caspian terns *Hydroprogne caspia*, double-crested cormorants *Phalacrocorax aurtius*, and gulls *Larus* spp. was evaluated by physical recovery of radio transmitters and by PIT-tag detection on Crescent and Foundation Islands in the McNary Dam Reservoir. Radio transmitters and PIT tags were recovered on nesting colonies during fall 2009 after the birds had abandoned their nesting colonies. Radio-tag serial numbers were used to identify individual tagged fish. PIT-tag detections and recovery of radio transmitters were provided by NMFS (S. Sebring, NMFS, personal communication) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication). There is an ongoing monitoring effort to detect PIT tags from active avian colonies in the region conducted by NOAA Fisheries and by the Columbia Bird Research group.

RESULTS

Fish Collection, Tagging, and Release

The 2009 study period encompassed the period between the 2nd and 82nd passage percentiles of the general population of yearling Chinook salmon and the period between the 1st and 73rd passage percentiles of the juvenile steelhead smolt passage index at Lower Monumental Dam (Figure 3).

We released 1,157 radio-tagged yearling Chinook salmon 7 km upstream from Lower Monumental Dam and 1,045 yearling Chinook salmon into the tailrace. For yearling Chinook salmon released above the dam, overall mean fork length was 140.8 mm (SD = 12.3; Tables 4 and 5) and overall mean weight was 26.3 g (SD = 7.6). For yearling Chinook salmon released below the dam, overall mean fork length was 141.0 mm (SD = 11.7) and overall mean weight was 26.32 g (SD = 7.2).

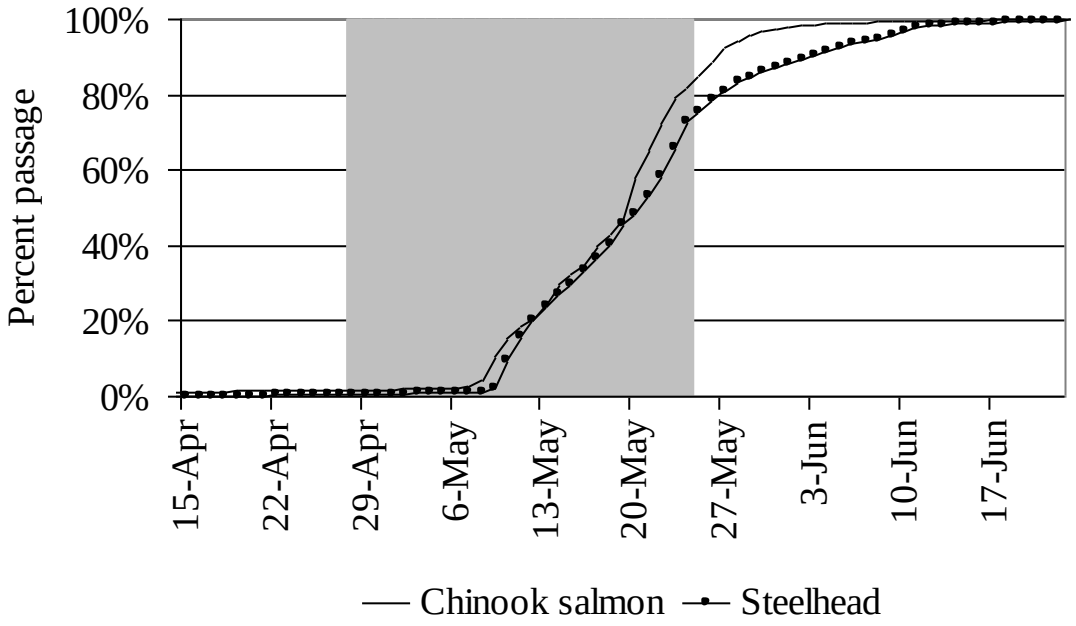


Figure 3. Cumulative passage distribution of hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam during 2009. Shaded area indicates study period.

Table 4. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged, yearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2009.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	34	118	183	144.5	16.1	---	---	---	---	---
28 Apr	35	124	172	147.9	11.4	36	121	179	147.3	14.7
29 Apr	36	124	173	148.2	13.3	37	119	185	147.0	16.4
30 Apr	44	114	180	140.3	16.2	41	111	167	140.9	14.0
1 May	48	115	178	144.0	14.8	40	116	165	142.3	11.8
2 May	48	117	172	141.2	13.5	42	117	166	141.8	12.0
3 May	46	112	177	142.8	16.7	40	108	177	136.8	14.6
4 May	46	122	184	141.6	14.3	42	124	174	144.5	12.2
5 May	47	116	169	141.6	11.2	40	116	169	137.8	12.2
6 May	45	115	186	142.0	14.0	41	119	160	139.4	11.9
7 May	47	116	165	138.0	12.2	42	117	163	136.7	11.8
8 May	45	116	168	137.4	10.9	41	118	164	140.9	9.6
9 May	47	113	164	140.8	11.0	41	123	183	142.6	12.3
10 May	47	118	180	139.9	14.8	41	125	178	144.4	12.5
11 May	45	113	167	136.8	12.6	41	115	166	138.1	11.7
12 May	46	124	166	140.2	9.5	41	123	177	141.0	11.7
13 May	46	122	190	142.2	12.4	42	122	179	141.8	12.7
14 May	47	120	176	138.4	11.0	41	114	174	138.3	11.3
15 May	44	121	157	139.3	8.7	39	120	155	140.9	8.6
16 May	46	119	160	136.7	9.2	41	121	155	137.5	7.6
17 May	46	125	160	138.8	9.8	42	121	164	138.9	8.8
18 May	45	116	174	139.2	10.6	39	112	162	140.9	10.2
19 May	46	118	160	140.2	8.8	39	116	156	140.9	8.8
20 May	48	123	166	143.5	9.4	41	122	169	143.0	8.3
21 May	44	125	160	140.7	7.8	41	117	158	140.4	9.6
22 May	39	124	158	139.2	6.8	39	120	154	138.8	8.8
23 May	---	---	---	---	---	35	126	175	145.4	10.4
Overall	1,157	112	190	140.8	12.3	1,045	108	185	141.0	11.7

Table 5. Sample size, range, mean, and standard deviation (SD) of weights (grams) for radio-tagged, yearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2009.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	34	17	54	31.1	10.3	---	---	---	---	---
28 Apr	35	17	44	30.9	7.0	36	17	52	31.2	9.0
29 Apr	36	18	52	31.7	9.0	37	14	61	32.2	10.7
30 Apr	44	14	56	27.9	9.7	41	14	45	28.7	8.6
1 May	48	14	53	28.5	9.0	40	14	42	28.4	7.1
2 May	48	17	56	30.1	9.1	42	17	48	29.0	7.7
3 May	46	14	54	29.6	10.2	40	13	51	25.8	8.2
4 May	46	16	61	26.8	9.4	42	15	45	28.2	7.7
5 May	47	16	48	27.1	7.4	40	15	49	24.3	7.2
6 May	45	13	57	26.9	8.7	41	15	42	25.5	7.1
7 May	47	15	45	26.6	7.3	42	16	46	26.5	7.5
8 May	45	15	40	23.8	6.0	41	15	39	24.7	5.2
9 May	47	14	40	25.4	5.9	41	16	56	26.8	7.9
10 May	47	14	53	25.1	8.6	41	17	51	27.1	7.9
11 May	45	15	52	26.0	7.9	41	15	48	26.5	7.0
12 May	46	17	43	24.6	5.3	41	15	53	25.8	7.6
13 May	46	17	64	25.6	8.1	42	16	54	26.4	7.6
14 May	47	15	46	23.8	6.3	41	15	49	24.2	6.2
15 May	44	17	34	24.0	4.7	39	17	36	25.1	4.6
16 May	46	16	40	25.2	4.7	41	17	35	25.5	4.5
17 May	46	17	37	23.4	4.7	42	14	42	22.8	4.9
18 May	45	14	47	23.4	6.2	39	14	37	23.3	5.1
19 May	46	16	38	24.9	5.3	39	15	36	24.5	4.8
20 May	48	13	38	24.5	5.3	41	15	43	24.7	5.4
21 May	44	17	32	23.9	3.7	41	15	36	25.0	4.5
22 May	39	19	46	26.6	5.1	39	17	36	25.9	5.5
23 May	---	---	---	---	---	35	18	48	26.7	6.8
Overall	1,157	13	64	26.3	7.6	1,045	13	61	26.3	7.2

We released 1,173 radio-tagged juvenile steelhead 7 km upstream from Lower Monumental Dam and 1,027 steelhead into the tailrace. For juvenile steelhead released upstream from the dam, overall mean fork length was 210.9 mm (SD = 20.6) and overall mean weight was 84.1 g (SD = 25.8; Tables 6 and 7). For juvenile steelhead released below Lower Monumental Dam, overall mean fork length was 210.6 mm (SD = 20.5) and overall mean weight was 83.2 g (SD = 25.7).

Post-tagging mortality was 0.9% (21 fish) for yearling Chinook salmon and 0.6% (13 fish) for juvenile steelhead. Fish that died during the post-tagging holding period were released in the tailrace to verify the assumption that dead fish were not detected on downstream survival arrays (Appendix Table A16). Treatment fish were released between 0849 and 0923 and between 1317 and 1400 PDT. Reference fish were released between 0831 and 1603 and between 2011 and 0325 PDT. Thirty-seven yearling Chinook salmon and 31 juvenile steelhead were excluded from all analysis because they either never entered the study area, were transported from Lower Monumental Dam, or their transmitters were not working at release (Table 8). Details of fish excluded from analysis are specified in Table 8.

Table 6. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged, juvenile steelhead released at Lower Monumental Dam to evaluate passage behavior and survival, 2009.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	36	177	252	211.4	19.6	---	---	---	---	---
28 Apr	36	161	244	205.5	19.4	34	170	263	212.5	21.2
29 Apr	40	167	258	201.6	18.6	33	151	235	196.6	20.2
30 Apr	43	158	244	205.5	19.3	40	170	243	201.9	18.9
1 May	46	167	243	194.9	14.8	41	141	240	195.8	20.6
2 May	46	167	246	198.9	17.2	42	152	238	199.6	19.0
3 May	46	159	250	197.1	21.0	41	150	225	189.4	19.2
4 May	46	153	241	199.5	21.3	39	167	228	200.7	16.9
5 May	47	159	234	191.9	15.6	41	167	225	191.1	12.7
6 May	48	154	232	196.8	18.1	41	166	238	198.7	17.0
7 May	47	166	243	198.6	15.9	41	172	254	207.0	17.5
8 May	48	170	247	209.9	17.0	42	170	264	208.6	18.7
9 May	44	156	249	212.8	22.5	42	162	239	207.9	17.0
10 May	47	169	253	211.9	15.7	42	163	242	216.0	17.4
11 May	46	173	249	213.6	16.7	41	179	246	213.9	16.8
12 May	47	179	262	224.9	19.3	41	190	254	219.0	16.1
13 May	47	183	265	226.3	19.5	40	178	260	218.6	19.2
14 May	47	197	271	225.8	18.6	41	188	283	222.3	20.4
15 May	47	189	259	218.0	17.9	39	184	265	218.5	16.9
16 May	47	188	260	216.6	13.4	41	181	253	219.1	15.9
17 May	46	176	261	218.9	15.9	41	178	254	218.2	18.0
18 May	48	177	258	217.2	18.9	36	187	261	218.3	16.9
19 May	48	180	257	218.2	16.2	38	184	265	223.2	17.9
20 May	47	195	254	223.5	16.4	37	190	274	222.8	16.2
21 May	43	199	251	219.0	14.4	39	196	259	222.0	18.1
22 May	40	180	262	223.6	18.4	39	182	258	218.0	17.4
23 May	---	---	---	---	---	35	181	247	218.0	16.6
Overall	1,173	153	271	210.9	20.6	1,027	141	283	210.6	20.5

Table 7. Sample sizes, range, mean, and standard deviation (SD) of weights (grams) for radio-tagged, juvenile steelhead released at Lower Monumental Dam to evaluate passage behavior and survival, 2009.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	36	48	145	89.0	26.8	---	---	---	---	---
28 Apr	36	34	130	80.0	22.2	34	42	163	87.7	25.8
29 Apr	40	38	151	73.4	23.6	33	27	113	68.8	23.0
30 Apr	43	34	147	78.7	23.8	40	40	142	74.5	23.7
1 May	46	42	138	65.9	17.6	41	28	131	71.2	24.7
2 May	46	37	138	70.7	21.9	42	29	124	72.5	22.8
3 May	46	33	137	68.3	23.6	41	28	91	60.1	16.5
4 May	46	33	120	71.0	22.9	39	41	102	70.0	18.1
5 May	47	38	119	61.9	18.2	41	39	104	59.5	14.0
6 May	48	31	107	66.1	20.2	41	37	121	67.1	18.7
7 May	47	43	129	74.0	19.6	41	46	158	85.1	24.0
8 May	48	37	132	79.0	21.1	42	40	164	75.6	22.7
9 May	44	32	142	85.1	27.3	42	37	121	77.5	19.7
10 May	47	48	141	90.0	18.8	42	37	132	87.3	22.5
11 May	46	46	136	91.9	22.2	41	53	149	94.4	25.5
12 May	47	50	169	101.3	25.4	41	56	146	91.7	23.1
13 May	47	54	170	103.1	29.5	40	49	172	92.2	26.4
14 May	47	63	185	101.2	27.5	41	52	192	97.2	31.3
15 May	47	49	159	88.9	26.7	39	50	168	86.6	24.2
16 May	47	64	153	97.3	17.6	41	52	161	99.2	23.7
17 May	46	46	157	90.9	21.3	41	47	155	91.2	25.4
18 May	48	43	136	87.6	21.9	36	44	141	87.1	21.8
19 May	48	42	135	88.7	21.2	38	48	166	95.7	26.6
20 May	47	59	156	94.1	24.4	37	56	160	92.8	21.5
21 May	43	58	129	85.9	17.8	39	61	150	93.4	23.2
22 May	40	50	172	103.2	28.8	39	57	162	98.1	23.8
23 May	---	---	---	---	---	35	52	133	87.7	22.0
Overall	1,173	31	185	84.1	25.8	1,027	27	192	83.2	25.7

Table 8. Numbers of yearling Chinook salmon and juvenile steelhead excluded from analysis of behavior and survival at Lower Monumental Dam, 2009.

	Yearling Chinook salmon		Juvenile steelhead	
	Treatment	Reference	Treatment	Reference
Tagged and released alive	1,157	1,045	1,173	1,027
Excluded from all analysis				
Transmitters were not working at release	12	1	4	7
Never entered the study area	20	NA	18	NA
Transported at Lower Monumental Dam	4	NA	2	NA
Total	36	1	24	7
Excluded from dam survival and forebay behavior analysis				
Entry and passage timing corresponded to different operational treatment blocks	236	NA	278	NA
Passage detection but not detected on entry line	9		3	NA
Sample size too small for treatment block	3	35	11	34
Total	248	35	292	34
Excluded from concrete survival and passage behavior analysis				
Did not pass the dam	26	NA	22	NA
Passage timing unknown to assign a treatment block	9	NA	3	NA
Sample size too small for treatment block	9	35	15	34
Total	44	35	40	34

Project Operations

During our study, project discharge averaged 101 kcfs, or approximately 119% of the previous 10-year average daily flow of 85 kcfs at Lower Monumental Dam (1998-2007; Figure 4). Project operations included a mix of voluntary and involuntary spill throughout the study period. Two spill patterns (uniform and bulk) were evaluated. Project operations during the uniform spill pattern averaged 98.6 kcfs total discharge, 62.5 kcfs powerhouse discharge, 36.1 kcfs spillway discharge (38% of total project discharge), and tailwater elevation of 440.5 ft msl (Table 9 and Figure 5). Project operations during the bulk spill pattern averaged 101.6 kcfs total discharge, 75.0 kcfs powerhouse discharge, 26.5 kcfs spillway discharge (27% of total project discharge), and tailwater elevation of 440.7 ft msl (Table 9 and Figure 5). Flow through the RSW averaged 7.1 kcfs during both the uniform and bulk spill treatments. Water temperature during tagging, the post-tagging holding period, and releases ranged from 9.2 to 12.9°C and averaged 10.8°C.

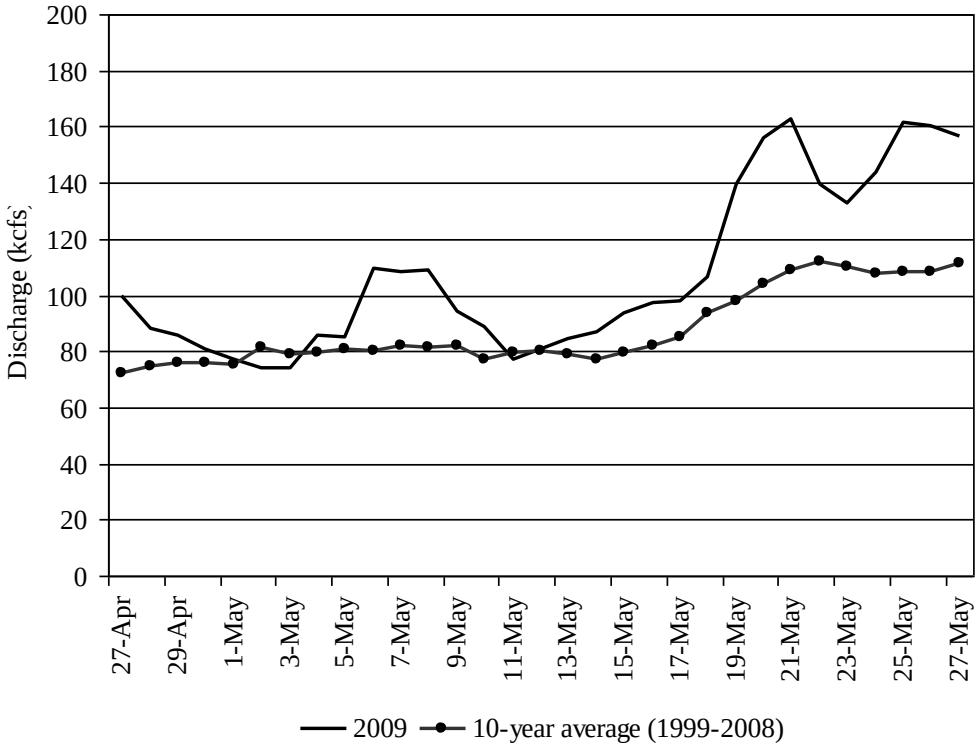


Figure 4. Average daily and 10-year average (1999-2008) project discharge during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead for evaluating passage and survival at Lower Monumental Dam, 2009.

Table 9. Range and average conditions by spill treatment during evaluation of passage and survival for radio tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2009.

Spill			Tailwater elevation (msl)		Spill discharge (kcfs)		Percent spill (%)		Project discharge (kcfs)	
Treatment	Start	End	Range	Average	Range	Average	Range	Average	Range	Average
Uniform 1	4/30 5:00	5/02 4:55	438.5-440.2	439.1	28.8-38.3	35.3	34-55	46	68.5-91.3	76.8
Uniform 2	5/04 5:00	5/06 4:55	438.9-441.1	439.8	27.6-38.8	36.0	28-53	42	71.4-108.6	87.0
Uniform 3	5/08 5:05	5/10 4:55	438.8-441.4	440.3	0-38.8	34.9	0-42	35	56.1-117.4	99.0
Uniform 4	5/10 5:00	5/12 4:55	437.9-441.0	439.4	0-38.2	34.5	0-49	43	37.1-109.3	80.2
Uniform 5	5/14 5:00	5/16 4:50	437.2-441.7	440.1	0-35.1	33.2	0-52	36	31.7-116.9	91.4
Uniform 6	5/20 5:00	5/22 4:50	441.8-445.0	444.0	0-55.4	42.5	0-32	27	111.8-172.2	157.1
Overall			437.2-445.0	440.5	0-55.4	36.1	0-55	38	31.7-172.2	98.6
Bulk 1	4/28 5:00	4/30 4:55	439.1-440.8	439.7	7.2-29.1	25.7	1-37	30	70.7-100.1	85.1
Bulk 2	5/02 5:00	5/04 4:55	438.7-439.7	439.0	28.7-29.7	28.9	37-43	39	69.1-77.3	73.4
Bulk 3	5/06 5:00	5/08 5:00	440.2-442.1	441.1	21.8-32.1	25.3	2-28	23	94.7-120.2	108.9
Bulk 4	5/12 5:00	5/14 4:55	438.7-440.5	439.7	0-26.7	25.0	0-38	30	63.1-97.5	83.4
Bulk 5	5/16 4:55	5/18 4:55	438.7-441.3	440.3	0-28.3	26.2	0-33	27	55.0-108.1	96.0
Bulk 6	5/18 5:00	5/20 4:55	440.3-444.5	442.4	0-40.3	28.5	0-29	22	96.6-157.0	128.2
Bulk 7	5/22 4:55	5/24 5:10	439.4-444.0	442.8	0-39.7	26.2	0-26	19	79.6-154.5	135.9
Overall			438.7-444.5	440.7	0-40.3	26.5	0-43	27	55.0-157.0	101.6

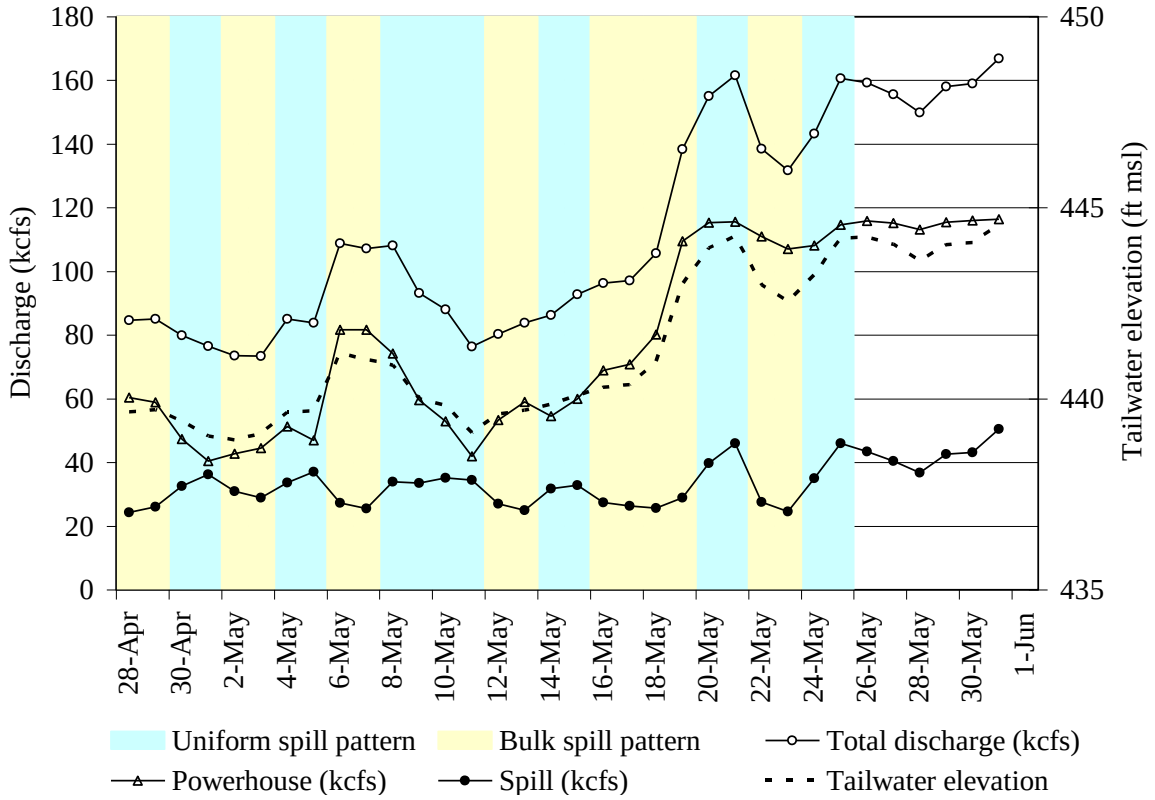


Figure 5. Average daily project discharge, powerhouse discharge, spillway discharge, and tailwater elevation during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2009. The timing of operational treatments (uniform and bulk spill patterns) is also shown.

Forebay Residence Time

Of the 1,141 radio-tagged yearling Chinook salmon released above Lower Monumental Dam (excluding fish with transmitters that were not working and fish transported at the dam), 1,132 (99.2%) were detected on the forebay entrance line at the upstream end of the BRZ. The percent of yearling Chinook salmon entering the Lower Monumental Dam forebay was lowest between 0600 and 1200 PDT and highest from 1300 to 2200 PDT (Figure 6). Yearling Chinook salmon passage followed a similar temporal pattern as forebay entry except it was shifted forward by approximately two to four hours. Median time spent in the forebay during the uniform spill pattern was 2.8 h (95% CI 2.3-3.3) and ranged from < 0.1 to 36 h (Table 10 and Figure 7). Median time spent in the forebay during the bulk spill pattern was 3.6 h (95% CI 3.0-4.3) and ranged from < 0.1 to 41 h (Table 10). While the median time spent in the forebay for yearling Chinook salmon during the uniform spill pattern was significantly shorter (P = 0.004) than during the bulk spill pattern, it was only about 50 minutes.

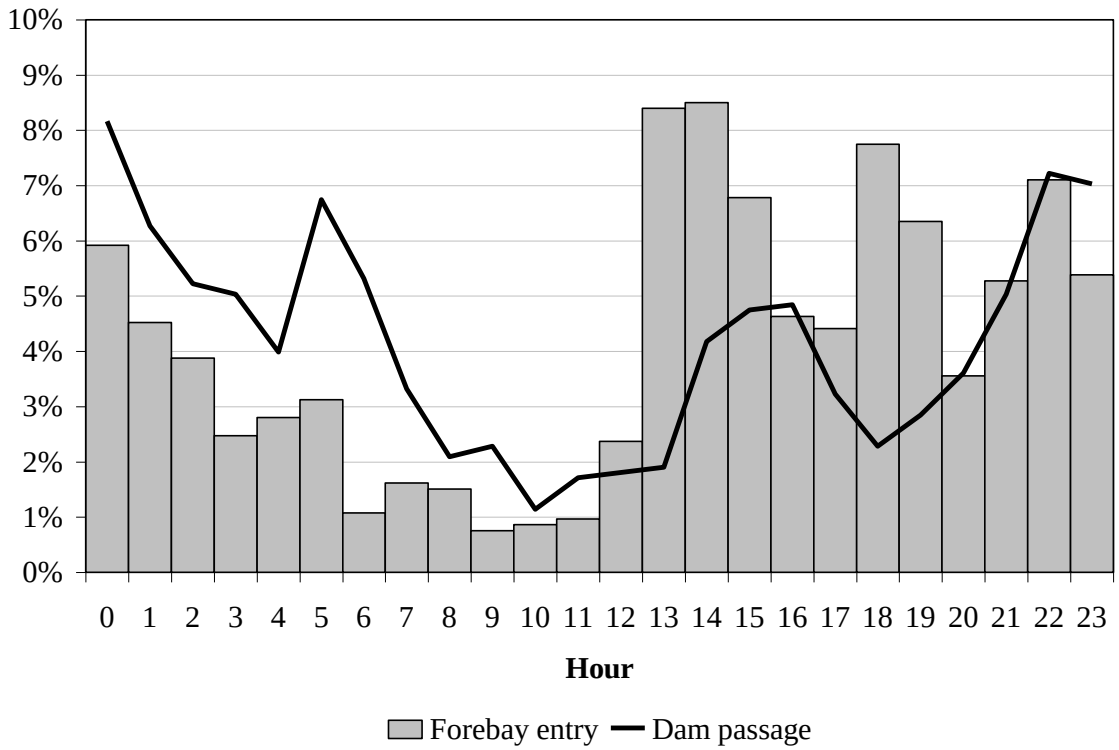


Figure 6. Hour of first detection in the forebay and time of passage at Lower Monumental Dam for radio-tagged yearling Chinook salmon, 2009.

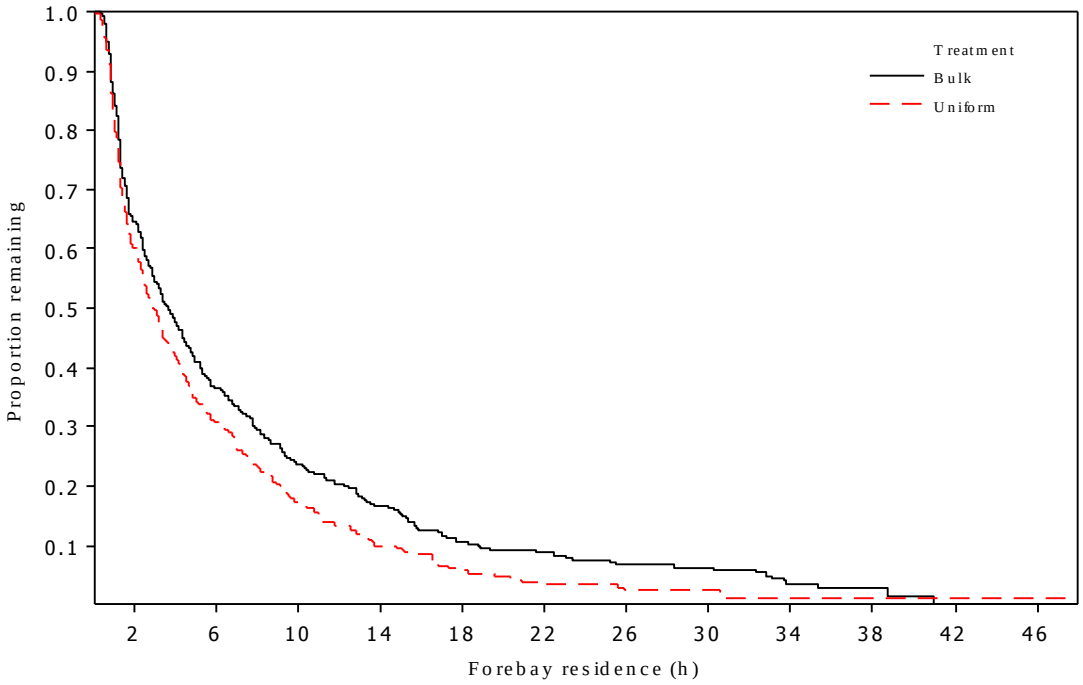


Figure 7. Kaplan-Meier survival curves of forebay residence (elapsed time in hours from first detection on the forebay entry line to time of passage) by spill treatment for radio-tagged hatchery yearling Chinook salmon at Lower Monumental Dam, 2009.

Of the 1,173 radio-tagged juvenile steelhead released above Lower Monumental Dam, (excluding those with transmitters that were not working and fish transported at the dam), 1,164 (99.7%) were detected on the forebay entrance line at the upstream end of the BRZ. The percent of juvenile steelhead entering the Lower Monumental Dam forebay was lowest between 1000 and 1100 PDT and highest from 1200 to 0500 and from 2300 to 0000 (Figure 8). Juvenile steelhead passage followed a similar temporal pattern of forebay entry, except for a shift forward of approximately 1 to 2 h. Median time spent in the forebay during the uniform spill pattern was 3.1 h (95% CI 2.4-4.2) and ranged from 0.2 to 40 h (Table 10 and Figure 9). Median time spent in the forebay during the bulk spill pattern was 3.2 h (95% CI 2.7-3.9) and ranged from 0.2 to 47 h (Table 10) and was not significantly different from the uniform spill pattern.

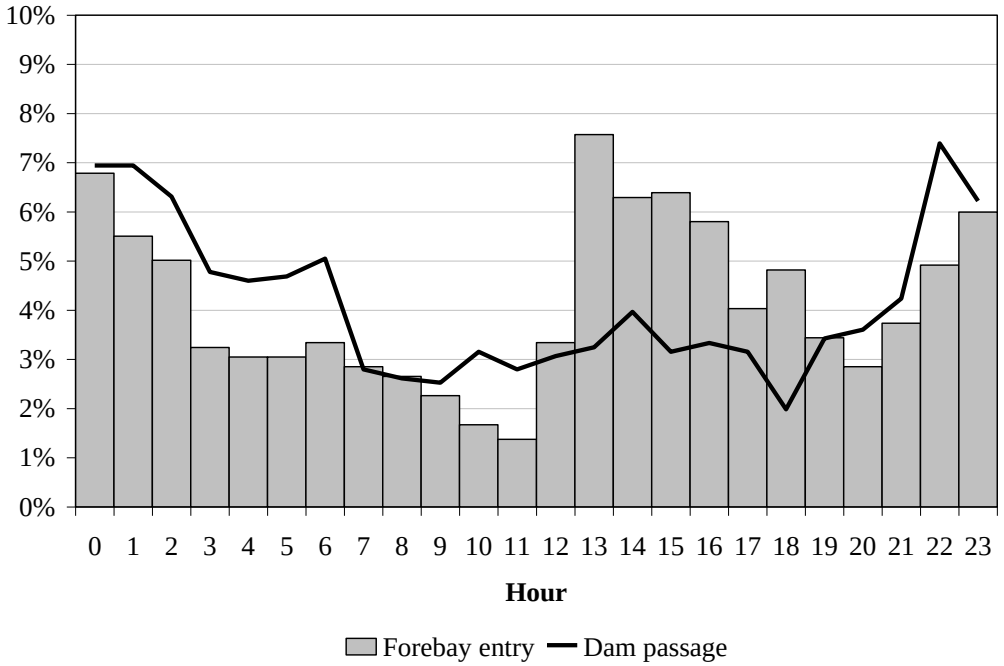


Figure 8. Hour of first detection in the forebay and time of passage at Lower Monumental Dam for radio-tagged juvenile steelhead, 2009.

Table 10. Forebay residence time by spill treatment for radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2009 (Elapsed time from first detection on the forebay entry line to passage).

	Forebay residence (h)			
	Yearling Chinook salmon		Juvenile steelhead	
Passage percentile	Uniform spill	Bulk spill	Uniform spill	Bulk spill
N	434	502	523	448
10th	0.7	0.8	0.7	0.7
20th	1.0	1.2	1.2	1.0
30th	1.3	1.5	1.5	1.4
40th	1.9	2.3	2.2	2.0
50th	2.8	3.6	3.2	3.1
60th	4.2	5.2	5.3	5.2
70th	6.2	7.7	7.9	8.3
80th	9.0	12.0	13.3	11.8
90th	13.7	18.5	23.5	20.9
95th	18.2	32.8	28.4	33.8
Minimum	< 0.1	< 0.1	0.2	0.2
Mean	5.5	7.4	7.9	7.7
Median	2.8	3.6	3.2	3.1
Maximum	36.3	41.0	47.3	40.3
SD	7.1	10.3	11.0	10.8

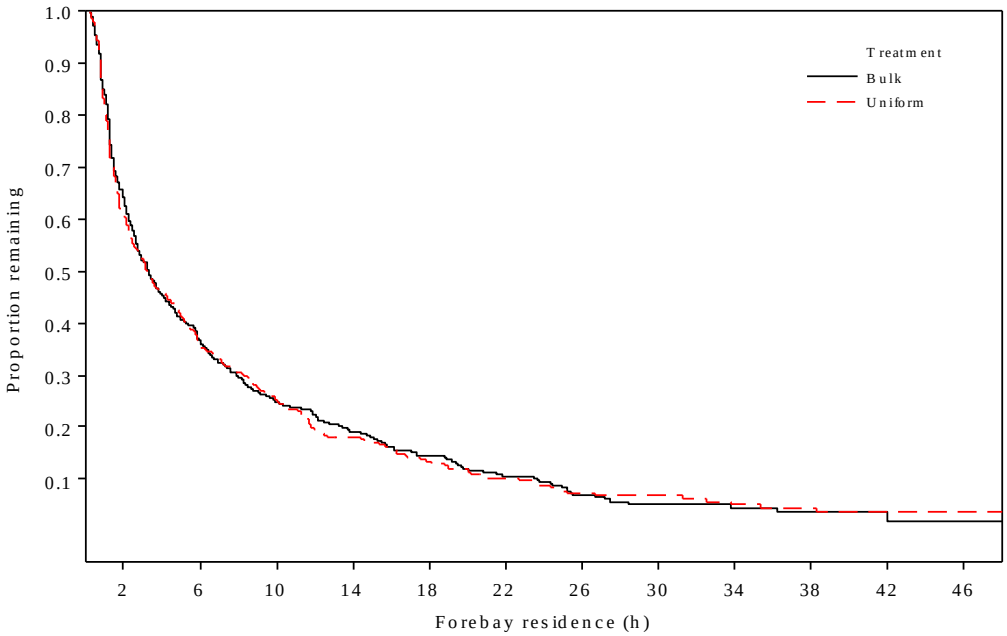


Figure 9. Kaplan-Meier survival curves of forebay residence (elapsed time in hours from first detection on the forebay entry line to time of passage) by spill treatment for radio-tagged juvenile steelhead at Lower Monumental Dam, 2009.

Approach and Passage-Route Distribution

A total of 1,132 yearling Chinook salmon entered the forebay of Lower Monumental Dam, and 97.7% of these fish (1,106) subsequently passed the dam. Eighty-two percent of the yearling Chinook salmon first approached the spillway portion of the dam during the uniform spill treatment and 76% approached the spillway portion during the bulk spill treatment. The majority (52%) of these approached at the RSW in Spillbay 8 with similar percents for both spill treatments (Figure 10). The approach distribution may have been biased due to the location of antennas on the RSW, which were farther upstream than antennas on the spillbays or turbine intakes because the RSW extends into the forebay. Passage distribution during the uniform spill pattern was 78% through the spillway, 16% through the JBS, and 3% through turbines. Passage distribution during the bulk spill pattern was 71% through the spillway, 23% through the JBS, and 3% though turbines. Approximately 3% of the yearling Chinook salmon passed through undetermined routes during both spill treatments. The greatest proportion of yearling Chinook salmon passed through the RSW in Spillbay 8 (59% during the uniform spill treatment and 55% during the bulk spill treatment; Figure 11).

A total of 1,164 juvenile steelhead entered the forebay of Lower Monumental Dam, and 98.1% of these fish (1,142) subsequently passed the dam. Seventy-six percent of the juvenile steelhead first approached the spillway portion of the dam during both spill treatments. The majority (38% during the uniform spill pattern and 42% during the bulk spill pattern) of these approached at the RSW in Spillbay 8 (Figure 12).
The approach distribution may have been biased due to the location of antennas on the RSW; these antennas were farther upstream than antennas on the spillbays or turbine intakes because the RSW extends into the forebay. Passage distribution during the uniform spill pattern was 70% through the spillway, 27% through the JBS, and 1% through turbines. Passage distribution during the bulk spill pattern was 68% through the spillway, 30% through the JBS, and 1% through turbines. Two percent of the juvenile steelhead during the uniform spill treatment and 1% during the bulk spill treatment passed through undetermined routes. The greatest proportion of juvenile steelhead passed through the RSW in Spillbay 8 (52% during the uniform spill treatment and 49% during the bulk spill treatment; Figure 13).

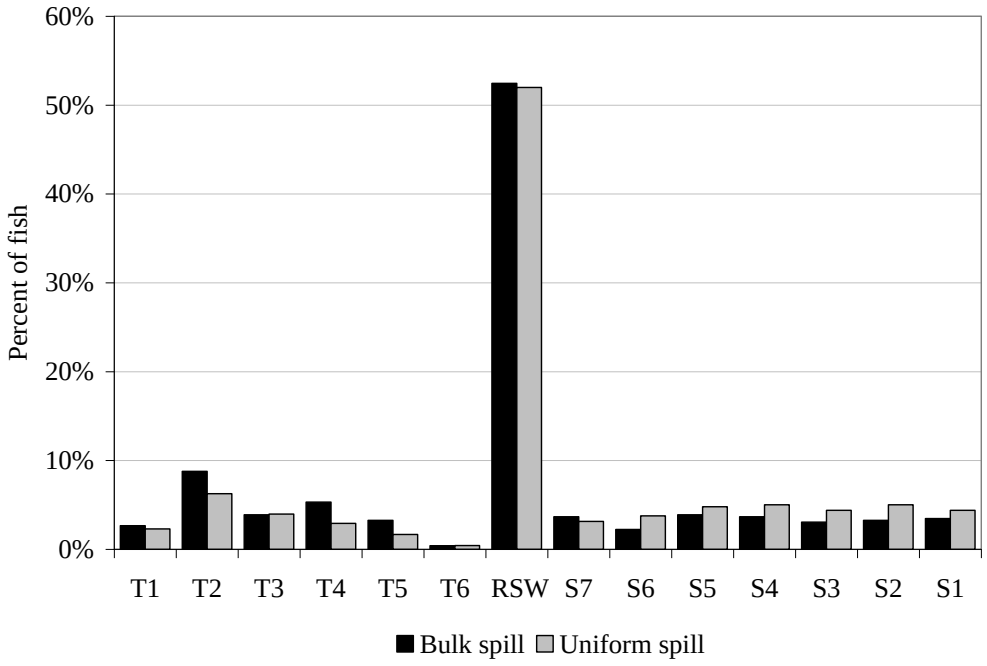


Figure 10. Horizontal approach distribution (within 18 m of the dam) for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam based on first detection at individual turbine intakes (T), the RSW, or spillbays (S) during the two spill treatments, 2009.

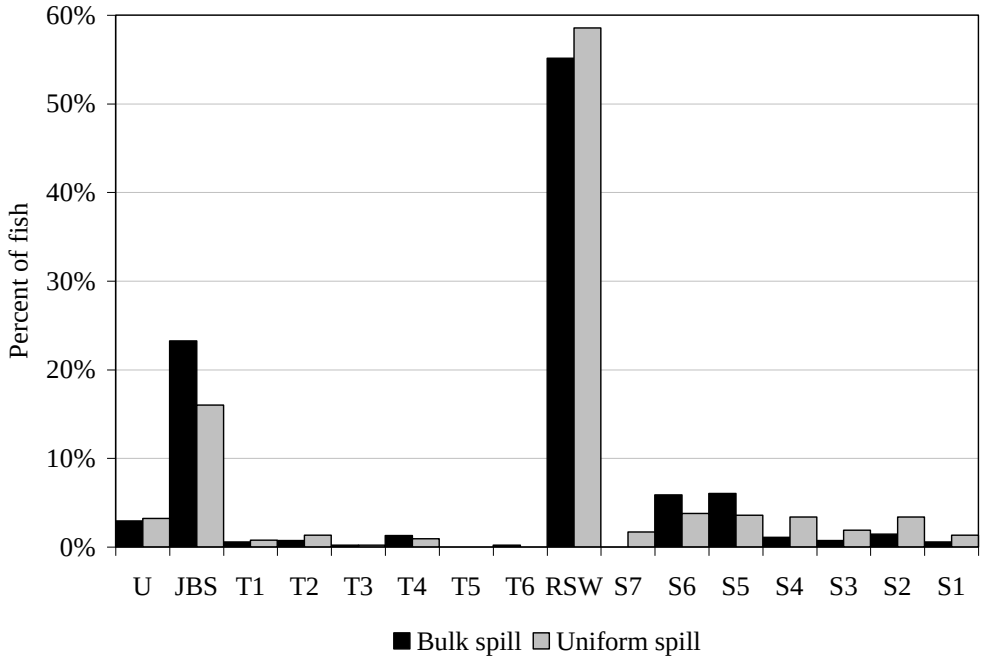


Figure 11. Passage route distribution for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam, 2009. Passage locations are U = unidentified route, JBS, T = individual turbine intakes, RSW, and S = individual spillbays.

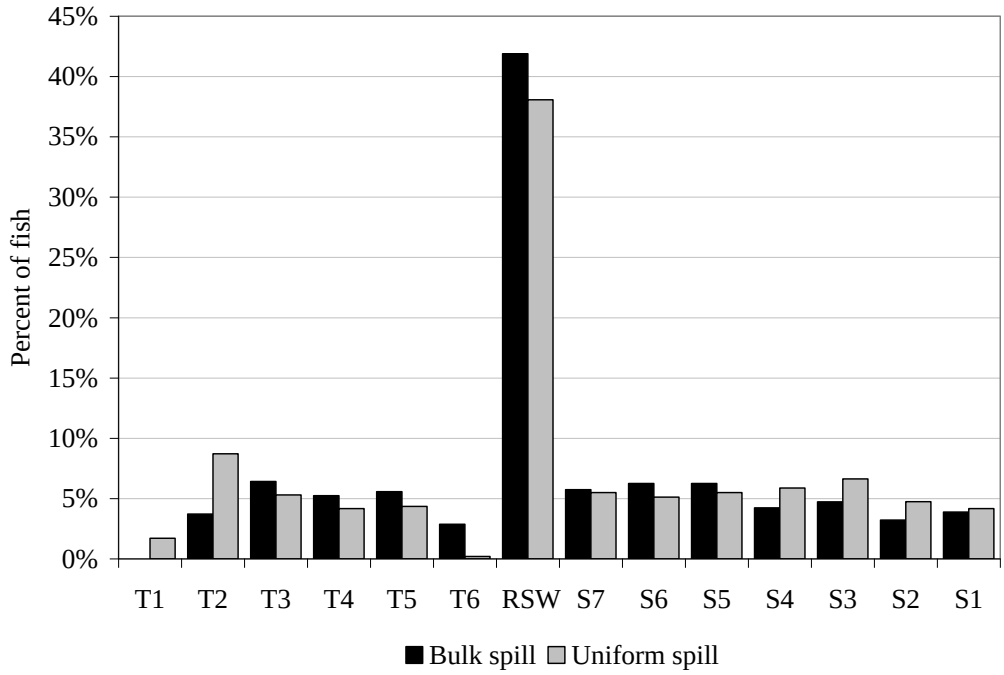


Figure 12. Horizontal approach distribution (within 18 m of the dam) for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam based on first detection at individual turbine intakes (T), the RSW, or spillbays (S) during the two spill treatments, 2009.

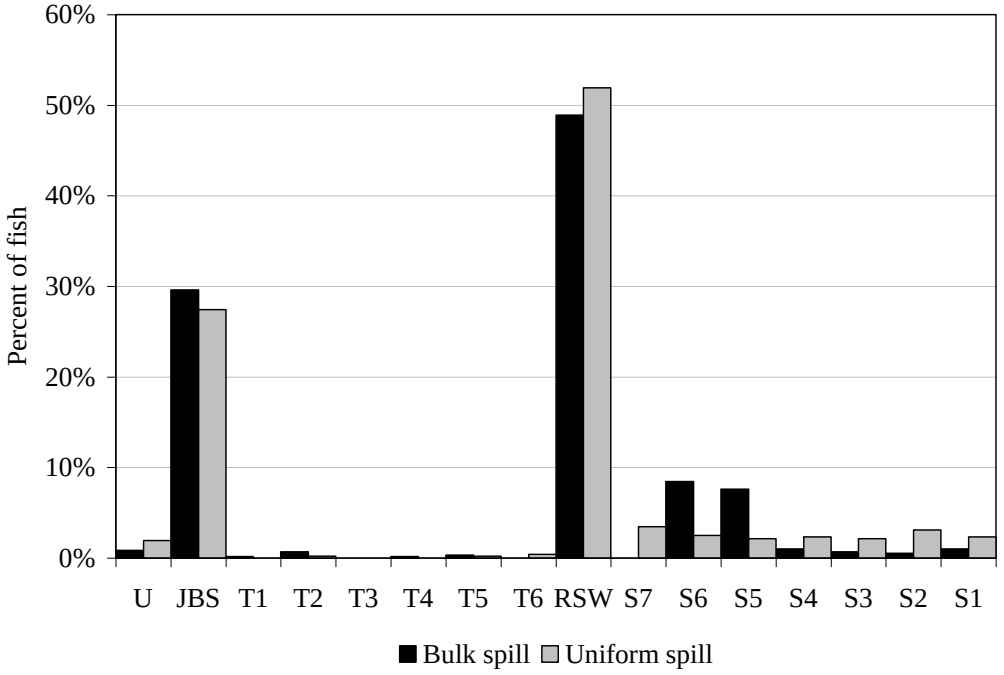


Figure 13. Passage distribution for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam, 2009. Passage locations are U = unidentified route, JBS, T = individual turbine intakes, RSW, and S = individual spillbays.

Fish Passage Performance Metrics

For yearling Chinook salmon passing Lower Monumental Dam, overall values for fish guidance efficiency, fish passage efficiency; surface outlet efficiency, and surface outlet effectiveness were similar during the uniform and bulk spill patterns (Table 11). Overall bypass passage efficiency was significantly lower, while the overall spill passage efficiency was significantly higher for yearling Chinook during the uniform spill pattern compared to the bulk spill pattern (Table 11). Overall spill passage efficiency was significantly greater during the uniform spill pattern than during the bulk spill pattern for yearling Chinook salmon (Table 11).

For juvenile steelhead passing Lower Monumental Dam overall values for fish passage efficiency, fish guidance efficiency, bypass passage efficiency, spill passage efficiency, surface outlet efficiency, and surface outlet effectiveness were similar during the uniform and bulk spill patterns (Table 12). Overall spill passage effectiveness was significantly less for juvenile steelhead passing during the uniform spill pattern than for those passing during the bulk spill pattern (Table 12).

Flow through the RSW at Lower Monumental Dam is regulated exclusively by forebay pool elevation, which is operated at minimum operating pool (MOP) and maintained within a 1-foot operating range from 3 April through approximately 1 September, per criteria in the 2008 FCRPS BiOp (NMFS 2008). This results in a relatively constant RSW discharge volume of 7.1 kcfs. As river flow increases, the proportion of flow through the RSW decreases, and as river flow decreases, the proportion of flow through the RSW increases. For both yearling Chinook salmon and juvenile steelhead, the proportion of fish passing the dam via the RSW increased as the proportion of river flow through the RSW increased or as total river flow decreased until a point at which fish passage through the RSW leveled off (Figures 14 and 15).

For yearling Chinook salmon, the point where RSW passage became relatively constant (50 to 57% of the fish passing the dam through the RSW) was when the proportion of river flow through the RSW was about 8% or more (<89 kcfs total river flow). The proportion of steelhead passing via the RSW was relatively constant (71 to 83% of the fish passing the dam through the RSW) when the proportion of river flow through the RSW was 6% or more (<118 kcfs total river flow).

Table 11. Passage distribution and mean estimates of fish passage metrics for radio-tagged hatchery yearling Chinook salmon passing Lower Monumental Dam during the uniform and bulk spill treatments, 2009 (95% CI estimates are in parenthesis). The comparison of overall differences between fish passage metrics during the uniform and bulk spill patterns are also shown.

	Passage distribution				Fish passage metrics		
Spill treatment	JBS	RSW	Spillway	Turbines	Fish passage efficiency (FPE)	Fish guidance efficiency (FGE)	Bypass efficiency (BPE)
Uniform 1	5	36	63	1	0.986	0.833	0.072
Uniform 2	23	44	68	6	0.938	0.793	0.237
Uniform 3	10	65	82	2	0.979	0.833	0.106
Uniform 4	5	65	84	0	1.000	1.000	0.056
Uniform 5	13	64	76	1	0.989	0.929	0.144
Uniform 6	29	37	39	7	0.907	0.806	0.387
Overall	85	311	412	17	0.967 (0.951-0.983)	0.833 (0.760-0.907)	0.165 (0.133-0.198)
Bulk 1	5	31	45	1	0.980	0.833	0.098
Bulk 2	18	28	55	1	0.986	0.947	0.243
Bulk 3	27	42	50	4	0.951	0.871	0.333
Bulk 4	16	47	58	2	0.974	0.889	0.211
Bulk 5	9	57	71	2	0.976	0.818	0.110
Bulk 6	30	45	51	4	0.953	0.882	0.353
Bulk 7	22	51	57	2	0.975	0.917	0.272
Overall	127	301	387	16	0.970 (0.955-0.985)	0.888 (0.835-0.941)	0.240 (0.203-0.277)
Difference between uniform and bulk patterns					-0.003	-0.055	-0.074
t					-0.27	-1.21	-3.00
P					0.790	0.227	0.003

Table 11. Continued.

	Passage distribution				Fish passage metrics			
Spill treatment	JBS	RSW	Spillway	Turbines	Spill efficiency (SPE)	Spill effectiveness (SPS)	Surface outlet efficiency (SOE)	Surface outlet effectiveness (SOS)
Uniform 1	5	36	63	1	0.913	1.973	0.522	5.589
Uniform 2	23	44	68	6	0.701	1.680	0.454	5.473
Uniform 3	10	65	82	2	0.872	2.484	0.691	10.033
Uniform 4	5	65	84	0	0.944	2.201	0.730	7.860
Uniform 5	13	64	76	1	0.844	2.315	0.711	9.224
Uniform 6	29	37	39	7	0.520	1.940	0.493	10.618
Overall	85	311	412	17	0.802 (0.766-0.837)	2.097 (2.017-2.202)	0.605 (0.562-0.648)	7.864 (7.304-8.425)
Bulk 1	5	31	45	1	0.882	2.922	0.608	7.213
Bulk 2	18	28	55	1	0.743	1.883	0.378	3.851
Bulk 3	27	42	50	4	0.617	2.644	0.519	7.876
Bulk 4	16	47	58	2	0.763	2.535	0.618	7.364
Bulk 5	9	57	71	2	0.866	3.210	0.695	9.548
Bulk 6	30	45	51	4	0.600	2.695	0.529	9.365
Bulk 7	22	51	57	2	0.704	3.684	0.630	12.138
Overall	127	301	387	16	0.730 (0.692-0.769)	2.671 (2.562-2.847)	0.568 (0.525-0.611)	7.741 (7.155-8.328)
Difference between uniform and bulk patterns					0.071	-0.595	0.037	0.123
t					2.73	-6.99	1.22	0.30
P					0.006	0.000	0.223	0.762

Table 12. Passage distribution and mean estimates of fish passage metrics for radio-tagged juvenile steelhead passing Lower Monumental Dam during the uniform and bulk spill treatments, 2009 (95% CI estimates are in parenthesis). The comparison of overall differences between fish passage metrics during the uniform and bulk spill patterns are also shown.

	Passage distribution				Fish passage metrics		
Spill treatment	JBS	RSW	Spillway	Turbines	Fish passage efficiency (FPE)	Fish guidance efficiency (FGE)	Bypass efficiency (BPE)
Uniform 1	7	35	62	0	1.000	1.000	0.101
Uniform 2	19	50	65	1	0.988	0.950	0.224
Uniform 3	28	47	55	0	1.000	1.000	0.337
Uniform 4	16	58	70	0	1.000	1.000	0.186
Uniform 5	37	44	60	0	1.000	1.000	0.381
Uniform 6	35	35	50	3	0.966	0.921	0.398
Overall	142	269	362	4	0.992 (0.984-1.000)	0.973 (0.946-1.000)	0.280 (0.240-0.319)
Bulk 1	11	30	46	1	0.983	0.917	0.190
Bulk 2	16	42	64	0	1.000	1.000	0.200
Bulk 3	37	34	53	2	0.978	0.949	0.402
Bulk 4	16	56	66	2	0.976	0.889	0.190
Bulk 5	20	52	72	0	1.000	1.000	0.217
Bulk 6	39	42	54	3	0.969	0.929	0.406
Bulk 7	36	33	48	0	1.000	1.000	0.429
Overall	175	289	403	8	0.986 (0.977-0.996)	0.956 (0.926-0.987)	0.299 (0.261-0.336)
Difference between uniform and bulk patterns					0.006	0.016	-0.019
t					0.93	0.80	-0.70
P					0.351	0.421	0.487

Table 12. Continued.

	Passage distribution				Fish passage metrics			
Spill treatment	JBS	RSW	Spillway	Turbines	Spill efficiency (SPE)	Spill effectiveness (SPS)	Surface outlet efficiency (SOE)	Surface outlet effectiveness (SOS)
Uniform 1	7	35	62	0	0.899	1.942	0.507	5.434
Uniform 2	19	50	65	1	0.765	1.833	0.588	7.098
Uniform 3	28	47	55	0	0.663	1.887	0.566	8.216
Uniform 4	16	58	70	0	0.814	1.898	0.674	7.258
Uniform 5	37	44	60	0	0.619	1.696	0.454	5.884
Uniform 6	35	35	50	3	0.568	2.120	0.398	8.560
Overall	142	269	362	4	0.713 (0.672-0.753)	1.865 (1.760-1.970)	0.530 (0.485-0.574)	6.883 (6.307-7.458)
Bulk 1	11	30	46	1	0.793	2.626	0.517	6.138
Bulk 2	16	42	64	0	0.800	2.027	0.525	5.343
Bulk 3	37	34	53	2	0.576	2.468	0.370	5.614
Bulk 4	16	56	66	2	0.786	2.610	0.667	7.939
Bulk 5	20	52	72	0	0.783	2.902	0.565	7.763
Bulk 6	39	42	54	3	0.563	2.527	0.438	7.739
Bulk 7	36	33	48	0	0.571	2.992	0.393	7.573
Overall	175	289	403	8	0.688 (0.649-0.726)	2.515 (2.375-2.655)	0.493 (0.452-0.534)	6.722 (6.159-7.285)
Difference between uniform and bulk patterns					0.025	-0.651	0.036	0.160
t					0.90	-7.43	1.20	0.40
P					0.370	0.000	0.230	0.691

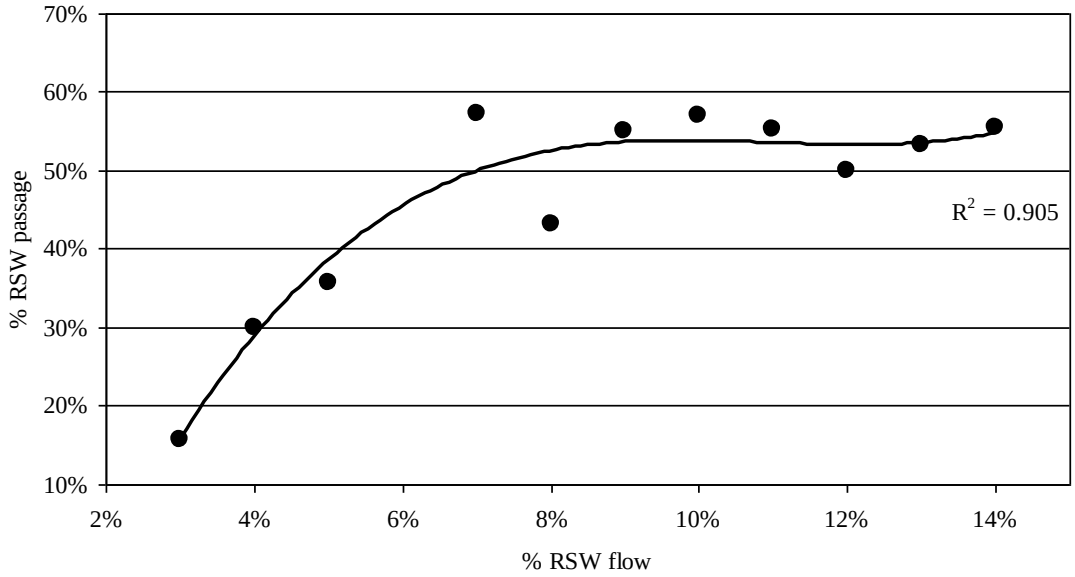


Figure 14. Relationship between percent of yearling Chinook salmon passing Lower Monumental via the RSW and the percent of total river flow passing through the RSW, 2008 and 2009.

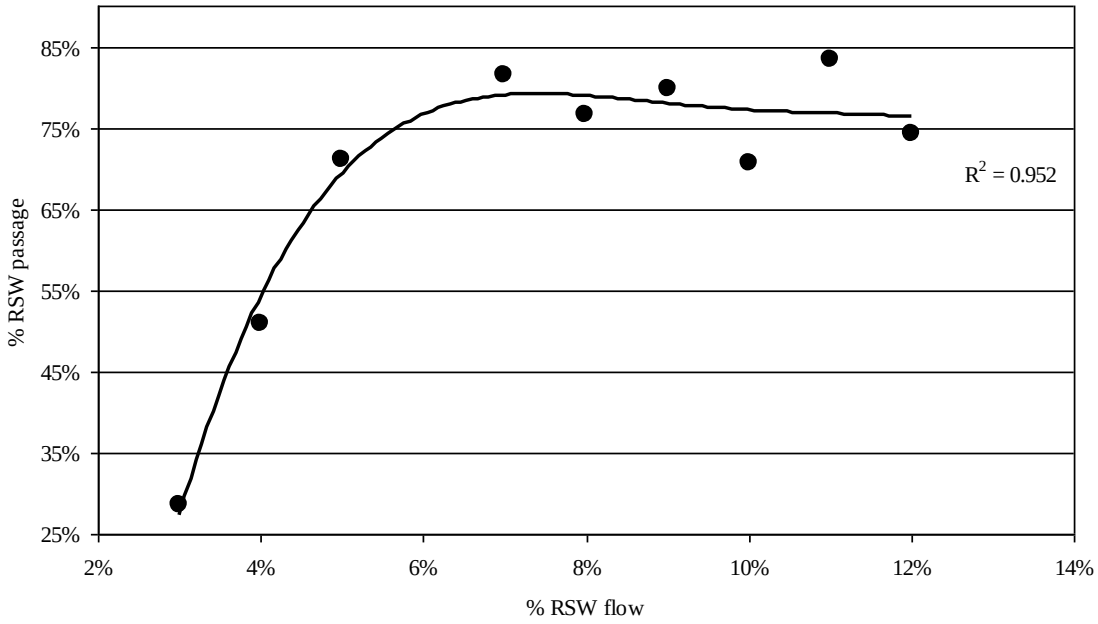


Figure 15. Relationship between percent of juvenile steelhead passing Lower Monumental via the RSW and the percent of total river flow passing through the RSW, 2008 and 2009.

Tailrace Egress

For yearling Chinook salmon passing Lower Monumental Dam, overall median tailrace egress time was 5.6 min (95% CI, 5.4-6.1) during the uniform spill and 5.4 min (95% CI, 5.2-5.7) during the bulk spill treatment (Tables 13 and 14). Median tailrace egress times were similar during uniform and bulk spill patterns for yearling Chinook salmon (difference 0.2 min; $P = 0.478$; Figure 16).

For juvenile steelhead passing Lower Monumental Dam, overall median tailrace egress time was 6.1 min (95% CI, 5.7-6.6) during uniform spill and 5.8 min (95% CI, 5.4-6.5) during bulk spill (Tables 15 and 16). Median tailrace egress times for juvenile steelhead were similar during the uniform and bulk spill patterns (difference 0.3 min; $P = 0.081$; Figure 17).

Table 13. Sample size, distribution, minimum, mean, median, mode, and maximum tailrace egress time (elapsed time from last detection in a passage route to last detection in the tailrace in minutes) by passage route and overall for radio tagged hatchery yearling Chinook salmon passing Lower Monumental Dam during the uniform spill treatment, 2009.

	Yearling Chinook tailrace egress time (min), Uniform spill treatment				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
n	82	346	260	15	443
10th	3.1	2.5	2.4	6.9	2.5
20th	5.4	3.3	3.2	7.6	3.4
30th	6.9	4.0	4.0	9.7	4.3
40th	7.9	4.7	4.6	11.5	5.0
50th	11.2	5.2	5.1	12.2	5.6
60th	12.9	5.7	5.7	12.4	6.4
70th	19.2	6.5	6.6	14.9	7.8
80th	33.1	7.9	7.9	19.0	11.7
90th	60.9	13.8	13.8	19.9	23.9
95th	152.6	27.7	28.1	472.6	56.0
minimum	1.0	1.0	1.0	5.7	1.0
mean	31.5	20.8	24.3	113.2	25.9
median	11.2	5.2	5.1	12.2	5.6
mode	1.0	4.7	4.0	N/A	4.7
maximum	517.8	2,866.1	2,866.1	1,527.7	2,866.1

Table 14. Sample size, distribution, minimum, mean, median, mode, and maximum tailrace egress time (elapsed time from last detection in a passage route to last detection in the tailrace in minutes) by passage route and overall for radio tagged hatchery yearling Chinook salmon passing Lower Monumental Dam during the bulk spill treatment, 2009.

	Yearling Chinook tailrace egress time (min), Bulk spill treatment				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
n	117	336	256	13	464
10th	4.1	2.3	2.3	4.8	2.4
20th	5.6	2.9	2.8	5.9	3.2
30th	6.6	3.5	3.3	7.5	4.1
40th	7.2	4.3	4.1	8.5	4.8
50th	7.8	4.8	4.6	9.3	5.4
60th	9.9	5.3	5.2	12.4	6.2
70th	12.1	5.9	5.7	13.6	7.3
80th	17.8	7.2	6.4	16.1	9.4
90th	34.5	10.8	8.2	37.6	19.5
95th	119.8	42.3	10.5	241.1	52.4
minimum	1.0	1.0	1.0	3.8	1.0
mean	94.0	76.1	42.3	52.7	80.2
median	7.8	4.8	4.6	9.3	5.4
mode	1.0	2.6	2.6	N/A	5.1
maximum	6,533.9	11,072.5	6,399.5	538.8	11,072.5

Table 15. Sample size, percentile distribution, minimum, mean, median, mode, and maximum tailrace egress time (elapsed time in minutes from last detection in a passage route to last detection in the tailrace in minutes) by passage route and overall for radio-tagged juvenile steelhead passing Lower Monumental Dam during the uniform spill treatment, 2009.

	Juvenile steelhead tailrace egress time (minutes), Uniform spill treatment				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
n	133	314	233	2	449
10th	4.6	2.1	2.1	6.6	2.5
20th	6.4	3.1	3.1	6.9	3.5
30th	7.6	3.8	3.6	7.1	4.4
40th	8.8	4.5	4.4	7.4	5.3
50th	11.0	5.2	5.2	7.7	6.1
60th	13.8	5.9	5.7	8.0	7.0
70th	18.7	6.8	6.5	8.2	8.6
80th	31.1	7.5	7.9	8.5	12.6
90th	111.5	13.3	14.6	8.8	31.2
95th	925.3	42.5	40.0	8.9	93.4
minimum	1.0	1.0	1.0	6.3	1.0
mean	190.1	20.3	15.2	7.7	70.5
median	11.0	5.2	5.2	7.7	6.1
mode	1.0	3.8	3.8	#N/A	5.3
maximum	8,446.0	1,630.0	948.4	9.0	8,446.0

Table 16. Sample size, percentile distribution, minimum, mean, median, mode, and maximum tailrace egress time (elapsed time in minutes from last detection in a passage route to last detection in the tailrace in minutes) by passage route and overall for radio-tagged juvenile steelhead passing Lower Monumental Dam during the bulk spill treatment, 2009.

	Juvenile steelhead tailrace egress time (minutes), Bulk spill treatment				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
n	169	356	258	7	532
10th	4.0	1.9	2.0	6.6	2.2
20th	5.9	2.7	2.6	8.7	3.3
30th	6.8	3.5	3.3	9.8	4.0
40th	7.6	4.1	3.9	10.4	4.9
50th	8.4	4.8	4.6	10.6	5.8
60th	10.0	5.4	5.1	12.3	6.6
70th	11.8	6.1	5.7	13.6	8.1
80th	15.4	7.1	6.6	14.4	10.7
90th	27.4	14.0	8.3	20.8	19.1
95th	576.3	36.4	13.4	25.4	64.3
minimum	1.0	1.0	1.0	4.0	1.0
mean	96.1	40.1	13.0	13.0	57.5
median	8.4	4.8	4.6	10.6	5.8
mode	1.0	3.6	3.6	#N/A	6.5
maximum	4,334.9	7,306.2	1,960.8	30.0	7,306.2

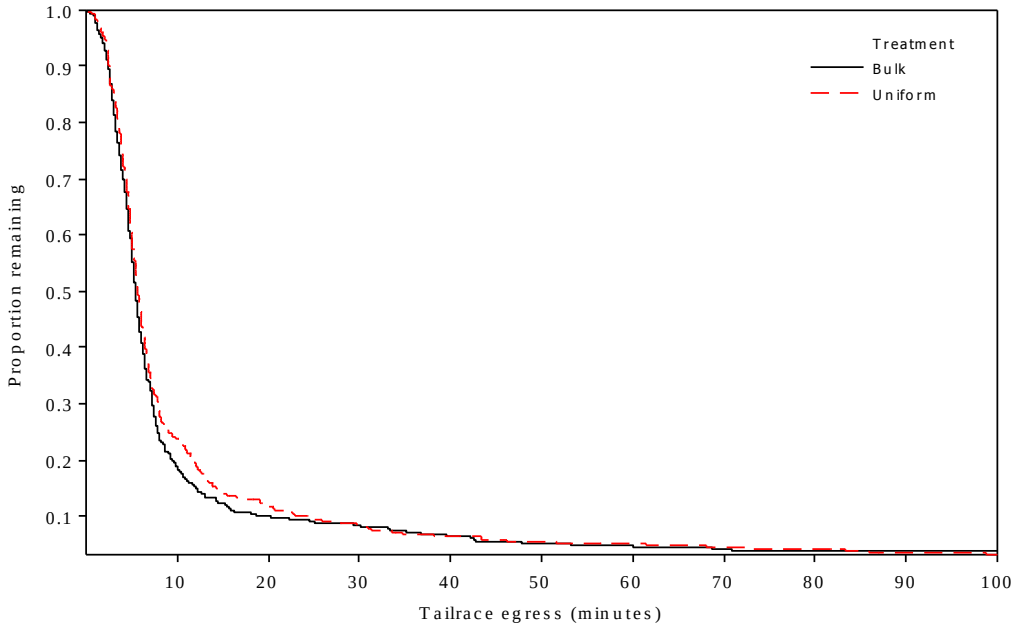


Figure 16. Kaplan-Meier survival curves of tailrace egress (elapsed time in minutes from passage until last detection on the tailrace exit line) by spill treatment for radio-tagged hatchery yearling Chinook salmon passing Lower Monumental Dam, 2009.

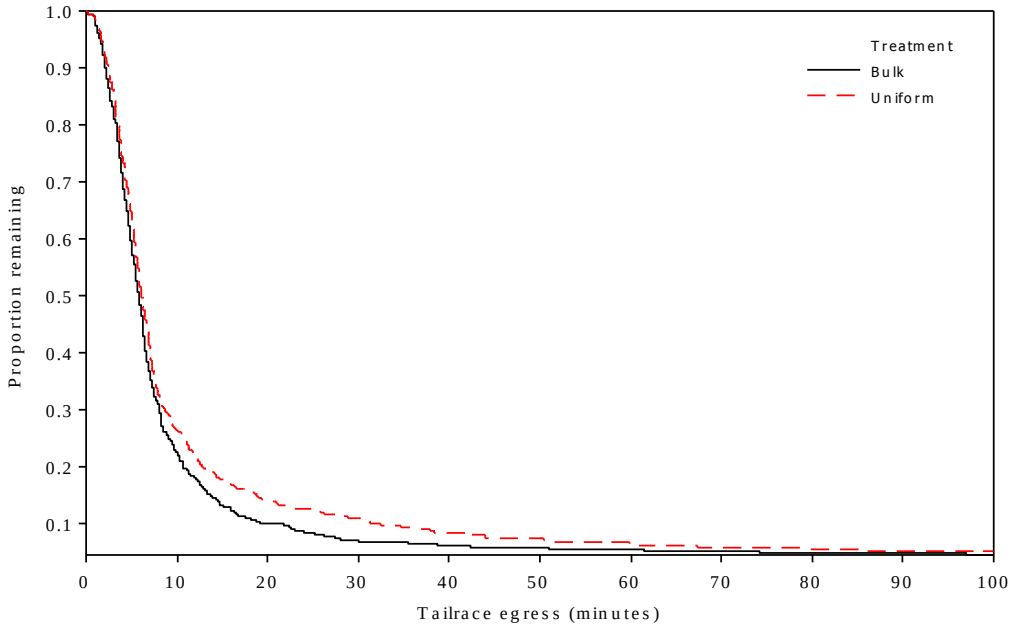


Figure 17. Kaplan-Meier survival curves of tailrace egress (elapsed time in minutes from passage until last detection on the tailrace exit line) by spill treatment for radio-tagged juvenile steelhead passing Lower Monumental Dam, 2009.

Survival Estimates

Detection Probability

Detection histories used for survival estimates are presented in Appendix Tables A1-A24. Detection probabilities at the primary survival array, 16 km downstream from Lower Monumental Dam, are presented for each species in Appendix Table A25. Survival estimates by treatment block for paired treatment and reference fish groups are presented in Appendix Tables B1-B10.

Relative Survival

Relative survival estimates were not significantly different between the uniform and bulk spill treatments for either yearling Chinook salmon (Table 17) or juvenile steelhead (Tables 18-20).

The 2008 Biological Opinion for the FCRPS (NMFS 2008) sets juvenile dam passage (referred to as concrete survival in this report) survival performance at 0.960 per project for yearling Chinook salmon and juvenile steelhead. In 2009, the targeted survival point estimate was met for both species under both spill conditions (Tables 17 and 18). Within the major routes of passage, turbine and JBS survival during the uniform spill pattern were below the targeted survival point estimate for yearling Chinook salmon.

For juvenile steelhead, JBS survival during both the uniform and bulk spill patterns was below the targeted survival estimate. Relocation of the JBS outfall to the location of our tailrace release groups would likely increase JBS survival above the targeted survival point estimate of 0.96. Relocation would allow increases in concrete survival of 0.7-0.9% for yearling Chinook salmon and 1.8-2.6% for juvenile steelhead, based on single-release model survival estimates (Table 21).

Table 17. Sample sizes and mean estimates of survival for radio-tagged hatchery yearling Chinook salmon passing Lower Monumental Dam (treatment) relative to fish released into the tailrace (reference) during the uniform and bulk spill treatments, 2009. Standard errors are in parenthesis.

	Hatchery Yearling Chinook: Uniform spill treatment							
	Treatment			Reference			Relative	
	n	Survival	95% CI	n	Survival	95% CI	Survival	95% CI
Project survival								
Dam survival	412	0.931 (0.006)	0.915-0.946	487	0.985 (0.005)	0.969-1.000	0.945 (0.008)	0.925-0.966
Concrete survival	531	0.958 (0.007)	0.940-0.976	487	0.985 (0.005)	0.969-1.000	0.973 (0.009)	0.951-0.996
Route-specific survival								
Spillway survival	412	0.962 (0.011)	0.934-0.989	487	0.985 (0.005)	0.969-1.000	0.976 (0.013)	0.944-1.010
JBS survival	85	0.931 (0.031)	0.852-1.011	487	0.985 (0.005)	0.969-1.000	0.943 (0.032)	0.864-1.030
RSW survival	311	0.973 (0.012)	0.941-1.005	487	0.985 (0.005)	0.969-1.000	0.988 (0.013)	0.956-1.021
Turbine survival*	17	0.941 (0.057)	0.827-1.055	487	0.985 (0.005)	0.969-1.000	0.956 (0.058)	0.846-1.080
	Hatchery Yearling Chinook: Bulk spill treatment							
	Treatment			Reference			Relative	
	n	Survival	95% CI	n	Survival	95% CI	Survival	95% CI
Project survival								
Dam survival	461	0.925 (0.014)	0.891-0.958	522	0.974 (0.012)	0.944-1.004	0.949 (0.014)	0.914-0.985
Concrete survival	546	0.950 (0.016)	0.910-0.990	522	0.974 (0.012)	0.944-1.004	0.975 (0.018)	0.931-1.020
Route-specific survival								
Spillway survival	387	0.947 (0.013)	0.914-0.979	522	0.974 (0.012)	0.944-1.004	0.972 (0.017)	0.930-1.015
JBS survival	127	0.943 (0.033)	0.863-1.023	522	0.974 (0.012)	0.944-1.004	0.965 (0.034)	0.885-1.052
RSW survival	301	0.963 (0.013)	0.931-0.995	522	0.974 (0.012)	0.944-1.004	0.988 (0.021)	0.937-1.042
Turbine survival*	16	1.000 (0.000)	1.000	522	0.974 (0.012)	0.944-1.004	1.021 (0.007)	1.008-1.034

*Pooled estimate due to sample size

Table 18. Sample sizes and mean estimates of survival for radio-tagged juvenile steelhead passing Lower Monumental Dam (treatment) relative to fish released into the tailrace (reference) during the uniform and bulk spill treatments, 2009. Standard errors are in parenthesis.

	Juvenile steelhead: Uniform spill treatment							
	Treatment			Reference			Relative	
	n	Survival	95% CI	n	Survival	95% CI	Survival	95% CI
Project survival								
Dam survival	373	0.963 (0.012)	0.933-0.993	473	0.992 (0.003)	0.983-1.001	0.970 (0.011)	0.942-1.000
Concrete survival	518	0.960 (0.012)	0.930-0.990	473	0.992 (0.003)	0.983-1.001	0.967 (0.011)	0.939-0.996
Route-specific survival								
Spillway survival	362	0.974 (0.009)	0.952-0.997	473	0.992 (0.003)	0.983-1.001	0.982 (0.009)	0.959-1.004
JBS survival	142	0.897 (0.042)	0.852-1.005	473	0.992 (0.003)	0.983-1.001	0.899 (0.044)	0.793-1.018
RSW survival	269	0.986 (0.009)	0.963-1.009	473	0.992 (0.003)	0.983-1.001	0.993 (0.009)	0.971-1.017
Turbine survival*	4	1.000 (0.000)	1.000	473	0.992 (0.003)	0.983-1.001	1.008 (0.004)	0.999-1.016
	Juvenile steelhead: Bulk spill treatment							
	Treatment			Reference			Relative	
	n	Survival	95% CI	n	Survival	95% CI	Survival	95% CI
Project survival								
Dam survival	447	0.969 (0.010)	0.946-0.993	513	0.992 (0.002)	0.986-0.997	0.977 (0.009)	0.955-1.000
Concrete survival	591	0.969 (0.010)	0.945-0.992	513	0.992 (0.002)	0.986-0.997	0.976 (0.009)	0.955-0.998
Route-specific survival								
Spillway survival	403	0.983 (0.009)	0.961-1.006	513	0.992 (0.002)	0.986-0.997	0.991 (0.009)	0.971-1.013
JBS survival	175	0.933 (0.026)	0.871-0.996	513	0.992 (0.002)	0.986-0.997	0.939 (0.026)	0.878-1.005
RSW survival	289	0.990 (0.005)	0.977-1.002	513	0.992 (0.002)	0.986-0.997	0.998 (0.005)	0.987-1.009
Turbine survival*	8	1.000 (0.000)	1.000	513	0.992 (0.002)	0.986-0.997	1.009 (0.004)	1.000-1.018

*Pooled estimate due to sample size

Table 19. Comparison of relative survival for radio tagged yearling Chinook salmon passing Lower Monumental Dam during the uniform and bulk spill treatments, 2009.

	Uniform spill treatment		Bulk spill treatment		Comparison				
	Relative survival	95% CI	Relative survival	95% CI	Mean difference	se	*t*	df	*P*
Project survival									
Dam survival	0.945	0.925-0.966	0.949	0.914-0.985	-0.004	0.017	0.240	11	0.814
Concrete survival	0.973	0.951-0.996	0.975	0.931-1.020	-0.002	0.020	0.079	11	0.938
Route-specific survival									
Spillway survival	0.976	0.944-1.010	0.972	0.930-1.015	0.004	0.022	0.207	11	0.840
JBS survival	0.943	0.864-1.030	0.965	0.885-1.052	-0.022	0.047	0.462	11	0.653
RSW survival	0.988	0.956-1.021	0.988	0.937-1.042	0.000	0.025	0.002	11	0.998
Turbine survival	0.956	0.846-1.080	1.021	1.008-1.034	-0.065	0.059	1.114	11	0.289

Table 20. Comparison of relative survival for radio tagged juvenile steelhead passing Lower Monumental Dam during the uniform and bulk spill treatments, 2009.

	Uniform spill treatment		Bulk spill treatment		Comparison				
	Relative survival	95% CI	Relative survival	95% CI	Mean difference	se	*t*	df	*P*
Project survival									
Dam survival	0.970	0.942-1.000	0.977	0.955-1.000	-0.007	0.015	0.479	11	0.641
Concrete survival	0.967	0.939-0.996	0.976	0.955-0.998	-0.009	0.014	0.662	11	0.521
Route-specific survival									
Spillway survival	0.982	0.959-1.004	0.991	0.971-1.013	-0.009	0.012	0.792	11	0.445
JBS survival	0.899	0.793-1.018	0.939	0.878-1.005	0.040	0.051	0.790	11	0.446
RSW survival	0.993	0.971-1.017	0.998	0.987-1.009	-0.005	0.010	0.449	11	0.662
Turbine survival	1.008	0.999-1.016	1.009	1.000-1.018	-0.001	0.006	0.214	11	0.835

Table 21. Potential change in JBS and concrete survival by relocating the JBS outfall to the location where the tailrace groups were released, 2009.

	Yearling Chinook salmon		Juvenile steelhead	
Spill pattern	Uniform	Bulk	Uniform	Bulk
2009 JBS single release survival estimate	0.931	0.943	0.897	0.933
2009 single release Reference Survival	0.985	0.974	0.992	0.992
Potential improvement in JBS survival	0.054	0.031	0.095	0.059
Bypass passage proportion	0.160	0.230	0.270	0.300
Potential change in Concrete Survival	0.009	0.007	0.026	0.018

Avian Predation

A total of 52 tags (2.4% of those released) from yearling Chinook salmon radio-tagged and released to evaluate Lower Monumental Dam passage and survival in 2009 were recovered from avian colonies on Crescent or Foundation Island in the McNary Dam Reservoir in 2009 (Table 22). The majority of these fish (37% of those recovered) were last detected between Ice Harbor Dam and the mouth of the Snake River. Five tags from yearling Chinook salmon (10% of those recovered) were last detected above our primary survival array (16 km downstream from Lower Monumental Dam) prior to being recovered. All five of these were last detected at the JBS.

The proportion of yearling Chinook salmon that passed the dam via the JBS, were last detected at this location, and were recovered from avian colonies at either Crescent or Foundation Islands was 2.4% (5 of 212 fish). Since not all tags of fish consumed by avian predators are dropped on colonies, and not all tag dropped on colonies are recovered, these tag recoveries are considered a minimum estimate of avian predation.

A total of 126 tags from radio tagged juvenile steelhead were recovered from avian colonies on Crescent or Foundation Island in the McNary Dam Reservoir (Table 22). The majority of these fish (52% of those recovered) were last detected between Ice Harbor Dam and McNary Dam. Of these 126 tags, 22 (17%) were from juvenile steelhead last detected above our primary survival array at the JBS. The proportion of juvenile steelhead that passed the dam via the JBS, were last detected at this location, and were recovered from avian colonies at either Crescent or Foundation Islands was 6.9% (22 of 317 fish).

During the 2009 study approximately 20 American white pelicans *Pelecanus erythrorhynchos* were observed at a variety of loafing sites from the tailrace of Lower Monumental Dam to 7 km downstream. In early May, a subset of this population began actively feeding near the JBS outfall 24-h/d (Figure 18). The impact of the pelicans on fish passing through the JBS could not be assessed because avian presence and activity is not currently systematically monitored at Lower Monumental Dam.

Table 22. Number and percent of tags (radio or PIT) from yearling Chinook salmon and juvenile steelhead recovered from avian colonies on Crescent Island and Foundation Islands. Fish were released to evaluate passage behavior and survival at Lower Monumental Dam, 2009. Recoveries are grouped by location of the last telemetry detection.

	Number and percent (%) of tags recovered			
	Yearling Chinook salmon		Juvenile steelhead	
Last location of telemetry detection	Treatment	Reference	Treatment	Reference
	Crescent Island			
Lower Monumental Dam forebay	0 (0.0)	N/A	0 (0.0)	N/A
Lower Monumental Dam bypass	4 (0.3)	N/A	14 (1.2)	N/A
Ice Harbor Dam pool	1 (0.1)	2 (0.2)	1 (0.1)	3 (0.3)
Ice Harbor forebay	0 (0.0)	1 (0.1)	2 (0.2)	0 (0.0)
Ice Harbor Dam bypass	1 (0.1)	0 (0.0)	5 (0.4)	5 (0.5)
Ice Harbor Dam to Snake River mouth	3 (0.3)	4 (0.4)	6 (0.5)	6 (0.6)
McNary Dam pool	4 (0.3)	7 (0.7)	19 (1.6)	16 (1.6)
Total	13 (1.1)	14 (1.3)	47 (4.0)	30 (2.9)
	Foundation Island			
Lower Monumental Dam forebay	0 (0.0)	N/A	0 (0.0)	N/A
Lower Monumental Dam bypass	1 (0.1)	N/A	8 (0.7)	N/A
Ice Harbor Dam pool	1 (0.1)	1 (0.1)	4 (0.3)	3 (0.3)
Ice Harbor forebay	3 (0.3)	1 (0.1)	0 (0.0)	3 (0.3)
Ice Harbor Dam bypass	1 (0.1)	4 (0.4)	6 (0.5)	7 (0.7)
Ice Harbor Dam to Snake River mouth	3 (0.3)	9 (0.9)	9 (0.8)	8 (0.8)
McNary Dam pool	0 (0.0)	1 (0.1)	0 (0.0)	1 (0.1)
Total	9 (0.8)	16 (1.5)	27 (2.3)	22 (2.1)

Figure 18. American white pelicans *Pelecanus erythrorhynchos* on 1 May 2009 near the Lower Monumental Dam JBS outfall. Note the juvenile steelhead in the upper photo and pelican response a few seconds later in the bottom photo. (Photos were provided by Jason P. Everett).

DISCUSSION

In this report we present the findings from the 7th year of study evaluating behavior and survival of volitionally passing radio-tagged juvenile steelhead and yearling Chinook salmon at Lower Monumental Dam. Results in 2009 represent the second year of these studies since installation of the removable spillway weir (RSW). In addition, the 2009 study evaluated passage and survival relative to two spill patterns (uniform and bulk). Spill at Lower Monumental Dam averaged 38% during the uniform spill pattern and 27% during the bulk spill pattern. Average daily flow during the 2009 evaluation was greater than the 10-year average project discharge (101 kcfs vs. 85 kcfs) and was similar to flow during the evaluation in 2008 (Hockersmith et al. 2010).

Similar to observations from the baseline study years of 2006 and 2007 (Hockersmith et al. 2008a,b) and during the first-year evaluation of the RSW in 2008 (Hockersmith et al. 2010), the majority of our radio-tagged fish (yearling Chinook salmon and juvenile steelhead combined) in 2009 approached and passed the dam in the thalweg of the river near Spillbay 8. Using hydroacoustics in 1997, Johnson et al. (1998) observed similar horizontal passage distribution patterns, where smolts approached Lower Monumental Dam at the midpoint of the thalweg. Slightly more yearling Chinook salmon approached the spillway portion of Lower Monumental Dam during the uniform spill pattern compared to the bulk spill pattern (82 vs. 76%). Approach distribution between the powerhouse and spillway was the same under both spill patterns for juvenile steelhead.

Operation of the RSW at Lower Monumental Dam has increased the proportion of yearling Chinook salmon and juvenile steelhead passing through Spillbay 8, while decreasing the proportions passing through turbines. In 2009 we observed higher proportions of yearling Chinook salmon and juvenile steelhead passing the dam via Spillbay 8 with the RSW operating. Findings in 2009 were similar to those in 2008, when higher proportions were also observed with the RSW in place (49-59% during 2008-2009). These were considerably higher proportions than passed through Spillbay 8 without an RSW during baseline studies in 2006 and 2007 (24-46%). Proportions of juvenile salmon passing the dam via turbines were also less with the RSW in 2008-2009 (1-3%) than during baseline studies in 2006 and 2007 (2-9%).

In 2009 overall, slightly more yearling Chinook salmon and juvenile steelhead passed Lower Monumental Dam through the spillway during uniform spill (70-78%) than during bulk spill (68-71%). Conversely, slightly fewer yearling Chinook salmon and juvenile steelhead passed Lower Monumental Dam through the JBS during uniform spill (16-27%) than during bulk spill (23-30%).

Hockersmith et al. (2010) reported shorter median forebay residence times for both yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam with the RSW operating during 2008 compared to results prior to its installation. During 2009, we did not observe a reduction in forebay residence time of yearling Chinook salmon with operation of the RSW. However, we observed shorter forebay residence time for juvenile steelhead with the RSW compared to results prior to its use (3.2 h in 2009 vs. 5.5-17.8 h in 2006-2007). Median forebay residence for yearling Chinook salmon was significantly shorter during the uniform spill pattern compared to the bulk spill pattern. However, the difference was less than 1 h, and thus unlikely to have had any biological significance. Median forebay residence time for juvenile steelhead was similar between uniform and bulk spill during 2009 at 3.1 and 3.2 h, respectively.

Overall median tailrace egress time during 2009 for both yearling Chinook salmon (5.4-5.6 min) and juvenile steelhead (5.8-6.1 min) was similar to the range of egress times observed during the baseline studies (5.4-6.1 min) and during the first year (2008) of RSW operation at Lower Monumental Dam (5.3-8.2 min). As observed during baseline studies and in 2008, tailrace egress times were longer (by seconds) for both species passing via the powerhouse (JBS and turbines) compared to the spillway. Median tailrace egress for yearling Chinook salmon and juvenile steelhead was similar between spill patterns during 2009.

Operation of the RSW at Lower Monumental Dam has increased fish passage efficiency (FPE) by increasing the proportion of fish passing through the spillway (SPE) for both yearling Chinook salmon and juvenile steelhead. Similar to findings from 2008, we observed higher FPE and SPE for both species during 2009 than during baseline studies in 2006 and 2007 (FPE 0.967 to 0.992 vs. 0.907 to 0.981; SPE 0.65 to 0.82 vs. 0.49 to 0.75). Overall, most fish passage metrics were similar between the uniform spill pattern compared to the bulk spill pattern. We observed significantly higher SPE and significantly lower bypass system efficiency (BPE) for yearling Chinook salmon during the uniform spill than the bulk spill treatment. The percent of fish passing through the RSW increased inversely with total river flow until total river flow dropped below a given threshold. This threshold was approximately 89 kcfs for yearling Chinook salmon and approximately 118 kcfs for juvenile steelhead. At flows levels below these points, the percent of fish passing through the RSW remain relatively constant, with approximately 50-57% of the yearling Chinook salmon and 71-83% of the juvenile steelhead passing through the RSW.

In 2009, none of the survival estimates were statistically different between spill treatments at Lower Monumental Dam. During both spill treatments, relative concrete survival for yearling Chinook salmon and juvenile steelhead were above the performance standard of 0.96 specified in the 2008 FCRPS BiOp (NMFS 2008). The precision

specified in the 2008 FCRPS BiOp (<0.03 ± 95 CI) was met by all of the concrete survival estimates except the estimate for yearling Chinook salmon passing the dam during the bulk spill treatment (± 0.045). Among major passage routes, the lowest survival estimates in 2009 for both yearling Chinook salmon and juvenile steelhead were from passage through the JBS. All of the tags recovered from the avian nesting colonies on Foundation and Crescent Islands that were last detected upstream from our primary survival array were last detected at the JBS. In addition, observations of avian predation activity near the JBS outfall indicated that the low estimates of JBS survival observed in 2009 were likely related to avian predation. Our estimates of turbine survival were based on small sample sizes (33 yearling Chinook salmon and 12 steelhead) and therefore may poorly represent turbine survival over spring 2009 smolt migration at Lower Monumental Dam.

RECOMMENDATIONS

1. Evaluate RSW Performance over a Wider Range of Conditions

In general, results from 2008 and 2009 indicate the RSW at Lower Monumental Dam appears to have increased the proportion of yearling Chinook salmon and juvenile steelhead passing the dam via the spillway, reduced delays associated with passing the dam, and increased survival. However, these results were only from years with above-average flows. At least one additional year of evaluation should be conducted to confirm the findings from 2008 and 2009 during average or below-average flows and to capture a wider range of conditions that occur across multiple years.

2. Improve JBS and Concrete Survival

On 14 April 1999 a transport barge collided with the JBS outfall pipes. As a temporary repair, the USACE shortened the bypass pipes by 7 m. However, since the temporary repair in 1999, fish return to the river closer to the shoreline and into a flow environment that encourages predators to maintain station near the outfall. Survival for both yearling Chinook salmon and juvenile steelhead passing through the JBS in 2009 was lower than for fish passing either the spillway or turbines. The relatively low bypass survival estimates in 2009 appears related to avian predation near the outfall at Lower Monumental Dam.

With 16 to 30% of the spring migrants passing Lower Monumental Dam via the JBS in 2008 and 2009, significant improvements in concrete survival could be achieved by increasing the relatively low JBS survival. Improving the avian predation management program could also improve JBS survival. Relocating the JBS outfall to an area that is farther from the shoreline, where the depth of the river is greater, and where water velocities are higher might also increase JBS survival. One possible location that would provide increased JBS survival is the location of our tailrace reference releases. Survival for the tailrace release groups was 3.1 to 5.4% and 5.9 to 9.5% higher than JBS survival for yearling Chinook salmon and juvenile steelhead, respectively.

3. Develop Surface Passage Pit-Tag Detection

Bypass systems were first utilized to divert salmonid smolts around hydroelectric facilities on the lower Snake River in the 1970s (Marsh et al. 1995). At Lower Monumental Dam, a PIT-tag detection system was added to the bypass system in 1993. Operation of the RSW at Lower Monumental Dam has increased the proportion of fish passing via the spillway while decreasing the proportion passing via the JBS. The

decrease in JBS passage has reduced PIT-tag detection probability at Lower Monumental Dam and thus reduced the precision of survival estimates based on these detections. Active tags such as those used in radio or acoustic telemetry remain unsuitable for evaluating passage and survival of most wild yearling Chinook salmon stocks and other stocks of small fish because of the size of the tag.

In 2008 and 2009, 73 to 78% of the yearling Chinook salmon and 79 to 86% of the juvenile steelhead passed either through the JBS or the RSW. Installation of PIT-tag detection systems in the RSW at Lower Monumental Dam would have provided increased detection numbers of smolts and thereby more precise estimates of survival in 2008 and 2009. The higher-than-average flows during 2008 and 2009 likely lowered passage proportions through the RSW for some stocks and increased the proportion of fish passing through the JBS. During a low-flow year like 2007, a smaller proportion of fish would likely be passing through the JBS than observed in 2008 and 2009, while a larger proportion would be passing through the RSW. The addition of PIT-tag detection capability in the RSW would provide information on surface passage use, behavior, and survival. This method of obtaining information is especially important for smaller fish stocks such as sockeye and wild Chinook, which cannot be tagged with active tags. It is also important for summer migrants, which need to be tagged in advance, since they migrate when temperatures are not conducive to handling and tagging.

4. Develop a Systematic Avian Predation Monitoring Program

The USACE collects project operations data at Lower Monumental Dam every five minutes, and this information has been extremely useful for interpreting the relationships between juvenile passage behavior and survival. Avian predators can have a significant impact on survival of juvenile fish; however, the USACE does not have a systematic monitoring program to assess avian presence and activity at Lower Monumental Dam. Development of a program would provide additional insight when interpreting survival estimates in relation to project operations.

5. Assess Effects of RSW Operations on Adult Passage

Spill operations at dams may cause delays in adult passage (Haynes and Gray 1980) as well as contribute to fallbacks for fish that pass the dam (Boggs et al. 2004). Upstream passage delays and fallbacks can contribute to difficulties in accurately estimating adult survival and may impact management actions (Dauble and Mueller 2000). Adult passage delays and fallback due to operation of the RSW and associated training spill at Lower Monumental Dam should be evaluated to ensure these operations are not causing passage issues for adult salmon and steelhead.

ACKNOWLEDGMENTS

We express our appreciation to all who assisted with this research. We thank the USACE who funded this research, particularly William Spurgeon, Lower Monumental Dam Project Biologist, Mark Plummer, Ice Harbor Dam Project Biologist, and Robert Johnson, Ann Setter and Tim Wik, Walla Walla USACE District office for their help coordinating research activities. Monty Price, and the staff of the Washington Department of Fish and Wildlife at Lower Monumental Dam provided valuable assistance with collecting and sorting of study fish. Staff of the Pacific States Marine Fisheries Commission provided valuable assistance in data acquisition.

For their ideas, assistance, encouragement, and guidance, we thank, Robb Anglesey, Steve Brewer, Kyle Bowers, Tyler Conrad, Scott Davidson, Doug Dey, Jason Everett, John Ferguson, Chris Hughes, Byron Iverson, Bruce Jonasson, Mark Kaminski, Ronald Marr, Jeffrey Moser, William Muir, Mark Neilsen, Sam Rambo, Thomas Ruehle, Jim Simonson, William Wassard, Alex Wentz, John Williams, and Galen Wolf of the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service.

REFERENCES

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Transactions of the American Fisheries Society 27:128-136.

Axel, G. A., E. E. Hockersmith, B. J. Burke, K. Frick, B. P. Sandford, and W. D. Muir, 2008. Passage Behavior and Survival of Radio-Tagged Yearling Chinook Salmon and Steelhead at Ice Harbor Dam, 2007. Report by Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration to the U.S. Army Corps of Engineers. Walla Walla District, Contract W68SBV92844866, 69 p.

Beeman, J. W., C. Grant, and P. V. Haner. 2004. Comparison of three underwater antennas for use in radio telemetry. North American Journal of Fisheries Management 24:275-281.

Beeman, J. W., and A. G. Maule. 2006. Migration depths of juvenile Chinook salmon and steelhead relative to total dissolved gas supersaturation in a Columbia River reservoir. Transactions of the American Fisheries Society 135:584-594.

Boggs, C. T., M. L. Keefer, C. A. Peery, T. C. Bjornn, and L. C. Stuehrenberg. 2004. Fallback, reascension, and adjusted fishway escapement estimates for adult Chinook salmon and steelhead at Columbia and Snake River dams. Transactions of the American Fisheries Society 133:932-949.

Cormack, R. M. 1964. Estimates of survival from sightings of marked animals. Biometrika 51:429-438.

Dauble, D. D., and R. P. Mueller. 2000. Difficulties in estimating survival for adult Chinook salmon in the Columbia and Snake rivers. Fisheries 25(8):24–34

Haynes, J. M., and R. H. Gray. 1980. Influence of Little Goose Dam on upstream movements of adult Chinook salmon. U.S. National Marine Fisheries Service Fishery Bulletin 78:185–190.

Hockersmith, E. E., G. A. Axel, M. B. Eppard, D. A. Ogden, and B. P. Sandford. 2005. Passage behavior and survival for hatchery yearling Chinook salmon at Lower Monumental Dam, 2004. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hockersmith, E. E., G. A. Axel, D. A. Ogden, B. J. Burke, K. E. Frick, B. P. Sandford, and R. F. Absolon. 2008a. Passage behavior and survival for radio-tagged yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2007. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hockersmith, E. E., G. A. Axel, D. A. Ogden, B. J. Burke, K. E. Frick, B. P. Sandford, and R. F. Absolon. 2008b. Passage behavior and survival for radio-tagged yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hockersmith E. E., G. A. Axel, R. F. Absolon, B. J. Burke, K. E. Frick, B. P. Sandford, and D. A. Ogden. 2010. Passage Behavior and Survival for Radio-Tagged Yearling Chinook Salmon and Juvenile Steelhead at Lower Monumental Dam, 2008. Report by Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration to the U.S. Army Corps of Engineers. Walla Walla District, Delivery Order W68SBV80438584, 82 p.

Hockersmith E. E., W. D. Muir, S. G. Smith, B. P. Sandford, N. S. Adams, J. M. Plumb, R. W. Perry, and D. W. Rondorf. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant juvenile Chinook salmon in the Snake and Columbia Rivers. North American Journal of Fisheries Management 23:404-413.

Holmes, H. B. 1952. Loss of salmon fingerlings in passing Bonneville Dam as determined by marking experiments. Unpublished manuscript, U.S. Bureau of Commercial Fisheries Report to U.S. Army Corps of Engineers, Northwestern Division, Portland, Oregon.

Hosmer, D. W., S. Lemeshow, and S. May. 2008. Applied Survival Analysis: Regression Modeling of Time-to-Event Data, 2nd Ed. Wiley & Sons. New Jersey

Johnson, G. E., N. S. Adams, R. L. Johnson, D. W. Rondorf, D. D. Dauble, and T. Y. Barila. 2000. Evaluation of the prototype surface bypass for salmonid smolts in spring 1996 and 1997 at Lower Granite Dam on the Snake River, Washington. Trans. Am. Fish. Soc. 129:381-397.

Johnson, G. E., R. A. Moursund, and J. R. Skalski. 1998. Fixed location hydroacoustic evaluation of spill effectiveness at Lower Monumental Dam in 1997. Report of Pacific Northwest National Laboratories to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometika 52:225-247.

Knight, A. E., G. Marancik, and J. B. Layzer. 1977. Monitoring movements of juvenile anadromous fish by radio telemetry. Progressive Fish-Culturist 39:148-150.

Lawless, J. F. 1982. Statistical Models and Methods for Lifetime Data. Wiley & Sons. New York.

Marsh, D. M., B. P. Sandford, and G. M. Matthews. 1995. Preliminary evaluation of the new juvenile collection, bypass, and sampling facilities at Lower Monumental Dam, 1993. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 48 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

Marsh, D. M., G. M. Matthews, S. Achord, T. E. Ruehle, and B. P. Sandford. 1999. Diversion of salmonid smolts tagged with passive integrated transponders from an untagged population passing through a juvenile collection system. North American Journal of Fisheries Management 19:1142-1146.

Muir, W. D., S. G. Smith, J. G. Williams, and B. P. Sandford. 2001. Survival of juvenile salmonids passing through bypass systems, turbines, and spillways with and without flow deflectors at Snake River Dams. North American Journal of Fisheries Management 21:135-146.

NMFS (National Marine Fisheries Service). 2000. Reinitiation of consultation on operation of the Federal Columbia River power system, including the juvenile fish transportation program and 19 Bureau of Reclamation projects in the Columbia Basin. Endangered Species Act - Section 7 Consultation, Biological Opinion. www.nwr.noaa.gov/1hydrop/hydroweb/docs/Final/2000BiOp.html (April 2005).

NMFS (National Marine Fisheries Service). 2008. Endangered Species Act Section 7(a)(2) Consultation Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation. NOAA. Log number F/NWR/2005/05883.

Peven, C., A. Giorgi, J. Skalski, M. Langeslay, A. Grassell, S. G. Smith, T. Counihan, R. Perry, S. Bickford. 2005. Guidelines and recommended protocols for conducting, analyzing, and reporting juvenile salmonid survival studies in the Columbia River Basin. Available at www.pnamp.org//web/workgroups/FPM/meetings/2007_0524/Guid__Sug_Prot_final.pdf (June 2008).

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, J. M. Sprando, G. T. George, N. S. Adams, and D. W. Rondorf. 2003. Behavior of radio-tagged juvenile Chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, Washington, 2002. Annual report to the U. S. Army Corps of Engineers, Contract W68SBV00104592, Walla Walla, Washington.

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, A. D. Cochran, T. K. Nation, J. M. Sprando, J. L. Schei, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2004. Behavior and survival of radio-tagged juvenile Chinook salmon and steelhead relative to the performance of a removable spillway weir at Lower Granite Dam, Washington, 2003. Annual report the U.S. Army Corps of Engineers, Contract W68SBV00104592, Walla Walla, Washington.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J. R., R. Townsend, J. Lady, A. E. Giorgi, J. R. Stevenson, and R. D. McDonald. 2002. Estimating route-specific passage and survival probabilities at a hydroelectric project from smolt radio telemetry studies. Canadian Journal of Fisheries and Aquatic Sciences 59:1385-1393.

Smith, S. G., J. R. Skalski, W. Schlechte, A. Hoffmann, and V. Cassen. 1994. Statistical survival analysis of fish and wildlife tagging studies. SURPH.1 Manual. (Available from University of Washington, School of Aquatic & Fisheries Science, 1325 Fourth Avenue, Suite 1820, Seattle, WA 98101-2509.)

Snedecor, G. W., and W. G. Cochran. 1980. Statistical Methods. 7th Ed. Iowa St. Univ. Press, Ames, IA. 507 pp.

Tableman, M., and J. S. Kim. 2004. Survival Analysis Using S. Chapman and Hall.

Whitney, R. R., L. Calvin, M. Erho, and C. Coutant. 1997. Downstream passage for salmon at hydroelectric projects in the Columbia River Basin: development, installation, and evaluation. U.S. Department of Energy, Northwest Power Planning Council, Portland, Oregon. Report 97-15. 101 p.

APPENDIX A

Evaluation of Study Assumptions

We used the CJS single-release model (Cormack 1964, Jolly 1965, Seber 1965) to estimate survival of radio-tagged juvenile Chinook salmon and juvenile steelhead released above and below Lower Monumental Dam. Ratios of these survival estimates (treatment survival divided by reference survival) were calculated to determine relative survival. Evaluation of critical model and biological assumptions of the study are detailed below.

A1. All tagged fish have similar probabilities of detection at a detection location.

Capture histories used for survival analysis are presented in Appendix Tables A1-A12 for yearling Chinook salmon and Appendix Tables A13-A24 for juvenile steelhead. The detection probability at our primary survival array 16 km downstream from Lower Monumental Dam used in survival analysis for yearling Chinook salmon was 0.992 overall and was 0.984 overall for juvenile steelhead (Appendix Table A25). In general, detection probabilities were near 100% at our primary survival array, with few fish detected downstream that were not detected at the primary array. With high detection probabilities for all fish, there was likely no disparity between detection probabilities of treatment and reference groups.

Appendix Table A1. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate dam passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detection locations downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (412)	0	0	29
	1	0	41
	0	1	3
	1	1	339
Reference group (487)	0	0	8
	1	0	32
	0	1	7
	1	1	440

Appendix Table A2. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate dam passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detection locations downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (461)	0	0	35
	1	0	37
	0	1	3
	1	1	386
Reference group (522)	0	0	11
	1	0	30
	0	1	2
	1	1	479

Appendix Table A3. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	N
Treatment group (531)	0	0	23
	1	0	53
	0	1	3
	1	1	452
Reference group (487)	0	0	8
	1	0	32
	0	1	7
	1	1	440

Appendix Table A4. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	N
Treatment group (546)	0	0	28
	1	0	43
	0	1	3
	1	1	472
Reference group (522)	0	0	11
	1	0	30
	0	1	2
	1	1	479

Appendix Table A5. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (412)	0	0	18
	1	0	39
	0	1	2
	1	1	353
Reference group (487)	0	0	8
	1	0	32
	0	1	7
	1	1	440

Appendix Table A6. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (387)	0	0	21
	1	0	29
	0	1	1
	1	1	336
Reference group (522)	0	0	11
	1	0	30
	0	1	2
	1	1	479

Appendix Table A7. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (85)	0	0	4
	1	0	10
	0	1	0
	1	1	71
Reference group (487)	0	0	8
	1	0	32
	0	1	7
	1	1	440

Appendix Table A8. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (127)	0	0	7
	1	0	12
	0	1	2
	1	1	106
Reference group (522)	0	0	11
	1	0	30
	0	1	2
	1	1	479

Appendix Table A9. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate RSW passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (311)	0	0	10
	1	0	28
	0	1	1
	1	1	272
Reference group (487)	0	0	8
	1	0	32
	0	1	7
	1	1	440

Appendix Table A10. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate RSW passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (301)	0	0	12
	1	0	22
	0	1	1
	1	1	266
Reference group (522)	0	0	11
	1	0	30
	0	1	2
	1	1	479

Appendix Table A11. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate turbine passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (17)	0	0	1
	1	0	1
	0	1	0
	1	1	15
Reference group (487)	0	0	8
	1	0	32
	0	1	7
	1	1	440

Appendix Table A12. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate turbine passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (16)	0	0	0
	1	0	1
	0	1	0
	1	1	15
Reference group (522)	0	0	11
	1	0	30
	0	1	2
	1	1	479

Appendix Table A13. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate dam passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detection locations downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (373)	0	0	14
	1	0	27
	0	1	6
	1	1	326
Reference group (473)	0	0	4
	1	0	28
	0	1	5
	1	1	436

Appendix Table A14. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate dam passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detection locations downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (447)	0	0	14
	1	0	22
	0	1	5
	1	1	406
Reference group (513)	0	0	5
	1	0	30
	0	1	5
	1	1	473

Appendix Table A15. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	N
Treatment group (518)	0	0	21
	1	0	33
	0	1	12
	1	1	452
Reference group (473)	0	0	4
	1	0	28
	0	1	5
	1	1	436

Appendix Table A16. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	N
Treatment group (591)	0	0	20
	1	0	34
	0	1	9
	1	1	528
Reference group (513)	0	0	5
	1	0	30
	0	1	5
	1	1	473

Appendix Table A17. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (362)	0	0	10
	1	0	22
	0	1	9
	1	1	321
Reference group (473)	0	0	4
	1	0	28
	0	1	5
	1	1	436

Appendix Table A18. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (403)	0	0	8
	1	0	21
	0	1	6
	1	1	368
Reference group (513)	0	0	5
	1	0	30
	0	1	5
	1	1	473

Appendix Table A19. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (142)	0	0	11
	1	0	11
	0	1	3
	1	1	117
Reference group (473)	0	0	4
	1	0	28
	0	1	5
	1	1	436

Appendix Table A20. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (175)	0	0	11
	1	0	12
	0	1	2
	1	1	150
Reference group (513)	0	0	5
	1	0	30
	0	1	5
	1	1	473

Appendix Table A21. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate RSW passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (269)	0	0	4
	1	0	17
	0	1	7
	1	1	241
Reference group (473)	0	0	4
	1	0	28
	0	1	5
	1	1	436

Appendix Table A22. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate RSW passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (289)	0	0	3
	1	0	13
	0	1	4
	1	1	269
Reference group (513)	0	0	5
	1	0	30
	0	1	5
	1	1	473

Appendix Table A23. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate turbine passage survival during the uniform spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (4)	0	0	0
	1	0	0
	0	1	0
	1	1	4
Reference group (473)	0	0	4
	1	0	28
	0	1	5
	1	1	436

Appendix Table A24. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate turbine passage survival during the bulk spill treatment in 2009. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (8)	0	0	0
	1	0	0
	0	1	1
	1	1	7
Reference group (513)	0	0	5
	1	0	30
	0	1	5
	1	1	473

Appendix Table A25. Detections at the primary survival array and below, and the resulting detection probabilities at the primary survival array 16 km downstream from the dam. These probabilities satisfied assumptions of the CJS model used in evaluating survival of yearling Chinook salmon and juvenile steelhead passing Lower Monumental Dam, 2009.

Release group	Detection at primary array or below	Detection below primary array	Detection probability
Yearling Chinook salmon			
Treatment	896	901	0.994
Reference	919	928	0.990
Totals	1,815	1,829	0.992
Juvenile steelhead			
Treatment	967	1,033	0.979
Reference	909	967	0.989
Totals	1,876	1,907	0.984

A2. Treatment and corresponding reference groups are evenly mixed and travel together through downstream reaches.

The difference in passage distribution of treatment and reference groups at the primary survival array (16 km downstream from the dam) were examined to determine if groups were evenly mixed and travel together through downstream reaches (Appendix Tables A26 and A27). Mixing was compared for specific percentiles (10th, 50th, 90th) of the passage distribution with t tests for differences in passage distributions (Tables A28 and A29). For mixing analysis, the date of passage of treatment fish at Lower Monumental Dam was paired with the release date of reference fish.

Tests of homogeneity in passage distributions at the primary survival array were not statistically different between treatment and reference groups used to calculate relative survival estimates for yearling Chinook salmon (Appendix Tables A26). Tests of homogeneity in passage distributions at the primary survival array showed statistically significant differences for juvenile steelhead between treatment and reference groups used to calculate relative survival estimates at the 50th percentile but not at the 10th or 90th percentiles. However the biological significance that was different was small (0.116 days or 2.8 hours), and is partly explained by the differential passage at Lower Monumental Dam of treatment (continuous) and control (systematically for six hours in daylight and darkness). We concluded the overall survival estimates were not biased regarding mixing through the common reach.

Appendix Table A26. Differences in passage timing at the primary survival array (16 km downstream from the dam) between treatment and reference groups in days for radio tagged hatchery yearling Chinook salmon used for estimating survival at Lower Monumental Dam in 2009. Standard errors are in parenthesis.

		Percentile		
Passage treatment block	n	10th	50th	90th
B1	82	-0.556	-0.430	-0.005
B2	143	0.074	-0.312	0.032
B3	153	-0.062	0.049	0.029
B4	155	0.086	-0.299	0.020
B5	152	0.179	-0.134	0.039
B6	165	0.025	0.444	-0.074
B7	158	0.143	0.090	0.066
U1	140	0.083	0.194	0.088
U2	176	-0.183	-0.399	-0.013
U3	169	0.055	0.058	0.058
U4	162	0.048	-0.136	-0.011
U5	164	-0.104	0.034	0.011
U6	150	0.045	-0.378	-0.081
Mean	1,969	-0.013 (0.5)	-0.094 (0.7)	0.012 (0.1)

Appendix Table A27. Differences in passage timing at the primary survival array (16 km downstream from the dam) between treatment and reference groups in days for radio tagged juvenile steelhead used for estimating survival at Lower Monumental Dam in 2009. Standard errors are in parenthesis.

		Percentile		
Passage treatment block	n	10th	50th	90th
B1	92	-0.617	-0.367	-0.437
B2	154	-0.183	-0.143	0.092
B3	159	0.043	-0.321	0.013
B4	162	-0.062	-0.016	0.018
B5	167	0.007	-0.225	-0.004
B6	167	-0.025	0.212	0.018
B7	160	-0.077	-0.149	0.055
U1	135	0.053	-0.209	0.057
U2	162	-0.052	0.088	-0.027
U3	149	0.055	-0.146	-0.011
U4	159	-0.060	-0.060	-0.015
U5	176	-0.123	-0.132	-0.005
U6	158	-0.025	-0.044	0.064
Mean	2,000	-0.082 (0.5)	-0.116 (0.4)	-0.014 (0.4)

Appendix Table A28. Mean difference and tests of homogeneity of passage timing at the primary survival array (16 km downstream from the dam) for treatment groups and reference groups of radio tagged hatchery yearling Chinook salmon used for estimating survival at Lower Monumental Dam in 2009. Significant differences in passage timing among tests was determined for α = 0.05.

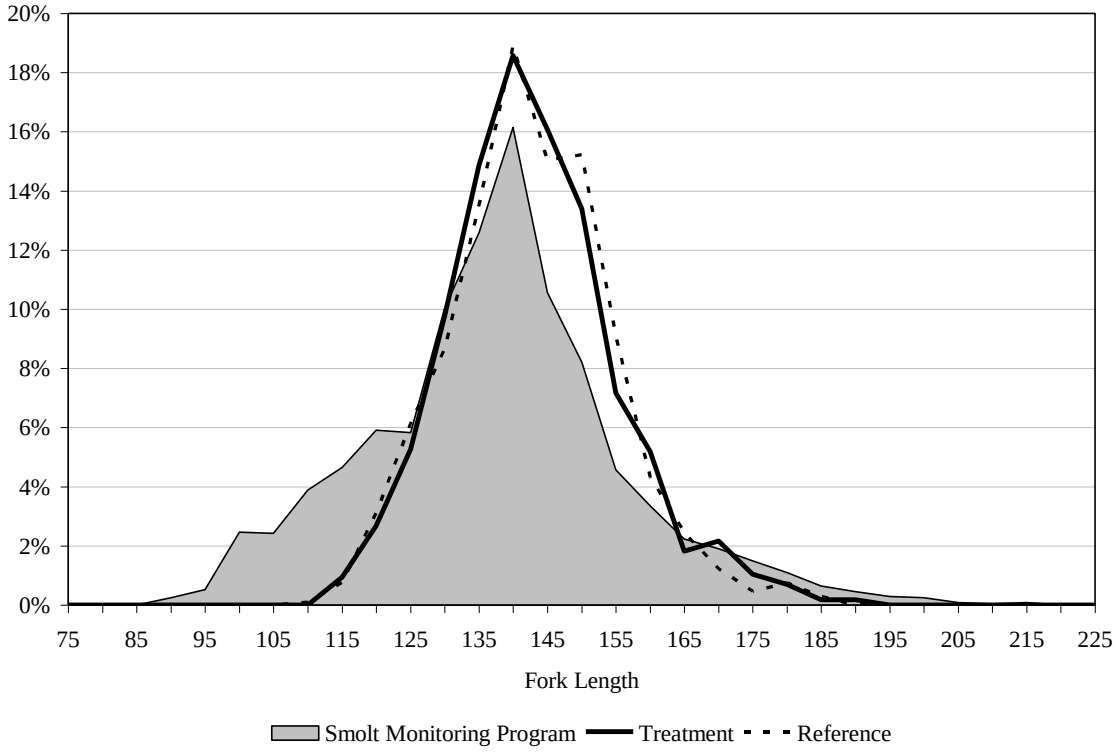
Passage percentile	Mean difference in timing (days)	*t*	df	*P*
10th	-0.013	-0.24	13	0.813
50th	-0.094	-1.27	13	0.225
90th	-0.012	0.89	13	0.390

Appendix Table A29. Mean difference and tests of homogeneity of passage timing at the primary survival array (16 km downstream from the dam) for treatment groups and reference groups of radio tagged steelhead used for estimating survival at Lower Monumental Dam in 2009. Significant differences in passage timing among tests was determined for α = 0.05.

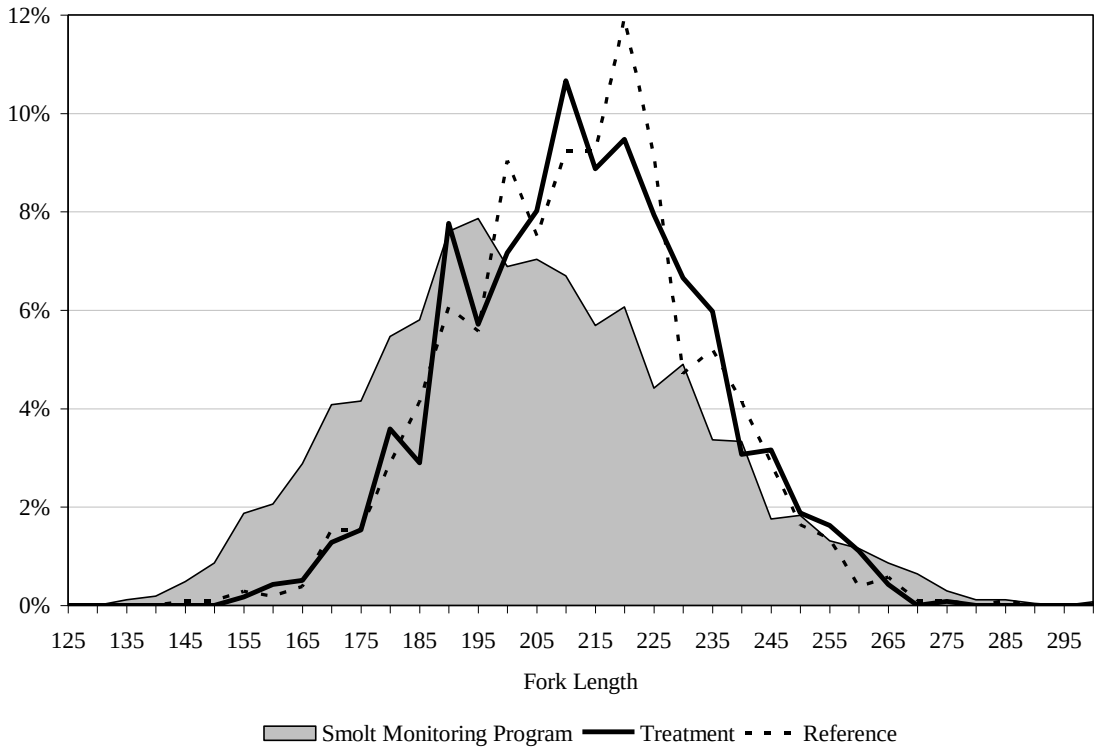
Passage percentile	Mean difference in timing (hours)	*t*	df	*P*
10th	-0.082	-1.70	13	0.114
50th	-0.116	-2.67	13	0.019
90th	-0.014	-0.38	13	0.709

A3. Individuals tagged for the study are a representative sample of the population of interest.

River run, hatchery yearling Chinook salmon and juvenile steelhead were collected at the Lower Monumental Dam smolt collection facility from 26 April to 22 May. Only fish not previously PIT tagged, without any visual signs of disease or injuries, and 13 g or larger were used. Tagging comprised the period between the 2nd and 82nd passage percentile for yearling Chinook salmon and between the 1st and 73rd passage percentile for juvenile steelhead at Lower Monumental Dam in 2009 (Figure 3). Overall the fork length distributions for our tagged yearling Chinook salmon and juvenile steelhead were similar to the fork length distributions measured by the smolt monitoring program at Lower Monumental Dam during our study. (Appendix Figures A1 and A2).



Appendix Figure A1. Fork length frequency distribution for radio tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate passage behavior and survival, 2009. The fork length frequency distribution measured by the smolt monitoring program at Lower Monumental Dam during our study is also shown.



Appendix Figure A2. Fork length frequency distribution for radio tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate passage behavior and survival, 2009. The fork length frequency distribution measured by the smolt monitoring program at Lower Monumental Dam during our study is also shown.

A4. The tag and/or tagging method do not significantly affect the subsequent behavior or survival of the marked individual.

Assumption A4 was not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have previously been evaluated by Adams et al. (1998) and Hockersmith et al. (2003). Based on their conclusions, we assumed that behavior and survival were not significantly affected over the length of our study area.

A5. Fish that die as a result of passing through a passage route are not subsequently detected at a downstream array used to estimate survival for that passage route.

In 2009, we conducted a limited test of the assumption that fish that die as a result of passage are not subsequently detected at a downstream array used to estimate survival. Past studies at Lower Monumental Dam have not observed a violation of this assumption. In 2009, we released 21 dead radio tagged hatchery yearling Chinook salmon and 13 dead juvenile steelhead into the tailrace of Lower Monumental Dam to test Assumption A5. In 2009, the first downstream telemetry array used to estimate survival was 16 km downstream of the release location, and 4 dead radio-tagged fish (3 juvenile steelhead and 1 yearling Chinook salmon) were detected on this array. Closer examination revealed that these fish were likely consumed by predators. The detections exhibited a combination of upstream movements and long residence times with periods of movement into and away from the detection field of the survival array. Since dead fish would not move upstream or into and out of a detection field we concluded that the fish had been consumed by a predator and that, as in past studies, fish detected at our primary survival array that did not show upstream movement were alive and migrating downstream at the time of detection.

A6. The radio transmitters functioned properly and for the predetermined period.

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish and prior to release, to ensure that the transmitter was functioning properly. Of 4,545 tags allocated for the evaluation of passage and survival at Lower Monumental Dam, 15 (0.3%) could not be activated and were therefore not used. A total of 4,426 tags were implanted in either hatchery yearling Chinook salmon or juvenile steelhead of which 24 (0.5%) were not working 24 h after tagging. An additional 30 tags were not used in the study because of duplicate tag codes. Of the live fish released with functional tags, a total of 7 (0.2% of those released) (2 yearling Chinook salmon and 3 juvenile steelhead released upstream and 1 yearling Chinook salmon and 1 juvenile steelhead released below Lower Monumental Dam) were subsequently detected at downstream PIT tag detection facilities and not detected on any radio telemetry arrays. The transmitters in these fish likely malfunctioned.

In addition, a total of 74 radio transmitters throughout the study were tested for tag life by allowing them to run in river water and checking them daily to determine if they functioned for the predetermined period of time. Nine tags (12.2%) failed prior to the preprogrammed shut down after 10 d (Appendix Table A30). Of these, two tags failed in less than 9 d. Ninety-nine percent of the fish had travel times to the primary array of less than 2 d, and the maximum travel time from release to our primary survival array was 8.0 d (Appendix Table A31). Although we documented transmitter failures during our study, the short travel times to our survival array and the relatively low failure rate were such that these failures would not have significantly changed our findings.

Appendix Table A30. Transmitter battery life testing, 2009.

Tags (n)	Tags (%)	Battery life (d)
0	0.0	1
0	0.0	2
0	0.0	3
0	0.0	4
0	0.0	5
1	1.4	6
1	1.4	7
0	0.0	8
7	9.5	9
65	87.8	10

Appendix Table A31. Travel time from release to detection at the primary survival array for radio tagged hatchery yearling Chinook salmon and juvenile steelhead released into the forebay and tailrace of Lower Monumental Dam, 2009.

	Travel time (d) to primary survival array by release location and species			
	Yearling Chinook salmon		Juvenile steelhead	
Percentile	Forebay	Tailrace	Forebay	Tailrace
10	0.4	0.1	0.4	0.1
20	0.5	0.1	0.5	0.1
30	0.5	0.1	0.6	0.1
40	0.6	0.1	0.7	0.1
50	0.7	0.1	0.8	0.1
60	0.8	0.1	0.9	0.1
70	0.9	0.1	1.1	0.1
80	1.1	0.2	1.4	0.2
90	1.5	0.2	1.8	0.3
Max	8.0	6.2	7.7	4.4
Time ≥ 5 d	4 (0.4%)	1 (0.1%)	8 (0.7%)	0 (0.0%)
n	1,042	1,025	1,084	1,012

APPENDIX B

Treatment and Reference Release Groups for Estimating Survival

Appendix Table B1. Grouping, samples sizes, and estimated dam survival for yearling Chinook salmon passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	61	0.953 (0.028)	78	0.977 (0.018)	0.976 (0.034)
Uniform spill 2	61	0.919 (0.035)	82	1.000 (0.000)	0.919 (0.035)
Uniform spill 3	78	0.938 (0.028)	83	1.002 (0.001)	0.937 (0.028)
Uniform spill 4	68	0.912 (0.034)	81	0.976 (0.017)	0.934 (0.039)
Uniform spill 5	69	0.928 (0.031)	83	0.977 (0.017)	0.949 (0.036)
Uniform spill 6	75	0.933 (0.029)	80	0.976 (0.018)	0.956 (0.034)
Overall uniform spill	412	0.931 (0.006)	487	0.985 (0.005)	0.945 (0.008)
Bulk spill 1	50	0.940 (0.034)	36	0.917 (0.046)	1.025 (0.063)
Bulk spill 2	63	0.857 (0.044)	82	0.952 (0.024)	0.901 (0.052)
Bulk spill 3	57	0.932 (0.034)	81	1.001 (0.001)	0.932 (0.034)
Bulk spill 4	70	0.945 (0.028)	82	0.988 (0.012)	0.957 (0.031)
Bulk spill 5	76	0.895 (0.035)	80	0.963 (0.021)	0.930 (0.042)
Bulk spill 6	73	0.959 (0.023)	81	1.000 (0.000)	0.959 (0.023)
Bulk spill 7	72	0.944 (0.027)	80	1.000 (0.000)	0.944 (0.027)
Overall bulk spill	461	0.925 (0.014)	522	0.974 (0.012)	0.949 (0.014)

Appendix Table B2. Grouping, samples sizes, and estimated concrete dam survival for yearling Chinook salmon passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	70	0.973 (0.020)	78	0.977 (0.018)	0.996 (0.028)
Uniform spill 2	100	0.971 (0.017)	82	1.000 (0.000)	0.971 (0.017)
Uniform spill 3	94	0.948 (0.023)	83	1.002 (0.001)	0.947 (0.023)
Uniform spill 4	91	0.945 (0.024)	81	0.976 (0.017)	0.968 (0.030)
Uniform spill 5	92	0.935 (0.026)	83	0.977 (0.017)	0.957 (0.031)
Uniform spill 6	84	0.976 (0.017)	80	0.976 (0.018)	1.000 (0.025)
Overall uniform spill	531	0.958 (0.007)	487	0.985 (0.005)	0.973 (0.009)
Bulk spill 1	52	0.962 (0.027)	36	0.917 (0.046)	1.049 (0.060)
Bulk spill 2	76	0.895 (0.035)	82	0.952 (0.024)	0.940 (0.044)
Bulk spill 3	85	0.919 (0.030)	81	1.001 (0.001)	0.918 (0.030)
Bulk spill 4	79	1.003 (0.002)	82	0.988 (0.012)	1.015 (0.013)
Bulk spill 5	85	0.918 (0.030)	80	0.963 (0.021)	0.953 (0.037)
Bulk spill 6	85	0.988 (0.012)	81	1.000 (0.000)	0.988 (0.012)
Bulk spill 7	84	0.964 (0.020)	80	1.000 (0.000)	0.964 (0.020)
Overall bulk spill	546	0.950 (0.016)	522	0.974 (0.012)	0.975 (0.018)

Appendix Table B3. Grouping, samples sizes, and estimated spillway survival for yearling Chinook salmon passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	63	0.986 (0.016)	78	0.977 (0.018)	1.010 (0.025)
Uniform spill 2	68	0.956 (0.025)	82	1.000 (0.000)	0.956 (0.025)
Uniform spill 3	82	0.953 (0.024)	83	1.002 (0.001)	0.951 (0.024)
Uniform spill 4	84	0.941 (0.026)	81	0.976 (0.017)	0.964 (0.031)
Uniform spill 5	76	0.934 (0.028)	83	0.977 (0.017)	0.956 (0.033)
Uniform spill 6	39	1.000 (0.000)	80	0.976 (0.018)	1.024 (0.018)
Overall uniform spill	412	0.962 (0.011)	487	0.985 (0.005)	0.976 (0.013)
Bulk spill 1	45	0.956 (0.031)	36	0.917 (0.046)	1.042 (0.062)
Bulk spill 2	55	0.927 (0.035)	82	0.952 (0.024)	0.975 (0.044)
Bulk spill 3	50	0.902 (0.043)	81	1.001 (0.001)	0.902 (0.043)
Bulk spill 4	58	1.000 (0.000)	82	0.988 (0.012)	1.012 (0.012)
Bulk spill 5	71	0.916 (0.033)	80	0.963 (0.021)	0.951 (0.040)
Bulk spill 6	51	0.980 (0.019)	81	1.000 (0.000)	0.980 (0.019)
Bulk spill 7	57	0.947 (0.030)	80	1.000 (0.000)	0.947 (0.030)
Overall bulk spill	387	0.947 (0.013)	522	0.974 (0.012)	0.972 (0.017)

Appendix Table B4. Grouping, samples sizes, and estimated RSW (spillway 8) survival for yearling Chinook salmon passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	36	1.000 (0.000)	78	0.977 (0.018)	1.024 (0.019)
Uniform spill 2	44	0.977 (0.023)	82	1.000 (0.000)	0.977 (0.023)
Uniform spill 3	65	0.987 (0.016)	83	1.002 (0.001)	0.985 (0.016)
Uniform spill 4	65	0.954 (0.026)	81	0.976 (0.017)	0.977 (0.032)
Uniform spill 5	64	0.922 (0.034)	83	0.977 (0.017)	0.943 (0.038)
Uniform spill 6	37	1.000 (0.000)	80	0.976 (0.018)	1.024 (0.018)
Overall uniform spill	311	0.973 (0.012)	487	0.985 (0.005)	0.988 (0.013)
Bulk spill 1	31	1.000 (0.000)	36	0.917 (0.046)	1.091 (0.055)
Bulk spill 2	28	0.964 (0.035)	82	0.952 (0.024)	1.013 (0.045)
Bulk spill 3	42	0.907 (0.046)	81	1.001 (0.001)	0.906 (0.045)
Bulk spill 4	47	1.000 (0.000	82	0.988 (0.012)	1.012 (0.012)
Bulk spill 5	57	0.930 (0.034)	80	0.963 (0.021)	0.966 (0.041)
Bulk spill 6	45	0.978 (0.022)	81	1.000 (0.000)	0.978 (0.022)
Bulk spill 7	51	0.961 (0.027)	80	1.000 (0.000)	0.961 (0.027)
Overall bulk spill	301	0.963 (0.013)	522	0.974 (0.012)	0.988 (0.021)

Appendix Table B5. Grouping, samples sizes, and estimated JBS survival for yearling Chinook salmon passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	5	0.800 (0.179)	78	0.977 (0.018)	0.819 (0.184)
Uniform spill 2	23	1.000 (0.000)	82	1.000 (0.000)	1.000 (0.000)
Uniform spill 3	10	0.900 (0.095)	83	1.002 (0.001)	0.899 (0.095)
Uniform spill 4	5	1.000 (0.000)	81	0.976 (0.017)	1.025 (0.018)
Uniform spill 5	13	0.923 (0.074)	83	0.977 (0.017)	0.945 (0.077)
Uniform spill 6	29	0.966 (0.034)	80	0.976 (0.018)	0.989 (0.039)
Overall uniform spill	85	0.931 (0.031)	487	0.985 (0.005)	0.943 (0.032)
Bulk spill 1	5	1.000 (0.000)	36	0.917 (0.046)	1.091 (0.055)
Bulk spill 2	18	0.778 (0.098)	82	0.952 (0.024)	0.817 (0.105)
Bulk spill 3	27	0.926 (0.050)	81	1.001 (0.001)	0.925 (0.050)
Bulk spill 4	16	1.010 (0.012)	82	0.988 (0.012)	1.022 (0.017)
Bulk spill 5	9	0.889 (0.105)	80	0.963 (0.021)	0.924 (0.111)
Bulk spill 6	30	1.000 (0.000)	81	1.000 (0.000)	1.000 (0.000)
Bulk spill 7	22	1.000 (0.000)	80	1.000 (0.000)	1.000 (0.000)
Overall bulk spill	127	0.943 (0.033)	522	0.974 (0.012)	0.965 (0.034)

Appendix Table B6. Grouping, samples sizes, and estimated dam survival for juvenile steelhead passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	59	0.932 (0.033)	72	0.986 (0.014)	0.945 (0.036)
Uniform spill 2	67	0.985 (0.015)	80	0.988 (0.012)	0.998 (0.020)
Uniform spill 3	56	0.923 (0.040)	83	0.990 (0.012)	0.933 (0.041)
Uniform spill 4	59	0.969 (0.024)	82	1.004 (0.003)	0.966 (0.024)
Uniform spill 5	61	0.984 (0.016)	81	1.000 (0.000)	0.984 (0.016)
Uniform spill 6	71	0.986 (0.014)	75	0.987 (0.013)	0.999 (0.019)
Overall uniform spill	373	0.963 (0.012)	473	0.992 (0.003)	0.970 (0.011)
Bulk spill 1	52	1.000 (0.000)	34	1.000 (0.000)	1.000 (0.000)
Bulk spill 2	58	0.931 (0.033)	83	0.989 (0.012)	0.941 (0.036)
Bulk spill 3	59	0.971 (0.024)	82	0.990 (0.012)	0.982 (0.027)
Bulk spill 4	65	0.969 (0.021)	81	0.988 (0.012)	0.981 (0.025)
Bulk spill 5	73	0.945 (0.027)	80	0.988 (0.012)	0.957 (0.029)
Bulk spill 6	74	1.000 (0.000)	75	0.988 (0.013)	1.012 (0.014)
Bulk spill 7	66	0.970 (0.021)	78	1.000 (0.000)	0.970 (0.021)
Overall bulk spill	447	0.969 (0.010)	513	0.992 (0.002)	0.977 (0.009)

Appendix Table B7. Grouping, samples sizes, and estimated concrete dam survival for juvenile steelhead passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	70	0.929 (0.031)	72	0.986 (0.014)	0.942 (0.034)
Uniform spill 2	87	0.989 (0.012)	80	0.988 (0.012)	1.002 (0.017)
Uniform \spill 3	83	0.926 (0.031)	83	0.990 (0.012)	0.936 (0.034)
Uniform spill 4	88	0.957 (0.022)	82	1.004 (0.003)	0.953 (0.022)
Uniform spill 5	98	0.991 (0.010)	81	1.000 (0.000)	0.991 (0.010)
Uniform spill 6	92	0.968 (0.019)	75	0.987 (0.013)	0.981 (0.023)
Overall uniform spill	518	0.960 (0.012)	473	0.992 (0.003)	0.967 (0.011)
Bulk spill 1	58	1.000 (0.000)	34	1.000 (0.000)	1.000 (0.000)
Bulk spill 2	80	0.925 (0.029)	83	0.989 (0.012)	0.935 (0.032)
Bulk spill 3	95	0.967 (0.021)	82	0.990 (0.012)	0.977 (0.025)
Bulk spill 4	84	0.976 (0.017)	81	0.988 (0.012)	0.988 (0.021)
Bulk spill 5	92	0.957 (0.021)	80	0.988 (0.012)	0.969 (0.025)
Bulk spill 6	98	0.980 (0.014)	75	0.988 (0.013)	0.991 (0.020)
Bulk spill 7	84	0.976 (0.017)	78	1.000 (0.000)	0.976 (0.017)
Overall bulk spill	591	0.969 (0.010)	513	0.992 (0.002)	0.976 (0.009)

Appendix Table B8. Grouping, samples sizes, and estimated spillway survival for juvenile steelhead passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	62	0.952 (0.027)	72	0.986 (0.014)	0.965 (0.031)
Uniform spill 2	65	1.001 (0.001)	80	0.988 (0.012)	1.014 (0.013)
Uniform spill 3	55	0.972 (0.026)	83	0.990 (0.012)	0.982 (0.029)
Uniform spill 4	70	0.960 (0.024)	82	1.004 (0.003)	0.957 (0.024)
Uniform spill 5	60	1.000 (0.000)	81	1.000 (0.000)	1.000 (0.000)
Uniform spill 6	50	0.961 (0.028)	75	0.987 (0.013)	0.974 (0.031)
Overall uniform spill	362	0.974 (0.009)	473	0.992 (0.003)	0.982 (0.009)
Bulk spill 1	46	1.000 (0.000)	34	1.000 (0.000)	1.000 (0.000)
Bulk spill 2	64	0.953 (0.026)	83	0.989 (0.012)	0.964 (0.029)
Bulk spill 3	53	0.986 (0.019)	82	0.990 (0.012)	0.997 (0.023)
Bulk spill 4	66	1.000 (0.000)	81	0.988 (0.012)	1.012 (0.013)
Bulk spill 5	72	0.944(0.027)	80	0.988 (0.012)	0.956 (0.030)
Bulk spill 6	54	1.000 (0.000)	75	0.988 (0.013)	1.012 (0.014)
Bulk spill 7	48	1.000 (0.000)	78	1.000 (0.000)	1.000 (0.000)
Overall bulk spill	403	0.983 (0.009)	513	0.992 (0.002)	0.991 (0.009)

Appendix Table B9. Grouping, samples sizes, and estimated RSW (spillway 8) survival for juvenile steelhead passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	35	0.943 (0.039)	72	0.986 (0.014)	0.956 (0.042)
Uniform spill 2	50	1.000 (0.000)	80	0.988 (0.012)	1.013 (0.013)
Uniform spill 3	47	0.988 (0.022)	83	0.990 (0.012)	0.998 (0.026)
Uniform spill 4	58	0.985 (0.017)	82	1.004 (0.003)	0.981 (0.017)
Uniform spill 5	44	1.000 (0.000)	81	1.000 (0.000)	1.000 (0.000)
Uniform spill 6	35	1.000 (0.000)	75	0.987 (0.013)	1.013 (0.014)
Overall uniform spill	269	0.986 (0.009)	473	0.992 (0.003)	0.993 (0.009)
Bulk spill 1	30	1.000 (0.000)	34	1.000 (0.000)	1.000 (0.000)
Bulk spill 2	42	0.976 (0.024)	83	0.989 (0.012)	0.987 (0.027)
Bulk spill 3	34	0.971 (0.029)	82	0.990 (0.012)	0.981 (0.032)
Bulk spill 4	56	1.000 (0.000)	81	0.988 (0.012)	1.012 (0.013)
Bulk spill 5	52	0.981 (0.019)	80	0.988 (0.012)	0.993 (0.023)
Bulk spill 6	42	1.000 (0.000)	75	0.988 (0.013)	1.012 (0.014)
Bulk spill 7	33	1.000 (0.000)	78	1.000 (0.000)	1.000 (0.000)
Overall bulk spill	289	0.990 (0.005)	513	0.992 (0.002)	0.998 (0.005)

Appendix Table B10. Grouping, samples sizes, and estimated JBS survival for juvenile steelhead passing Lower Monumental Dam during the uniform and bulk spill treatment, 2009. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Treatment block	n	Survival	n	Survival	
Uniform spill 1	7	0.714 (0.171)	72	0.986 (0.014)	0.724 (0.173)
Uniform spill 2	19	0.947 (0.051)	80	0.988 (0.012)	0.959 (0.053)
Uniform spill 3	28	0.838 (0.075)	83	0.990 (0.012)	0.847 (0.077)
Uniform spill 4	16	0.938 (0.061)	82	1.004 (0.003)	0.934 (0.060)
Uniform spill 5	37	0.975 (0.027)	81	1.000 (0.000)	0.975 (0.027)
Uniform spill 6	35	0.971 (0.028)	75	0.987 (0.013)	0.984 (0.031)
Overall uniform spill	142	0.897 (0.042)	473	0.992 (0.003)	0.899 (0.044)
Bulk spill 1	11	1.000 (0.000)	34	1.000 (0.000)	1.000 (0.000)
Bulk spill 2	16	0.813 (0.098)	83	0.989 (0.012)	0.821 (0.099)
Bulk spill 3	37	0.953 (0.038)	82	0.990 (0.012)	0.964 (0.040)
Bulk spill 4	16	0.875 (0.083)	81	0.988 (0.012)	0.886 (0.084)
Bulk spill 5	20	1.000 (0.000)	80	0.988 (0.012)	1.013 (0.013)
Bulk spill 6	39	0.949 (0.035)	75	0.988 (0.013)	0.960 (0.038)
Bulk spill 7	36	0.944 (0.038)	78	1.000 (0.000)	0.944 (0.038)
Overall bulk spill	175	0.933 (0.026)	513	0.992 (0.002)	0.939 (0.026)

APPENDIX C: Telemetry Data Processing and Reduction

Data Collection and Storage

Data from radio telemetry studies are stored in the Juvenile Salmon Radio Telemetry project, an interactive database maintained by staff of the Fish Ecology Division at the NOAA Fisheries Northwest Fisheries Science Center. This project tracks migration routes and passage of juvenile salmon and steelhead past dams within the Columbia and Snake Rivers using a network of radio receivers to record signals emitted from radio transmitters ("tags") implanted into the fish. Special emphasis is placed on routes of passage and on survival for individual routes at hydroelectric dams on the lower Columbia and Snake Rivers. The database includes observations of tagged fish and the locations and configurations of radio receivers and antennas.

The majority of data supplied to the database are observations of tagged fish recorded at the various radio receivers, which the receivers store in hexadecimal format. The files are saved to a central computer four times daily and placed on an FTP server automatically once per day for downloading into the database.

In addition, data in the form of daily updated tagging files were collected. These files contain the attributes of each fish tagged, along with the channel and code of the transmitter used and the date, time, and location of release after tagging.

Data are consolidated into blocks in a summary form that lists each fish and the receiver on which it was detected. This summary includes the specific time of the first and last detection and the total number of detections in each block, with individual blocks defined as sequential detections having no more than a 5 min gap between detections. These summarized data were used for analyses.

The processes in this database fall into three main categories or stages in the flow of data from input to output; loading, validation, and summarization. These are explained below and summarized in Appendix Figure C1.

The loading process consists of copying data files from their initial locations to the database server, converting the files from their original format into a format readable by SQL, and having SQL read the files and stores the data in preliminary tables.

Data Validation

During the validation process, the records stored in the preliminary tables are analyzed. We determine the study year, site identifier, antenna identifier, and tag identifier for each record, flagging them as invalid if one or more of these identifiers cannot be determined. Records are flagged by storing brief comments in the edit notes field. Values of edit notes associated with each record are as follows:

Null: denotes a valid observation of a tag

Not Tagged: denotes an observation of a channel code combination that was not in use at the time. Such values are likely due to radio frequency noise being picked up at an antenna.

Noise Record: denotes an observation where the code is equal to 995, 997, or 999. These are not valid records, and relate to radio frequency noise being picked up at the antenna.

Beacon Record: hits recorded on channel = 5, code = 575, which indicate a beacon being used to ensure proper functioning of the receivers. This combination does not indicate the presence of a tagged fish.

Invalid Record Date: denotes an observation whose date/time is invalid (occurring before we started the database, i.e., prior to 1 January 2004, or some time in the future). Due to improvements in the data loading process, such records are unlikely to arise.

Invalid Site: denotes an observation attributed to an invalid (non existent) site. These are typically caused by typographical errors in naming hex files at the receiver end. They should not be present in the database, since they should be filtered out during the data loading process.

Invalid Antenna: Denotes an observation attributed to an invalid (non existent) antenna. These are most likely due to electronic noise within the receiver.

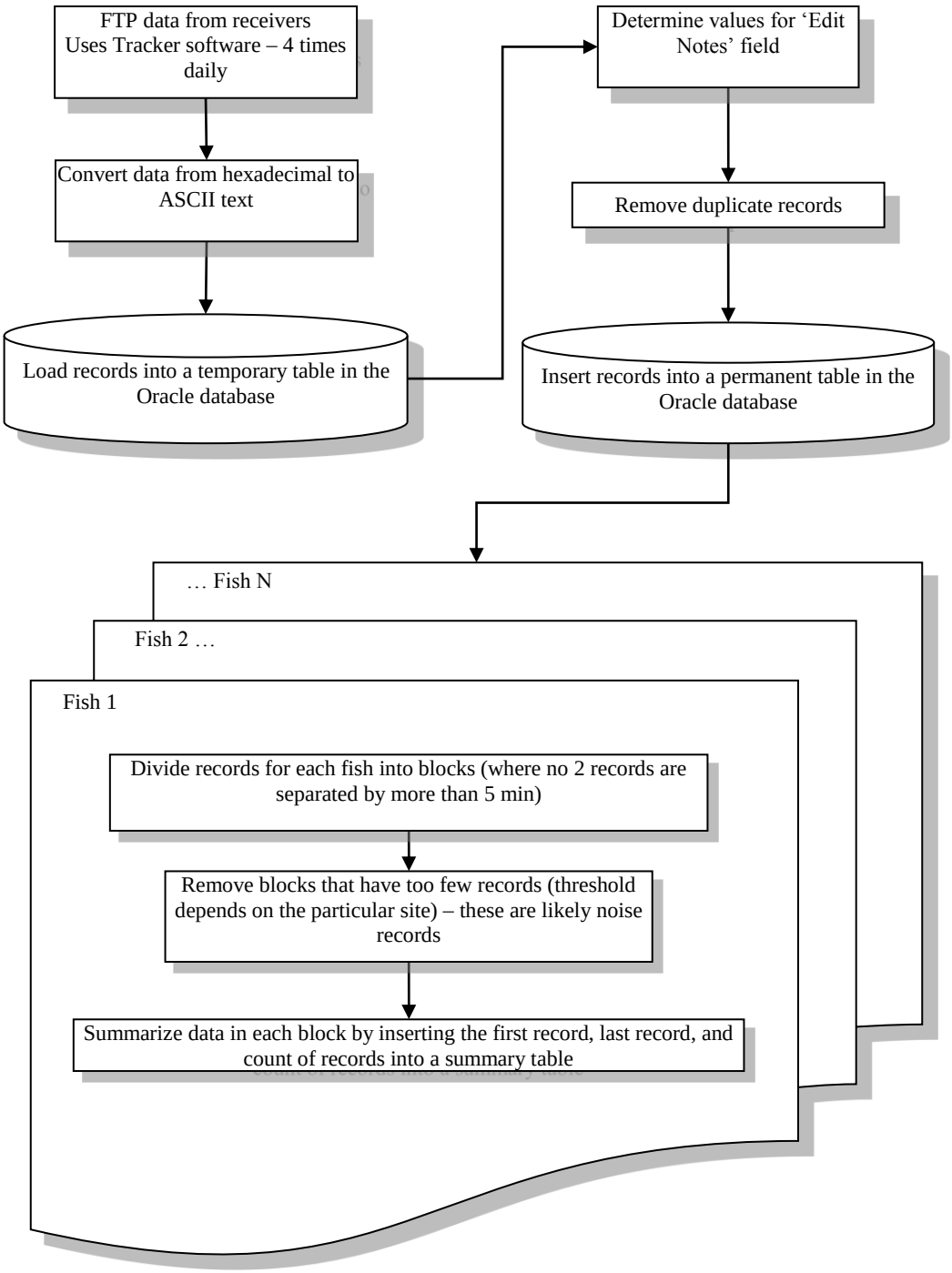
Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time). Note: these records are produced by radio frequency noise.

Gt end time: Assigned to records occurring after the end time on a tag (tags run for 10 d once activated). Note: these records are produced by radio frequency noise.

In addition, duplicate records (records for which the channel, code, site, antenna, date and time are the same as those of another record) are considered invalid. Finally, the records are copied from the preliminary tables into the appropriate storage table based on study year. The database can accommodate multiple years with differing sites and antenna configurations. Once a record's study year has been determined, its study year, site, and antenna are used to match it to a record in the sites table.

Generation of the Summary Tables

The summary table summarizes the first detection, last detection, and count of detections for blocks of records within a site for a single fish where no two consecutive records are separated by more than a specified number of minutes (currently using 5 min).



Appendix Figure C1. Flowchart showing steps for processing and reduction of radiotelemetry detection data used in evaluating behavior and survival at Lower Monumental Dam for yearling Chinook salmon and juvenile steelhead, 2009.