Passage Behavior and Survival for Radio-Tagged Yearling Chinook Salmon and Juvenile Steelhead at Lower Monumental Dam, 2008

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EXECUTIVE SUMMARY

In 2008, NOAA Fisheries evaluated passage behavior and estimated relative survival of radio-tagged river-run hatchery yearling Chinook salmon *Oncorhynchus tshawytscha* and juvenile steelhead *O. mykiss* at Lower Monumental Dam on the Snake River in relation to operation of a removable spillway weir (RSW). Fish were PIT tagged, and surgically implanted with a radio transmitter at Lower Monumental Dam. Treatment groups were comprised of 1,183 yearling Chinook salmon and 1,187 juvenile steelhead released 41 km upstream from Lower Monumental Dam. Reference groups were comprised of 980 yearling Chinook salmon and 994 juvenile steelhead released into the tailrace of Lower Monumental Dam. Releases occurred during both daytime and nighttime operations for 26 d from 28 April to 22 May. Project operations during the evaluation included either voluntary or involuntary spill 24 h per day. River flow, percent spill, and tailwater elevation during releases averaged 99 kcfs, 34%, and 441 ft msl, respectively.

For yearling Chinook salmon, median forebay delay was 2.2 h overall. During passage, the largest proportion (44%) of yearling Chinook salmon first approached Lower Monumental Dam near the middle of the dam in the vicinity of the RSW in spillbay 8. Passage route distribution was 62, 28, 6, and 4% through the spillway, juvenile bypass system (JBS), turbines, and undetermined routes, respectively. Within the spillway, the greatest proportion (45%) of yearling Chinook salmon passed through the RSW in Spillbay 8. For fish with a known passage route, fish guidance efficiency (FGE) was 83% and fish passage efficiency (FPE) was 94%. Median tailrace egress was 7 min overall, and spill efficiency was 1.91 to 1.

Relative survival was estimated from detections of treatment and reference groups at a series of downstream telemetry transects between Lower Monumental Dam on the lower Snake River and McNary Dam on the lower Columbia River. Relative dam survival (~500 m upstream to ~1 km downstream from the dam) for yearling Chinook salmon was 0.934 (95% CI, 0.902-0.968). Relative concrete survival (all passage routes combined to approximately 1 km downstream from the dam) for yearling Chinook salmon was 0.963 (95% CI, 0.929-0.997). Relative survival was 0.976 (95% CI, 0.943-1.010) for yearling Chinook salmon passing through the spillway and 0.936 (95% CI, 0.886-0.985) for fish passing through the JBS. Survival for yearling Chinook salmon passing through the RSW in Spillbay 8 was 1.012 (95% CI, 0.979–1.046).

For juvenile steelhead, median forebay delay was 2.2 h. The greatest proportion of steelhead (48%) first approached Lower Monumental Dam near the middle of the dam

in the vicinity of the RSW in Spillbay 8. Passage distribution was 80, 16, 1, and 2% through the spillway, JBS, turbines, and undetermined routes, respectively. Within the spillway, the greatest proportion of steelhead (70%) passed through the RSW in Spillbay 8. For fish with a known passage route, FGE was 93% and FPE was 99%. Median tailrace egress was 5 minutes overall, and spill efficiency was 2.43 to 1.

Relative dam survival for juvenile steelhead was 0.982 (95% CI, 0.960-1.005) and relative concrete survival was 1.006 (95% CI, 0.987-1.026). Relative survival was 1.014 (95% CI, 0.990-1.037) for juvenile steelhead passing through the spillway and 0.977 (95% CI, 0.930-1.023) for steelhead passing through the JBS. Survival for steelhead passing through the RSW in Spillbay 8 was 1.026 (95% CI, 1.004–1.048).

CONTENTS

INTRODUCTION

The Columbia and Snake River Basins have historically produced some of the largest runs of Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* in the world (Netboy 1980). More recently, however, some stocks have decreased to levels that warrant listing under the U.S. Endangered Species Act of 1973 (NMFS 1991, 1992, 1998, 1999). Anthropogenic factors that have contributed to the decline and loss of some salmonid stocks include overfishing, hatchery practices, logging, mining, agricultural practices, and dam construction and operation (Nehlsen et al. 1991). A primary focus of recovery efforts for depressed stocks has been assessing and improving fish passage conditions at mainstem dams.

The spillway has long been considered the safest passage route for migrating juvenile salmonids at Columbia and Snake River 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. The RSW at Lower Granite Dam reduced migrational delays, improved fish passage efficiency, and provided increased passage survival (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 we examined passage behavior and survival at Lower Monumental Dam in conjunction with operation of the new RSW for yearling Chinook salmon and juvenile steelhead. 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.

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 USACE, Northwestern Division, Anadromous Fish Evaluation Program.

METHODS

Study Area

The study area included a 160-km river reach of the Snake and Columbia Rivers from 5 km downstream of Little Goose Dam (rkm 635) on the lower Snake River to McNary Dam (rkm 470) on the lower Columbia River (Figure 1). Lake Herbert G. West, the reservoir behind the dam extends 46 km upstream. 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. 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. Fish entering the powerhouse that are not diverted pass through turbines. The spillway is 156 m long and consists of 8 spill bays, numbered 1 to 8 from south to north. Spill bay 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 (spill bay 8), where flow is regulated exclusively by forebay pool elevation. The RSW was installed during the winter of 2007/2008 and was first operated for fish passage during spring 2008. The spillway crest for conventional spillbays is at elevation 483 ft msl and for the RSW bay at 525 ft msl.

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, and weighed 0.8 g in air. Each tag had a 30-cm long external antenna.

River-run, hatchery yearling Chinook salmon and juvenile steelhead were collected from the smolt collection facility at either Lower Monumental or Little Goose Dams from 26 April to 22 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 12 g or more. 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 smolt-monitoring sample and transferred through a water-filled, 10.2-cm hose to a

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

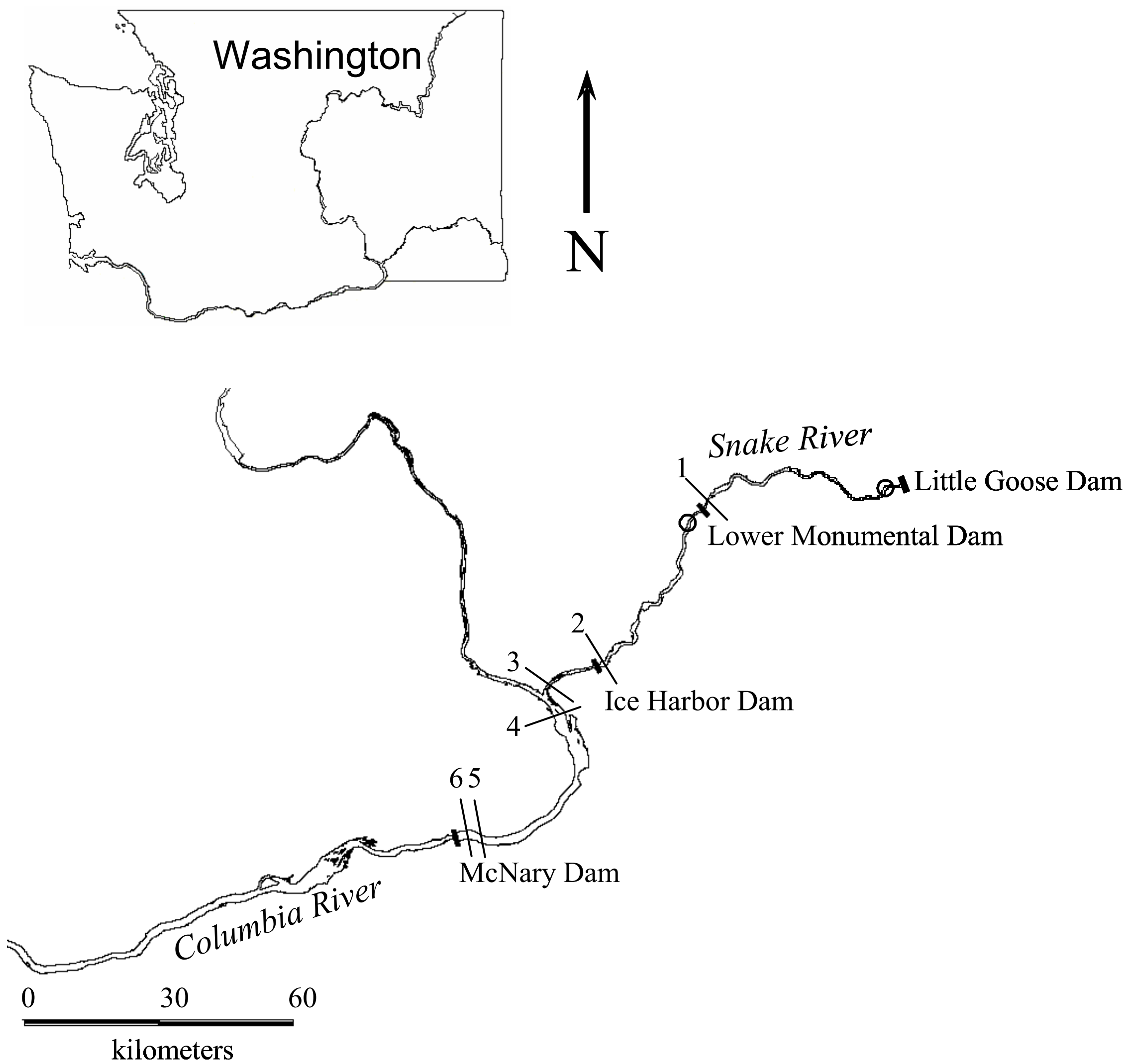

Figure 1. Detail of the study area showing release locations (O) for radio tagged fish and radio telemetry transects used for estimating survival at Lower Monumental Dam in 2008. Transects include: 1 = forebay of Lower Monumental Dam, 2 = Lower Monumental Dam primary survival transect 30 km downstream of the dam in the forebay of Ice Harbor Dam, 3 = transect at the mouth of the Snake River; 4 = transect at Burbank/Finely Railroad Bridge, and 5 and 6 = transects in the forebay of McNary Dam. The tailrace and all routes of passage at Lower Monumental and Ice Harbor Dams were also monitored.

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.

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 test fish could be separated by code in the fish collection system 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) that accommodated up to 28 buckets and supplied with flow-through 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 2004 at Lower Monumental Dam during a study to evaluate passage and survival (Hockersmith et al. 2005) except the treatment release location was further upstream in 2008. After a post-tagging recovery period, fish were transported in their recovery buckets to release locations (41 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 41 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 the rear of a truck and then driven to their release location 1,250 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 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 (flat and bulk spill patterns) that followed a 4-d random block operating schedule with each pattern operated for 2 d. Both treatments utilized the RSW. In general, the maximum difference in the gate openings for spillbays 1 though 6 was less than 2 stops during the flat spill pattern and more than 2 stops for the bulk spill pattern. Project operation data were collected every 5 min by the USACE. Project operations assigned to treatment fish were those corresponding to conditions recorded at the time closest to the time of fish 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. The two spill patterns to be evaluated (flat and bulk) at flows greater than approximately 100 kcfs converge. Therefore, based on a recommendation by the Studies Review Regional Work Group (SRWG), if Snake River discharge were high in 2008, the operational treatments would be ignored and data grouped into daily replicates.

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 2008 are summarized in Table 1 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 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 Figure 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

Table 1. Locations of fixed-site telemetry receivers for evaluating passage behavior and survival at Lower Monumental Dam, 2008.

Location	Number of receivers	Type of monitoring	Antenna type
2 km Forebay	2	Entrance line and timing	3-element Yagi
0.5 km 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	Bypass passage	Tuned loop
Turbine unit draft tubes	3	Project passage	Underwater dipole
Tailrace exit	2	Project passage and egress	3-element Yagi
Total receivers	25		

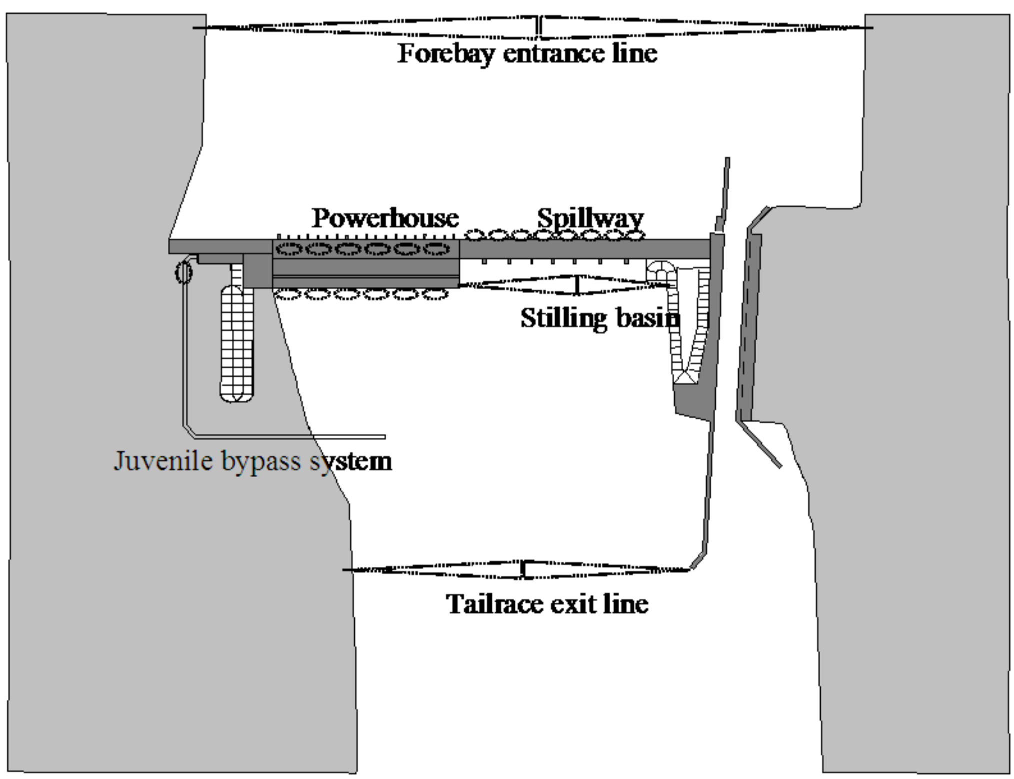

Figure 2. Lower Monumental Dam plan view showing approximate locations of detection zones for radio telemetry receivers in 2008. Oval lines represent underwater antennas, and triangular lines represent aerial antennas.

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 500 m upstream from the face of the dam). Forebay residence time 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 time 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.

Overall forebay residence time was characterized by constructing means and 95% confidence intervals (i.e. the mean ± $t_{(0.05,\, n-1)}$ standard errors, where t was the t-value, given n - 1 degrees of freedom and $\alpha = 0.05$, and was approximately 2.0) for the 10^{th}, 50^{th}, and 90^{th} percentiles of the residence time distributions. Replicates were fish grouped by day of dam passage. These intervals were also constructed by passage route (i.e., bypass, turbine, and spillway) where reasonable. For groups with insufficient sample size for replicates, intervals for all or some percentiles were not constructed (e.g., turbine and some bypass groups). Time in the bypass route was divided into gatewell and post-gatewell segments.

Differences in forebay residence time for bypassed vs. non-bypassed fish were estimated for paired replicates by constructing confidence intervals as above for the 10th, 50th (median), and 90th percentiles. Paired t-tests were calculated to assess statistical significance for $\alpha = 0.05$.

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. 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.

Spillway 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 eight antenna arrays that were 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 juvenile bypass system (JBS) passage based on the presence or absence of a detection in the JBS (either PIT-tag or telemetry detection). Fish that were assigned to powerhouse passage, but were not detected 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, detected entering the forebay, detected again in a passage route, and detected a third time in the immediate tailrace either on the stilling-basin, turbine draft tube, or tailrace-exit telemetry receivers.

Fish Passage Performance Metrics

Fish passage performance 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 juvenile bypass system divided by the total number of fish passing the dam.

Tailrace Egress

For analysis of tailrace egress, we included only fish that had been released upstream from Lower Monumental Dam, detected entering the forebay, detected again in a passage route, and detected a third time 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 (500 m downstream of the dam).

Overall tailrace egress time was characterized by constructing means and 95% confidence intervals (i.e. means +- $t_{(0.05,\, n-1)}$ standard errors, where t was the t-value, given n-1 degrees of freedom and $\alpha = 0.05$, and was approximately 2.0) for the 10th, 50th and 90th percentiles of the egress time distributions. Replicates were fish grouped by passage day. These intervals were also constructed by route of passage (i.e., bypass, turbine, and spillway) where reasonable. For groups with insufficient sample size for replicates, intervals for all or some percentiles were not constructed (e.g., turbine and some bypass groups).

Survival Estimates

Survival estimates were based on detections of individual fish at Snake River telemetry transects at Ice Harbor Dam, at the mouth of the Snake River, at Columbia River transects near Burbank, WA, and in the forebay of McNary Dam (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). Pool survival was a 41 km reach of the Snake River that extended from ~500 m upstream from Lower Monumental Dam to the release location ~5 km downstream of Little Goose Dam. The estimates of pool survival were a single-release estimate. 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 (500 m upstream of the dam) to the tailrace control release location. The tailrace release location (reference fish) was approximately 1,250 m downstream from Lower Monumental Dam.

Concrete survival is 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 (30 km downstream from Lower Monumental Dam at Ice Harbor Dam forebay) and detection downstream from Ice Harbor Dam. Treatment groups for estimates of survival were comprised of fish released above Lower Monumental Dam and subsequently detected on the forebay entrance array 500 m upstream from the dam. For estimates of dam, concrete, and route-specific survival, treatment groups were formed based on the date of passage. Fish that did not pass the dam were grouped based on date of forebay entry. Reference fish groups were formed based on release date. For estimates of relative survival, treatment fish that passed the dam on day *i* were paired with reference fish that were released to the tailrace on the same day (i.e., day *i*). Relative survival was estimated at the ratio of survival estimates between treatment (numerator) and reference (denominator) fish groups for each day. The geometric mean of the daily 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 daily 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 30 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 passage date and were "paired" with tailrace fish grouped by release date. 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 if their passage was confirmed by detection in the immediate tailrace. We excluded from analysis any fish that had not been detected on the forebay entrance array.

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. 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 comorants *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 2008 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, NOAA Fisheries, 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 2008 study period encompassed between the 3rd and 89th percentile for yearling Chinook salmon and between the 1st and 87th percentile for juvenile steelhead smolt passage index at Lower Monumental Dam (Figure 3).

We released 1,183 radio-tagged yearling Chinook salmon 41 km upstream from Lower Monumental Dam and 980 yearling Chinook salmon into the tailrace. For yearling Chinook salmon released above the dam, overall mean fork length was 141.9 mm (SD = 13.1) and overall mean weight was 28.9 g (SD = 8.7). For yearling Chinook salmon released below the dam, overall mean fork length was 142.9 mm (SD = 12.3) and overall mean weight was 28.6 g (SD = 7.8; Tables 2 and 3).

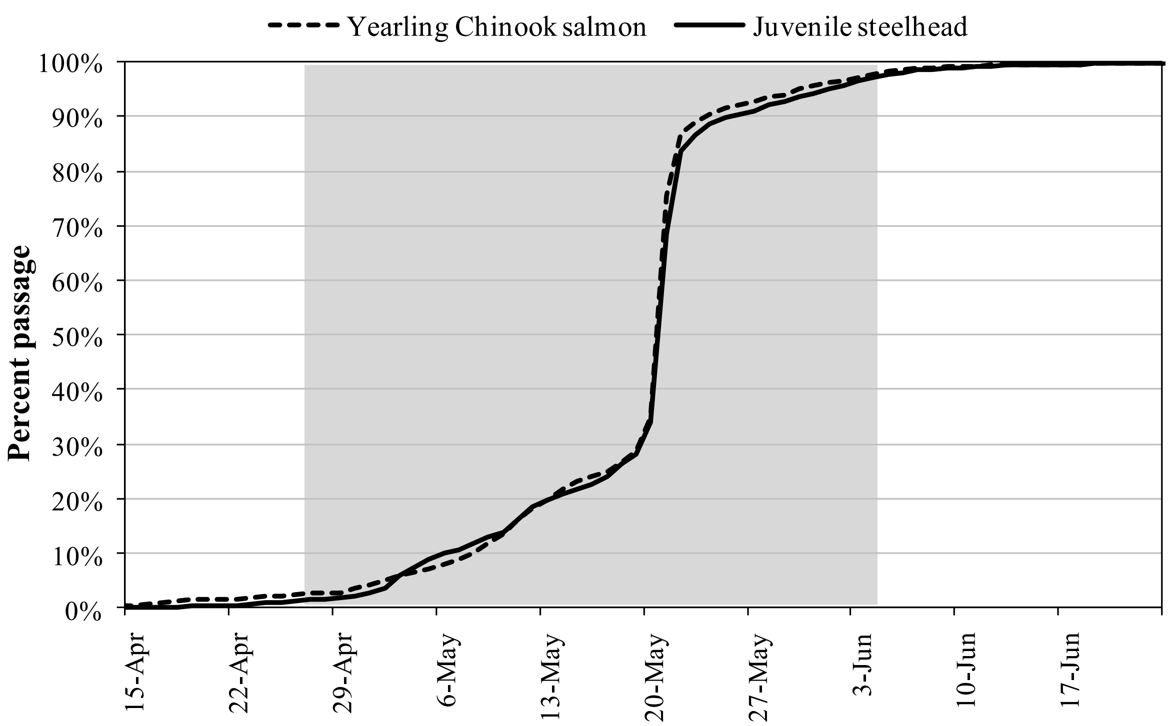

Figure 3. Cumulative passage distribution of hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam during 2008. Gray area indicates study period.

Table 2. 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, 2008.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	30	124	184	145.0	14.6	---	---	---	---	---
28 Apr	47	106	168	137.9	16.1	---	---	---	---	---
29 Apr	34	110	165	136.0	13.5	32	106	167	143.7	14.9
30 Apr	51	116	186	144.2	15.3	34	112	172	140.6	14.0
1 May	53	115	171	138.8	16.1	36	115	159	136.2	13.7
2 May	51	113	185	146.6	17.1	36	120	189	148.1	16.1
3 May	52	112	180	143.9	17.2	34	111	195	149.8	18.5
4 May	52	113	193	146.4	19.7	33	122	176	148.9	14.6
5 May	48	118	182	145.4	14.7	43	118	187	138.8	13.0
6 May	48	117	169	138.6	10.7	42	111	188	140.2	16.7
7 May	53	123	181	143.4	11.6	44	117	178	144.1	12.5
8 May	50	118	185	138.4	12.9	42	112	172	138.2	13.6
9 May	53	114	183	140.2	13.6	44	114	165	141.1	12.0
10 May	51	114	177	141.4	14.0	41	123	182	144.8	12.5
11 May	52	125	163	144.9	9.0	44	122	188	145.4	12.1
12 May	51	125	163	144.0	8.0	45	122	158	138.9	9.6
13 May	51	118	169	136.4	9.9	44	125	162	140.3	8.8
14 May	51	124	166	144.1	10.2	44	121	163	142.0	9.0
15 May	48	115	158	138.3	10.5	45	122	173	141.9	10.1
16 May	50	125	161	141.7	8.7	42	122	163	144.7	9.6
17 May	52	120	162	143.4	9.1	41	126	168	142.9	9.0
18 May	51	122	159	142.6	8.3	43	121	176	145.0	11.6
19 May	52	118	159	141.2	9.7	44	121	160	142.2	7.9
20 May	52	123	161	142.0	8.7	44	125	162	144.3	8.8
21 May	---	---	---	---	---	43	122	164	143.3	9.5
22 May	---	---	---	---	---	40	129	163	146.4	8.2
Overall	1,183	106	193	141.9	13.1	980	106	195	142.9	12.3

Table 3. 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, 2008.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	30	20	64	33.1	10.6	---	---	---	---	---
28 Apr	47	13	47	28.2	9.4	---	---	---	---	---
29 Apr	34	14	50	27.3	8.5	32	12	49	31.8	9.2
30 Apr	51	17	64	32.2	10.7	34	15	55	29.5	9.1
1 May	53	15	52	28.5	10.5	36	16	43	26.6	8.3
2 May	51	15	54	30.5	10.6	36	16	55	30.6	9.6
3 May	52	15	66	32.7	12.0	34	15	72	34.9	12.6
4 May	52	15	78	33.4	14.4	33	17	53	33.8	9.8
5 May	48	18	61	31.8	9.7	43	16	56	27.3	8.0
6 May	48	18	51	28.9	6.7	42	17	64	30.7	11.4
7 May	53	17	57	29.0	8.4	44	17	54	30.2	8.0
8 May	50	16	57	26.4	8.1	42	15	54	26.9	8.2
9 May	53	15	57	27.5	8.6	44	16	45	28.3	7.3
10 May	51	16	50	28.3	8.9	41	16	57	29.7	8.2
11 May	52	18	44	30.4	5.8	44	16	59	28.2	8.5
12 May	51	20	47	30.2	5.6	45	16	40	25.8	5.5
13 May	51	17	44	27.1	6.5	44	18	50	27.8	6.1
14 May	51	18	56	29.1	6.8	44	17	43	27.6	5.9
15 May	48	16	37	25.6	5.8	45	17	50	27.3	6.4
16 May	50	18	43	27.3	5.4	42	18	42	28.1	5.6
17 May	52	16	41	27.0	5.1	41	18	45	27.0	6.0
18 May	51	16	39	26.5	5.1	43	17	52	27.7	7.0
19 May	52	16	39	27.0	5.3	44	16	39	28.3	4.8
20 May	52	18	40	25.7	4.8	44	17	39	26.3	4.9
21 May	---	---	---	---	---	43	19	38	27.8	5.2
22 May	---	---	---	---	---	40	20	42	28.5	5.3
Overall	1,183	13	78	28.9	8.7	980	12	72	28.6	7.8

We released 1,187 radio-tagged juvenile steelhead 41 km upstream from Lower Monumental Dam and 994 steelhead into the tailrace. For juvenile steelhead released upstream from the dam, overall mean fork length was 206.1 mm (SD = 21.7) and overall mean weight was 78.8 g (SD = 25.0; Tables 4 and 5). For juvenil steelhead released below Lower Monumental Dam, overall mean fork length was 208.4 mm (SD = 21.8) and overall mean weight was 79.8 g (SD = 25.4; Tables 4 and 5).

Post-tagging mortality was 2.7% (59 fish) for yearling Chinook salmon and 1.7% (36 fish) for juvenile steelhead. Fish that died during the post-tagging holding period were released in the planned location to verify the assumption that dead fish were not detected on downstream survival arrays (Appendix Table A16). Treatment fish were released between 0956 and 1110 and between 1341 and 1512 PDT. Reference fish were released between 0828 and 1619 and between 2016 and 0401 PDT. One hundred and ninety-five yearling Chinook salmon and 78 juvenile steelhead were excluded from the analysis because they were not detected entering the forebay. In addition, nine yearling Chinook salmon and 21 juvenile steelhead were excluded from analysis of the treatment fish because they were either transported at Lower Monumental Dam, or their passage timing was either before or after the period of time during reference releases. Fifty yearling Chinook salmon and 56 juvenile steelhead were excluded from analysis of the reference fish because their release timing was either before or after the period of time when treatment fish were passing the dam.

Table 4. 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, 2008.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	34	187	239	213.8	13.3	---	---	---	---	---
28 Apr	45	173	282	213.1	19.4	---	---	---	---	---
29 Apr	35	180	261	209.4	19.4	35	165	234	203.1	14.5
30 Apr	52	162	235	196.0	14.2	36	169	215	189.8	11.5
1 May	52	168	209	192.7	9.4	34	170	208	191.5	8.3
2 May	53	179	213	196.6	8.9	36	177	273	207.9	20.1
3 May	52	168	244	205.3	16.2	35	162	246	201.6	19.2
4 May	52	164	242	198.2	17.0	35	179	259	205.0	16.9
5 May	50	156	240	199.5	16.2	48	169	230	196.3	14.0
6 May	51	155	267	196.0	19.0	44	166	232	201.0	18.0
7 May	53	147	240	198.4	22.3	44	158	260	196.6	18.9
8 May	52	154	253	200.7	23.0	44	159	248	200.5	24.3
9 May	53	143	214	185.6	14.9	43	168	222	189.8	13.2
10 May	50	146	266	204.5	24.6	44	149	278	206.6	27.4
11 May	44	148	261	224.3	24.4	45	164	267	217.2	22.7
12 May	54	153	249	206.0	25.9	45	168	254	208.7	24.0
13 May	53	155	252	203.3	22.7	44	135	253	211.0	26.0
14 May	51	150	249	209.1	23.9	44	161	250	209.1	22.6
15 May	51	156	248	208.7	20.6	45	172	249	212.9	21.7
16 May	54	161	249	216.1	22.4	44	153	249	213.0	18.7
17 May	49	162	253	215.8	19.9	41	186	253	221.8	16.7
18 May	52	172	253	217.6	17.5	42	180	256	224.1	17.7
19 May	49	186	253	222.5	16.2	41	182	244	222.7	18.1
20 May	46	189	264	225.6	18.4	41	188	253	222.7	16.7
21 May	---	---	---	---	---	44	167	258	221.9	18.2
22 May	---	---	---	---	---	40	189	248	220.4	16.3
Overall	1,187	143	282	206.1	21.7	994	135	278	208.4	21.8

Table 5. 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, 2008.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
27 Apr	34	34	59	120	89.5	---	---	---	---	---
28 Apr	45	45	46	197	90.7	---	---	---	---	---
29 Apr	35	35	51	158	85.3	35	44	121	76.5	15.6
30 Apr	52	52	38	123	68.6	36	41	88	61.8	10.9
1 May	52	52	43	86	64.7	34	39	77	63.0	8.2
2 May	53	53	47	85	65.2	36	46	169	74.7	20.9
3 May	52	52	42	137	79.2	35	37	136	76.9	22.9
4 May	52	52	41	140	72.6	35	44	134	73.6	20.8
5 May	50	50	32	117	70.3	48	38	111	66.2	15.4
6 May	51	51	35	172	73.6	44	43	117	78.5	20.2
7 May	53	53	26	126	71.0	44	32	146	67.1	20.7
8 May	52	52	31	150	74.1	44	35	118	72.1	26.3
9 May	53	53	26	84	54.5	43	39	84	57.3	11.2
10 May	50	50	27	155	77.2	44	26	189	78.6	31.6
11 May	44	44	25	152	101.6	45	40	178	91.4	30.5
12 May	54	54	31	142	78.7	45	40	149	79.4	28.3
13 May	53	53	32	135	80.4	44	22	142	87.8	31.6
14 May	51	51	29	124	81.4	44	35	160	81.5	29.7
15 May	51	51	30	121	77.1	45	42	135	81.8	27.4
16 May	54	54	36	139	90.4	44	27	147	83.3	23.6
17 May	49	49	32	146	87.0	41	53	131	97.9	18.5
18 May	52	52	40	132	84.9	42	53	136	99.1	21.8
19 May	49	49	54	141	97.8	41	52	147	99.3	25.4
20 May	46	46	48	147	95.6	41	48	133	88.0	21.5
21 May	---	---	---	---	---	44	38	131	90.7	20.9
22 May	---	---	---	---	---	40	56	136	88.1	20.5
Overall	1,187	25	197	78.8	25.0	994	22	189	79.8	25.4

Project Operations

During our study period, project discharge averaged 99 kcfs, or approximately 111% of the previous 10-year average daily flow of 89 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 (flat and bulk) were planned to be evaluated, however, at flows greater than approximately 100 kcfs, the two spill patterns converge. Flow above 100 kcfs occurred for more than 25% of the time resulting in insufficient replication of the treatment operations, and a lack of consistent adherence to the treatment schedule for the experimental design (Appendix Table B9 and B10). Therefore, the operational treatments were ignored for analysis and data was grouped into daily replicates. Daily project operations during the study averaged 98.7 kcfs total discharge, 65.5 kcfs powerhouse discharge, 33.3 kcfs spillway discharge (34% of total project discharge), and tailwater elevation of 440.7 ft msl (Table 6 and Figure 5). Flow through the RSW averaged 7.1 kcfs during the study. Water temperature during tagging, the post-tagging holding period, and releases ranged from 9.1 to 12.0°C and averaged 10.5°C.

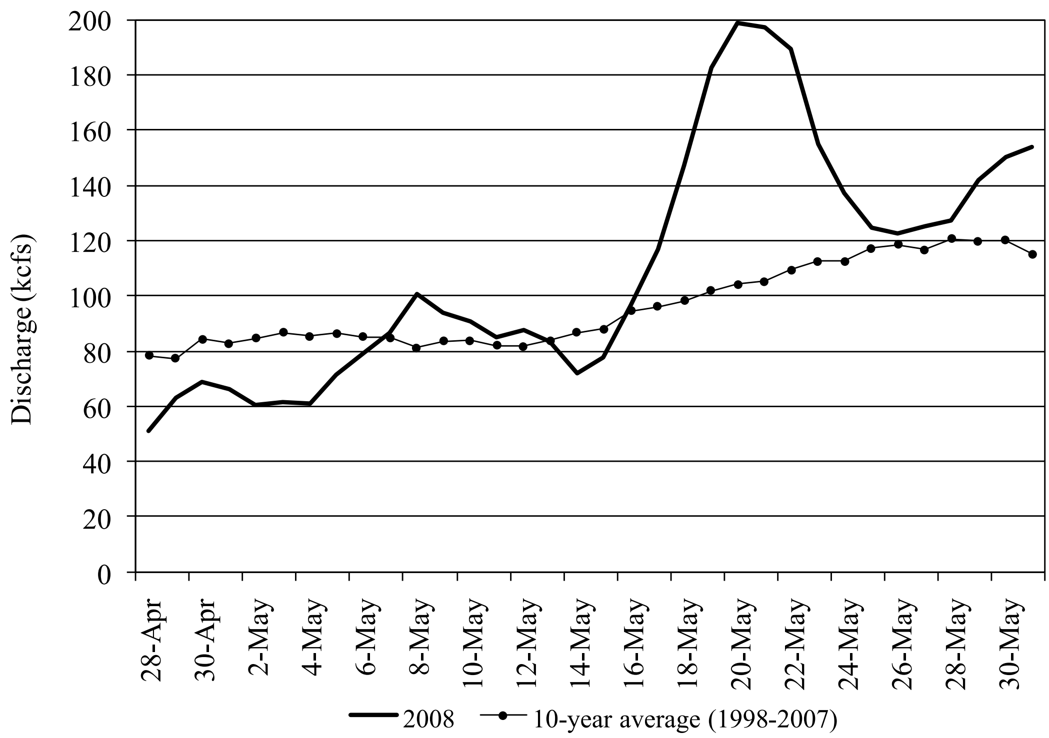

Figure 4. Average daily project discharge during passage and survival study of hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2008. Ten-year average discharge during this period is also shown.

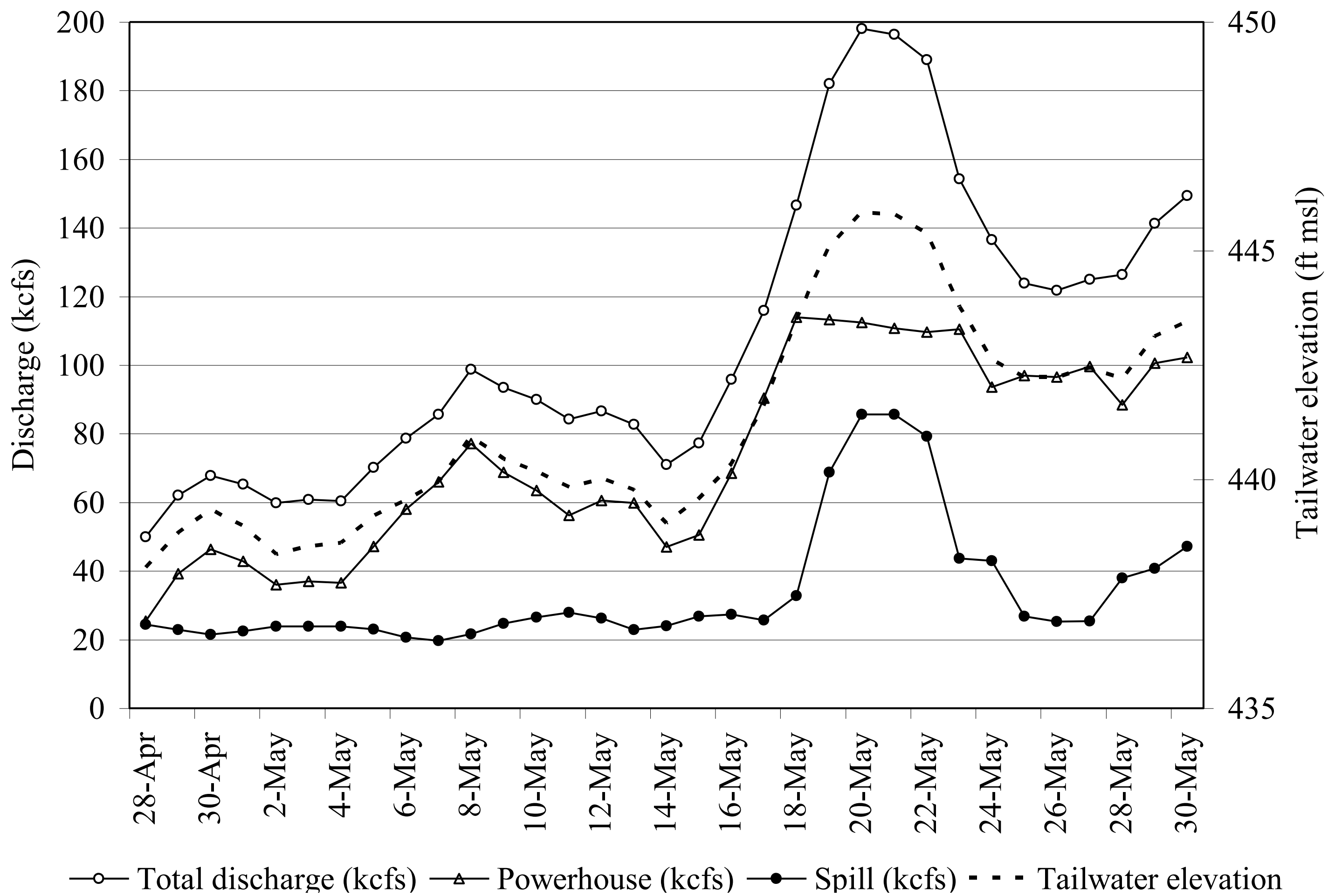

Figure 5. Average daily project discharge, powerhouse discharge, spillway discharge, and tailwater elevation by date during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2008.

Table 6. Average daily conditions during evaluation of passage and survival of radio tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2008.

Release date	Total discharge (kcfs)	Powerhouse (kcfs)	Spill (kcfs)	Spill (%)	Water temperature (°C)	Tailwater elevation (ft msl)
28-Apr	49.9	25.4	24.5	53	9.2	438.1
29-Apr	62.1	39.2	22.9	40	9.6	438.8
30-Apr	67.8	46.3	21.5	32	9.4	439.3
1-May	65.3	42.8	22.5	37	9.1	439.0
2-May	59.8	36.0	23.8	42	9.2	438.4
3-May	60.8	37.0	23.8	40	9.6	438.5
4-May	60.4	36.6	23.8	40	9.6	438.6
5-May	70.2	47.1	23.1	36	9.8	439.2
6-May	78.6	58.0	20.6	27	10.4	439.5
7-May	85.7	66.0	19.7	23	11.0	439.9
8-May	98.8	77.1	21.7	23	10.7	440.9
9-May	93.4	68.8	24.6	27	10.5	440.4
10-May	90.0	63.4	26.6	30	10.7	440.2
11-May	84.2	56.3	27.9	33	11.0	439.8
12-May	86.6	60.5	26.2	31	11.1	440.0
13-May	82.6	59.8	22.8	28	11.1	439.8
14-May	71.0	47.0	24.0	34	10.8	439.1
15-May	77.2	50.5	26.8	35	10.6	439.6
16-May	95.8	68.5	27.3	29	10.8	440.4
17-May	116.0	90.3	25.6	23	11.0	441.6
18-May	146.6	113.9	32.7	22	11.3	443.5
19-May	182.0	113.2	68.8	38	11.6	445.1
20-May	198.1	112.4	85.6	42	12.0	445.8
21-May	196.3	110.7	85.7	43	11.6	445.8
22-May	189.0	109.7	79.3	42	10.8	445.4
Average	98.7	65.5	33.3	34	10.5	440.7

Forebay Residence Time

Of the 1,183 radio-tagged yearling Chinook salmon released above Lower Monumental Dam, 988 (84%) were detected on the forebay entrance line at the upstream end of the BRZ. Yearling Chinook salmon forebay entry at Lower Monumental Dam was relatively consistent across all hours (Figure 6). Median forebay residence time was 2.2 h (95% CI 1.6-2.7) and ranged from 0.2 to 98.3 h (Table 7). Median forebay residence time of yearling Chinook salmon that passed through the JBS (5.9 h; 95% CI 3.3-8.5) was significantly longer than for fish passing through the spillway (1.8 h; 95% CI 1.3-2.4) or turbines (1.0 h, no 95% CI calculated; *P* = 0.001).

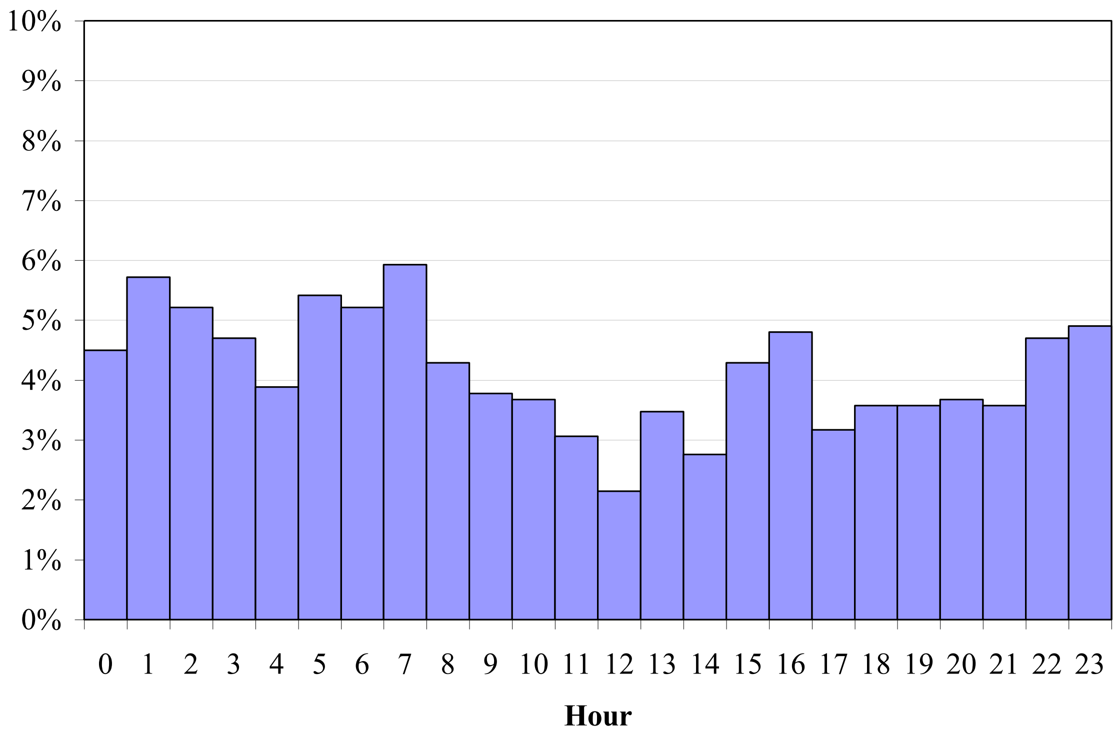

Figure 6. Hour of first detection for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam and detected in the forebay of Lower Monumental Dam, 2008.

Table 7. Sample size, percentile distribution, minimum, mean, median, mode, and maximum forebay residence time (elapsed time in hours from first detection on the forebay entry line to time of passage) by passage route and overall for radio-tagged hatchery yearling Chinook salmon at Lower Monumental Dam, 2008.

	Forebay residence time (h)				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
N	265	586	425	56	907
10th	1.2	0.6	0.7	0.6	0.7
20th	1.6	0.8	0.9	0.7	0.9
30th	2.6	1.1	1.2	0.8	1.2
40th	4.1	1.3	1.5	0.8	1.6
50th	5.9	1.8	2.1	1.0	2.2
60th	8.0	2.5	3.1	1.2	3.6
70th	10.9	3.8	4.6	1.3	5.8
80th	15.4	6.8	7.4	1.6	8.9
90th	33.0	12.2	14.3	5.2	16.3
95th	51.0	19.5	19.5	6.1	27.7
Minimum	0.6	0.2	0.3	0.2	0.2
Mean	12.2	4.8	5.3	1.9	6.8
Median	5.9	1.8	2.1	1.0	2.2
Mode	1.2	0.7	0.9	0.8	0.8
Maximum	98.3	81.0	81.0	19.3	98.3

Of the 1,187 radio-tagged juvenile steelhead released above Lower Monumental Dam, 1,109 (93%) were detected on the forebay entrance line at the upstream end of the BRZ. Seventy-nine percent of the juvenile steelhead entered the forebay of Lower Monumental Dam between 0500 and 1900 PDT (Figure 7). Median forebay residence time was 2.2 h (95% CI 1.8-2.5) and ranged from 0.2 to 146.3 h (Table 8). Median forebay residence time of steelhead that passed through the JBS (8.5 h; 95% CI 5.0-12.0) was significantly longer than for fish passing through the spillway (1.8 h; 95% CI 1.5-2.1) or turbines (2.9 h, no 95% CI calculated; $P < 0.001$).

Median gatewell residence time was 0.5 h for yearling Chinook salmon and 0.2 h for juvenile steelhead that passed the dam through the JBS (Table 9). For yearling Chinook salmon that passed via the JBS, median gatewell residence time accounted for 24% of delay associated with forebay residence time. For juvenile steelhead that passed via the JBS, median gatewell residence time accounted for 7% of the delay associated with forebay residence time.

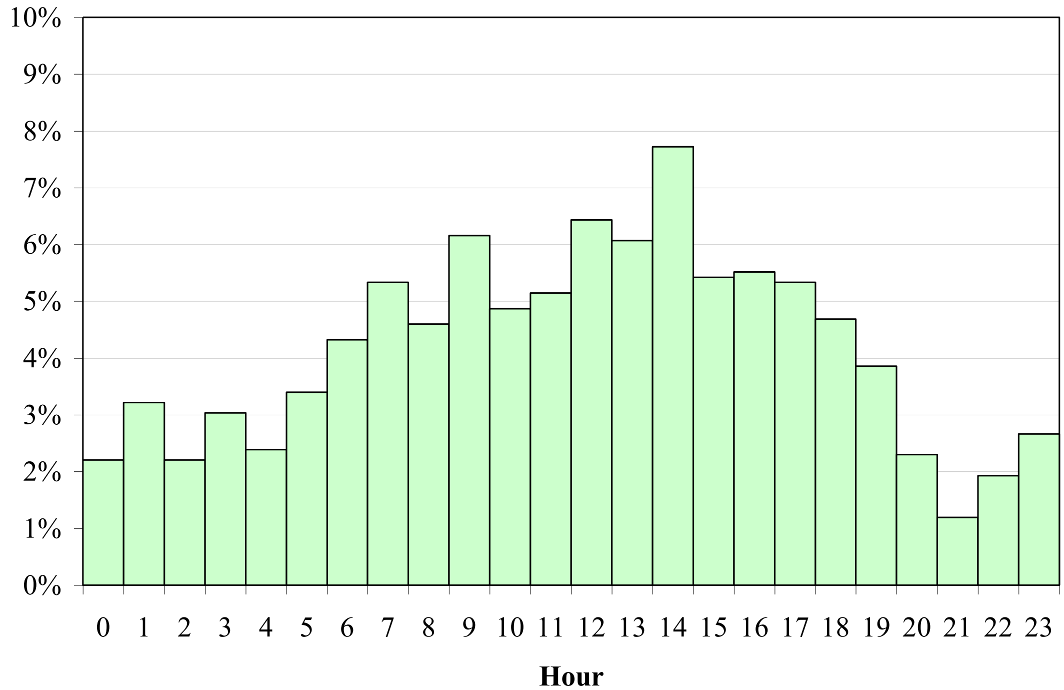

Figure 7. Hour of first detection for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam and detected in the forebay of Lower Monumental Dam, 2008.

Table 8. Sample size and forebay residence time (from first detection on forebay entry line to passage) statistics by passage route and overall for juvenile steelhead at Lower Monumental Dam, 2008.

	Forebay residence time (h)				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
N	175	851	740	14	1,040
10th	1.7	0.6	0.6	0.6	0.6
20th	3.3	0.8	0.8	0.8	0.9
30th	4.4	1.0	1.0	0.9	1.2
40th	6.2	1.3	1.3	1.1	1.7
50th	8.5	1.8	1.8	2.9	2.2
60th	11.4	2.3	2.3	4.4	3.1
70th	14.9	3.2	3.2	4.6	4.4
80th	21.7	4.7	4.6	5.4	7.1
90th	44.5	8.7	8.4	6.8	13.1
95th	63.4	12.8	12.5	10.2	20.3
Minimum	0.7	0.2	0.2	0.4	0.2
Mean	17.3	3.5	3.5	3.8	5.8
Median	8.5	1.8	1.8	2.9	2.2
Mode	1.1	0.9	1.0	NA	0.9
Maximum	146.3	41.3	41.3	15.4	146.3

Table 9. Sample size, percentile distribution, minimum, mean, median, mode, and maximum gatewell residence time (elapsed time in hours from first detection in the gatewell to time of passage) for radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2008.

	Gatewell residence time (h)	
Passage percentile	Yearling Chinook salmon	Juvenile steelhead
n	234	156
10th	0.1	0.1
20th	0.1	0.1
30th	0.2	0.1
40th	0.3	0.1
50th	0.5	0.2
60th	2.2	0.2
70th	5.1	0.3
80th	8.7	0.6
90th	25.2	2.8
95th	45.2	8.4
Minimum	0.0	0.0
Mean	7.6	1.3
Median	0.5	0.2
Mode	0.1	0.1
Maximum	88.1	20.0

Approach and Passage-Route Distribution

A total of 979 yearling Chinook salmon entered the forebay of Lower Monumental Dam, and 93% of these fish (907) subsequently passed the dam. Seventy percent of the yearling Chinook salmon first approached the spillway portion of the dam, with the majority of these (44%) approaching the RSW in Spillbay 8 (Figure 8). Passage-route distribution was 62, 28, and 6%, through the spillway, JBS, and turbines, respectively. The remaining 4% passed through undetermined routes. The greatest proportion of yearling Chinook passed through the RSW in Spillbay 8 (45%; Figure 9).

A total of 1,088 juvenile steelhead entered the forebay of Lower Monumental Dam and 96% of these fish (1,040) subsequently passed the dam. Eighty-six percent of juvenile steelhead first approached the spillway portion of the dam, with the majority of these (48%) approaching the RSW in Spillbay 8 (Figure 10). Passage-route distribution was 80, 16, and 1% through the spillway, JBS, and turbines, respectively. The remaining 2% passed via undetermined routes. The largest proportion of juvenile steelhead passed through the RSW in Spillbay 8 (70%; Figure 11).

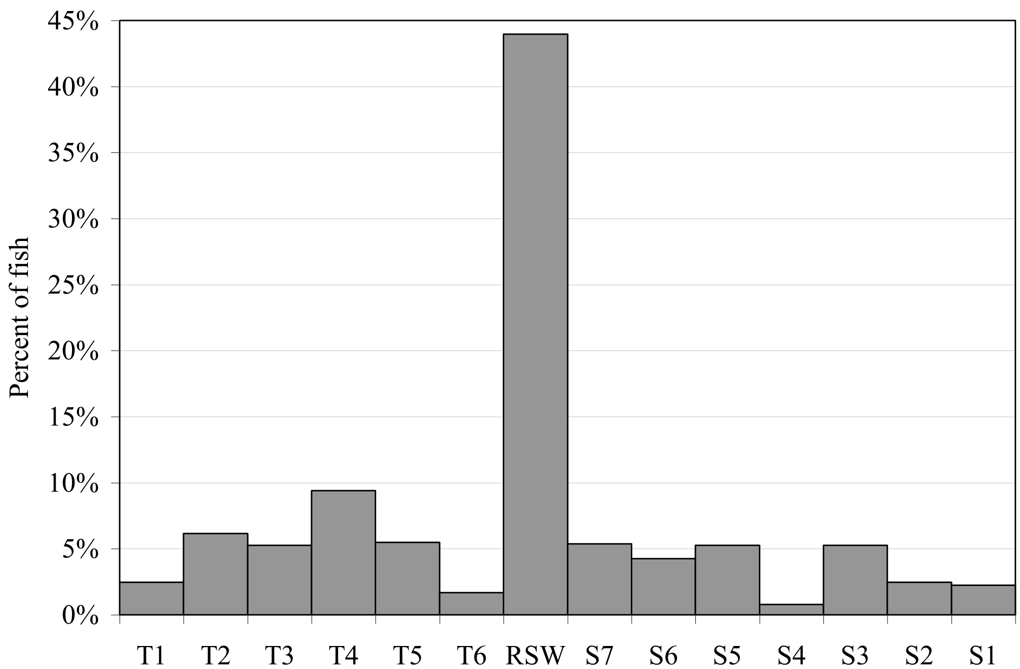

Figure 8. Horizontal approach distribution (within 18 m of the dam) for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam based on first detection at individual turbine intakes (T), the RSW, or spillbays (S), 2008.

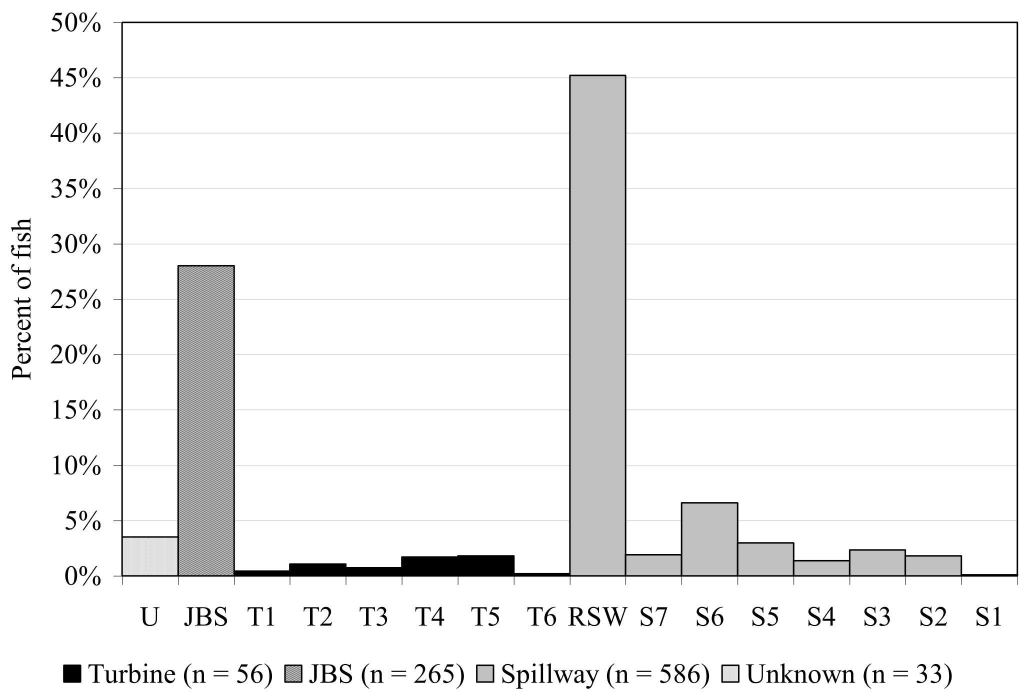

Figure 9. Passage route distribution for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam, 2008. Passage locations are U = unidentified route, JBS, T = individual turbine intakes, RSW, and S = individual spillbays.

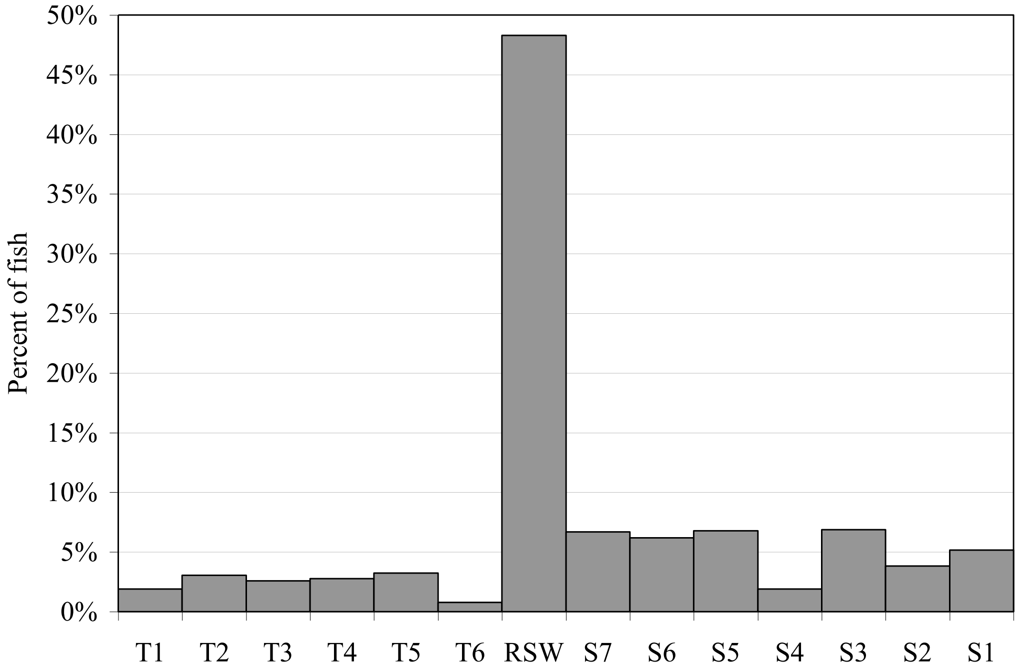

Figure 10. Horizontal approach distribution (within 18 m of the dam) for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam based on first detections at either individual turbine intakes (T) or spillbays (S), 2008.

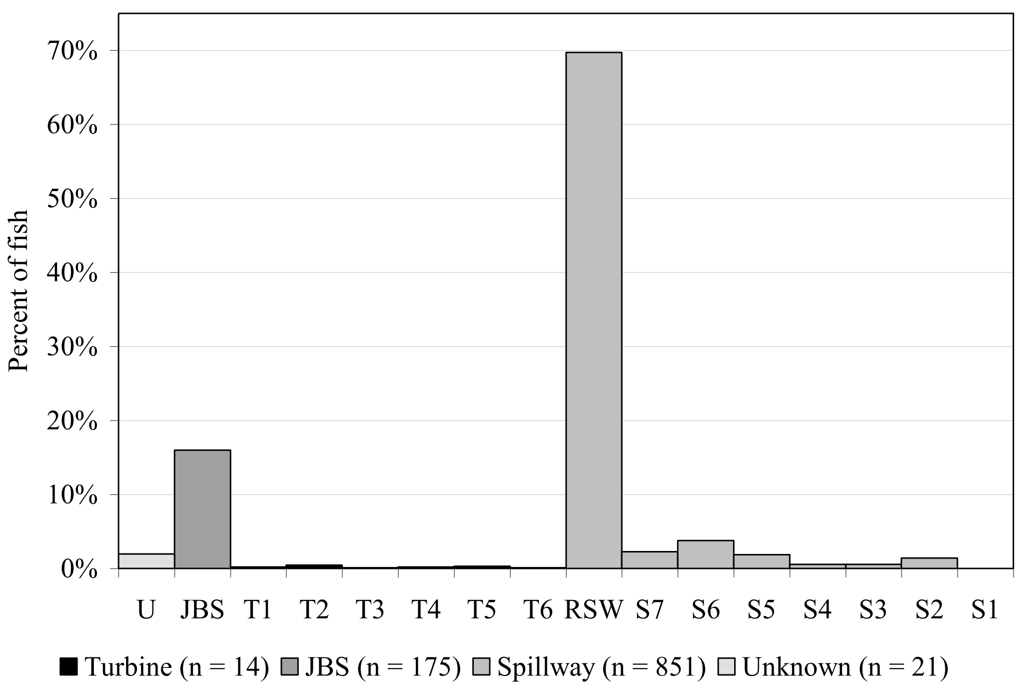

Figure 11. Passage distribution for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam, 2008. Passage locations are U = unidentified route, JBS, T = individual turbine intakes, RSW, and S = individual spillbays.

Fish Passage Performance Metrics

For radio-tagged yearling Chinook salmon and steelhead with a known passage route, fish passage metrics are summarized below:

	Yearling Chinook Salmon		Steelhead	
		95% CI		95% CI
FGE	0.826	0.783-0.868	0.926	0.888-0.964
FPE	0.938	0.922-0.954	0.987	0.979-0.994
BPE	0.292	0.262-0.322	0.168	0.145-0.191
SPE	0.646	0.614-0.677	0.818	0.794-0.842
SOE	0.469	0.435-0.502	0.712	0.683-0.740
SPS (mean spill of 34%)	1.91 to 1		2.43 to 1	
SOS (mean surface spill of 7%)	6.51 to 1		9.89 to 1	

Tailrace Egress

Overall median tailrace egress time was 6.6 min (95% CI, 5.7-7.6) for yearling Chinook salmon and ranged from 1 to 9,756 min (Table 10). Median tailrace egress time was significantly longer for yearling Chinook that passed through the powerhouse (JBS 10.2 min, 95% CI, 4.5-15.8; turbines 10.3 min, no 95% CI calculated) than for those that passed through the spillway (5.1 min, 95% CI, 4.5-5.7; $P = 0.013$).

Overall median tailrace egress for juvenile steelhead was 5.3 min (95% CI, 4.7-5.8) and ranged from 1 to 3,167 min (Table 11). Median tailrace egress time was significantly longer for juvenile steelhead that passed through the powerhouse (JBS 8.5 min, 95% CI 4.6-12.4; turbines 16.5 min, no 95% CI calculated) than for those that passed through the spillway (4.9 min, 95% CI, 4.3-5.4; P- = 0.045). The longer egress times for JBS passage of both yearling Chinook salmon and steelhead were likely related to the proximity of the powerhouse and strong clockwise eddy in the tailrace.

Table 10. 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) by passage route and overall for radio tagged hatchery yearling Chinook salmon at Lower Monumental Dam, 2008.

	Yearling Chinook tailrace egress time (min)				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
n	235	463	326	42	740
10th	4.7	2.0	2.0	6.4	2.7
20th	6.2	3.3	3.4	6.9	3.7
30th	7.5	3.8	3.9	7.6	4.7
40th	8.5	4.5	4.5	8.9	5.5
50th	10.2	5.1	5.2	10.3	6.6
60th	13.6	5.8	6.1	11.3	7.8
70th	17.5	6.9	6.9	11.8	9.8
80th	23.0	8.6	8.5	18.1	16.2
90th	41.9	22.5	18.5	146.4	35.1
95th	373.5	269.6	124.8	421.7	328.8
minimum	1.0	1.0	1.0	5.0	1.0
mean	159.0	183.0	132.8	140.9	173.0
median	10.2	5.1	5.2	10.3	6.6
mode	0.0	3.4	3.4	#N/A	4.9
maximum	9620.3	9755.7	9227.9	3211.8	9755.7

Table 11. 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) by passage route and overall for radio-tagged juvenile steelhead at Lower Monumental Dam, 2008.

	Juvenile steelhead tailrace egress time (min)				
Passage percentile	JBS	Spillway	RSW	Turbine	Overall
n	147	628	534	11	786
10th	4.2	2.0	2.0	4.8	2.2
20th	5.2	2.8	2.9	5.1	3.1
30th	6.5	3.6	3.6	11.1	4.0
40th	7.5	4.3	4.3	12.0	4.6
50th	8.5	4.9	4.9	16.5	5.3
60th	10.0	5.4	5.4	19.2	6.0
70th	13.6	6.1	6.1	24.2	7.2
80th	19.9	7.4	7.2	36.8	9.3
90th	27.0	10.8	10.1	120.0	17.4
95th	44.8	21.1	20.0	688.9	30.6
minimum	1.0	1.0	1.0	3.3	1.0
mean	41.9	9.8	8.4	137.4	17.6
median	8.5	4.9	4.9	16.5	5.3
mode	0.0	0.0	0.0	#N/A	0.0
maximum	3167.0	449.7	409.0	1257.9	3167.0

Survival Estimates

Detection Probability

Detection histories used for survival estimates are presented in Appendix Tables A1-A10. Detection probabilities at the primary survival array, 30 km downstream from Lower Monumental Dam, are presented for each species in Appendix Table A11. Daily survival estimates for paired treatment and reference fish groups are presented in Appendix Tables B1-B8.

Pool Survival

For yearling Chinook salmon, single-release pool survival (from release ~5 km downstream of Little Goose Dam to ~500 m upstream from Lower Monumental Dam), was estimated at 0.912 (geomean; SE = 0.038; 95% CI, 0.889-0.934). For juvenile steelhead, single-release pool survival was estimated at 0.958 (geomean; SE = 0.026; 95% CI, 0.946-0.968).

Project Survival

For yearling Chinook salmon, relative dam survival (~500 m upstream to ~1 km downstream from the dam) was estimated at 0.934 (geomean; SE = 0.016; 95% CI, 0.902-0.968; Table 12). Relative concrete survival (all passage routes combined to approximately 1 km downstream from the dam) was estimated at 0.963 (geomean; SE = 0.016; 95% CI, 0.929-0.997).

For juvenile steelhead, relative dam survival was estimated at 0.982 (geomean; SE = 0.011; 95% CI, 0.960-1.005; Table 13) and relative concrete survival at 1.006 (geomean; SE = 0.009; 95% CI, 0.987-1.026).

Route-Specific Survival

For radio-tagged yearling Chinook salmon, relative survival (treatment/reference) was estimated at 0.976 (geomean; SE = 0.016; 95% CI, 0.943-1.010) for fish passing via the spillway, 0.936 (pooled; SE = 0.025; 95% CI, 0.886-0.985) for those passing via the JBS, and 1.012 (geomean; SE = 0.016; 95% CI, 0.979-1.046) for those passing via the RSW (Table 12). Insufficient numbers of yearling Chinook salmon passed through turbines to estimate survival with acceptable precision.

Table 12. Sample sizes and mean estimates of survival for radio-tagged hatchery yearling Chinook salmon passing (treatment) Lower Monumental Dam relative to fish released into the tailrace (reference), 2008. Standard errors are in parenthesis.

	Yearling Chinook salmon							
	Treatment			Reference			Relative	
	n	Survival	95% CI	n	Survival	95% CI	Survival	95% CI
Project survival								
Dam survival	979	0.860 (0.013)	0.834-0.887	930	0.919 (0.009)	0.902-0.937	0.934 (0.016)	0.902-0.968
Concrete survival	907	0.886 (0.013)	0.860-0.913	930	0.919 (0.009)	0.902-0.937	0.963 (0.016)	0.929-0.997
Route-specific survival								
Spillway survival	586	0.899 (0.013)	0.871-0.926	930	0.919 (0.009)	0.902-0.937	0.976 (0.016)	0.943-1.010
JBS survival*	265	0.862 (0.021)	0.819-0.904	930	0.921 (0.009)	0.903-0.939	0.936 (0.025)	0.886-0.985
RSW survival	425	0.932 (0.013)	0.906-0.958	930	0.919 (0.009)	0.902-0.937	1.012 (0.016)	0.979-1.046

* Pooled estimate due to few replicates and limited sample sizes.

For radio-tagged juvenile steelhead passing Lower Monumental Dam, relative survival was estimated at 1.014 (geomean; SE = 0.011; 95% CI, 0.990-1.037) for fish passing via the spillway, 0.977 (pooled; SE = 0.023; 95% CI, 0.930—1.023) for fish passing via the JBS, and 1.026 (geomean; SE = 0.011; 95% CI, 1.004-1.048) for those passing via the RSW (Table 13).

Avian Predation

A total of 17 tags from radio-tagged yearling Chinook salmon released to evaluate Lower Monumental Dam passage in 2008 were recovered from avian colonies on Crescent or Foundation Island in the McNary Dam Reservoir, Columbia River (Table 14). The majority of these fish (53%) were last detected between Ice Harbor Dam and the mouth of the Snake River. Only three tags from yearling Chinook salmon were last detected above our primary survival array (30 km downstream from Lower Monumental Dam) prior to being recovered on Crescent Island.

A total of 66 tags from radio tagged juvenile steelhead were recovered from avian colonies on Crescent or Foundation Island (Table 15). The majority of these fish (76%) were last detected between Ice Harbor Dam and the mouth of the Snake River. Only five tags from juvenile steelhead were last detected above our primary survival array prior to being recovered from Crescent Island.

Table 13. Sample sizes and mean estimates of survival for radio-tagged hatchery juvenile steelhead passing (treatment) Lower Monumental Dam relative to fish released into the tailrace (reference), 2008. Standard errors are in parenthesis.

	Juvenile steelhead							
	Treatment			Reference			Relative	
	n	Survival	95% CI	n	Survival	95% CI	Survival	95% CI
Project survival								
Dam survival	1,088	0.927 (0.010)	0.907-0.947	940	0.943 (0.006)	0.930-0.956	0.982 (0.011)	0.960-1.005
Concrete survival	1,040	0.949 (0.007)	0.933-0.964	940	0.943 (0.006)	0.930-0.956	1.006 (0.009)	0.987-1.026
Route-specific survival								
Spillway survival	851	0.956 (0.008)	0.939-0.973	940	0.943 (0.006)	0.930-0.956	1.014 (0.011)	0.990-1.037
JBS survival*	175	0.921 (0.021)	0.880-0.962	940	0.943 (0.008)	0.839-1.003	0.977 (0.023)	0.930-1.023
RSW survival	740	0.967 (0.008)	0.951-0.984	940	0.943 (0.006)	0.930-0.956	1.026 (0.011)	1.004-1.048

* Pooled estimate due to few replicates and limited sample sizes.

Table 14. Number and proportion of radio tags from yearling Chinook salmon recovered from avian colonies on Crescent or Foundation Island. Yearling Chinook were released to evaluate passage behavior and survival at Lower Monumental Dam, 2008. Recoveries are grouped by location of the last telemetry detection.

	Number and proportion (%) of yearling Chinook tags recovered on avian colonies	
Last location of telemetry detection	Treatment	Reference
Upstream of Lower monumental Dam forebay	0 (0.0)	N/A
Lower Monumental Dam forebay	1 (0.1)	N/A
Ice Harbor Dam pool	0 (0.0)	2 (0.2)
Ice Harbor forebay	0 (0.0)	0 (0.2)
Ice Harbor Dam to Snake River mouth	6 (0.6)	3 (0.3)
McNary Dam pool	2 (0.2)	3 (0.3)
McNary Dam forebay	0 (0.0)	0 (0.0)
Total	9 (0.9)	8 (0.9)

Table 15. Number and proportion of radio tags from juvenile steelhead recovered from avian colonies on Crescent or Foundation Island. Steelhead were released to evaluate passage behavior and survival at Lower Monumental Dam, 2008. Recoveries are grouped by location of the last telemetry detection.

	Number and proportion (%) of juvenile steelhead tags recovered on avian colonies	
Last location of telemetry detection	Treatment fish	Reference fish
Upstream of Lower monumental Dam forebay	0 (0.0)	N/A
Lower Monumental Dam forebay	1 (0.1)	N/A
Ice Harbor Dam pool	2 (0.2)	2 (0.2)
Ice Harbor forebay	1 (0.1)	0 (0.0)
Ice Harbor Dam to Snake River mouth	24 (2.2)	26 (2.8)
McNary Dam pool	5 (0.5)	3 (0.3)
McNary Dam forebay	2 (0.2)	0 (0.0)
Total	35 (3.2)	48 (3.3)

DISCUSSION

This report summarizes the first year of study evaluating behavior and survival of volitionally passing radio-tagged juvenile steelhead and yearling Chinook salmon at Lower Monumental Dam with the new RSW installed. In 2006 and 2007, baseline studies evaluated behavior and survival for volitionally passing radio-tagged juvenile steelhead and yearling Chinook salmon. Spring flows during the baseline studies were considerably different between years, with high flows in 2006 and low flows in 2007. Snake River flows in spring 2007 at Lower Monumental Dam averaged 79 kcfs, or 74% of the 10-year average (107 kcfs from 1996 through 2005; Hockersmith et al. 2008a). In contrast, Snake River flows in spring 2006 averaged 139 kcfs, or 130% of the 10-year average (Hockersmith et al. 2008b). Although flow conditions were vastly different between years during the baseline studies, Lower Monumental Dam project operations were relatively similar between years, with 26% of the river spilled in 2006 and 27% in 2007. In 2008, flows at Lower Monumental Dam (99 kcfs average) were in between the flow conditions during the baseline studies, and the proportion spilled averaged 34%, which was 31% more than during the baseline studies.

As in the baseline study years of 2006 and 2007 the majority of our radio-tagged fish (yearling Chinook salmon and juvenile steelhead combined) approached and passed the dam in the thalweg of the river near Spillbay 8. Johnson et al. (1998), using hydroacoustics, observed similar horizontal distribution patterns, where smolts approached Lower Monumental Dam at the midpoint of the thalweg. We observed similar proportions of yearling Chinook salmon passing via the spillway in 2008 with the RSW operating compared to the baseline studies in 2006 and 2007 (62% vs. 58 to 74%) even though the proportion of river spilled was higher in 2008 (34% vs. 26 to 27%). We observed a higher proportion of juvenile steelhead passing via the spillway in 2008 with the RSW operating compared to the baseline studies in 2006 and 2007 (80% vs. 48 to 62%) and this may have been influenced by either the RSW operation, or the increased proportion of river spilled (34% vs. 26 to 27%).

For both species (yearling Chinook salmon and juvenile steelhead), the RSW appeared to reduce forebay delay during 2008 compared to results during pre-RSW years. Median forebay residence time for yearling Chinook salmon during 2008 was slightly less than observed during the baseline studies of 2006 and 2007 (2.2 vs. 2.5 h). Median forebay residence times for juvenile steelhead were 2.5 to 8 times shorter during 2008 with the RSW operating than observed during the baseline studies (2.2 vs. 5.5 to 17.8 h).

Median tailrace egress time during 2008 for both species (yearling Chinook salmon and juvenile steelhead) was similar to the range of egress times observed during the baseline studies of 2006 and 2007 (6.6 vs. 6.0-8.2 minutes). As observed during the baseline studies, tailrace egress times were longer for fish passing via the powerhouse (JBS and turbines) compared to the spillway during 2008 for both yearling Chinook salmon and juvenile steelhead.

Spill effectiveness for yearling Chinook salmon was lower during 2008 compared to results during pre-RSW years of 2006 and 2007 (1.91 vs. 2.31-2.76). The lower level of spill effectiveness observed for yearling Chinook salmon was likely influenced by the increased proportion of river spilled during 2008 compared to during the baseline studies (34% vs. 26 to 27%). Spill effectiveness for juvenile steelhead was towards the upper end of the range of spill effectiveness observed during pre-RSW years of 2006 and 2007 (2.43 vs. 1.88 to 2.45). For juvenile steelhead, spill effectiveness remained high during 2008 due to the increased proportion of fish passing via the RSW, even though the level of spill during 2008 was higher than during baseline studies.

Relative dam, concrete, and spillway survival for yearling Chinook salmon were slightly higher in 2008 compared to results during pre-RSW years of 2006 and 2007 (0.934 vs. 0.924 to 0.930; 0.963 vs. 0.943 to 0.952; and 0.976 vs. 0.925-0.959, respectively). Relative bypass survival was slightly lower in 2008 compared to results during pre-RSW years of 2006 and 2007 (0.936 vs. 0.941 to 0.987). For juvenile steelhead, relative dam, concrete, and spillway survival were higher in 2008 compared to results during pre-RSW years of 2006 and 2007 (0.982 vs. 0.888 to 0.980; 1.006 vs. 0.955 to 1.000; and 1.014 vs. 0.939-0.999, respectively). Relative bypass survival was slightly lower in 2008 compared to results during pre-RSW years of 2006 and 2007 (0.977 vs. 0.986 to 1.010) for juvenile steelhead.

RECOMMENDATIONS

In general, 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. These results however, are only for one year, and flows during 2008 were above average. At least one additional year of evaluation should be conducted to confirm the findings from 2008. In addition, it would be useful to evaluate operation of the RSW during low flows to capture a wider range of conditions that occur across multiple years.

The two-spill treatment test planned for 2008 was not evaluated due to high Snake River flows during the study, and a lack of consistent adherence to the treatment schedule. When conditions allow, this evaluation should be attempted again if there continues to be interest in alternative spill patterns by the regional fish management agencies.

Juvenile 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 the PIT-tag detection probability at Lower Monumental Dam and reduced the precision of PIT-tag survival estimates. Active tags such as those used in radio or acoustic telemetry remain unsuitable for evaluating most wild yearling Chinook salmon stocks and Snake River sockeye passage and survival because of the size of the tag.

In 2008, 73% of the yearling Chinook salmon and 86% of the juvenile steelhead passed either through the JBS or the RSW. The development of PIT-tag detection in the RSW at Lower Monumental Dam would have provided increased PIT-tag detection of smolts in 2008. The higher-than-average flows during 2008 likely lowered passage proportions through the RSW for some stocks and increased the proportion through the JBS. During a low-flow year like 2007, the proportion of fish passing through the JBS would likely be even lower than observed in 2008, while the proportion passing through the RSW would likely be higher. The addition of PIT-tag detection in the RSW could provide information on surface passage use, behavior, and survival for sockeye, wild stocks, and for various ESUs; information which is currently very limited.

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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.

Of the 979 radio-tagged yearling Chinook salmon released above Lower Monumental Dam and detected on the forebay entrance array, 821 (85.5% of those released) were detected either at or below our primary survival array 30 km downstream from Lower Monumental Dam. Of the 930 radio-tagged yearling Chinook salmon released into the tailrace of Lower Monumental Dam, 860 (92.5% of those released) were detected either at or below our primary survival array 30 km downstream from Lower Monumental Dam. Capture histories for survival analysis of yearling Chinook salmon are presented in Appendix Tables A1-A5.

Of the 1,088 radio-tagged steelhead released above Lower Monumental Dam and detected on the forebay entrance array, 1,009 (92.7% of those released) were detected either at or below our primary survival array 30 km downstream from Lower Monumental Dam. Of the 940 radio-tagged steelhead released into the tailrace of Lower Monumental Dam, 886 (94.3% of those released) were detected either at or below our primary survival array 30 km downstream from Lower Monumental Dam. Capture histories for survival analysis of juvenile steelhead are shown in Appendix Tables A6-A10.

Detection probability for yearling Chinook salmon used in survival analysis was 0.930 overall (Appendix Table A11), which was slightly lower than we have observed previously. The detection probability for juvenile steelhead used in survival analysis was near 100% (0.984 overall; Appendix Table A11), which is similar to detection probability observed previously. Field testing of detection depth of radio transmitters at our entrance and survival arrays indicated tags were delectable to a depth of approximately 8 m; however, range from the receiving antenna decreased detection capability at depth.

Beeman and Maule (2006) found that Chinook salmon smolts migrated at greater depths than steelhead smolts. If Chinook salmon in 2008 were migrating at a greater depth than juvenile steelhead, they would likely have a slightly lower detection probability. In general, detection probabilities were greater than 90% at our primary 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 in 2008. The primary survival array was 30 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 (979)	0	0	142
	1	0	16
	0	1	48
	1	1	773
Reference group (930)	0	0	70
	1	0	16
	0	1	68
	1	1	776

Appendix Table A2. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival in 2008. The primary survival array was 30 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 (907)	0	0	107
	1	0	15
	0	1	45
	1	1	740
Reference group (930)	0	0	70
	1	0	16
	0	1	68
	1	1	776

Appendix Table A3. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival in 2008. The primary survival array was 30 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 (586)	0	0	62
	1	0	10
	0	1	32
	1	1	482
Reference group (930)	0	0	70
	1	0	16
	0	1	68
	1	1	776

Appendix Table A4. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival in 2008. The primary survival array was 30 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 (265)	0	0	37
	1	0	4
	0	1	10
	1	1	214
Reference group (930)	0	0	70
	1	0	16
	0	1	68
	1	1	776

Appendix Table A5. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate RSW passage survival in 2008. The primary survival array was 30 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 (425)	0	0	35
	1	0	8
	0	1	23
	1	1	359
Reference group (930)	0	0	70
	1	0	16
	0	1	68
	1	1	776

Appendix Table A6. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate dam passage survival in 2008. The primary survival array was 30 km downstream from the dam and detections downstream from the primary array are shown in Figure 1. Detection histories recorded as: 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (1,088)	0	0	79
	1	0	14
	0	1	18
	1	1	977
Reference group (940)	0	0	54
	1	0	19
	0	1	11
	1	1	856

Appendix Table A7. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival in 2008. The primary survival array was 30 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 (1,040)	0	0	52
	1	0	13
	0	1	16
	1	1	959
Reference group (940)	0	0	54
	1	0	19
	0	1	11
	1	1	856

Appendix Table A8. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival in 2008. The primary survival array was 30 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 (851)	0	0	38
	1	0	8
	0	1	11
	1	1	794
Reference group (940)	0	0	54
	1	0	19
	0	1	11
	1	1	856

Appendix Table A9. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival in 2008. The primary survival array was 30 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	14
	1	0	6
	0	1	4
	1	1	151
Reference group (940)	0	0	54
	1	0	19
	0	1	11
	1	1	856

Appendix Table A10. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate RSW passage survival in 2008. The primary survival array was 30 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 (740)	0	0	25
	1	0	8
	0	1	10
	1	1	697
Reference group (940)	0	0	54
	1	0	19
	0	1	11
	1	1	856

Appendix Table A11. Detections at the primary survival array and below, and the resulting detection probabilities at the primary survival array 30 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, 2008.

Release group	Detection at primary array or below	Detection below primary array	Detection probability
Yearling Chinook salmon			
Treatment	773	821	0.941
Reference	776	844	0.919
Totals	1,549	1,665	0.930
Juvenile steelhead			
Treatment	977	995	0.982
Reference	856	867	0.987
Totals	1833	1,862	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 (30 km downstream from the dam) were examined to determine if groups were evenly mixed and travel together through downstream reaches (Appendix Tables A12 and A13). Mixing was compared for specific percentiles (10th, 50th, 90th) of the passage distribution with t tests for differences in passage distributions (Tables A14 and A15). 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 showed statistically significant differences for both species between treatment and reference groups used to calculate relative survival estimates (Appendix Tables A14 and A15). However the biological significance is small (-3.6 and -3.4 hours for yearling Chinook salmon and steelhead, respectively), 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 A12. Differences in passage timing at the primary survival array (30 km downstream from the dam) between treatment and reference groups in hours for radio tagged hatchery yearling Chinook salmon used for estimating survival at Lower Monumental Dam in 2008. Standard errors are in parenthesis.

		Percentile		
Date	n	10th	50th	90th
30 Apr	30	-10.7	-24.0	-32.9
1 May	49	-6.7	-12.7	-15.8
2 May	45	17.3	3.6	22.3
3 May	62	-2.6	-2.1	-19.6
4 May	68	-5.7	-1.1	-1.6
5 May	60	-2.6	4.4	-4.0
6 May	77	-1.6	-2.6	-5.4
7 May	67	0.1	-3.3	6.2
8 May	66	-10.1	-5.4	-18.3
9 May	83	-3.3	-0.5	5.8
10 May	79	-2.9	-3.5	-17.0
11 May	76	-2.7	-0.7	6.5
12 May	72	4.1	2.7	-3.9
13 May	68	-2.8	-6.1	0.5
14 May	86	-5.8	-6.6	-20.8
15 May	71	-3.5	1.4	-1.2
16 May	88	-2.4	-4.2	-14.8
17 May	83	-3.3	-0.9	1.2
18 May	79	1.0	-0.7	-5.1
19 May	83	0.6	-4.2	-5.1
20 May	94	-0.7	-4.0	-3.3
21 May	85	-1.5	-2.7	-4.3
22 May	86	-6.2	-8.7	-12.2
Mean		-2.3 (1.1)	-3.6 (1.2)	-6.2 (2.4)

Appendix Table A13. Differences in passage timing at the primary survival array (30 km downstream from the dam) between treatment and reference groups in hours for radio tagged juvenile steelhead used for estimating survival at Lower Monumental Dam in 2008. Standard errors are in parenthesis.

		Percentile		
Date	n	10th	50th	90th
1 May	65	-1.1	-11.4	-3.0
2 May	64	1.9	-4.2	0.0
3 May	66	0.3	-0.6	-3.1
4 May	85	3.4	-3.5	-14.3
5 May	84	-1.5	0.0	-4.4
6 May	102	-5.3	-2.8	-8.2
7 May	86	5.8	1.5	0.1
8 May	85	2.6	0.7	-4.9
9 May	87	4.3	1.6	-1.5
10 May	72	1.4	0.8	-2.9
11 May	92	0.9	0.7	-5.1
12 May	88	0.7	-8.7	-4.4
13 May	71	5.0	-7.1	-5.3
14 May	72	2.3	2.1	-1.7
15 May	90	-0.1	-3.9	2.2
16 May	93	-0.8	-1.3	-7.5
17 May	87	-0.4	1.6	-5.9
18 May	95	1.2	-4.6	-5.7
19 May	92	0.9	-6.3	-7.9
20 May	82	1.9	-2.3	-9.6
21 May	86	-2.3	-6.7	-5.7
22 May	72	0.7	-5.2	-10.8
Mean		0.8 (0.6)	-3.4 (1.1)	-4.9 (0.8)

Appendix Table A14. Mean difference and tests of homogeneity of passage timing at the primary survival array (30 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 2008. Significant differences in passage timing among tests was determined for $\alpha = 0.05$.

Passage percentile	Mean difference in timing (hours)	*t*	df	*P*
10^{th}	-2.3	-1.99	23	0.059
50^{th}	-3.6	-2.88	23	0.008
90^{th}	-6.2	-2.55	23	0.018

Appendix Table A15. Mean difference and tests of homogeneity of passage timing at the primary survival array (30 km downstream from the dam) for treatment groups and reference groups of radio tagged steelhead used for estimating survival at Lower Monumental Dam in 2008. Significant differences in passage timing among tests was determined for $\alpha = 0.05$.

Passage percentile	Mean difference in timing (hours)	*t*	df	*P*
10^{th}	0.8	1.35	23	0.191
50^{th}	-3.4	-3.22	23	0.004
90^{th}	-4.9	-6.23	23	<0.000

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 1 to 26 May. Only fish not previously PIT tagged, without any visual signs of disease or injuries, and 12 g or larger were used. Tagging comprised the period between the 3rd and 82nd passage percentile for yearling Chinook salmon and between the 2nd and 84th passage percentile for juvenile steelhead at Lower Monumental Dam in 2008 (Figure 3). Overall mean fork lengths for yearling Chinook salmon were 141.9 mm (SD = 13.1) and 142.9 mm (SD = 12.3) for fish released into the forebay and tailrace of Lower Monumental Dam, respectively (Table 2). Overall mean fork lengths for juvenile steelhead were 206.1 mm (SD = 21.7) and 208.4 mm (SD = 21.8) for fish released into the forebay and tailrace of Lower Monumental Dam, respectively (Table 4).

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 that is used to estimate survival for that passage route.

In 2008, we conducted a very limited test of the assumption that fish that die as a result of passing through a passage route are not subsequently detected at a downstream array that is used to estimate survival for that passage route because past studies at Lower Monumental Dam have not observed a violation of this assumption. We released 52 dead radio tagged hatchery yearling Chinook salmon and 33 dead juvenile steelhead into the tailrace of Little Goose Dam and the tailrace of Lower Monumental Dam to test Assumption A5 (Appendix Table A16). Forebay releases were 41 km upstream from the forebay entrance array. The distance between release at Lower Monumental Dam and the first downstream telemetry array used to estimate survival was 30 km. Similar to past findings, no dead radio tagged fish were detected at any downstream telemetry arrays.

Appendix Table A16. Numbers of dead fish released and subsequent detections downstream from release locations. These releases were used to test the study assumption that fish that die as a result of passing through a passage route at Lower Monumental Dam are not subsequently detected on downstream survival arrays.

	Dead fish releases					
	Yearling Chinook salmon			Juvenile steelhead		
	Treatment	Reference	Overall	Treatment	Reference	Overall
Number released	31	21	52	21	13	33
Percent of total released (%)	3.2	2.3	2.7	1.9	1.4	1.7
Number detected below release site	0	0	0	0	0	0

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

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 9 (0.2%) could not be activated and were therefore not used. A total of 4,467 tags were implanted in either hatchery yearling Chinook salmon of juvenile steelhead of which 2 (0.04%) were not working 24 h after tagging. An additional 28 tags were not used in the study because of duplicate tag codes. Of the live fish released with functional tags, a total of 4 fish (0.1% of those released) (2 yearling Chinook salmon 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. All fish with tags that were known to be not functioning properly were excluded from the study.

In addition, a total of 69 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. Ten tags (14.5%) failed prior to the preprogrammed shut down after 10 d (Appendix Table A17). Of these, no tags failed in less than 9 d. Ninety-nine percent of the fish had travel times to the primary array of less than 9 d, and the maximum travel time from release to our primary survival array was 13.4 d (Appendix Table A18). 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 they would not have significantly changed our findings.

Appendix Table A17. Transmitter battery life testing, 2008.

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
0	0.0	6
0	0.0	7
0	0.0	8
10	14.5	9
59	85.5	10

Appendix Table A18. 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, 2008.

	Travel time (d) to primary survival array by release location and species			
	Yearling Chinook salmon		Juvenile steelhead	
Percentile	Forebay	Tailrace	Forebay	Tailrace
10	1.7	0.8	1.6	0.7
20	2.2	1.1	1.9	0.9
30	2.6	1.2	2.1	1.0
40	2.9	1.4	2.2	1.1
50	3.2	1.5	2.5	1.2
60	3.5	1.7	2.8	1.3
70	3.9	2.0	3.0	1.4
80	4.3	2.3	3.1	1.5
90	5.1	2.7	3.6	1.8
Max	13.4	7.4	13.3	7.9
Time ≥ 9 d	2 (0.2%)	0 (0.0%)	1 (0.1%)	0 (0.0%)
n	836	858	1,013	887

APPENDIX B

Treatment and Reference Release Groups for Estimating Survival

Appendix Table B1. Daily dam survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2008. Standard errors are in parenthesis.

Date	Treatment n	Treatment Survival	Reference n	Reference Survival	Relative survival
30 April	11	0.909 (0.087)	24	0.875 (0.068)	1.039 (0.127)
1 May	22	0.925 (0.065)	33	0.884 (0.058)	1.047 (0.100)
2 May	16	0.859 (0.112)	35	0.951 (0.040)	0.903 (0.124)
3 May	35	0.919 (0.048)	36	0.889 (0.052)	1.033 (0.081)
4 May	49	0.860 (0.050)	34	0.869 (0.063)	0.990 (0.092)
5 May	39	0.872 (0.054)	35	0.914 (0.047)	0.954 (0.077)
6 May	62	0.760 (0.055)	42	0.842 (0.059)	0.903 (0.090)
7 May	38	0.847 (0.060)	43	0.886 (0.049)	0.956 (0.086)
8 May	42	0.791 (0.064)	39	0.872 (0.054)	0.907 (0.092)
9 May	51	0.877 (0.050)	43	0.935 (0.039)	0.938 (0.066)
10 May	47	0.791 (0.060)	44	0.987 (0.024)	0.801 (0.064)
11 May	46	0.828 (0.056)	41	0.978 (0.024)	0.847 (0.061)
12 May	38	0.790 (0.066)	43	0.978 (0.023)	0.808 (0.070)
13 May	33	0.758 (0.075)	46	0.935 (0.036)	0.810 (0.086)
14 May	63	0.778 (0.052)	44	0.865 (0.052)	0.899 (0.081)
15 May	37	0.811 (0.064)	44	0.934 (0.038)	0.868 (0.078)
16 May	54	0.870 (0.046)	45	0.936 (0.037)	0.930 (0.061)
17 May	48	0.917 (0.040)	43	0.939 (0.040)	0.977 (0.059)
18 May	50	0.881 (0.046)	41	0.902 (0.046)	0.976 (0.071)
19 May	44	0.932 (0.038)	45	0.956 (0.031)	0.975 (0.051)
20 May	61	0.918 (0.035)	41	0.951 (0.034)	0.965 (0.050)
21 May	45	0.956 (0.031)	44	0.955 (0.031)	1.001 (0.046)
22 May	48	0.938 (0.035)	45	0.9111(0.0424)	1.028 (0.061)
Overall	979	0.860 (0.013)	930	0.919 (0.009)	0.934 (0.016)

Appendix Table B2. Daily concrete survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2008. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	N	Survival	Relative survival
30 April	10	0.900 (0.095)	24	0.875 (0.068)	1.029 (0.134)
1 May	21	0.969 (0.051)	33	0.884 (0.058)	1.097 (0.092)
2 May	14	0.884 (0.101)	35	0.951 (0.040)	0.929 (0.114)
3 May	33	0.914 (0.051)	36	0.889 (0.052)	1.028 (0.083)
4 May	44	0.867 (0.052)	34	0.869 (0.063)	0.998 (0.094)
5 May	32	0.875 (0.059)	35	0.914 (0.047)	0.957 (0.081)
6 May	52	0.790 (0.057)	42	0.842 (0.059)	0.938 (0.094)
7 May	32	0.913 (0.052)	43	0.886 (0.049)	1.031 (0.082)
8 May	34	0.919 (0.049)	39	0.872 (0.054)	1.054 (0.086)
9 May	50	0.872 (0.050)	43	0.935 (0.039)	0.932 (0.067)
10 May	43	0.841 (0.057)	44	0.987 (0.024)	0.852 (0.061)
11 May	42	0.859 (0.054)	41	0.978 (0.024)	0.878 (0.059)
12 May	36	0.834 (0.062)	43	0.978 (0.023)	0.853 (0.067)
13 May	33	0.758 (0.075)	46	0.935 (0.036)	0.810 (0.086)
14 May	60	0.800 (0.052)	44	0.865 (0.052)	0.925 (0.081)
15 May	37	0.811 (0.064)	44	0.934 (0.038)	0.868 (0.078)
16 May	53	0.868 (0.047)	45	0.936 (0.037)	0.928 (0.062)
17 May	46	0.935 (0.036)	43	0.939 (0.040)	0.996 (0.057)
18 May	45	0.934 (0.037)	41	0.902 (0.046)	1.035 (0.067)
19 May	41	0.976 (0.024)	45	0.956 (0.031)	1.020 (0.041)
20 May	57	0.947 (0.030)	41	0.951 (0.034)	0.996 (0.047)
21 May	44	0.977 (0.023)	44	0.955 (0.031)	1.024 (0.041)
22 May	48	0.938 (0.035)	45	0.9111(0.0424)	1.029 (0.061)
Overall	907	0.886 (0.013)	930	0.919 (0.009)	0.963 (0.016)

Appendix Table B3. Daily spillway survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2008. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
30 April	7	0.857 (0.132)	24	0.875 (0.068)	0.980 (0.169)
1 May	14	1.032 (0.036)	33	0.884 (0.058)	1.167 (0.086)
2 May	11	0.955 (0.106)	35	0.951 (0.040)	1.003 (0.119)
3 May	27	0.897 (0.062)	36	0.889 (0.052)	1.009 (0.091)
4 May	38	0.899 (0.050)	34	0.869 (0.063)	1.034 (0.095)
5 May	26	0.846 (0.071)	35	0.914 (0.047)	0.926 (0.091)
6 May	29	0.831 (0.071)	42	0.842 (0.059)	0.987 (0.108)
7 May	22	0.864 (0.073)	43	0.886 (0.049)	0.975 (0.099)
8 May	21	0.958 (0.047)	39	0.872 (0.054)	1.099 (0.086)
9 May	31	0.872 (0.060)	43	0.935 (0.039)	0.933 (0.075)
10 May	26	0.896 (0.065)	44	0.987 (0.024)	0.908 (0.069)
11 May	26	0.885 (0.063)	41	0.978 (0.024)	0.905 (0.068)
12 May	22	0.818 (0.082)	43	0.978 (0.023)	0.837 (0.086)
13 May	21	0.762 (0.093)	46	0.935 (0.036)	0.815 (0.104)
14 May	43	0.861 (0.053)	44	0.865 (0.052)	0.995 (0.085)
15 May	28	0.893 (0.059)	44	0.934 (0.038)	0.956 (0.074)
16 May	48	0.896 (0.044)	45	0.936 (0.037)	0.957 (0.061)
17 May	34	0.971 (0.029)	43	0.939 (0.040)	1.034 (0.054)
18 May	22	0.864 (0.073)	41	0.902 (0.046)	0.957 (0.095)
19 May	23	0.957 (0.043)	45	0.956 (0.031)	1.000 (0.055)
20 May	22	1.000 (0.000)	41	0.951 (0.034)	1.051 (0.037)
21 May	26	0.962 (0.038)	44	0.955 (0.031)	1.007 (0.052)
22 May	19	0.895 (0.070)	45	0.9111(0.0424)	0.982 (0.090)
Overall	586	0.899 (0.013)	930	0.919 (0.009)	0.976 (0.016)

Appendix Table B4. Daily estimates of survival through the RSW in Spillbay 8 for yearling Chinook salmon passing Lower Monumental Dam, 2008. Standard errors are in parenthesis.

	Treatment		Reference		
Date	N	Survival	n	Survival	Relative survival
30 April	4	1.000 (0.000)	24	0.875 (0.068)	1.143 (0.088)
1 May	13	1.039 (0.044)	33	0.884 (0.058)	1.175 (0.091)
2 May	8	0.938 (0.148)	35	0.951 (0.040)	0.985 (0.161)
3 May	20	0.900 (0.067)	36	0.889 (0.052)	1.012 (0.096)
4 May	26	0.853 (0.072)	34	0.869 (0.063)	0.981 (0.109)
5 May	19	0.895 (0.070)	35	0.914 (0.047)	0.979 (0.092)
6 May	24	0.877 (0.068)	42	0.842 (0.059)	1.042 (0.108)
7 May	13	0.923 (0.074)	43	0.886 (0.049)	1.042 (0.101)
8 May	20	1.006 (0.007)	39	0.872 (0.054)	1.154 (0.071)
9 May	30	0.901 (0.055)	43	0.935 (0.039)	0.964 (0.071)
10 May	21	0.952 (0.047)	44	0.987 (0.024)	0.965 (0.053)
11 May	18	0.833 (0.088)	41	0.978 (0.024)	0.852 (0.092)
12 May	17	0.882 (0.078)	43	0.978 (0.023)	0.902 (0.083)
13 May	14	0.857 (0.094)	46	0.935 (0.036)	0.916 (0.106)
14 May	32	0.844 (0.064)	44	0.865 (0.052)	0.976 (0.094)
15 May	26	0.923 (0.052)	44	0.934 (0.038)	0.988 (0.069)
16 May	36	0.917 (0.046)	45	0.936 (0.037)	0.980 (0.063)
17 May	24	0.958 (0.041)	43	0.939 (0.040)	1.021 (0.061)
18 May	14	0.929 (0.069)	41	0.902 (0.046)	1.029 (0.093)
19 May	10	1.000 (0.000)	45	0.956 (0.031)	1.046 (0.034)
20 May	10	1.000 (0.000)	41	0.951 (0.034)	1.051 (0.037)
21 May	17	1.000 (0.000)	44	0.955 (0.031)	1.048 (0.034)
22 May	9	1.000 (0.000)	45	0.9111(0.0424)	1.098 (0.051)
Overall	425	0.932 (0.013)	930	0.919 (0.009)	1.012 (0.016)

Appendix Table B5. Grouping, samples sizes, and estimated dam survival for juvenile steelhead passing Lower Monumental Dam, 2008. Standard errors are in parenthesis.

	Treatment		Reference		
Date	N	Survival	n	Survival	Relative survival
30 Apr	36	0.973 (0.027)	29	0.966 (0.034)	1.008 (0.045)
1 May	36	0.944 (0.038)	34	0.912 (0.049)	1.036 (0.069)
2 May	35	0.972 (0.028)	32	0.938 (0.043)	1.037 (0.056)
3 May	37	0.892 (0.051)	36	0.972 (0.027)	0.917 (0.058)
4 May	56	0.893 (0.041)	37	0.946 (0.037)	0.944 (0.057)
5 May	61	0.967 (0.023)	33	0.939 (0.042)	1.030 (0.052)
6 May	61	0.969 (0.023)	45	0.978 (0.022)	0.991 (0.032)
7 May	46	0.935 (0.036)	45	0.981 (0.022)	0.953 (0.043)
8 May	56	0.875 (0.044)	46	0.935 (0.036)	0.936 (0.060)
9 May	47	0.957 (0.029)	43	0.954 (0.032)	1.004 (0.046)
10 May	36	0.917 (0.046)	42	0.929 (0.040)	0.987 (0.065)
11 May	61	0.803 (0.051)	45	0.935 (0.037)	0.859 (0.064)
12 May	49	0.920 (0.039)	45	0.979 (0.022)	0.940 (0.045)
13 May	37	0.892 (0.051)	44	0.886 (0.048)	1.006 (0.079)
14 May	40	0.825 (0.060)	44	0.886 (0.048)	0.931 (0.084)
15 May	50	0.940 (0.034)	45	0.957 (0.031)	0.983 (0.047)
16 May	53	0.962 (0.026)	43	0.954 (0.032)	1.009 (0.044)
17 May	47	0.915 (0.041)	45	0.978 (0.022)	0.936 (0.047)
18 May	55	0.982 (0.018)	44	0.932 (0.038)	1.053 (0.047)
19 May	59	0.952 (0.029)	40	0.902 (0.048)	1.056 (0.064)
20 May	49	0.959 (0.028)	39	0.897 (0.049)	1.069 (0.066)
21 May	44	0.955 (0.031)	44	0.978 (0.023)	0.976 (0.039)
22 May	37	0.919 (0.045)	40	0.950 (0.035)	0.967 (0.059)
Overall	1,088	0.927 (0. 010)	940	0.943 (0.006)	0.982 (0.011)

Appendix Table B6. Grouping, samples sizes, and estimated concrete survival for juvenile steelhead passing Lower Monumental Dam, 2008. Standard errors are in parenthesis.

	Treatment		Reference		
Date	N	Survival	n	Survival	Relative survival
30 Apr	36	0.973 (0.027)	29	0.966 (0.034)	1.008 (0.045)
1 May	35	0.971 (0.028)	34	0.912 (0.049)	1.065 (0.065)
2 May	34	1.001 (0.001)	32	0.938 (0.043)	1.068 (0.049)
3 May	34	0.912 (0.049)	36	0.972 (0.027)	0.938 (0.057)
4 May	55	0.891 (0.042)	37	0.946 (0.037)	0.942 (0.058)
5 May	55	0.964 (0.025)	33	0.939 (0.042)	1.026 (0.053)
6 May	59	0.985 (0.017)	45	0.978 (0.022)	1.007 (0.029)
7 May	43	0.954 (0.032)	45	0.981 (0.022)	0.972 (0.039)
8 May	47	0.894 (0.045)	46	0.935 (0.036)	0.956 (0.061)
9 May	47	0.957 (0.029)	43	0.954 (0.032)	1.004 (0.046)
10 May	35	0.943 (0.039)	42	0.929 (0.040)	1.015 (0.061)
11 May	55	0.891 (0.042)	45	0.935 (0.037)	0.953 (0.059)
12 May	48	0.918 (0.040)	45	0.979 (0.022)	0.938 (0.046)
13 May	35	0.914 (0.047)	44	0.886 (0.048)	1.031 (0.077)
14 May	37	0.892 (0.051)	44	0.886 (0.048)	1.006 (0.079)
15 May	48	0.979 (0.021)	45	0.957 (0.031)	1.024 (0.039)
16 May	53	0.962 (0.026)	43	0.954 (0.032)	1.009 (0.044)
17 May	45	0.956 (0.031)	45	0.978 (0.022)	0.977 (0.038)
18 May	54	1.000 (0.001)	44	0.932 (0.038)	1.073 (0.044)
19 May	57	0.985 (0.018)	40	0.902 (0.048)	1.093 (0.061)
20 May	49	0.959 (0.028)	39	0.897 (0.049)	1.069 (0.066)
21 May	43	0.977 (0.023)	44	0.978 (0.023)	0.999 (0.033)
22 May	36	0.944 (0.038)	40	0.950 (0.035)	0.994 (0.054)
Overall	1,040	0.949 (0.007)	940	0.943 (0.006)	1.006 (0.052)

Appendix Table B7. Grouping, samples sizes, and estimated spillway survival for juvenile steelhead passing Lower Monumental Dam, 2008. Standard errors are in parenthesis.

Date	Treatment		Reference		Relative survival
	N	Survival	n	Survival	
30 Apr	33	0.970 (0.030)	29	0.966 (0.034)	1.004 (0.047)
1 May	32	0.969 (0.031)	34	0.912 (0.049)	1.063 (0.066)
2 May	31	1.000 (0.000)	32	0.938 (0.043)	1.067 (0.049)
3 May	31	0.936 (0.044)	36	0.972 (0.027)	0.962 (0.053)
4 May	54	0.889 (0.043)	37	0.946 (0.037)	0.940 (0.058)
5 May	51	0.980 (0.019)	33	0.939 (0.042)	1.044 (0.051)
6 May	53	0.983 (0.019)	45	0.978 (0.022)	1.005 (0.030)
7 May	35	0.971 (0.028)	45	0.981 (0.022)	0.991 (0.037)
8 May	42	0.881 (0.050)	46	0.935 (0.036)	0.942 (0.065)
9 May	37	0.946 (0.037)	43	0.954 (0.032)	0.992 (0.051)
10 May	29	0.931 (0.047)	42	0.929 (0.040)	1.003 (0.066)
11 May	46	0.891 (0.046)	45	0.935 (0.037)	0.953 (0.062)
12 May	41	0.953 (0.034)	45	0.979 (0.022)	0.973 (0.041)
13 May	25	1.000 (0.000)	44	0.886 (0.048)	1.128 (0.061)
14 May	28	0.929 (0.049)	44	0.886 (0.048)	1.048 (0.079)
15 May	43	0.977 (0.023)	45	0.957 (0.031)	1.021 (0.041)
16 May	50	0.960 (0.028)	43	0.954 (0.032)	1.007 (0.045)
17 May	35	1.000 (0.000)	45	0.978 (0.022)	1.023 (0.023)
18 May	44	1.001 (0.001)	44	0.932 (0.038)	1.073 (0.044)
19 May	39	0.977 (0.026)	40	0.902 (0.048)	1.084 (0.064)
20 May	33	1.000 (0.000)	39	0.897 (0.049)	1.114 (0.060)
21 May	21	0.952 (0.047)	44	0.978 (0.023)	0.974 (0.053)
22 May	18	0.889 (0.074)	40	0.950 (0.035)	0.936 (0.085)
Overall	851	0.956 (0.008)	940	0.943 (0.006)	1.014 (0.011)

Appendix Table B8. Grouping, samples sizes, and estimated survival for juvenile steelhead passing Lower Monumental Dam via the RSW in Spillbay 8, 2008. Standard errors are in parenthesis.

	Treatment		Reference		
Date	N	Survival	n	Survival	Relative survival
30 Apr	31	1.000 (0.000)	29	0.966 (0.034)	1.036 (0.036)
1 May	30	0.967 (0.033)	34	0.912 (0.049)	1.060 (0.067)
2 May	25	1.000 (0.000)	32	0.938 (0.043)	1.067 (0.049)
3 May	25	0.920 (0.054)	36	0.972 (0.027)	0.946 (0.062)
4 May	48	0.896 (0.044)	37	0.946 (0.037)	0.947 (0.060)
5 May	46	0.978 (0.022)	33	0.939 (0.042)	1.041 (0.051)
6 May	48	1.002 (0.002)	45	0.978 (0.022)	1.025 (0.023)
7 May	31	0.968 (0.032)	45	0.981 (0.022)	0.987 (0.039)
8 May	38	0.868 (0.055)	46	0.935 (0.036)	0.929 (0.069)
9 May	36	0.944 (0.038)	43	0.954 (0.032)	0.990 (0.052)
10 May	26	0.962 (0.038)	42	0.929 (0.040)	1.035 (0.060)
11 May	41	0.951 (0.034)	45	0.935 (0.037)	1.017 (0.054)
12 May	37	1.000 (0.000)	45	0.979 (0.022)	1.022 (0.023)
13 May	21	1.000 (0.000)	44	0.886 (0.048)	1.128 (0.061)
14 May	28	0.929 (0.049)	44	0.886 (0.048)	1.048 (0.079)
15 May	41	1.000 (0.000)	45	0.957 (0.031)	1.045 (0.034)
16 May	41	0.976 (0.024)	43	0.954 (0.032)	1.023 (0.043)
17 May	32	1.000 (0.000)	45	0.978 (0.022)	1.023 (0.023)
18 May	39	1.001 (0.001)	44	0.932 (0.038)	1.073 (0.044)
19 May	29	0.971 (0.035)	40	0.902 (0.048)	1.077 (0.069)
20 May	20	1.000 (0.000)	39	0.897 (0.049)	1.114 (0.060)
21 May	15	1.000 (0.000)	44	0.978 (0.023)	1.023 (0.024)
22 May	12	0.917 (0.080)	40	0.950 (0.035)	0.965 (0.091)
Overall	740	0.967 (0.008)	940	0.943 (0.006)	1.026 (0.011)

Appendix Table B9. Planned treatment operations for spring 2008 at Lower Monumental Dam of a 4-d random block schedule with each pattern operated for 2 d. The operational treatment included two spill patterns (flat and bulk spill patterns) with both treatments utilizing the RSW. In general, the maximum difference in gate openings for spillbays 1 though 6 was less than 2 stops during the flat spill pattern and more than 2 stops for the bulk spill pattern.

Block	Treatment	Start	End	Duration (days)
1	Bulk spill	27 April 0500	29 April 0459	2.0
1	Flat spill	29 April 0500	1 May 0459	2.0
2	Bulk spill	1 May 0500	3 May 0459	2.0
2	Flat spill	3 May 0500	5 May 0459	2.0
3	Bulk spill	5 May 0500	7 May 0459	2.0
3	Flat spill	7 May 0500	9 May 0459	2.0
4	Bulk spill	9 May 0500	11 May 0459	2.0
4	Flat spill	11 May 0500	13 May 0459	2.0
5	Flat spill	13 May 0500	15 May 0459	2.0
5	Bulk spill	15 May 0500	17 May 0459	2.0
6	Flat spill	17 May 0500	19 May 0459	2.0
6	Bulk spill	19 May 0500	21 May 0459	2.0
7	Bulk spill	21 May 0500	23 May 0459	2.0
7	Flat spill	23 May 0500	25 May 0459	2.0
8	Bulk spill	25 May 0500	27 May 0459	2.0
8	Flat spill	27 May 0500	29 May 0459	2.0
9	Flat spill	29 May 0500	31 May 0459	2.0
9	Bulk spill	31 May 0500	2 June 0459	2.0

Appendix Table B10. Actual treatment operations for spring 2008 at Lower Monumental Dam. The treatments utilized two spill patterns (flat and bulk spill patterns) with both treatments utilizing the RSW.

Treatment	Start	End	Duration (d)	Deviation from scheduled plan
Bulk spill	27 April 0500	30 April 0605	3.0	Treatment 1 d long
Flat spill	30 April 0605	2 May 0555	2.0	Included unscheduled bulk spill for 1.5 h
Bulk spill	2 May 0555	4 May 0650	2.0	
Flat spill	4 May 0650	6 May 0540	1.9	
Bulk spill	6 May 0540	8 May 0600	2.0	
Flat spill	8 May 0600	10 May 0600	2.0	
Flat spill	10 May 0600	12 May 0635	2.0	
Bulk spill	12 May 0635	14 May 0550	2.0	
Flat spill	14 May 0550	16 May 0645	2.0	Included unscheduled bulk spill for 1 h
Bulk spill	16 May 0645	19 May 0720	3.0	Treatment 1 d long and included unscheduled flat spill for 2.5 h
Flat spill	19 May 0720	22 May 2335	3.7	Treatment 1.7 d long and included unscheduled bulk spill for 2 h
Bulk spill	22 May 2335	24 May 0110	1.1	Treatment 0.9 d short
Flat spill	24 May 0110	26 May 0335	2.1	
Flat spill	26 May 0335	28 May 0600	2.1	
Bulk spill	28 May 0600	30 May 0100	1.8	Included unscheduled flat spill for 5 h
Bulk spill	30 May 0100	31 May 2355	2.0	Included unscheduled flat spill for 5 h

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.

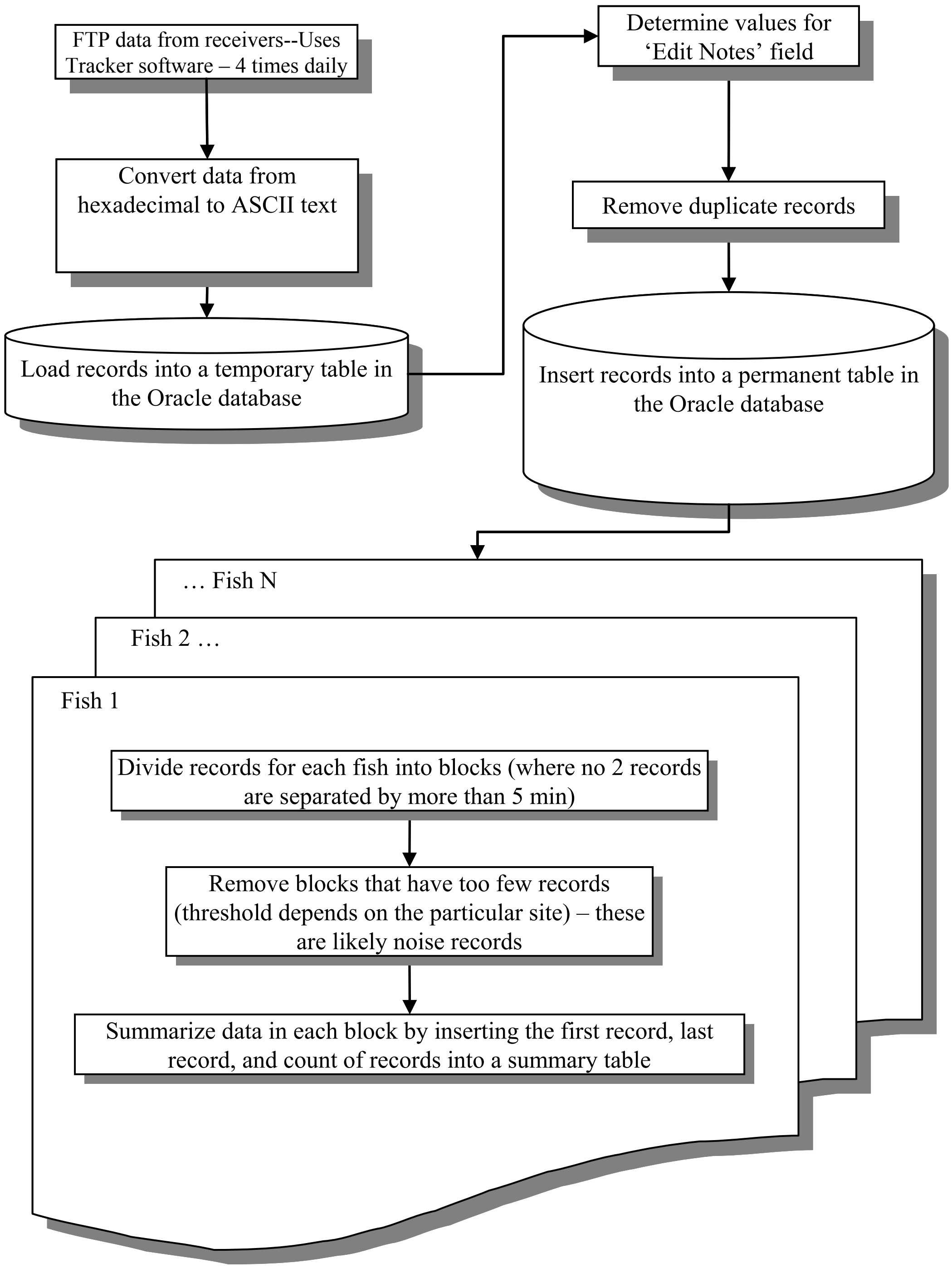
Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time). Note: these records are produced by radio frequency noise.

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 of telemetry data processing and reduction used in evaluating behavior and survival at Lower Monumental Dam for yearling Chinook salmon, 2008.