Passage Behavior and Survival of Radio-Tagged Subyearling Chinook Salmon at Lower Monumental Dam, 2009

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EXECUTIVE SUMMARY

During 2009, we evaluated passage behavior and survival of subyearling Chinook salmon with the removable spillway weir (RSW) at Lower Monumental Dam. This was the second year of post-construction evaluation of RSW performance. River-run subyearling Chinook salmon were collected from 6 June through 1 July 2009 at the juvenile fish facility at Lower Monumental Dam. Collected fish were surgically tagged with both a radio and a passive integrated transponder (PIT) tag and released either 7 km upstream from the dam (treatment) or 1.25 km below the dam (reference). The primary survival array was approximately 20 km downstream from the dam.

The study was conducted from10 June through 4 July, a period that included the 53rd through 88th percentiles of the cumulative passage index for subyearling Chinook salmon at Lower Monumental Dam. Treatment groups were comprised of 2,302 radio-tagged fish, and reference groups were comprised of 2,050 fish. Treatment fish were released twice a day in a bulk release and allowed to move volitionally to the study entrance line in the forebay of Lower Monumental Dam, where fish were regrouped into daily virtual release groups. The median morning and afternoon release times were 0911 and 1325 PDT, respectively. Reference fish were released two at a time, about every 15 min over a 6-h period during daytime and nighttime shifts. Median release times for day and night releases were 1150 and 2339 PDT, respectively.

Of the 2,302 fish released upstream from Lower Monumental Dam, 1,973 were used in the evaluation of relative survival. The proportion of fish not detected after release was similar to that observed in previous years for subyearling Chinook salmon. The fate of undetected fish was unknown, but likely included loss to predators, failure to move downstream to the detection arrays, or downstream movement delayed until after the radio tag had expired.

Median river flow during the 2009 evaluation was 87.3 kcfs, which was lower than flows during the 2008 study (median 106.4 kcfs), but higher than the 10-year average (median 70.5 kcfs).

Estimated relative dam survival from the study entry line to the primary survival line was 0.862 (95% CI, 0.838-0.888), relative concrete survival was 0.929 (0.908-0.951), relative spillway survival was 0.927 (0.899-0.954), relative RSW survival was 0.956 (0.924-0.988), relative juvenile bypass system (JBS) survival was 0.937 (0.910-0.965), and relative turbine survival was 0.891 (0.841-0.941). All estimates were geometric means except the turbine survival estimate that was a pooled estimate due to small sample sizes.

Spillway passage was estimated at 57.6%, with the majority of fish passing through the RSW (46.2% of the fish passing the dam). JBS passage was 28.4% and turbine passage was 8.0% of the fish that passed the dam. There were 116 fish (5.9%) that passed the dam via an unknown route. Spill efficiency was estimated at 0.615 (95% CI, 0.592-0.637), fish guidance efficiency at 0.787 (0.756-0.818), and fish passage efficiency at 0.918 (0.905-0.931). Median forebay residence was 3.4 h (range 0.3-139.2 h), and median tailrace egress time was 7 min (range 4-10,114.4 min).

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INTRODUCTION

Assessing and improving fish passage conditions at dams is a primary focus of recovery efforts for depressed stocks of Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss*. For juvenile salmonids at Columbia and Snake River dams, the spillway has long been considered the most favorable passage route. As early as the 1940s, survival estimates of 96 to 97% were reported for smolts passing via the spillway at Bonneville Dam (Holmes 1952). Whitney et al. (1997) reviewed 13 estimates of spillway mortality at Snake and Columbia River dams published from 1961 to 1995. They found mortality rates for fish passing standard spillways most often ranged from 0 to 2%. More recent studies of juvenile salmonid passage at lower Snake River dams also indicated that survival was highest through spillways, followed by bypass systems, then turbines (Muir et al. 2001).

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, at dams on the lower Columbia and Snake Rivers, existing juvenile passage systems require fish to dive to depths of 15 to 18 m in order to enter a passage route. To provide a more surface-oriented passage route, engineers and biologists from the U.S. Army Corps of Engineers (USACE) and from state, tribal, and federal fishery agencies, developed a removable spillway weir (RSW).

The RSW was designed to attach to the upstream face of a traditional spillway, and a prototype was installed at Lower Granite Dam on the Snake River in 2001. Initial evaluations indicated that the RSW reduced migrational delay, improved fish passage efficiency, and increased passage survival (Plumb et al. 2003, 2004). A second RSW was installed at Ice Harbor Dam in 2005 (Axel et al. 2005), and a third at Lower Monumental Dam in winter 2007-2008. The RSW location at Lower Monumental Dam was based on biological studies that determined the majority of fish first approach the dam at Spillbay 8 (Hockersmith et al. 2005; Johnson et al. 1998).

At Lower Monumental Dam, a combination of voluntary spill and collection of fish for transport has been used to improve passage survival for migrating juvenile salmonids. The 2008 Federal Columbia River Power System Biological Opinion (NMFS 2008) calls for dam passage survival rates (through the concrete) of 96% for spring migrants and 93% for summer migrants at each project in the Federal Columbia River Power System (FCRPS, NMFS 2008).

In 2008, we began evaluation of passage behavior and survival for subyearling Chinook salmon *O. tshawytscha* at Lower Monumental Dam in conjunction with operation of the new RSW (Absolon et al. 2010). The present study was initiated by USACE Walla Walla District to evaluate passage behavior and survival of subyearling Chinook salmon for a second year. 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 and Reasonable and Prudent Alternative Action (RPA) 23.4 of the 2008 Biological Opinion for the Federal Columbia River Power System (NMFS 2008).

METHODS

Study Area

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

In the powerhouse, each turbine unit intake is outfitted with standard length submersible traveling screens, which divert downstream-migrating salmonids into the juvenile fish bypass system (JBS). Fish that enter the powerhouse without being diverted pass through turbines. The spillway is 156 m long and consists of 8 spillbays, numbered 1 to 8 from south to north. Spillbay flow is regulated by operation of Tainter-style radial spill gates (15 m wide × 18 m high) with the exception of the RSW bay (Spillbay 8), where flow is regulated exclusively by forebay pool elevation. The RSW was installed during winter 2007-2008 and was first operated for fish passage during spring 2008. The spillway crest for conventional spillbays is at elevation 483 ft msl and for the RSW bay at 525 ft msl.

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were collected at the juvenile fish facility at Lower Monumental Dam. We had planned to begin tagging on 7 June, but because fish arriving at the dam were too small for tagging, we did not begin until 9 June. We tagged only fish that were not previously tagged, did not have any gross injury or deformity, and were at least 100 mm in fork length or 9 g in weight. The minimum size criteria were chosen to ensure a tag burden of less than 7.7% of fish body weight. Brown et al. (1999) found that swimming performance was not affected by tag burdens up to 12% of body weight.

Fish were collected from the smolt monitoring sample until the target number was obtained each day. The number of fish tagged each day was not weighted to the passage index because this tagging design often results in insufficient detections of the smaller groups released at the beginning and end of the passage distribution. Without sufficient data from the entire passage period, our analysis could miss temporal trends in survival.

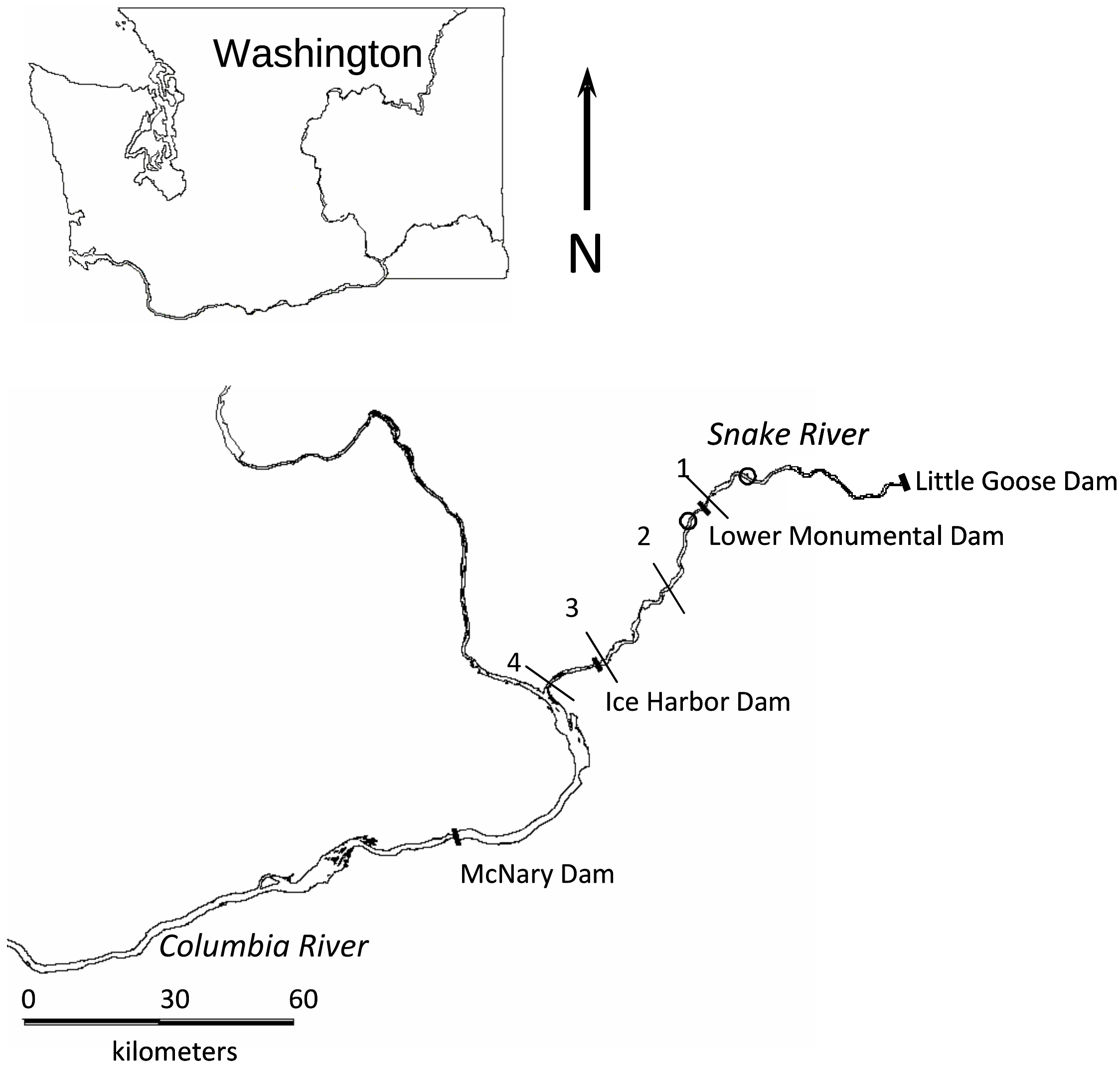

Figure 1. Detail of the study area showing release locations (○) for radio tagged fish and radio telemetry transects used for estimating survival at Lower Monumental Dam in 2009. Transects included: 1 = forebay entry line (rkm 590), 2 = primary survival line (16 km downstream from the dam at rkm 573) , 3 = secondary survival line (50 km downstream of the dam in the forebay of Ice Harbor Dam), and 4 = mouth of the Snake River. The tailrace and all routes of passage at Lower Monumental and Ice Harbor Dams were also monitored.

Therefore, to ensure sufficient detection numbers to identify any temporal trends in survival over the juvenile migration season, each day was considered a replicate and similar numbers of fish were tagged each day. Collected fish were anesthetized with tricaine methanesulfonate (MS-222) and sorted in a recirculating anesthetic system. Fish retained for tagging were transferred through a water-filled, 10.2-cm hose to a 935-L tank, where they were maintained via flow-through river water for 24 h prior to tagging.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a predetermined tag life of 10 d, and were pulse-coded for unique identification of individual fish. On average, each radio tag weighed 0.691 g in air and measured 12 mm in length by 5 mm in width. Fish were surgically implanted with a radio transmitter using techniques described by Adams et al. (1998). During surgery, a PIT tag was inserted with the radio transmitter to facilitate data collection on tagged fish and to potentially add data from PIT-tag detections at downstream facilities. Tagging was conducted simultaneously at three tagging stations.

Immediately after tagging, fish were placed into a 19-L container (2 fish per container) with aeration until they had recovered from the anesthesia. Containers were then covered and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers. Fish holding containers were perforated with 1.3-cm holes in the top 30.5 cm to allow exchange of water during holding. During tagging and holding, all containers were supplied with flow-through river water at ambient temperature. Fish were held a minimum of 24 h for recovery from the anesthetic and surgery and to determine post-tagging mortality. After the recovery period, radio-tagged fish were moved in the recovery containers from the holding area to release locations in the forebay and tailrace (Figure 2).

Treatment groups were released twice per day about 7 km upstream from Lower Monumental Dam at approximately rkm 596 (Figure 2). To release fish, the holding containers were first transferred from the holding tank to a similar tank mounted on a truck. During this transfer, all containers were checked for any mortality, and all tags were checked to confirm they operated properly. The tank on the truck was filled with river water prior to the transfer of containers, and was aerated with oxygen during transport. At the release area, containers were again transferred to a tank mounted on an 8.5- by 2.4-m barge. On the barge, the tank was supplied with flow-through river water during transport to the release location, and fish were released mid-channel using water-to-water transfer methods.

[1] Use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

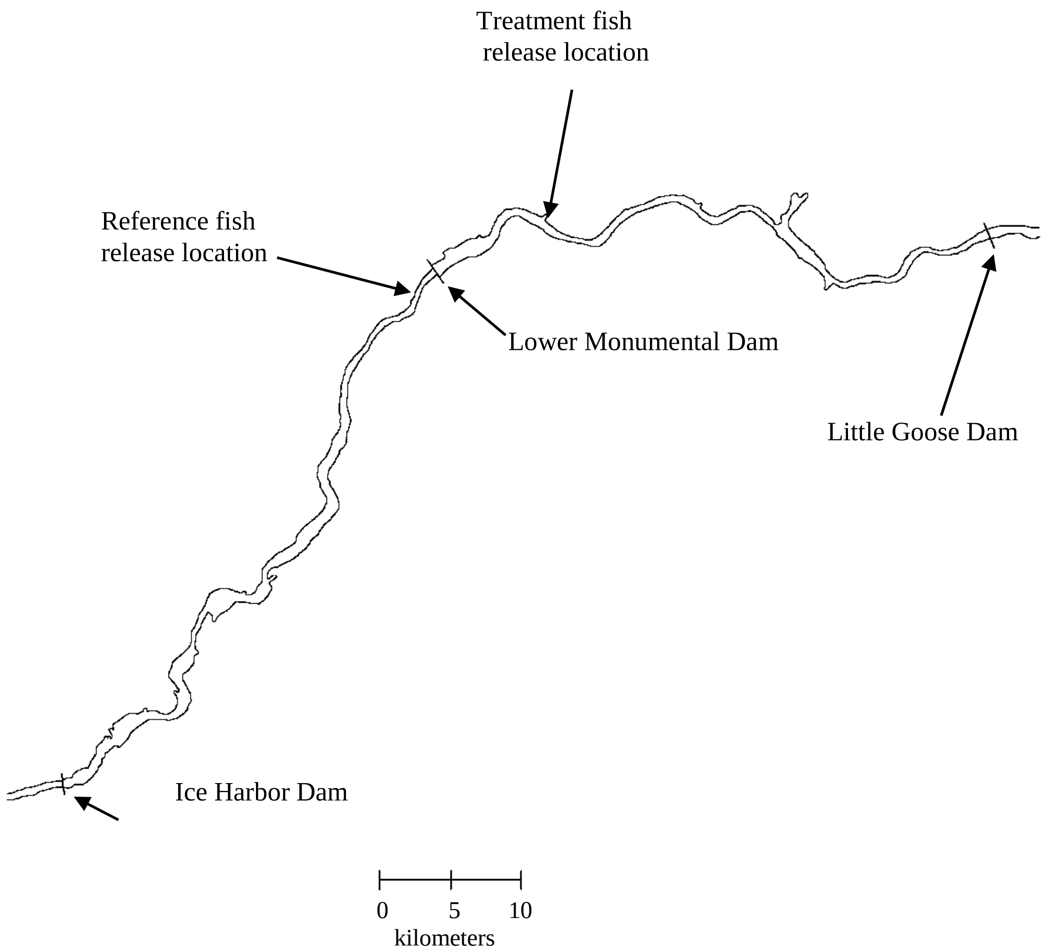

Figure 2. Lower Snake River showing Ice Harbor (rkm 538), Lower Monumental (rkm 589), and Little Goose Dam (rkm 635) and release locations for treatment (rkm 596) and reference groups (rkm 587) of radio-tagged subyearling Chinook salmon, 2009.

Bulk releases of treatment fish were made twice per day, with morning and afternoon releases at approximately 0911 and 1325 PDT, respectively. A total of 2,302 radio-tagged fish were released over 23 d from 10 June to 2 July. On average, 50 fish were released per release period for a total of 100 fish released per day.

Reference fish were transferred in recovery containers to a holding tank on a truck in the same manner as treatment fish, with containers checked for mortalities and all tags checked for correct operation. Trucks were driven to the release site 1.25 km downstream from Lower Monumental Dam. The tank on the truck was aerated with oxygen during transport to the release area. Upon arrival at the release site, fish were maintained with flow-through river water until release. Reference fish were released one or two at a time into the tailrace over a period of 5-6 h during both daytime and nighttime hours. Releases were made through a flume that extended a minimum of 7.6 m from the north shoreline toward mid-river, similar to reference releases methods during 2007 and 2008.

The release site for reference fish was chosen based on its proximity to the boat release location, depth of water, and ability to position the release flume. Other than these criteria, the reference release site was based on tailrace conditions observed in a 1:55 scale model of Lower Monumental Dam at the USACE Research and Development Center in Vicksburg, MS. For daytime releases of reference fish, the median start time was approximately 0846 PDT and median end time 1251. For nighttime releases of reference fish, median start time was approximately 2018 and median end time was 0249. A total of 2,050 radio-tagged reference fish were released over 23 d with approximately 89 fish released per day.

Monitoring and Data Analysis

Radio telemetry receivers and multiple-element aerial antennas were used to establish detection transects located at the forebay entry, 1 km upstream from Lower Monumental Dam, and at the primary survival transect 16 km downstream from the dam (Figure 1). Receivers using dipole or multiple-element aerial antennas were positioned to determine forebay entrance, dam approach, route of passage, tailrace egress and downstream detection. The locations of fixed-site receivers at Lower Monumental Dam are summarized in Table 1 and Figures 1 and 3. We did not use a double array (Skalski et al. 2002) for evaluating routes of passage because based on past experience with a single array, the proportion of fish with undetermined passage routes has typically been less than 3%.

Telemetry data was retrieved through an automated process that downloaded networked telemetry receivers up to four times daily. After downloading, individual data files were compressed by recording the first time a radio-tagged fish was detected and counting the number of subsequent detections at the same location where the time difference was less than or equal to 5 min. If the time between subsequent detections was greater than 5 min, the last detection time was recorded and a new line of data created. To allow a quick response to address any problems within the system, automated cell phone and email messages were sent to electronic shop personnel when problems occurred. In addition, daily logs of system operation were received by study personnel.

All compressed data were combined and loaded to a database, where automated scripts were used to remove erroneous data (Appendix B). Using 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 pattern, passage route and timing, tailrace exit timing, and timing of downstream detections for individual radio-tagged fish.

Table 1. Fixed-site telemetry receivers for evaluating passage behavior and survival of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2009.

Site description	Type of monitoring	Antenna type
Forebay (1 km upstream)		
north shore	Entrance line and residence time	3-element Yagi
mid channel	Entrance line and residence time	3-element Yagi
south shore	Entrance line and residence time	3-element Yagi
Turbine units 1-6	Approach and passage	Stripped coax
Spillbays 1-7	Approach and passage	Underwater dipole
RSW	Approach and passage	Tuned loop & underwater dipole
Draft tube units 1-6	Project passage	Underwater dipole
Stilling basin		
north shore	Project passage	Tuned loop
south shore	Project passage	Tuned loop
JBS	Bypass passage	Tuned loop
Tailrace exit		
north shore	Project passage and tailrace egress	2-element Yagi
south shore	Project passage and tailrace egress	3-element Yagi
Primary survival		
north shore	Project passage and survival	3-element Yagi
south shore	Project passage and survival	3-element Yagi

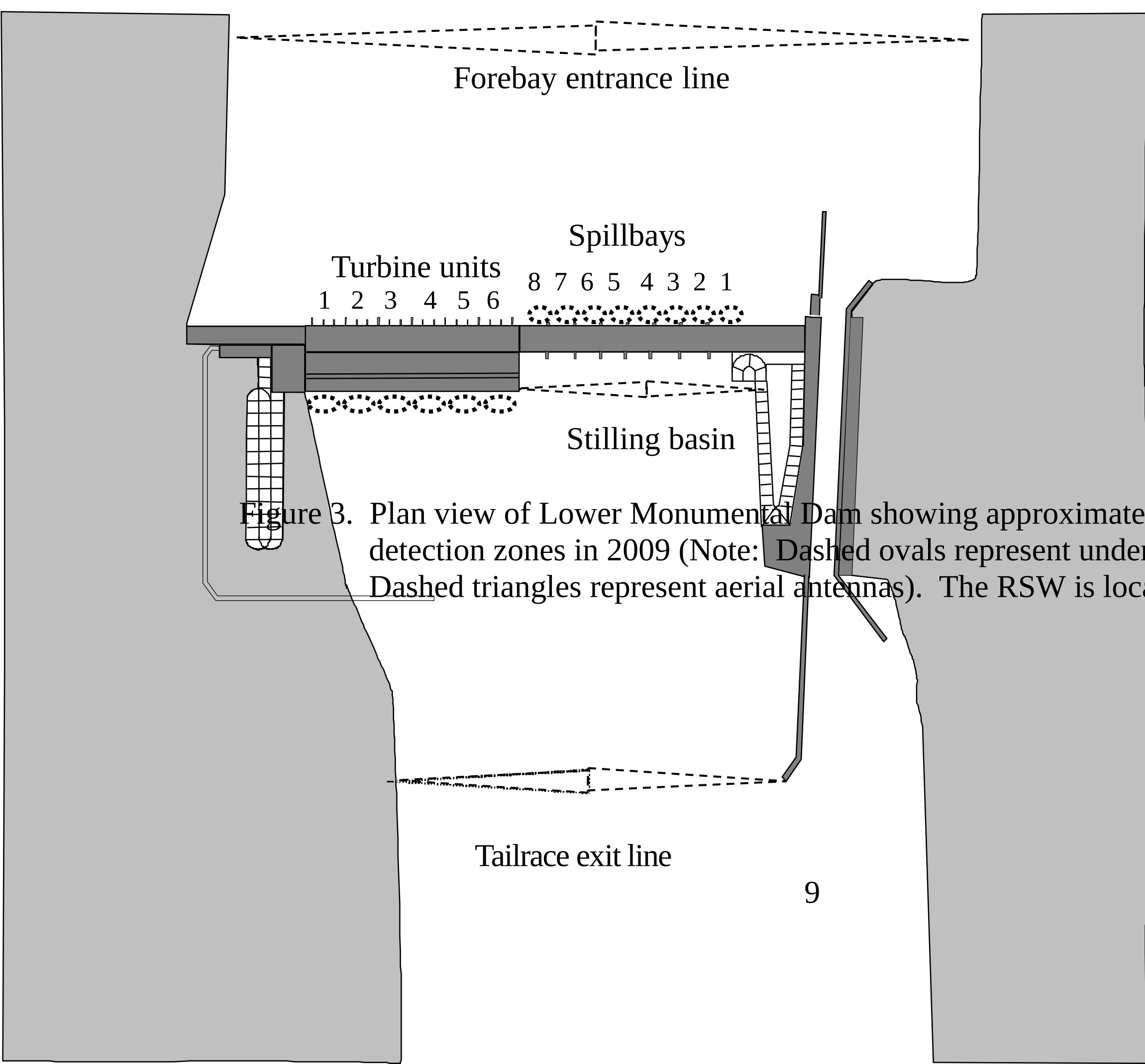

Figure 3. Plan view of Lower Monumental Dam showing approximate radio-telemetry detection zones in 2009 (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas). The RSW is located in Spillbay 8.

Survival Estimates

A paired-release study design was used to estimate relative survival where groups of radio-tagged fish were released at one of two sites; upstream (treatment) and downstream (reference) from Lower Monumental Dam (Figure 2). Treatment groups were formed by grouping daily detections of radio-tagged fish either as they entered the forebay or as they passed Lower Monumental Dam. Reference groups were released directly into the tailrace of Lower Monumental Dam (Figure 2) and grouped by day of release. Data were analyzed using the Survival with Proportional Hazards (SURPH) statistical software developed at the University of Washington (Smith et al. 1994). Definitions of survival followed the guidelines described by Peven et al. (2005), as follows:

Relative dam survival was defined as survival of treatment fish through the immediate forebay and all passage routes combined relative to survival of tailrace-released fish. The immediate forebay extended approximately 675 m upstream from the face of the dam The "effect zone" extended from the forebay entrance array (~675 m upstream of the dam) to the tailrace release location.

Relative c*oncrete survival* was defined as survival of 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 release location. Concrete survival did not include any losses in the forebay.

The CJS (Cormack-Jolly-Seber) single-release model was used to estimate probabilities of detection and survival from release to the primary survival array (16 km downstream of the dam) for both treatment and reference groups (Cormack 1964; Jolly 1965; Seber 1965). This model provides unbiased estimates of survival for individual release groups if model assumptions are met (Zabel et al. 2002; Smith et al. 2003). A critical model assumption is that detection or recapture probability at a downstream site is not affected by previous detection upstream; that is, radio-tagged fish had equal probabilities of detection at each telemetry array, regardless of previous radiotelemetry detections.

Relative survival estimates were expressed as the ratio of geometric mean survival estimates for treatment fish to those for reference fish. An additional critical assumption of the single-release model is that treatment and reference groups have similar probabilities of detection and survival in the reach that is common to both groups (Burnham et al. 1987). To ensure the validity of this assumption, we evaluated detection data to determine whether treatment and reference groups were mixed temporally upon arrival (detection) at the primary survival array. Details of this evaluation and of other critical assumptions evaluated for our study design are reported in Appendix A.

Passage Behavior and Timing

Forebay residence time was defined as elapsed time from detection on the forebay entrance transect to detection on a passage-route receiver. Forebay arrival time was based on the first time a fish was detected on the forebay entrance transect at the upstream end of the boat restricted zone (BRZ) at Lower Monumental Dam. Evaluations of forebay residence time included only fish that had been released upstream from the dam, detected on the forebay entrance transect, detected a second time in a passage route, and detected a third time in the immediate tailrace, either on the stilling basin, draft tube, or tailrace-exit array (Figure 3). Forebay residence time for individual fish was measured as the time between first detection on the forebay entrance transect and last detection in a passage route. Stilling basin, draft tube, and/or tailrace exit detection was used to confirm dam passage. Tailrace egress time was defined as the time from last detection on a passage route to last detection on the tailrace exit transect.

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

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

where n_i was the number of individuals remaining in the forebay at the beginning of interval *i*, d_i was the number of fish passing at the end of interval *i*, and *t* was measured as the time between intervals k and $k + 1$. Thus, the estimated proportion remaining was produced by multiplying together the probability of surviving through each time increment. The summary statistic we used to describe the “location” parameter of the K-M curve was the time at which 50% (median) of the fish had passed.

Approach and Passage Distribution

Approach patterns were established based on first detection on one of the receivers located at each spillbay and turbine unit. Route of passage through the dam was based on the last time a fish was detected on a passage-route receiver prior to detection in the tailrace. Routes were assigned only to fish detected in the tailrace of the dam, meaning at least one valid detection was required on receivers monitoring the stilling basin, draft tubes, or tailrace exit line (Figures 3). Spillway passage was assigned to fish whose last detection in the forebay was on one of the antenna arrays deployed in each spillbay. The spillway was monitored by four underwater dipole antennas in each spillbay; two antennas were installed along each of the pier noses at depths of 6 and 12 m. Range testing showed this configuration monitored the entire spillway. Similarly, turbine passage was assigned to fish last detected in the forebay on a turbine intake antenna. To detect fish passage in the turbine units, draft tubes, and JBS, we used armored coaxial cable, stripped at the end. Antennas in turbine units were attached on both ends of the downstream side of the fish-screen support frame located within each slot of the turbine intake. Passage through the JBS was assigned to fish detected in the JBS. Fish detected on fish-screen antennas could then be assigned a passage route by their subsequent detection on either the bypass system antenna, which indicated JBS passage, or draft tube antennas, which indicated turbine passage. Subsequent detection in the tailrace was required to confirm passage through either a spillway, turbine, or the JBS.

Fish Passage Metrics

Fish-passage metrics evaluated were spill efficiency, spill effectiveness, RSW efficiency, RSW effectiveness, fish guidance efficiency (FGE), and fish passage efficiency (FPE). These evaluations were based on radiotelemetry detections at the same locations used for passage-route evaluations. Spill efficiency was estimated as the number of fish passing the dam via the spillway divided by the total number of fish passing the dam. Spill effectiveness was estimated as the proportion of fish passing the dam via the spillway divided by the proportion of water spilled. Efficiency for the RSW was estimated as the number of fish passing through the RSW divided by the total number of fish passing the dam. Effectiveness for the RSW was estimated as the proportion of fish passing the dam via the RSW divided by the proportion of water passing through the RSW. Fish guidance efficiency was estimated as the number of fish passing the dam through the JBS divided by the total number of fish passing the dam through the powerhouse (either through the turbines or JBS). Fish passage efficiency was estimated as the number of fish passing the dam through non-turbine routes divided by the total number of fish passing the dam.

Avian Predation

Predation by Caspian Terns *Hydroprogne caspia*, Double-crested Cormorants *Phalacrocorax aurtius* and gulls *Larus* spp. was evaluated by physical recovery of radio transmitters and by PIT-tag detection on Crescent and Foundation Islands in the McNary Dam Reservoir. Radio transmitters and PIT tags were recovered on nesting colonies during fall 2009 after the birds had abandoned their nesting colonies. Radio tags were collected by physically walking the islands looking for visible tags. Radio-tag serial numbers were used to identify individual tagged fish. PIT tags were also "recovered" using the mobile PIT-tag detection system described by Ryan et al. (2001). PIT-tag detections and recovery of radio transmitters were provided by NOAA Fisheries (S. Sebring, NOAA Fisheries, personal communication) and Real Time Research (A. Evans, Real Time Research, personal communication). Both NOAA and RTR conduct an ongoing monitoring effort to detect PIT tags from active avian colonies in the region.

RESULTS

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were tagged at Lower Monumental Dam and released over a period of 24 d, from 9 June through 2 July 2009. Tagging began after 53% of the juvenile subyearling Chinook salmon run had passed Lower Monumental Dam and was completed when 88% of these fish had passed (Figure 4). During 2009, the subyearling Chinook salmon median run-timing was a few days earlier than during the 10-year average. The study plan was to begin the project earlier; however, the size of fish in the population was smaller than the targeted fish size of a 100 mm. Fish condition information and data on the size and timing of the juvenile migration for 2009 are reported on the Fish Passage Center website (www.fpc.org).

Overall mean fork length was 113 mm (range 101-148 mm) for treatment fish and 113 mm (range 102-157 mm) for reference fish (Table 2). Mean fork length of the run at large sampled at Lower Monumental Dam by the Smolt Monitoring Program during the study was 101 mm (M. Price, WDFW, personal communication; Table 3). Overall mean weight was 12.6 g (range 10-37 g) for treatment fish and 12.8 g (range 9-43 g) for reference fish (Table 4).

Handling and tagging mortality for subyearling Chinook salmon was 1.5% (66 fish). Fish that died during the post-tagging recovery period were released in the tailrace, along with reference fish, to verify the assumption that dead fish are not detected on downstream survival arrays.

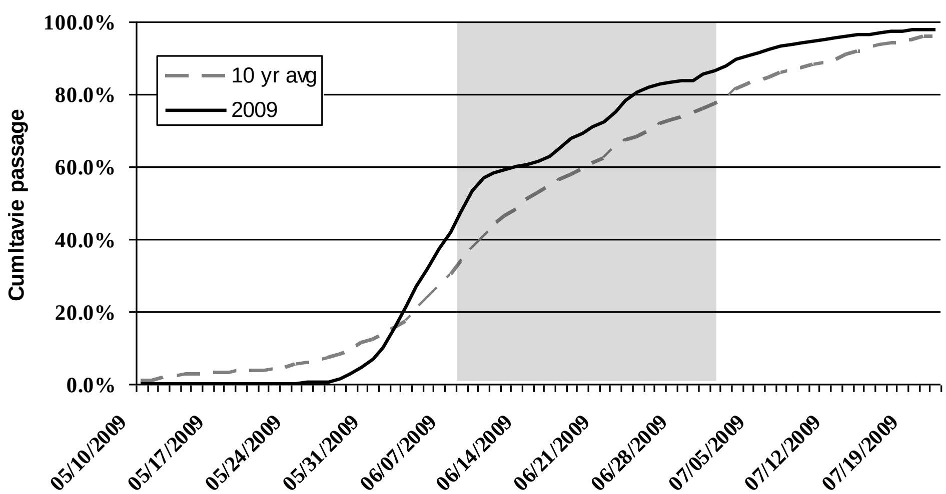

Figure 4. Cumulative distribution of subyearling Chinook salmon passing Lower Monumental Dam, during 2009 compared to the 10-year average (2000-2009).

Table 2. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) by release timing for replicate groups of radio-tagged subyearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2009.

Release date	Fish length (mm) Forebay releases N	Mean	Range	SD	Tailrace releases N	Mean	Range	SD
				Daytime releases				
10 June	28	111	104-120	4.4				
11 June	26	113	108-120	2.7	23	112	105-119	3.8
12 June	28	109	103-115	3.4	25	111	105-127	4.8
13 June	33	110	104-116	3.5	27	111	104-122	4.3
14 June	28	112	106-125	4.3	25	111	104-119	4.2
15 June	33	112	106-126	4.2	31	113	105-122	3.9
16 June	55	112	106-127	4.0	43	114	103-124	4.3
17 June	55	114	106-125	4.2	50	114	107-133	5.0
18 June	104	115	106-138	5.8	68	116	106-130	5.6
19 June	56	114	106-126	5.0	49	114	105-127	5.1
20 June	56	116	105-130	4.4	47	114	106-131	4.8
21 June	55	116	106-133	5.8	50	115	105-126	4.7
22 June	55	113	104-121	4.1	50	113	106-124	4.4
23 June	55	113	105-125	4.4	48	114	105-136	6.0
24 June	55	113	104-126	4.4	49	113	105-133	6.4
25 June	98	113	104-135	5.8	68	112	105-136	5.3
26 June	56	113	106-123	4.5	47	114	105-130	5.9
27 June	54	112	104-126	4.2	49	111	104-120	3.6
28 June	55	111	105-120	3.9	50	112	104-130	6.0
29 June	51	113	103-135	6.7	43	111	102-137	6.4
30 June	55	113	102-134	7.4	49	113	104-153	8.2
1 July	53	111	103-124	5.1	49	111	103-144	7.2
2 July	51	117	106-148	8.1	44	114	103-132	7.3
3 July					49	114	104-129	4.8
Subtotal	1,195	113	102-148	5.3	1,033	113	102-153	5.7

Table 2. Continued.

Release date	Fish length (mm) Forebay releases N	Mean	Range	SD	Tailrace releases N	Mean	Range	SD
				Nighttime releases				
10 June	29	111	101-121	4.3				
11 June	28	113	107-121	3.5	25	111	105-125	5.7
12 June	29	110	105-118	4.0	24	112	106-126	5.2
13 June	32	114	106-123	5.2	30	112	105-125	4.6
14 June	26	111	105-125	5.4	22	113	105-125	4.8
15 June	33	115	106-128	5.5	29	114	107-124	4.7
16 June	55	113	105-128	4.2	44	114	105-128	5.2
17 June	56	114	105-127	5.2	49	115	104-128	5.0
18 June	56	113	105-126	5.1	66	113	105-127	4.8
19 June	56	114	105-126	4.6	50	115	106-126	3.9
20 June	55	114	105-129	5.4	45	115	105-122	4.6
21 June	56	115	108-128	4.5	50	113	106-125	3.9
22 June	55	114	106-130	5.7	49	113	107-127	4.5
23 June	55	112	104-131	4.5	48	114	105-124	5.1
24 June	56	113	107-124	4.0	43	113	103-125	4.5
25 June	52	113	106-122	3.5	69	114	103-128	5.7
26 June	56	114	105-125	5.1	50	113	104-126	3.4
27 June	54	112	106-124	4.1	49	113	107-125	7.2
28 June	56	112	104-134	5.8	50	114	105-136	5.0
29 June	56	112	104-123	4.2	40	111	104-124	6.7
30 June	54	112	104-134	6.2	48	113	104-135	10.0
1 July	54	114	104-134	7.3	45	117	105-157	7.5
2 July	48	113	104-145	7.4	43	112	103-135	7.4
3 July					49	117	104-137	4.5
Subtotal	1,107	113	101-145	5.2	1,017	114	103-157	5.7
Total	2,302	113	101-148	5.3	2,050	113	102-157	5.3

Table 3. Sample size, mean and range of fork length by collection day for river-run subyearling Chinook salmon (hatchery and wild origin fish combined) collected at the Lower Monumental Dam smolt monitoring facility, 2009.

	Fish length (mm)		
Collection	N	Mean	Range
8-Jun	200	98.0	75-115
9-Jun	100	97.0	65-115
10-Jun	100	100.3	75-120
11-Jun	103	98.2	45-120
12-Jun	87	101.1	80-120
13-Jun	174	99.8	75-120
14-Jun	200	99.7	50-125
15-Jun	200	101.6	55-120
16-Jun	103	102.0	55-140
17-Jun	101	100.6	55-120
18-Jun	102	99.5	45-130
19-Jun	99	97.1	45-125
20-Jun	200	100.7	75-120
21-Jun	200	101.3	45-125
22-Jun	200	103.0	75-130
23-Jun	100	99.7	45-130
24-Jun	100	99.7	75-120
25-Jun	100	105.2	80-135
26-Jun	100	99.2	75-130
27-Jun	188	102.6	85-125
28-Jun	200	102.2	70-145
29-Jun	200	103.4	50-150
30-Jun	102	100.6	50-125
1-Jul	101	103.1	50-135
2-Jul	100	104.6	60-135
3-Jul	200	107.7	90-150
Total/overall	3,845	101.3	45-150

Table 4. Sample size, range, mean, and standard deviation (SD) of weight (g) by release timing for replicate groups of radio-tagged subyearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2009.

Release date	Fish weight (g)							
	Forebay releases				Tailrace releases			
	N	Mean	Range	SD	N	Mean	Range	SD
	Daytime releases							
10 June	28	13.3	11-17	1.5				
11 June	26	12.2	11-15	1.0	23	12.3	10-16	1.6
12 June	28	11.8	10-15	1.4	25	12.2	10-20	2.0
13 June	33	11.2	10-13	1.1	27	11.3	10-15	1.3
14 June	28	11.8	10-16	1.4	25	11.8	10-15	1.3
15 June	33	11.9	10-17	1.6	31	12.2	10-15	1.3
16 June	55	12.1	10-16	1.2	43	12.8	10-16	1.6
17 June	55	12.5	10-18	1.6	50	12.3	10-22	2.0
18 June	104	12.9	10-22	2.1	68	13.3	10-20	2.2
19 June	56	12.7	10-17	1.6	49	12.6	10-17	1.7
20 June	56	12.8	10-17	1.5	47	12.6	10-19	1.8
21 June	55	13.1	10-19	2.0	50	12.5	10-16	1.6
22 June	55	12.5	10-16	1.5	50	12.3	11-17	1.4
23 June	55	12.6	10-18	1.7	48	13.4	10-27	2.8
24 June	55	12.2	10-17	1.5	49	12.5	10-21	2.4
25 June	98	12.7	10-23	2.4	68	13.0	10-25	2.3
26 June	56	12.3	10-16	1.5	47	12.9	10-20	2.4
27 June	54	12.0	10-18	1.6	49	11.6	10-17	1.2
28 June	55	12.1	10-17	1.7	50	12.5	10-21	2.4
29 June	51	13.1	10-24	2.9	43	12.2	10-24	2.5
30 June	55	13.6	10-23	3.0	49	13.5	10-36	4.1
1 July	53	12.5	10-18	1.9	49	12.7	10-31	3.3
2 July	51	14.8	10-37	4.4	44	13.6	10-20	2.8
3 July					49	13.8	10-19	2.0
Subtotal	1,195	12.6	10-37	2.1	1,033	12.7	10-36	2.3

Table 4. Continued.

Release date	Fish weight (g)							
	Forebay releases				Tailrace releases			
	N	Mean	Range	SD	N	Mean	Range	SD
	Nighttime releases							
10 June	29	12.9	11-15	1.2				
11 June	28	12.2	11-15	1.2	25	11.6	9-17	1.7
12 June	29	11.7	10-16	1.5	24	12.5	10-18	1.9
13 June	32	12.6	10-16	1.9	30	11.9	10-18	2.2
14 June	26	11.7	10-17	1.8	22	12.1	11-17	1.6
15 June	33	12.8	10-20	2.0	29	12.6	10-17	1.6
16 June	55	12.2	10-18	1.5	44	12.8	10-20	1.8
17 June	56	12.3	10-18	1.8	49	13.1	10-18	1.9
18 June	56	12.4	10-17	1.6	66	12.2	10-17	1.8
19 June	56	12.6	10-18	1.7	50	12.5	10-18	1.7
20 June	55	12.5	10-20	2.0	45	12.6	11-16	1.4
21 June	56	12.5	10-18	1.7	50	12.2	10-16	1.7
22 June	55	12.9	10-20	2.2	49	12.4	10-18	1.5
23 June	55	12.3	10-19	1.5	48	13.1	10-17	1.7
24 June	56	12.4	10-17	1.7	43	12.8	10-18	1.7
25 June	52	12.2	10-16	1.3	69	12.3	10-17	1.6
26 June	56	12.8	10-16	1.6	50	12.4	10-18	2.0
27 June	54	12.0	10-18	1.6	49	12.4	11-18	1.4
28 June	56	12.8	10-24	2.5	50	13.3	10-23	3.1
29 June	56	12.2	10-17	1.6	40	12.2	10-18	2.0
30 June	54	13.1	10-22	2.7	48	13.1	10-24	2.7
1 July	54	13.2	10-22	3.0	45	15.6	11-43	5.9
2 July	48	13.2	10-29	3.3	43	13.0	10-24	3.0
3 July					49	14.8	10-24	3.1
Subtotal	1,117	12.5	10-29	2.0	1,017	12.8	9-43	2.5
Total	2,302	12.6	10-37	2.1	2,050	12.8	9-43	2.4

Project Operations

During the 9 June through 4 July study period; average spill was 19.2 kcfs or 22.0% of total discharge (Table 5). Spill occurred throughout the study period except for short periods when it was interrupted in relation to operations for the fish transport barges to safely cross the river from the navigation lock to the barge loading area. Average daily spill ranged from 16.9 to 25.8 kcfs, powerhouse flow ranged from 46.2 to 98.9 kcfs, and total river flow ranged from 63.3 to 118.8 kcfs. The average daily tailwater elevation ranged from 438.7 to 441.8 ft msl, and water temperature in the tailrace, measured by the USACE water quality monitor, ranged from 14.0 to 18.4°C (Table 5). No specific operations were requested for this study, and the operations followed the criteria in the Fish Passage Plan.

The Fish Passage Plan at Lower Monumental Dam during 2009 called for a bulk spill pattern, with spill not exceeding total dissolved gas limits "gas cap" from the start of the study through 21 June. Under the bulk spill pattern, the majority of spilled water passes through Spillbays 2, 6 and 8. The "gas cap" was generally reached with spill levels of 19-26 kcfs, and was based on maintaining total dissolved gas levels below the mandated limits of 120% in the tailrace of Lower Monumental Dam or 115% in the forebay of Ice Harbor Dam. From 22 June until the end of the study the spill level was maintained at 17 kcfs.

Average daily total river flow during the study in 2009 (87.3 kcfs) was relatively high, similar to 2008 (106.4 kcfs). The 10-year average flow at Lower Monumental Dam during the study period (from 1999 to 2008) was 70.5 kcfs and ranged from 32.4 kcfs in 2001 to 106.4 in 2008. The spill pattern used in 2009 is presented in Appendix C.

Table 5. Average daily conditions during releases and passage of radio-tagged hatchery subyearling Chinook salmon at Lower Monumental Dam, 2009.

Date	Spill (kcfs)	Powerhouse (kcfs)	Total discharge (kcfs)	Tailwater elevation (ft msl)	Water temperature (°C)
10 June	20.0	98.9	118.8	441.8	14.2
11 June	19.6	82.9	102.6	440.9	14.0
12 June	20.0	83.0	102.9	440.9	14.0
13 June	19.5	73.6	93.1	440.2	14.2
14 June	20.0	73.6	93.6	440.2	14.5
15 June	20.2	76.7	97.0	440.4	14.7
16 June	21.9	82.5	104.4	440.9	15.2
17 June	21.3	76.3	97.7	440.5	15.5
18 June	23.0	76.6	99.6	440.7	15.9
19 June	24.4	74.1	98.5	440.6	16.1
20 June	25.8	61.1	86.9	439.7	15.9
21 June	17.2	67.1	84.3	439.8	15.8
22 June	17.5	65.5	83.0	439.7	15.7
23 June	17.1	89.0	106.0	441.1	15.8
24 June	17.5	76.3	93.8	440.3	16.1
25 June	17.3	62.0	79.3	439.5	16.2
26 June	17.5	63.6	81.1	439.6	16.2
27 June	16.9	59.3	76.2	439.3	16.2
28 June	17.5	59.4	76.9	439.4	16.1
29 June	17.3	56.8	74.0	439.2	16.3
30 June	17.5	54.0	71.5	439.1	16.5
1 July	17.6	50.1	67.7	439.0	16.9
2 July	17.5	47.7	65.1	438.7	17.5
3 July	17.1	46.2	63.3	438.7	17.9
4 July	17.5	47.8	65.3	440.0	18.4
Average	19.2	68.2	87.3	440.0	15.8

Migration and Passage Behavior

Forebay behavior, tailrace behavior, passage distribution, fish passage metrics, and passage survival results were based on fish that entered the study area from 10 June through 3 July.

Forebay Behavior

Of the 2,302 radio-tagged treatment fish released above Lower Monumental Dam, 1,957 (85%) were detected on the forebay entrance line at the upstream end of the BRZ. The percent of subyearling Chinook salmon entering the Lower Monumental Dam forebay was lowest between 0600 and 1200 PDT and highest from 0200 to 0500 PDT (Figure 5). Of the 1,957 fish that approached the dam, the majority (68%) were first detected at the RSW (Figure 6). This proportion was higher than we observed prior to installation of the RSW, but the approach distribution may have been biased due to the location of antennas on the RSW, which were farther upstream than antennas on the spillbays or turbine intakes because the RSW extends into the forebay. In 2009, 25% of the subyearling Chinook salmon first approached the powerhouse, compared to 27% in 2008, 16% in 2006, and 7% in 2007.

Average percent spill in 2009 (22%) was similar to 2008 (24%), but much less than the percent spill during 2007 (50%) or 2006 (32%). The lower percent spill during 2009 may have contributed to the increased powerhouse approach during 2009 compared to approach distributions during 2006 and 2007. In 2009, approach to the spillway and powerhouse by diel period were similar (Figure 7). During past studies the approach distribution between the spillway and powerhouse were similar by diel period except for 2006, when powerhouse approach was higher at night even though a higher proportion of flow went through the spillway at night (Absolon et al. 2008a, 2008b).

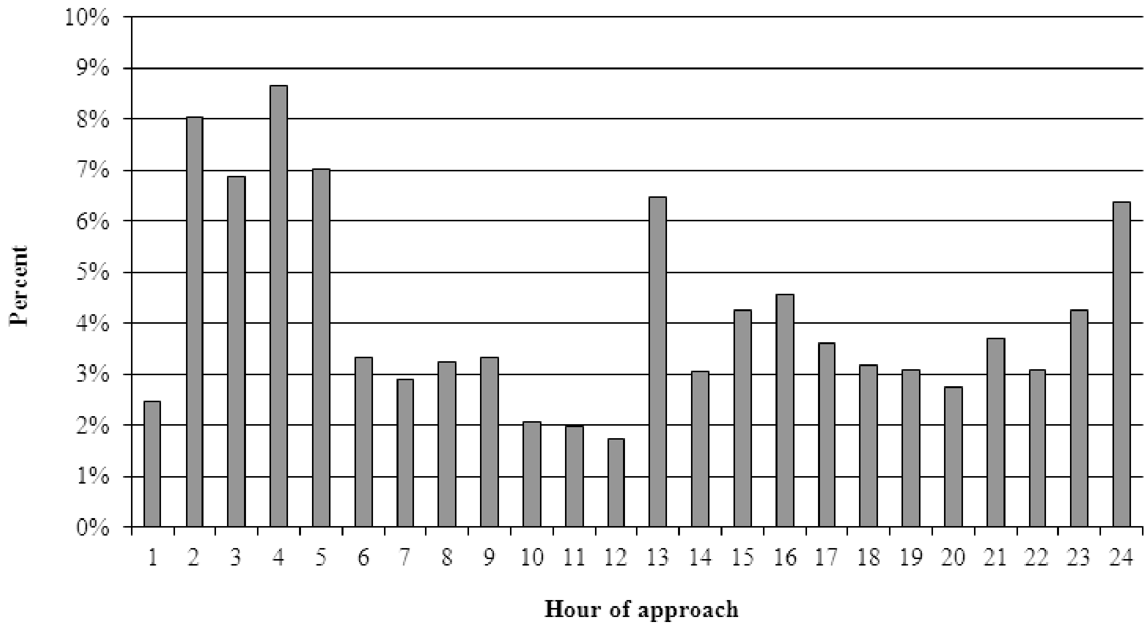

Figure 5. Hour of first detection in the forebay at Lower Monumental Dam for radio-tagged subyearling Chinook salmon, 2009.

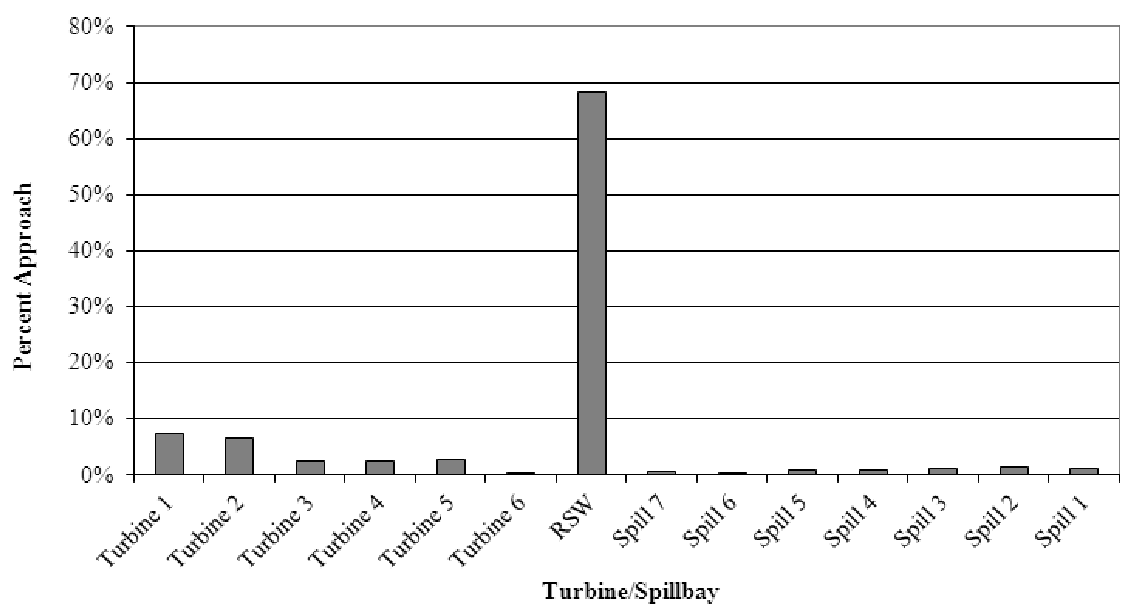

Figure 6. Horizontal approach distribution (within 18 m of the dam) for radio-tagged subyearling Chinook salmon released upstream of Lower Monumental Dam based on first detection at individual turbine intakes, the RSW, or spillbays, 2009.

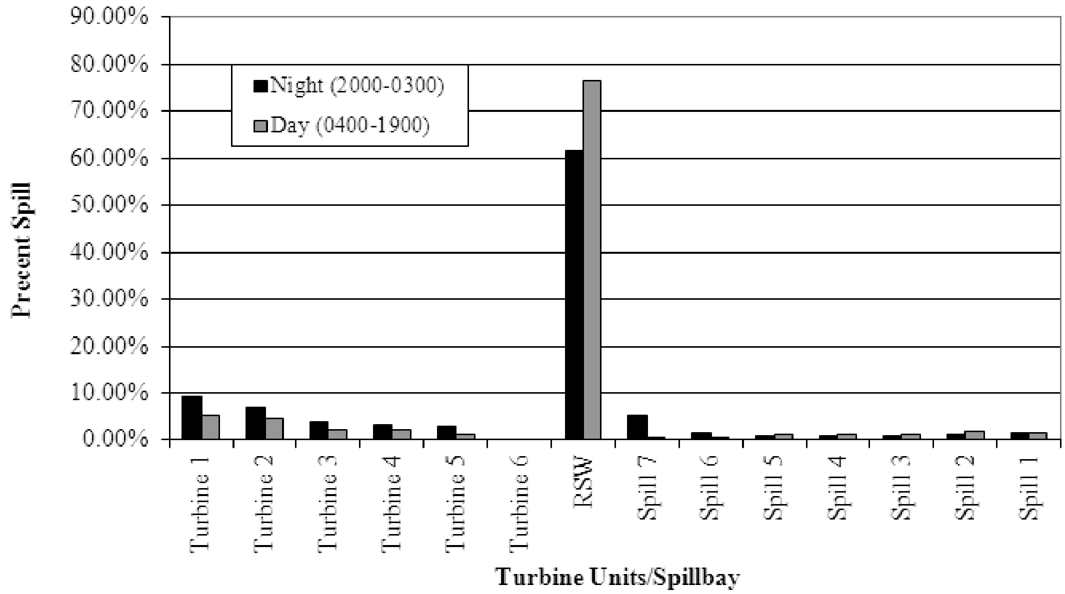

Figure 7. Horizontal approach distribution (within 18 m of the dam) for radio-tagged subyearling Chinook salmon released upstream of Lower Monumental Dam based on first detection at individual turbine intakes, the RSW, or spillbays by diel period, 2009.

Forebay residence time was calculated for 1,697 fish, each of which were detected on the forebay entrance transect and subsequently detected passing the dam on a passage-route receiver. Fish that were not detected in these areas were excluded from analysis of forebay residence timing. Median forebay residence time was 0.9 h for fish that passed via the spillway, 3.7 h for fish that passed via the JBS, 0.9 h for fish that passed via the turbines, and 1.3 h overall (range 0.4-164.4 h; Table 6; Figure 8). Median forebay residence time was relatively consistent throughout the study (Table 7).

Table 6. Forebay residence in hours for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2009.

Passage Percentile	Forebay residence (h)			
	Turbine	JBS	Spillway	Overall
N	147	526	1,024	1,697
Minimum	0.4	0.8	0.3	0.3
10^{th}	0.4	0.8	0.3	0.3
20^{th}	0.4	1.1	0.4	0.5
30^{th}	0.5	1.5	0.5	0.7
40^{th}	0.7	2.3	0.7	0.9
50^{th} (median)	0.9	3.7	0.9	1.3
60^{th}	1.4	5.6	1.2	1.7
70^{th}	1.9	8.0	1.6	2.6
80^{th}	3.1	11.0	2.3	4.6
90^{th}	4.8	20.2	4.2	9.0
Mean	2.4	8.2	1.9	3.9
Mode	0.4	1.3	0.2	0.2
Maximum	68.1	88.5	164.4	164.4

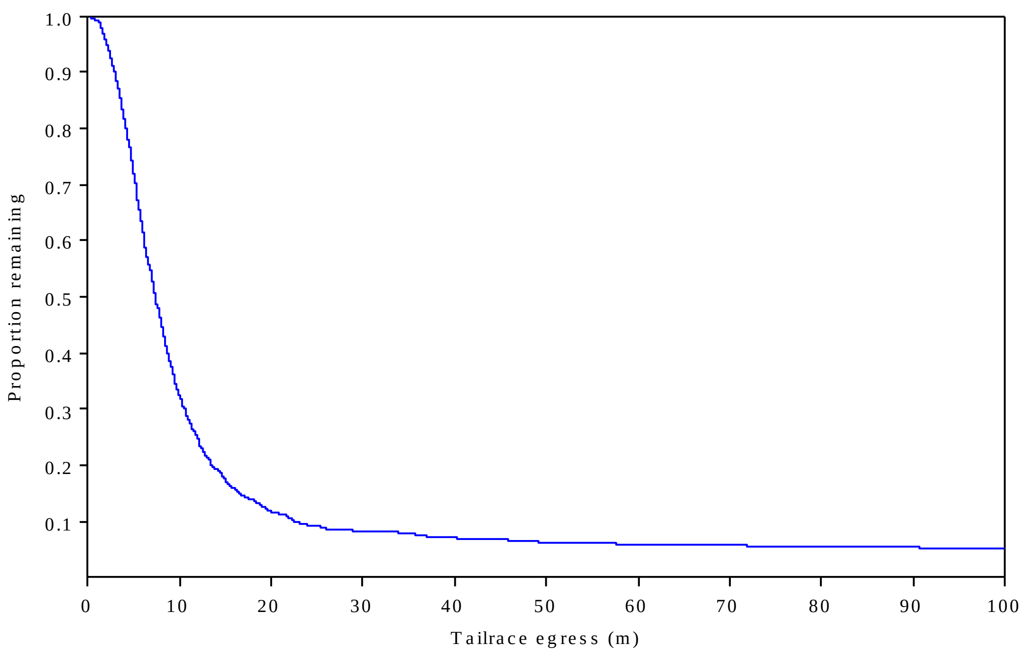

Figure 8. Kaplan-Meier survival curves of forebay residence (elapsed time in hours from first detection on the forebay entry line to time of passage) for radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2009.

Table 7. Forebay residence time for all passage routes combined for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2009. Residence time is shown by forebay entry date for the 10th, 50th (median), and 90th percentiles.

		Forebay residence time (h)		
Forebay entry date	N	10th	50th	90th
10 June	20	0.3	0.6	3.4
11 June	28	0.4	1.1	6.9
12 June	43	0.4	1.3	13.3
13 June	53	0.3	0.9	11.5
14 June	55	0.6	2.4	14.7
15 June	44	0.3	1.2	7.8
16 June	78	0.4	1.2	7.4
17 June	76	0.3	1.0	6.5
18 June	108	0.4	1.8	9.6
19 June	116	0.3	0.9	7.7
20 June	65	0.3	0.8	2.8
21 June	97	0.3	1.5	8.1
22 June	101	0.3	1.2	5.8
23 June	102	0.4	1.6	14.3
24 June	48	0.6	1.0	6.2
25 June	67	0.4	1.5	9.0
26 June	87	0.5	1.6	10.3
27 June	90	0.4	1.4	9.2
28 June	74	0.4	1.6	12.5
29 June	81	0.4	1.4	7.7
30 June	57	0.4	1.3	10.8
1 July	76	0.3	1.0	9.0
2 July	77	0.3	1.1	8.0
3 July	47	0.3	1.5	8.3
Total/mean	1,690	0.4	1.3	8.8
SE		0.02	0.08	0.62
95% CI		0.38-0.42	1.22-1.38	8.18-9.42

Passage Behavior

Of the 2,302 radio-tagged treatment fish released, 210 (9%) were not detected after release and 140 (6%) did not pass the dam. One hundred and sixteen fish passed the dam (5% of those known to have passed the dam), however their route of passage could not be determined. Of the 1,836 fish that passed the dam through a known passage route, 902 (49%) passed through the RSW, 223 (12%) passed through the remaining spillbays, 555 (30%) passed via the JBS, and 156 (8%) passed via the turbines (Figure 9). The percentage of time each spillbay was open during the study period and the percentage of fish that passed through each spillbay is presented in Figure 10. The hourly passage distribution of subyearling Chinook salmon exhibited and inverse relationship with project discharge in 2009 (Figure 11).

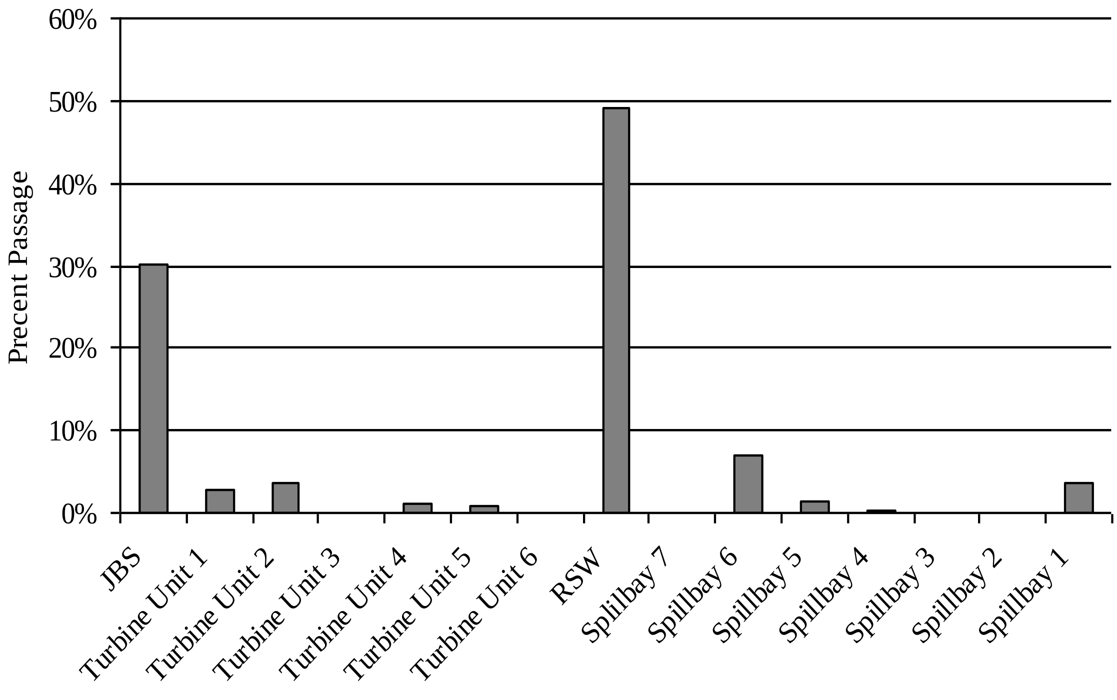

Figure 9. Passage route distribution of radio-tagged subyearling Chinook salmon released upstream from Lower Monumental Dam, 2009.

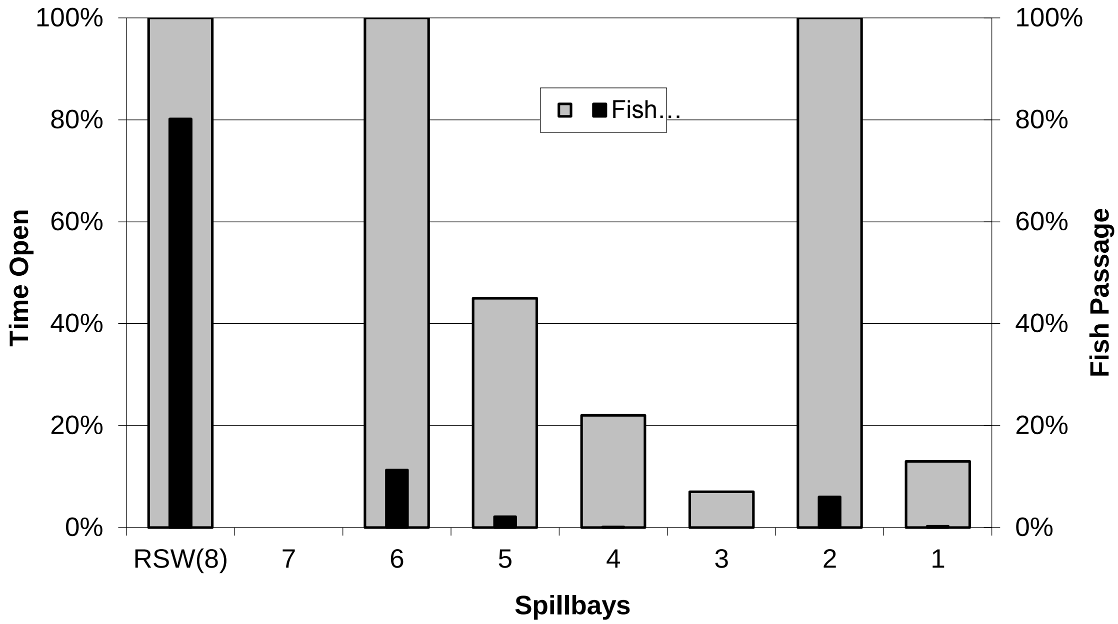

Figure 10. Percent time individual spillbays were open and Lower Monumental Dam spillway passage distribution for radio-tagged subyearling Chinook salmon, 2009.

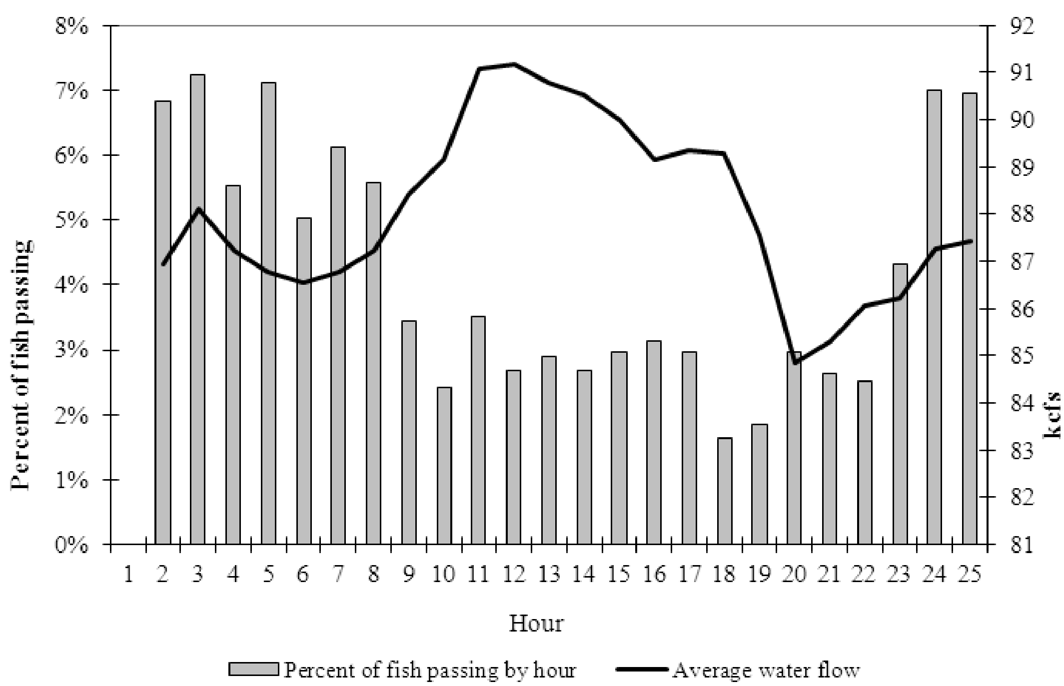

Figure 11. Percentage of radio-tagged subyearling Chinook salmon passing Lower Monumental Dam and average total project discharge by hour, 2009.

Fish passage metrics for subyearling Chinook salmon passing Lower Monumental Dam in 2009 were calculated by pooling data for all releases, resulting in the following point estimates and 95% CIs; fish passage efficiency (FPE) was 0.918 (0.905-0.931), spill efficiency was 0.615 (0.592-0.637), spill effectiveness was 2.74:1 (2.64-2.84), RSW efficiency was 0.493 (0.470-0.517), RSW effectiveness was 5.91 (5.63-6.19), and fish guidance efficiency (FGE) was 0.787 (0.756-0.818).

Tailrace Egress

Tailrace egress was calculated for 1,696 radio-tagged, river-run subyearling Chinook salmon. Median tailrace egress time was 7.4 min overall, 5.4 min for fish that had passed through the spillway (n = 1,032), 9.7 min for those that passed through the JBS (n = 521), and 12.5 min for those that passed through turbine units (n = 143; Table 8 and Figure 12).

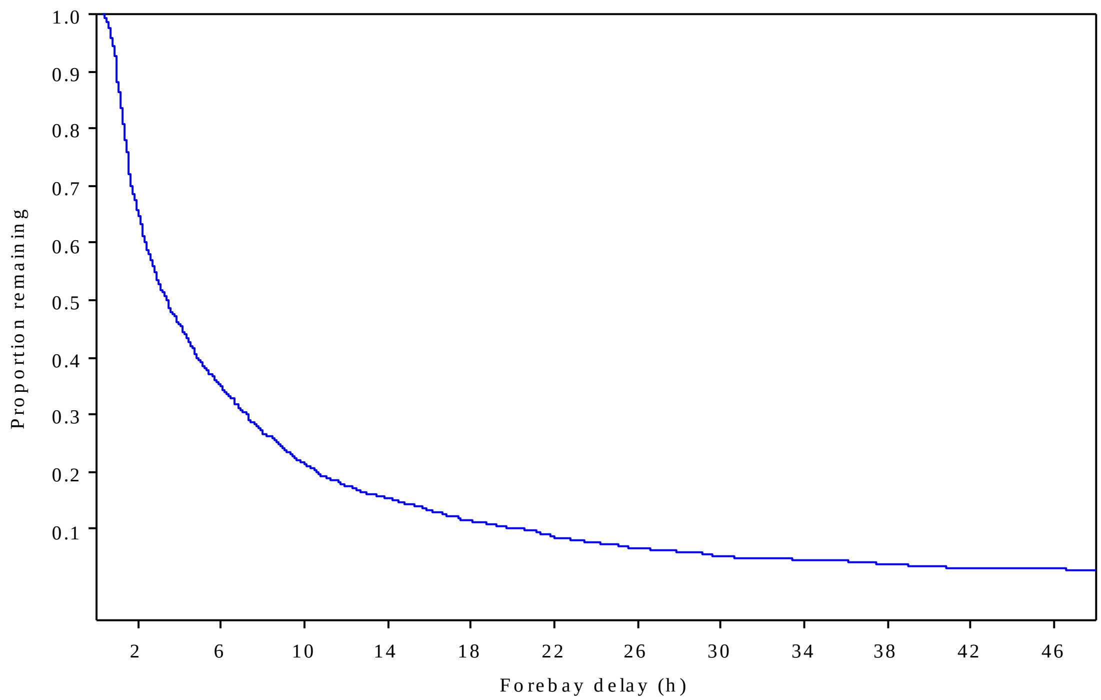

Figure 12. Kaplan-Meier survival curves of tailrace egress (elapsed time in minutes from passage until last detection on the tailrace exit line) for radio-tagged subyearling Chinook salmon passing Lower Monumental Dam, 2009.

Table 8. Tailrace egress timing in minutes for radio-tagged, river-run subyearling Chinook salmon passing through the turbines, JBS, and spillway at Lower Monumental Dam, 2009.

	Tailrace egress time (min)			
Passage percentile	Turbines	JBS	Spillway	Overall
N	143	521	1,032	1,696
Minimum	3.6	0.2	0.1	0.1
10th	7.7	6.3	2.4	3.0
20th	8.9	7.2	3.4	4.3
30th	10.3	8.0	4.2	5.3
40th	11.3	8.8	4.8	6.2
50th (median)	12.5	9.7	5.4	7.4
60th	14.1	10.9	6.2	8.8
70th	15.8	12.7	7.5	10.5
80th	18.9	15.8	9.9	13.5
90th	26.0	29.0	18.9	22.5
Mean	225.6	235.3	154.2	185.2
Mode	11.3	8.1	4.3	4.3
Maximum	9,263.6	11,033.6	11,450.7	11,450.7

Tailrace egress time for fish that passed through the JBS was calculated as the time from PIT-tag detection at the JBS exit to last detection on a tailrace exit transect. By using PIT-tag detections from the JBS exit, which is the farthest downstream detection location in the JBS, travel time through the bypass system was excluded. This provided a truer picture of tailrace egress time for fish that passed via the JBS. Tailrace egress by release date is presented in Table 9.

Table 9. Tailrace egress time for passage of radio-tagged river-run subyearling Chinook salmon through all routes combined at Lower Monumental Dam, 2009. Egress time is shown by forebay passage date for the 10th, 50th (median) and 90th percentiles.

		Tailrace egress (min)		
Forebay passage date	N	10th	50th (median)	90th
10 June	17	1.8	3.8	8.6
11 June	26	4.1	6.7	9.7
12 June	37	3.5	7.9	77.7
13 June	48	3.7	7.2	10.5
14 June	53	3.0	7.5	16.1
15 June	46	3.3	7.9	48.1
16 June	63	3.5	7.0	21.9
17 June	75	3.6	6.3	13.1
18 June	94	3.7	8.2	15.1
19 June	112	2.7	6.4	14.6
20 June	77	3.3	6.7	23.2
21 June	80	3.0	7.6	19.7
22 June	95	3.0	7.1	39.2
23 June	85	2.7	6.5	15.1
24 June	57	2.5	7.2	14.9
25 June	63	2.8	8.1	18.3
26 June	82	3.0	8.1	16.3
27 June	91	3.3	8.6	33.8
28 June	73	2.8	8.0	20.7
29 June	82	2.6	7.1	16.7
30 June	82	2.0	9.2	44.4
1 July	93	2.9	8.6	48.7
2 July	104	3.5	9.1	33.0
3 July	51	4.6	12.1	35.9
4 July	10	5.0	15.5	219.0
All routes	1,696	3.2	7.9	33.4
SE		0.1	0.4	8.4
95% CI		2.1-3.2	7.5-8.3	25.0-41.8

Detection Probability and Estimated Survival

Detection probabilities at the primary survival array for treatment and reference groups were 99.8 and 99.9%, respectively. Overall detection probability for both groups combined was 99.9% (Appendix Table A1).

For treatment fish, relative survival was estimated from the release location to the forebay entry line and from release location to dam passage (through any route). Pooled survival estimates were 0.916 (95% CI, 0.899-0.933) from release to forebay entry and 0.842 (0.819-0.866) from release to dam passage. Relative dam survival (from the forebay BRZ to the tailrace approximately 1 km downstream from the dam) was estimated at 0.862 (0.838-0.888), and relative concrete survival (all passage routes combined to approximately 1 km downstream from the dam) was estimated at 0.929 (0.908-0.951). Estimated relative survival was 0.956 (0.924-0.988) through the RSW and 0.927 (0.899-0.954) through the entire spillway, including the RSW. Relative turbine survival was estimated at 0.891 (0.841-0.941), and relative JBS survival was 0.937 (0.910-0.965).

Relative survival estimates for the dam, concrete, spillway, RSW and JBS by forebay entry date are presented in Table 10. Detection histories of fish used in survival analysis are presented in Appendix D.

Table 10. Subyearling Chinook salmon daily estimates of relative survival at Lower Monumental Dam, 2009. Dam survival includes approximately 500 m of forebay from the boat restricted zone deadline to the concrete.

	Dam survival		Concrete survival	
Date	Estimate	SE	Estimate	SE
10 June	1.017	0.058	1.059	0.043
11 June	0.912	0.049	0.966	0.034
12 June	0.862	0.064	0.941	0.062
13 June	0.800	0.054	0.873	0.045
14 June	0.973	0.039	0.931	0.047
15 June	0.833	0.065	0.914	0.058
16 June	0.884	0.037	0.858	0.043
17 June	0.887	0.045	0.977	0.035
18 June	0.913	0.037	0.975	0.033
19 June	0.886	0.035	0.931	0.030
20 June	0.861	0.044	0.918	0.039
21 June	0.814	0.041	0.939	0.036
22 June	0.771	0.045	0.829	0.041
23 June	0.922	0.035	0.969	0.030
24 June	0.840	0.049	0.937	0.032
25 June	0.772	0.044	0.940	0.034
26 June	0.819	0.036	0.908	0.029
27 June	0.916	0.033	0.958	0.024
28 June	0.872	0.039	0.938	0.031
29 June	0.857	0.038	0.956	0.022
30 June	0.775	0.061	0.852	0.040
1 July	0.865	0.050	0.974	0.038
2 July	0.837	0.039	0.924	0.024
3 July	0.855	0.070	0.867	0.066
Overall geomean	0.862	0.012	0.929	0.010
95% CI	0.838-0.888		0.908-0.951	

Table 10. Continued.

Date	Spillway survival		RSW survival		JBS survival	
	Estimate	SE	Estimate	SE	Estimate	SE
10 June	1.059	0.043	1.059	0.043	1.059	0.043
11 June	1.000	0.000	0.900	0.095	0.923	0.074
12 June	0.911	0.098	1.052	0.036	0.990	0.069
13 June	0.839	0.066	0.957	0.043	0.944	0.054
14 June	1.036	0.026	1.036	0.026	0.858	0.076
15 June	0.878	0.087	1.062	0.029	1.003	0.063
16 June	0.808	0.069	1.011	0.011	0.923	0.060
17 June	0.986	0.041	0.963	0.052	0.972	0.056
18 June	0.936	0.057	0.941	0.063	0.983	0.042
19 June	0.919	0.038	0.943	0.037	0.990	0.036
20 June	0.948	0.041	0.988	0.037	0.818	0.087
21 June	0.948	0.043	0.917	0.050	0.897	0.078
22 June	0.831	0.052	0.979	0.034	0.870	0.068
23 June	0.978	0.036	0.932	0.046	0.971	0.047
24 June	0.983	0.026	0.730	0.084	0.902	0.071
25 June	0.892	0.050	0.939	0.046	1.020	0.014
26 June	0.926	0.036	0.980	0.020	0.885	0.063
27 June	0.961	0.029	0.970	0.029	0.914	0.065
28 June	0.923	0.039	0.987	0.026	0.963	0.048
29 June	0.951	0.028	1.000	0.000	0.950	0.049
30 June	0.831	0.049	0.902	0.046	1.015	0.129
1 July	0.959	0.045	0.964	0.047	0.992	0.058
2 July	0.932	0.029	0.954	0.026	0.893	0.059
3 July	0.855	0.077	0.838	0.092	0.806	0.128
Overall geomean	0.927	0.013	0.956	0.016	0.937	0.013
95% CI	0.899-0.954		0.924-0.988		0.900-0.965	

Avian Predation

A total of 250 radio tags (5.7% of those released) were recovered from subyearling Chinook salmon released to evaluate passage and survival at Lower Monumental Dam in 2009. All 250 tags were recovered on Crescent or Foundation Island, with the majority (241) being recovered on Crescent Island. Of the 250 fish with tags found on avian colonies, 156 (7.6%) had been released below Lower Monumental Dam as reference fish, and 94 (4.1%) had been released above Lower Monumental Dam as treatment fish   Since not all tags of fish consumed by avian predators are dropped on colonies, and not all tags dropped on colonies are recovered, these tag recoveries are considered a minimum estimate of avian predation.

Of the 94 tags from treatment fish, only 6 were last seen in the forebay of Lower Monumental Dam, while 28 were last detected in the JBS at Lower Monumental Dam. The majority of tags recovered from nesting colonies on Crescent and Foundation Islands were from treatment or reference fish last detected in the Ice Harbor pool (103 fish with McNary Dam pool at (40 fish) and Ice Harbor Dam and the Snake River mouth taking another (36 fish)

DISCUSSION

In this report we present findings from the second year of study evaluating behavior and survival of radio-tagged juvenile subyearling Chinook salmon volitionally passing Lower Monumental Dam after RSW installation. Average total river flow in 2009 was 87.3 kcfs compared to 106.4 kcfs in 2008. The 10-year average (1999-2008) project discharge during this period was 65.6 kcfs, and project discharge during the two baseline years prior to the RSW installation averaged 50.6 kcfs in 2006 and 38.7 kcfs in 2007.

As in previous years, during 2009 the majority (68%) of subyearling Chinook salmon approached Lower Monumental Dam through the thalweg of the river, in the middle of the dam near the RSW (Absolon et al, 2007; 2008a, 2008b). The percent of river flow spilled was slightly lower in 2009 (22%) than in 2008 (24%). Forebay residence time was longer in 2009 than in 2008 (3.4 vs. 2.3 h), which was likely related to the lower flows and percentages of spill in 2009 compared to 2008. Tailrace egress time was slightly longer in 2008 (8 min) than in 2009 (7 min).

With river flows lower in 2009, a higher percentage of fish passed the dam through the RSW in 2009 (49%) compared to 2008 (24%). The higher flows in 2008 resulted in more subyearling Chinook salmon passing Lower Monumental Dam via the powerhouse (JBS and turbine combined, 59%) compared to the proportion that passed via the powerhouse in 2009 (38%). The higher passage proportion through the spillway and RSW during 2009 increased both spill efficiency and effectiveness in 2009 compared to 2008 (in 2008 and 2009, respectively, spill efficiency was 0.404 and 0.615 and spill effectiveness was 1.46 and 2.74; Table 11).

During 2009, high estimates of survival for fish passing through the RSW in Spillbay 8 (95.6%) and the JBS (93.7%; Table 12), combined with the high proportion of fish passing through these two routes (79%), resulted in an estimated concrete survival rate of 92.9%. This rate of survival was just below the standard of 93% for subyearling Chinook salmon prescribed by the 2008 Biological Opinion (NMFS 2008).

Estimates of relative survival for fish passing through spillbays 1-7 were much lower (geomean 80.3%) than those of fish passing via the RSW (geomean 95.6%). Lower estimates of survival through these spillbays contributed to an overall geomean estimate of survival that was lower for concrete than for either the JBS or the RSW. Spill patterns that reduce the tailrace eddy or decrease the number of fish passing through spillbays 1-7 may increase concrete survival in similar flow years to levels that meet or exceed standards of the 2008 Biological Opinion.

Table 11. Summary of conditions and behavior for radio tagged subyearling Chinook salmon passing Lower Monumental Dam, 2006-2009 (95% confidence intervals in parentheses).

	2006	2007	2008	2009
Average spill (%)	32	50	24	22
Average spill volume (kcfs)	16.1	19.5	25.5	19.2
Average Project discharge (kcfs)	50.6	38.7	106.4	87.3
Average spillway passage (%)	82	91	40	61
Average JBS passage (%)	12	7	46	30
Average turbine passage (%)	7	2	13	8
Fish passage efficiency	0.947 (0.925-0.968)	0.982 (0.971-0.993)	0.866 (0.849-0.883)	0.918 (0.905-0.931
Spill efficiency	0.820 (0.754-0.886)	0.914 (0.876-0.951)	0.404 (0.380-0.428)	0.615 (0.592-0.637)
Spill effectiveness	2.58 (2.39-2.77)	1.84 (1.75-1.93)	1.46 (1.37-1.54)	2.74 (2.64-2.84)
RSW efficiency	n/a	n/a	0.24 (0.189-0.281)	0.493 (0.470-0.517)
RSW effectiveness	n/a	n/a	3.33 (3.30-3.36)	5.913 (5.633-6.194)
Fish guidance efficiency	0.645 (0.480-0.810)	0.796 (0.681-0.911)	0.775 (0.749-0.802)	0.787 (0.756-0.818)
Median forebay residence time (h)	2.7	3.6	2.3	3.4
Median tailrace egress time (min)	11	13	8	7

Table 12. Relative survival estimates for subyearling Chinook salmon passing Lower Monumental Dam, 2006-2009 (95% confidence intervals in parentheses). All estimates are a geomean except estimates of Spillbay 2, Spillbay 6, and the JBS in 2007 which were pooled estimates. Passage through Spillbay 8 during 2008 and 2009 was through the RSW.

	Relative passage survival for subyearling Chinook salmon			
Route	2006	2007	2008	2009
Dam	0.896 (0.888-0.904)	0.762 (0.690-0.841)	0.879 (0.835-0.925)	0.862 (0.838-0.888)
Concrete	0.943 (0.936-0.950)	0.845 (0.807-0.883)	0.932 (0.888-0.979)	0.929 (0.908-0.951)
Spillway	0.943 (0.918-0.968)	0.838 (0.797-0.882)	0.920 (0.864-0.980)	0.927 (0.899-0.954)
Spillbay 8*	0.970 (0.976-0.995)	0.903 (0.862-0.945)	0.974 (0.920-1.032)	0.956 (0.924-0.988)
Spillbay 6	0.909 (0.828-0.998)	0.779 (0.700-0.867)	Not estimated	Not estimated
Spillbay 2	Not estimated	0.697 (0.586-0.829)	Not estimated	Not estimated
JBS	Not estimated	0.949 (0.750-1.149)	0.928 (0.866-0.994)	0.937 (0.900-0.965)

* RSW bay in 2008 and 2009

Overall avian predation of subyearling Chinook salmon from tag recoveries on Crescent and Foundation Island bird colonies during 2009 was 5.8% of those released and almost twice the rate of 2.9% in 2008. Among passage routes, 5.1% of the subyearling Chinook salmon last detected in the JBS were subsequently recovered from these avian colonies. Improvements in the JBS outfall location would likely increase JBS and concrete survival by reducing the avian predation on fish passing via this route.

CONCLUSIONS AND RECOMMENDATIONS

1.) Evaluate RSW Performance over a Wider Range of Conditions

Both evaluations of RSW performance (2008 and 2009) were conducted during above-average flow conditions. Average project discharge was 106 kcfs during 2008 and 87 kcfs during 2009, while the 10-year average (2000-2009) was only 66 kcfs. High flow generally produces higher survival estimates because it reduces migrational delay and exposure to predators. Thus, the survival estimates obtained during 2008 and 2009 may not be representative of typical performance during a normal flow year. The RSW at Lower Monumental Dam should be evaluated during normal and low flow conditions to provide insight into passage behavior and survival for subyearling Chinook salmon under flow conditions they are likely to encounter in future years.

2.) Relocate JBS Outfall to Decrease Vulnerability to Predation

On 14 April 1999, a transport barge collided with the JBS outfall pipes at Lower Monumental Dam. As a temporary repair, the USACE shortened the bypass pipes by 7 m. Therefore, since 1999, fish have been returned to the river closer to the shoreline and into a flow environment that allows predators to maintain station. In 2009, at least 5.1% of the subyearling Chinook salmon that passed Lower Monumental Dam via the JBS were taken by avian predators shortly after returning to the river in the tailrace. Of all tagged subyearling Chinook salmon passing Lower Monumental Dam, 46% passed via the JBS in 2008 and 30% passed using this route in 2009.

A permanent repair is needed to relocate the JBS outfall to an area that is further from the shoreline, where river depth is greater and water velocities higher. This work would likely increase both JBS and concrete survival. One possible relocation site, which would likely increase JBS survival, is near the tailrace release site used for this study. In 2009, survival of tailrace release groups was 5.9% higher than that of fish passing through the JBS. Improvements in the avian predation management program could also improve JBS survival.

3.) Develop PIT-Tag Detection for Surface Passage

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 installed in 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. This decrease in JBS passage has reduced PIT-tag detection probability at Lower Monumental Dam and subsequently reduced the precision of PIT-tag survival estimates.

Because of their size, active tags such as radio or acoustic telemetry tags remain unsuitable for evaluation of passage and survival for most wild subyearling Chinook and sockeye salmon stocks. In 2008 and 2009, 70-79% of PIT-tagged subyearling Chinook salmon passed either through the JBS or the RSW. Development of PIT-tag detection capability in the RSW at Lower Monumental Dam would provide a means of obtaining passage information for these fish. Increased PIT-tag detection of smolts at Lower Monumental Dam will result in more precise estimates of reach survival than those obtained in 2008 and 2009.

During 2008 and 2009, higher-than-average flows likely reduced proportions passing through the RSW for some stocks and increased proportions passing 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 and 2009, while the proportion passing through the RSW would likely be higher. The addition of PIT-tag detection capability in the RSW would provide information on surface passage, general passage behavior, and survival for sockeye salmon, wild stocks, and summer migrants. For these smaller fish, the PIT-tag is often the only viable option, as they are either too small for active tags at the time of migration or they migrate when temperatures are not conducive to handling and tagging (and must therefore be tagged earlier, and at a smaller size).

4.) Develop a Systematic Avian Predation Monitoring Program

The USACE collects project operations data at Lower Monumental Dam every 5 min, and this information has been extremely useful for interpreting relationships between operating conditions and juvenile passage behavior and survival. Avian predators can have a significant impact on survival of juvenile fish; however, the USACE does not have a systematic monitoring program to assess avian presence and activity at Lower Monumental Dam. Development of a systematic avian monitoring program at Lower Monumental Dam would provide important insight when interpreting survival estimates in relation to project operations.

5.) Assess Effects of RSW Operations on Adult Passage

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

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APPENDIX A

Evaluation of Study Assumptions

We used the CJS model (Cormack 1964; Jolly 1965; Seber 1965) to estimate survival of radio-tagged subyearling Chinook salmon released above and below Lower Monumental Dam. Ratios of treatment to reference survival estimates 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.

Radio-telemetry detection probability at our primary survival array 16 km downstream of the dam approached 100%, with only 3 fish detected downstream that were not detected at the primary survival array. With detection probabilities at or near 100% for both groups, there was no disparity between detection probabilities of treatment and reference groups (Appendix Table A1).

Appendix Table A1. Detections at and below the primary survival array (16 km downstream of the dam) and detection probabilities at the primary survival array for evaluating survival of hatchery subyearling Chinook salmon passing Lower Monumental Dam, 2009.

Release group	Detection at primary array or below	Detection below primary array	Detection probability of fish at the primary survival array
Treatment	1,166	1,168	0.998
Reference	1,436	1,437	0.999
Totals	2,602	2,605	0.999

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

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 the release groups have similar passage distributions at downstream detection sites, in this case, the primary and secondary survival arrays 16 km and 50 km downstream of the dam. To evaluate this assumption, we compared passage date percentiles (10th, 20th,…80th, 90th) at both sites for treatment fish versus reference fish. Treatment fish were grouped into virtual release groups based on the date of passage and were "paired" with reference fish that were grouped were released on the same date. These were the same pairings used in the survival analysis. Confidence intervals (95%) and *t*-tests were constructed for statistical comparison. In addition, the reasonableness of the assumption was evaluated based on the biological size of these differences.

Test of homogeneity of arrival distributions at the primary survival array was statistically significant for all percentiles except the 10^{th}, 60^{th}, 80^{th}, and 90^{th} (Appendix table A2). In general the reference fish arrived at the primary survival array after the treatment fish except for the 90^{th} percentile. These differences ranged from -0.23 days (-5.5 h) to 0.02 days (0.6 h). We believe differences of only a few hours in arrival distributions were unlikely to have been biologically meaningful and thus it is reasonable to conclude that the survival estimates were not significantly biased by violation of the assumption regarding mixing through the common reach.

Appendix Table A2. Test of homogeneity of arrival timing at the primary survival array for treatment and reference groups of radio-tagged hatchery subyearling Chinook salmon used for estimating survival at Lower Monumental Dam, 2009. Negative numbers indicate reference fish arriving later than treatment fish at the primary survival array. Shaded cells indicate significant differences in passage timing among tests (α = 0.05).

Group date	Arrival difference at the primary survival array (days)								
	10th	20th	30th	40th	50th	60th	70th	80th	90th
10 June	-0.478	-0.507	-0.416	-0.416	-0.431	-0.571	-0.426	-0.267	0.047
11 June	0.015	0.048	-0.194	-0.150	-0.061	0.143	0.003	-0.005	0.001
12 June	-0.003	-0.068	-0.321	-0.349	-0.408	-0.549	-0.440	-0.390	-0.109
13 June	0.054	0.118	0.216	0.018	0.045	0.112	0.050	0.049	0.046
14 June	-0.006	-0.228	-0.232	-0.156	-0.075	-0.108	-0.145	0.012	0.026
15 June	-0.017	-0.277	-0.275	-0.190	0.032	0.011	-0.046	0.023	0.033
16 June	-0.028	-0.376	-0.398	-0.366	-0.273	-0.229	-0.136	-0.001	0.024
17 June	-0.031	-0.310	-0.297	-0.106	0.093	0.163	0.088	0.016	0.032
18 June	0.002	-0.001	-0.311	-0.333	-0.361	-0.357	-0.354	-0.133	-0.018
19 June	-0.006	-0.017	-0.355	-0.395	-0.365	-0.271	-0.150	-0.118	0.006
20 June	0.055	0.138	-0.149	-0.137	-0.098	0.082	0.047	0.038	0.029
21 June	0.024	0.004	-0.167	-0.105	-0.037	-0.038	-0.005	0.051	0.033
22 June	-0.034	-0.028	-0.279	-0.240	-0.053	0.078	-0.007	0.000	-0.016
23 June	-0.039	-0.054	-0.208	-0.206	-0.245	-0.109	-0.085	-0.089	-0.029
24 June	-0.701	-0.744	-0.581	-0.493	0.535	0.358	0.328	0.353	0.406
25 June	0.010	0.052	-0.144	-0.040	0.028	-0.012	0.003	0.041	0.035
26 June	0.033	0.068	-0.141	-0.131	-0.106	-0.053	-0.032	0.009	0.011
27 June	0.079	0.094	-0.097	-0.043	-0.003	-0.026	-0.073	-0.059	0.005
28 June	0.003	0.137	-0.098	-0.085	-0.020	-0.069	-0.078	-0.008	0.015
29 June	0.068	-0.162	-0.172	-0.173	-0.144	-0.070	-0.111	-0.043	0.011
30 June	0.057	0.035	-0.161	-0.163	-0.113	-0.069	-0.055	-0.036	0.027
1 July	0.003	-0.052	-0.211	-0.214	-0.078	-0.071	0.052	0.033	0.016
2 July	-0.004	-0.321	-0.364	-0.323	-0.330	-0.341	-0.404	-0.309	-0.083
Summary (mean difference in days)									
Mean	-0.041	-0.107	-0.233	-0.208	-0.107	-0.087	-0.086	-0.036	0.024
SE	0.037	0.047	0.032	0.028	0.044	0.046	0.038	0.030	0.019
P	0.285	0.034	0.000	0.000	0.022	0.072	0.032	0.245	0.225
Lower 95% CI	-0.118	-0.205	-0.299	-0.267	-0.198	-0.182	-0.164	-0.100	-0.016
Upper 95% CI	0.037	-0.009	-0.167	-0.150	-0.017	0.009	-0.008	0.027	0.063

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

River-run hatchery subyearling Chinook salmon were collected at the Lower Monumental Dam smolt monitoring facility from 6 June to 3 July. Subyearling Chinook salmon, not previously PIT-tagged, without any visual signs of disease or injuries, and weighing 9 g or more were used. The tagging period encompassed the passage period between the 53rd and 88th percentile based on the 10-year average subyearling Chinook salmon smolt index at Lower Monumental Dam. Overall mean length of study fish was 113 mm for fish released both upstream and downstream from Lower Monumental Dam (Table 2). The overall mean length of river-run subyearling Chinook salmon collected at the Lower Monumental Dam Smolt Monitoring Facility during the study period was 101 mm (Table 3). Mean overall weight of both treatment and control fish was 13 g (Table 4).

The study encompassed about 35% of the subyearling Chinook salmon migration period, and the mean length of study fish was greater than that of river-run fish overall. Either (or both) of these conditions may have violated assumption A3, and should be kept in mind when considering the results. However, for the relative survival estimates, fish sizes and release dates were not different between treatment and reference groups.

A4. The tag and/or tagging method does 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 has previously been evaluated by Adams et al. (1988) and Hockersmith et al. (2003). From 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.

Assumption A5 was not vigorously tested for validation in this study. The distance between the release at Lower Monumental Dam and the primary survival array was 16 km. Axel et al. (2003) found that dead radio-tagged fish released into the bypass systems at Ice Harbor and McNary Dams were not subsequently detected at telemetry transects, more than 3.2 km downstream. We released 63 tagged fish that had died prior to release at the reference release location and none were detected on downstream arrays.

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, 36 (0.8%) could not be activated and were therefore not used. Tags were checked again prior to release, to ensure that the transmitter was functioning properly. Several tags were held out of each days tagging to evaluate tag life performance. Of the 69 tags that were held to evaluate tag performance, 99% ran at least 8 days (Appendix Table A3). Although we documented transmitter failures during our study, the short travel times (Appendix Table A4) to our survival array and the relatively low failure rate were such that these failures would not have significantly changed our findings.

Appendix Table A3. Transmitter battery life testing, 2009.

Tags (n)	Tags (%)	Battery life (d)
0	0.0	1
0	0.0	2
0	0.0	3
0	0.0	4
1	1.4	5
1	1.4	6
2	2.9	7
2	2.9	8
6	8.7	9
57	82.6	10

Appendix Table A4. Travel time from release to detection at the primary survival array for radio tagged subyearling Chinook salmon released into the forebay and tailrace of Lower Monumental Dam, 2009.

	Travel time (d) to primary survival array by release location and species	
	Yearling Chinook salmon	
Percentile	Forebay	Tailrace
10	0.5	0.1
20	0.6	0.1
30	0.7	0.1
40	0.8	0.1
50	0.9	0.1
60	1.1	0.1
70	1.3	0.1
80	1.6	0.2
90	2.2	0.3
Max	7.0	5.7
Time ≥ 5 d	16 (0.9%)	1 (0.1%)
n	1,773	2,000

A7. Treatment fish that pass through a specific route are appropriately assigned to that route.

The route of passage for individual fish was determined from telemetry receivers and antenna arrays that monitored individual turbine intakes, individual spillbays, and the JBS. Passage routes were assigned to individual fish based on the last detection within a passage route and confirmed by subsequent detection in the immediate tailrace. Tailrace detections were used to validate passage because it was possible for fish to be detected on a passage array while still in the forebay. Prior to the start of study extensive field testing was conducted to tune and balance detection fields. During the study beacon tags that transmitted 6 times every hour on each frequency were used to monitor the performance of each site. The combination of pre-study system tuning and balancing with the study performance monitoring were instrumental in ensuring that fish were appropriately assigned to passage routes.

APPENDIX B

Telemetry Data Processing and Reduction Flowchart

Data Collection and Storage

Data from radiotelemetry studies are stored in the Juvenile Salmon Radiotelemetry 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 analysis.

The processed 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 B1.

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 store the data in preliminary tables.

Data Validation

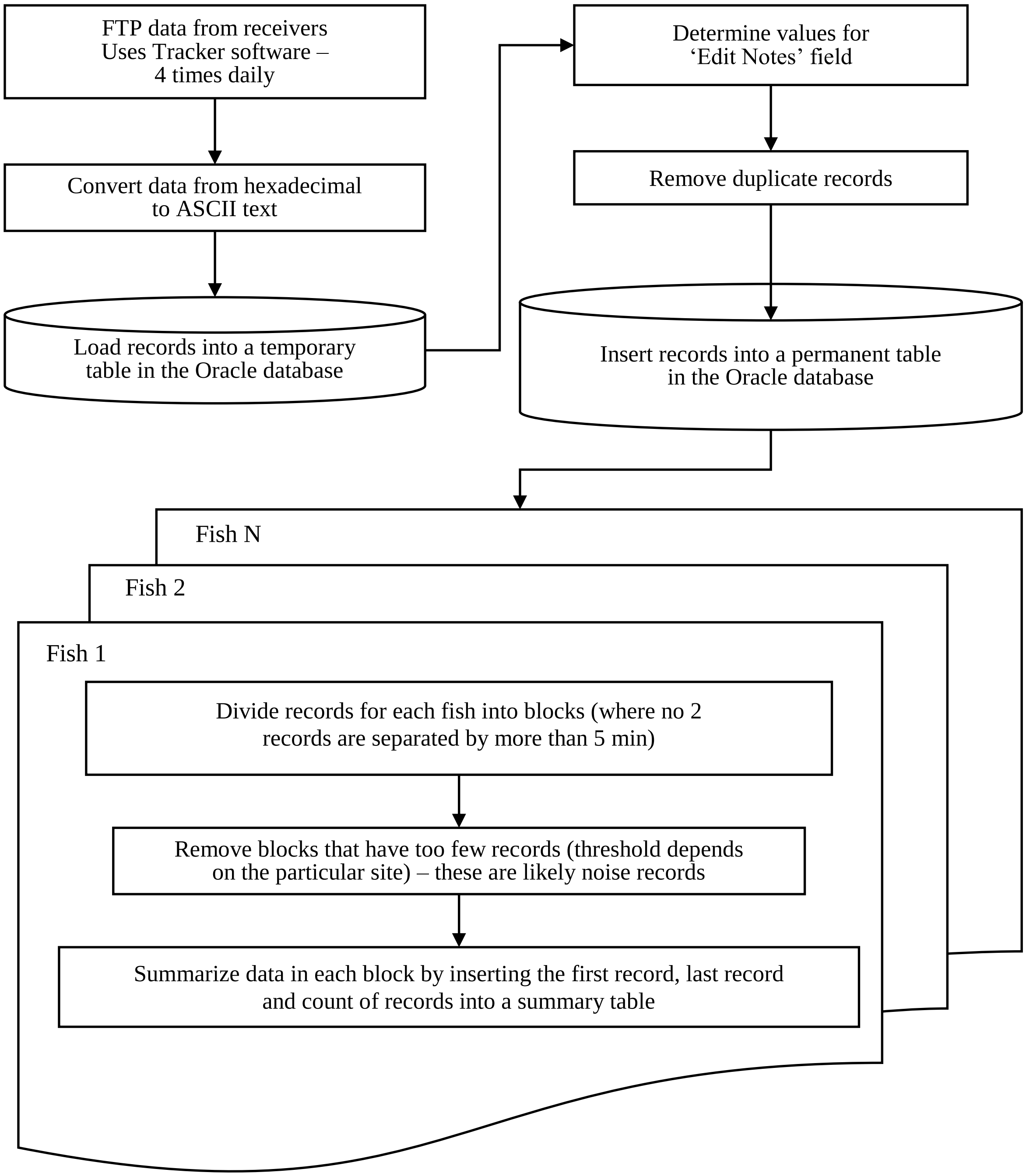
During the validation process, the records stored in the preliminary tables are analyzed. We determine the study year, site identifier, antenna identifier, and tag identifier for each record, flagging them as invalid if one or more of these identifiers cannot be determined. Records are flagged by storing 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 at tag was activated (its start time).
Gt end time:	Assigned to records occurring after the end time on a tag (tags run for 10 d once activated).

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 had 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 the count of detections for blocks for 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 B1. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival at Lower Monumental Dam for subyearling Chinook salmon, 2009.

APPENDIX C

Spill Pattern

Appendix Figure C1. Lower Monumental Dam spill pattern for 2009. RSW in Spillbay 8 has a flow equivalent of 4.5 stops at elevation 537.0 ft msl. Summer spill pattern is shaded.

Spill bay/stops								Total	
1	2	3	4	5	6	7	8	Stops	Spill
0	1	0	0	0	0	0	R	5.5	7.9
0	2	0	0	0	0	0	R	6.5	9.6
0	2	0	0	0	1	0	R	7.5	10.7
0	2	0	0	0	2	0	R	8.5	12.4
0	2	0	0	0	3	0	R	9.5	14.1
0	2	0	0	0	4	0	R	10.5	15.8
0	3	0	0	0	4	0	R	11.5	17.5
0	3	0	0	1	4	0	R	12.5	18.6
0	3	0	0	1	5	0	R	13.5	20.3
1	3	0	0	1	5	0	R	14.5	21.4
1	1	1	1	1	6	0	R	15.5	21.9
1	1	1	1	2	6	0	R	16.5	23.6
1	1	1	2	2	6	0	R	17.5	25.3
1	1	1	2	4	5	0	R	18.5	27.0
1	1	1	2	5	5	0	R	19.5	28.7
2	1	1	2	5	5	0	R	20.5	30.4
2	1	2	2	5	5	0	R	21.5	32.1
2	2	2	2	5	5	0	R	22.5	33.8
3	2	2	2	5	5	0	R	23.5	35.5
3	3	2	2	5	5	0	R	24.5	37.2
3	3	2	2	5	5	1	R	25.5	38.3
3	3	2	2	5	5	2	R	26.5	40.0
3	3	2	3	5	5	2	R	27.5	41.7
3	3	3	3	5	5	2	R	28.5	43.4
3	3	3	3	5	6	2	R	29.5	45.1
3	3	3	3	6	6	2	R	30.5	46.8
3	3	3	3	6	6	3	R	31.5	48.5
3	3	3	3	6	6	4	R	32.5	50.2
3	3	3	3	6	6	5	R	33.5	51.9
3	3	3	3	6	6	6	R	34.5	53.6
3	3	3	4	6	6	6	R	35.5	55.3
3	3	4	4	6	6	6	R	36.5	57.0
3	4	4	4	6	6	6	R	37.5	58.7
4	4	4	4	6	6	6	R	38.5	60.4
4	4	4	5	6	6	6	R	39.5	62.1
4	4	5	5	6	6	6	R	40.5	63.8
4	5	5	5	6	6	6	R	41.5	65.5
5	5	5	5	6	6	6	R	42.5	67.2

APPENDIX D

Detection History Data

Appendix Table D1. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate dam passage survival in 2009. The primary survival array was 16 km downstream from the dam; additional downstream arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection histories for dam survival estimates		
	Primary survival array	Post primary array	N
Treatment group (2,302)			
	0	0	540
	1	0	594
	0	1	2
	1	1	1,166
Reference group (2,050)			
	0	0	49
	1	0	565
	0	1	1
	1	1	1,436

APPENDIX E

Study Summary

Year: 2009
Study site: Lower Monumental Dam

Objectives of study:

Evaluation of:	Forebay residence time	Passage distribution
	Fish passage efficiency	Spill effectiveness
	Fish guidance efficiency	Route-specific survival
	Project survival	Tailrace egress timing

Fish: Species-race: river-run subyearling Chinook salmon
Source: Lower Monumental Dam smolt monitoring facilities

Fish size:	Length	Weight
	median: 113 mm	median: 12.6 g
	range: 101-157 mm	range: 9-43 g

Tag: Type: Advanced Telemetry Systems
Weight (g): 0.698 in air Volume (mm^3): 268

Implant procedure: surgical, study fish also PIT tagged at time of surgery

Survival estimates

Type	Value	SE	Sample size for replicates	No. of replicates	Analytical model
Dam	0.862	0.012	mean 82 (range 26-125)	24	CJS
Concrete	0.929	0.010	mean 81 (range 17-123)	24	CJS
Spillway	0.927	0.013	mean 46 (range11-74)	24	CJS
RSW	0.956	0.016	mean 37 (range 9-65)	24	CJS
JBS	0.937	0.013	mean 23(range 5 -44)	24	CJS

Passage metrics

FPE	0.918	0.013	1,827	Pooled	
SPE	0.615	0.022	1,827	Pooled	
Spill effectiveness	2.74	0.100	1,827	Pooled	
FGE	0.787	0.031	704	Pooled	

Characteristics of estimate: survival estimates are relative to tailrace (control) releases

Environmental/operating conditions

Daily operations/conditions	Mean	Range
Spill (%)	22	15.9-29.4
Total river flow (kcfs)	87	64.3-119.6
Water temperature (°C)	15.8	14.0-18.4