Passage Behavior and Survival for Radio-Tagged Subyearling Chinook Salmon at Lower Monumental Dam, 2007

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EXECUTIVE SUMMARY

This study was initially designed to evaluate passage of subyearling Chinook salmon with a removable spillway weir (RSW) at Lower Monumental Dam. The RSW was scheduled for installation at the dam in spillbay 8 prior to the 2007 juvenile salmonid migration season. Due to construction delays, installation of the RSW was postponed until spring 2008. Although the RSW could not be installed in time for the 2007 juvenile salmonid migration, a decision was made in April 2007 to continue with the study in order to collect additional baseline information on subyearling Chinook salmon behavior and passage survival.

River-run subyearling Chinook salmon were collected at Lower Monumental Dam from 12 June through 4 July. Fish were surgically tagged with both a radio and PIT tag, and evaluations were based on detection at the primary telemetry array, 16 km downstream from the dam.

Data from fish reaching the forebay entry line from 13 June through 4 July were used in the analysis, which included the 57th through the 85th percentiles of the cumulative subyearling Chinook salmon passage index at Lower Monumental Dam. We released 860 and 833 radio-tagged fish into the forebay and tailrace of Lower Monumental Dam, respectively. Releases were made twice per day during the study period.

Of the 860 fish released into the forebay, only 571 were used in the evaluation of relative survival. The number of fish not detected after release was higher than expected for this time of year. In previous years, at both Ice Harbor and Lower Monumental Dams, we have had lower detection rates for fish released after about 4 July, but relatively high detection rates before that date. The fate of these fish is unknown, but likely includes being consumed by predators, not moving downstream to the detection arrays, or not moving downstream until after the life of the radio tag had expired. Average total river flow was lower in 2007 (38.4 kcfs) than either 2006 (68.8 kcfs) or the 10-year average (62.8 kcfs) for the study period, which may have contributed to the lower than expected detection rates.

Estimated relative dam survival was 0.762 (95% CI, 0.690-0.841), relative concrete survival was 0.845 (0.807-0.883), relative spillway passage survival was 0.838 (0.797-0.882), and through Spillbay 8 was 0.903 (0.862-0.945). Pooled relative survival estimates for Spillbay 6 and Spillbay 2 were 0.779 (0.700-0.867) and 0.697 (0.568-0.829), respectively. The pooled relative survival estimate for fish passing through the juvenile bypass system was 0.949 (0.750-1.149). All estimates were geometric means.

Spillway passage was estimated at 91.4%, juvenile bypass passage at 6.9%, and turbine passage at 1.8%. There were 10 fish (1.2% of fish released into forebay) that passed the dam via an unknown route. Spill efficiency was estimated at 0.914 (95% CI, 0.890-0.937), fish guidance efficiency at 0.796 (0.681-0.911), and fish passage efficiency at 0.982 (0.971-0.993). Median overall forebay residence time was 3.6 h (range 0.3-141.5 h), and median tailrace egress time was 13.1 min (range 1.3-10,673.6 min).

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INTRODUCTION

The Columbia and Snake River Basins have historically produced some of the largest runs of Pacific salmon *Oncorhynchus* spp. 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). Factors associated with human activities 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 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 smolts passing Bonneville Dam spillway during the 1940s. Based on a review of 13 estimates of spillway mortality published from 1961 to 1995, Whitney et al. (1997) concluded that the most likely range of mortality rates for fish passing standard spillways is 0 to 2%.

Similarly, recent survival studies on 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), project operations at Lower Monumental Dam have relied on a combination of voluntary spill and collection of fish for transportation to improve hydrosystem passage survival for migrating juvenile salmonids.

The current spill program at Lower Monumental Dam calls for voluntary spill to achieve goals for both fish passage efficiency and total dissolved gas levels. In 2002, the U.S. Army Corps of Engineers (USACE) modified the spillway at Lower Monumental Dam by adding flow deflectors to the end bays in conjunction with a contract to repair damage to the stilling basin. With the addition of end-bay flow deflectors, new spill patterns using all eight bays were developed prior to the 2003 juvenile salmonid migration. In 2003, after construction of end-bay deflectors at Lower Monumental Dam, radiotelemetry studies were initiated to evaluate spillway survival (Hockersmith et al. 2004, 2005, 2007, 2008a,b; Absolon et al. 2007).

The present study was initiated by the Walla Walla District USACE to evaluate a removable spillway weir (RSW) scheduled for installation prior to the 2007 juvenile salmonid migration. However, delays in construction caused a postponement of the installation until the fall of 2007. We proceeded with the study to collect additional baseline data to supplement the background data we collected during 2005-2006.

No specific operations were requested for this study, and thus passage metrics were evaluated under extant flow conditions. A bulk spill pattern, with spill limited by the "gas cap" was used through 20 June, with most flow passing through spillbays 6 and 8. This "gas cap" was generally found to be 25-40 kcfs, and was based on maintaining total dissolved gas (TDG) levels below the mandated limits of 120% in the tailrace of Lower Monumental Dam or 115% in the forebay of Ice Harbor Dam. From 21 June through the end of the study period, spill was 17 kcfs.

This study was conducted with the same telemetry equipment and personnel used during the spring evaluation of yearling Chinook salmon and steelhead at Lower Monumental Dam (Hockersmith et al. 2008b). Telemetry equipment was located at the same sites as in 2006.

METHODS

Study Area

The primary study area included a 27-km reach of the Snake River extending from the forebay entrance line (9 km upstream from Lower Monumental dam at river kilometer 589) to the primary telemetry 18 km downstream from the dam at rkm 571 (Figure 1). In 2006, the primary telemetry array was moved approximately 8 km downstream from the Windust Park location used in previous years to Burr Canyon. This was done to further ensure that fish that died during dam passage would not reach the survival line and be recorded as live fish. Thus, this potential for bias in the estimates was effectively eliminated. Additional data were obtained from telemetry receivers located at Ice Harbor Dam (rkm 537).

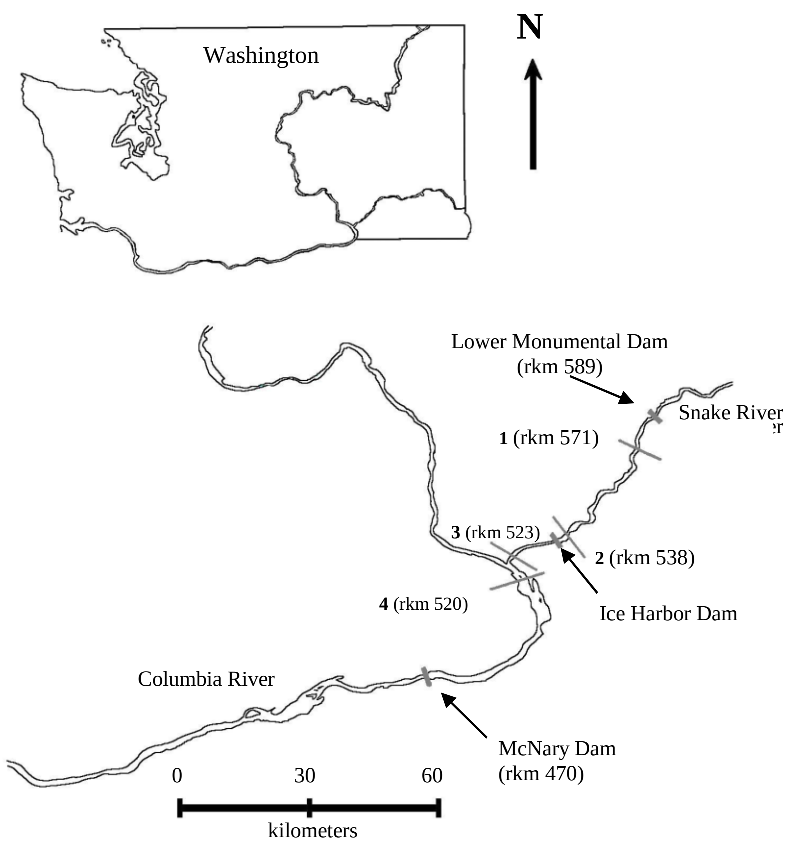

Figure 1. Study area and location of telemetry transects used to estimate survival of subyearling Chinook salmon at Lower Monumental Dam in 2007. Transect locations were 1= Burr Canyon, 2 = forebay of Ice Harbor Dam, 3 = Sacajawea State Park, and 4 = Burbank railroad bridge. The forebay, tailrace, and all routes of passage at Lower Monumental and Ice Harbor Dams were also monitored.

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were collected primarily at the Lower Monumental Dam smolt collection facility, with additional fish collected at the Little Goose Dam smolt collection facility. We chose fish that did not have any gross injury or deformity and were of sufficient size for tagging. Minimum sizes for tagging were 95 mm fork length or 10 g. The minimum fish-size criteria was chosen to ensure a tag burden of less than 7.5% 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 of fish was obtained each day. Only fish not previously tagged with a passive integrated transponder (PIT) were used. The number of fish tagged each day was not weighted to the passage index. For analysis, each day was considered a replicate, so it was important that similar numbers of fish were released each day.

Fish were anesthetized with tricaine methane sulfonate (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 radio-transmitter implantation.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[†] had a predetermined tag life of 10 d, and were pulse-coded for unique identification of individual fish. Each radio tag weighed 0.691 g in air, measured an average of 12 mm in length, and had an average maximum width of 5 mm, bringing the volume of the tag to 240 mm^3.

Fish were surgically implanted with a radio transmitter using techniques described by Adams et al. (1998). A PIT tag was inserted with the radio transmitter during the surgical procedure to facilitate data collection on tagged fish, and potentially to add data from PIT-tag detections of fish at downstream facilities. Tagging was conducted simultaneously at three tagging stations. Immediately following 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 of the container to allow an exchange of water during holding. During tagging and holding, all containers were supplied with flow-through water at ambient temperature and were aerated with oxygen during transport to release locations.

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

After tagging, fish were held a minimum of 24 h with flow-through water for recovery and determination of post-tagging mortality. After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas (the forebay and tailrace).

Treatment groups were transferred in the recovery buckets from the holding tanks to a release tank mounted on an 8.5- by 2.4-m barge, transported to the release location, and released mid-channel water-to-water. Releases of treatment fish were done over a short period of time, allowing for travel time to the forebay entry line, to spread arrival over the diel period. 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, fish were maintained via 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 both during the day and at night. These 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.

For releases of treatment fish, median start times for morning and afternoon releases were 0855 and 1347 PDT, respectively. For daytime releases of reference fish, median start time was 0900 and median end time 1500. For nighttime releases of reference fish, median start time was 2059 and median end time was 0300. Treatment fish were released twice per day in 18 groups of approximately 24 fish per group. A total of 860 radio-tagged fish were released 9-km upstream (treatment) and a total of 833 radio-tagged fish were released 1.2 km downstream (reference) of Lower Monumental Dam (Figure 2).

Treatment fish were released in the same location in all 3 years of the study. Releases have been made twice per day in all 3 years, though timing of the releases has varied due to logistical and safety obstacles. Treatment fish were regrouped for analysis based on time of arrival at the forebay entrance detection line; therefore, differences in time of release were not likely to have affected the results.

Reference groups were released twice per day over several hours in all 3 years of the study. The release location was changed this year from a barge near the north shore to the flume release on the shore adjacent to the previous years release location.

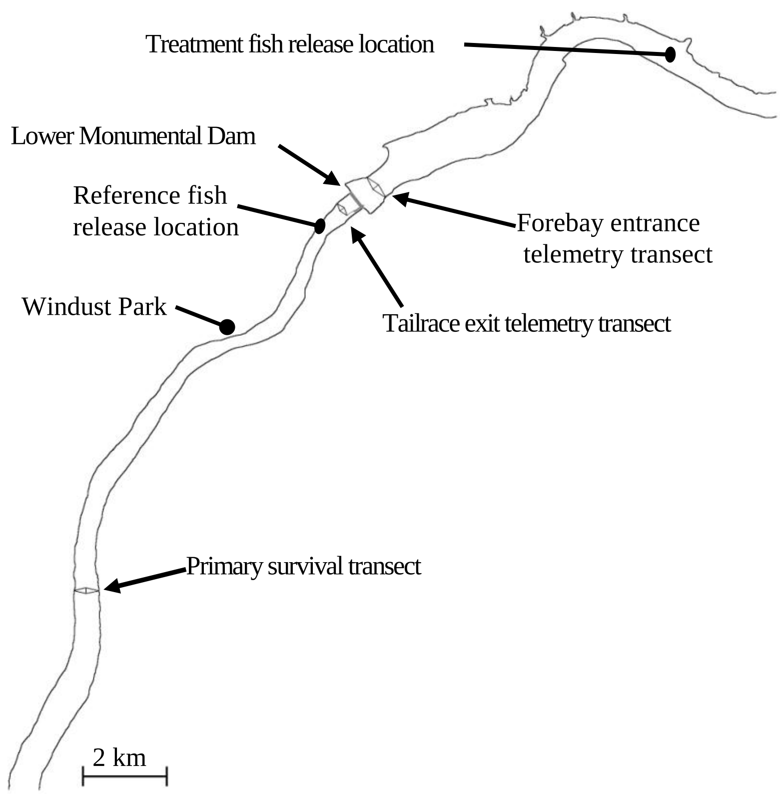

Figure 2. Lower Snake River and Lower Monumental Dam (rkm 589) showing release locations for treatment (rkm 598) and reference groups (rkm 587) of radio-tagged subyearling Chinook salmon, 2007. Also shown are radiotelemetry transects used to detect fish entering the forebay (rkm 590), leaving the tailrace (rkm 589), and to evaluate survival (rkm 571).

Monitoring and Data Analysis

Radiotelemetry receivers and multiple-element aerial antennas were used to establish detection transects between the forebay of Lower Monumental Dam and the primary survival transect near Burr Canyon (Figure 1). Receivers using underwater dipole or multiple-element aerial antennas were used to monitor entrance into the forebay and approach to and exit from the dam. Underwater antennas were used to monitor passage routes (Figures 2 and 3). Monitored passage routes included the juvenile bypass system (JBS), individual spillbays, and all turbine unit gate slots (Table 1).

Telemetry data was retrieved through an automated process that downloaded network 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.

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.

Forebay arrival time was based on the first time a fish was detected on the forebay entry 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 entry transect, detected a second time in a passage route, and detected a third time in the immediate tailrace on either the stilling-basin or tailrace-exit telemetry transect (Figure 3). Forebay residence time for individual fish was measured as the time between first detection on the forebay entry transect and last detection in a passage route. Stilling basin and/or tailrace exit detection was used to confirm dam passage.

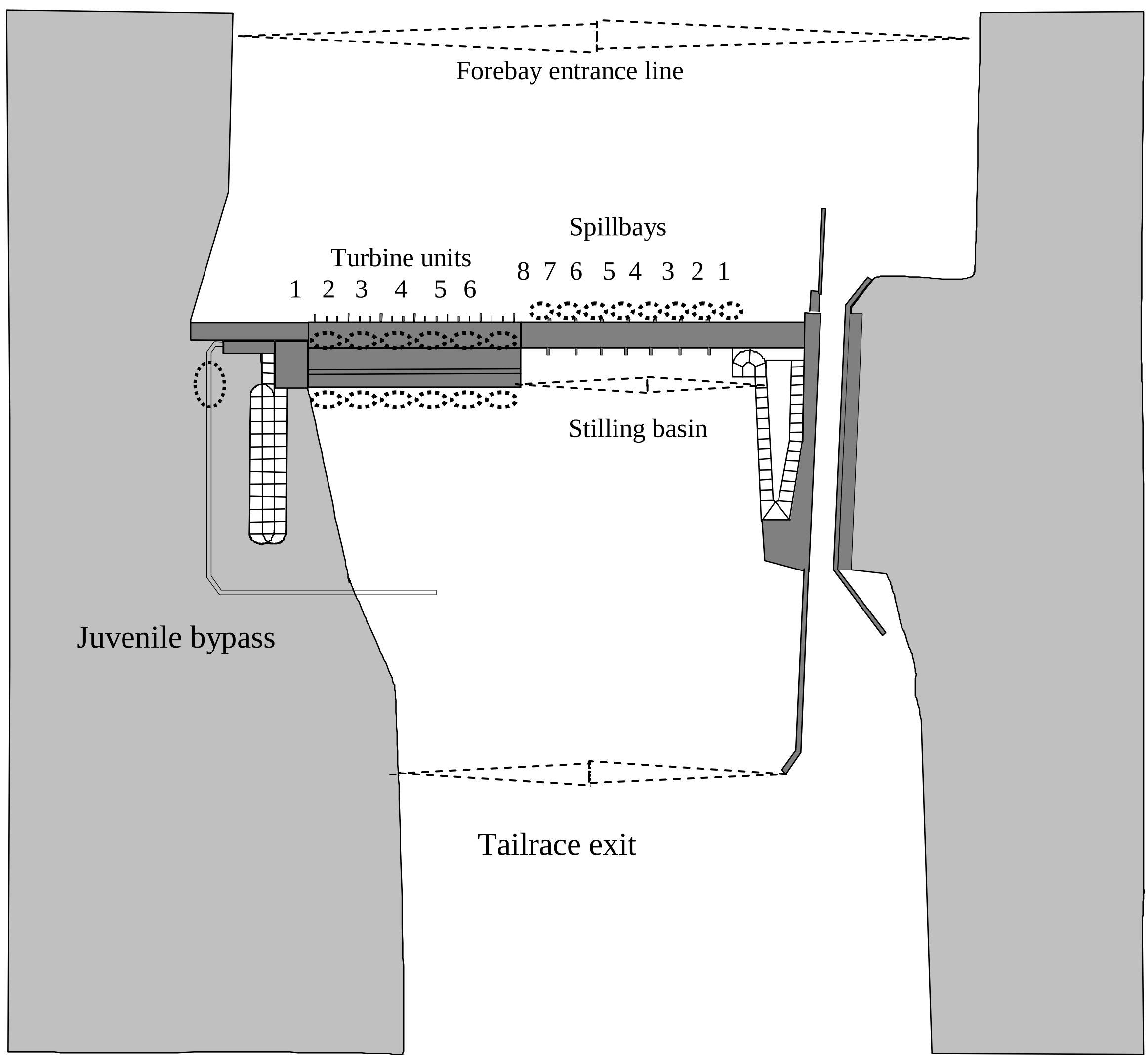

Figure 3. Plan view of Lower Monumental Dam showing approximate radiotelemetry detection zones in 2007 (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas).

Table 1. Fixed-site telemetry receivers for evaluating passage behavior and survival of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2007.

Site description	Type of monitoring	Antenna type
Forebay		
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	Striped coax
Spillbays 1-8	Approach and passage	Underwater dipole
Draft tube units 1-6	Project passage	Striped coax
Stilling basin		
north shore	Project passage	Tuned loop
south shore	Project passage	Tuned loop
Juvenile bypass system	Bypass passage	Tuned loop
Tailrace exit		
north shore	Project passage and tailrace egress	3-element Yagi
south shore	Project passage and tailrace egress	3-element Yagi
Burr Canyon		
north shore	Project passage and survival	3-element Yagi
south shore	Project passage and survival	3-element Yagi

Approach patterns were established based on the first detection on one of the receivers located at each spillway 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 on the stilling basin, tailrace exit transect, or at the primary survival transect near Burr Canyon (Figures 2 and 3). Spillway passage was assigned to fish last detected in the forebay on one of the antenna arrays deployed in each spillway. Similarly, turbine passage was assigned to fish last detected in the forebay on a turbine intake prior to detection in the draft tube and tailrace. Passage through the JBS was assigned to fish detected in the juvenile bypass system prior to detection in the tailrace.

Survival Estimates

A paired-release study design was used for estimating relative survival where groups of radio-tagged fish were released at one of two sites; upstream (treatment) and downstream (reference) of Lower Monumental Dam (Figure 2). Treatment groups were formed by grouping daily detections of radio-tagged fish as they entered the forebay of Lower Monumental Dam. Reference groups were released directly into the tailrace of Lower Monumental Dam (Figure 2). Data were analyzed using the Survival with Proportional Hazards (SURPH) statistical software developed at the University of Washington (Smith et al. 1994).

Dam survival was defined as survival of treatment fish through all passage routes combined relative to survival of tailrace-released fish. Dam survival was estimated from the immediate forebay, approximately 500 m upstream from the face of the dam, to the tailrace release location, approximately 1 km downstream from the dam.

Concrete survival was defined as the ratio of survival for treatment fish from the upstream face of the dam to the tailrace release location to that for reference fish. 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 Burr Canyon 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 then expressed as the ratio of survival estimates for treatment fish to those for reference fish and were calculated using geometric means (Muir et al. 2001). 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; tailrace egress was defined as the time from detection on a passage route to first detection on the tailrace exit transect.

Passage Route Distribution

To determine the route of passage used by individual fish at Lower Monumental Dam, we monitored the spillway, fish guidance screens, draft tubes, and JBS. The spillway was monitored by four underwater dipole antennas in each spillway; two antennas were installed along each of the pier noses at depths of 20 and 40 ft. Previous range testing showed that this configuration monitored the entire spillway. 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.

We also placed an underwater antenna in the JBS upstream from the primary dewatering structure. Fish that were detected on fish screen antennas could then be assigned a passage route by their subsequent detection on the bypass system antenna, indicating bypass passage, or detection on draft tube antennas, indicating turbine passage.

Fish Passage Metrics

Fish-passage evaluated were spill efficiency, spill effectiveness, fish guidance efficiency (FGE), and fish passage efficiency (FPE). These evaluations used radiotelemetry detections from 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. 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 (turbine and 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.

Confidence intervals were constructed for these metrics as the average $\pm$ 1.96 standard errors using temporal treatment groups. For some metrics there were only enough fish to get pooled estimates, so confidence intervals were based on assumed binomial distributions.

RESULTS

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were collected and tagged at Lower Monumental Dam and released over a period of 18 d from 12 June through 4 July. The number of fish tagged each day was not weighted to the passage index. Tagging began after 57% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and was completed when 85% of these fish had passed (Figure 4). Fish condition information and data on the size and timing of the juvenile migration is reported on the Fish Passage Center website (www.fpc.org).

Overall mean fork length was 115 mm (range 102-142 mm) for treatment fish and 116 mm (range 103-145 mm) for reference fish (Table 2). Mean length of the run at large sampled at the Lower Monumental smolt collection facility was 109 mm (M. Price, WDFW, personal communication; Table 3). Overall mean weight was 14 g (range 10-29 g) for treatment fish and 14 g (range 10-33 g) for reference fish (Table 4). During the study period, handling and tagging mortality for subyearling Chinook salmon held for a minimum of 24 h after tagging was 1.0%.

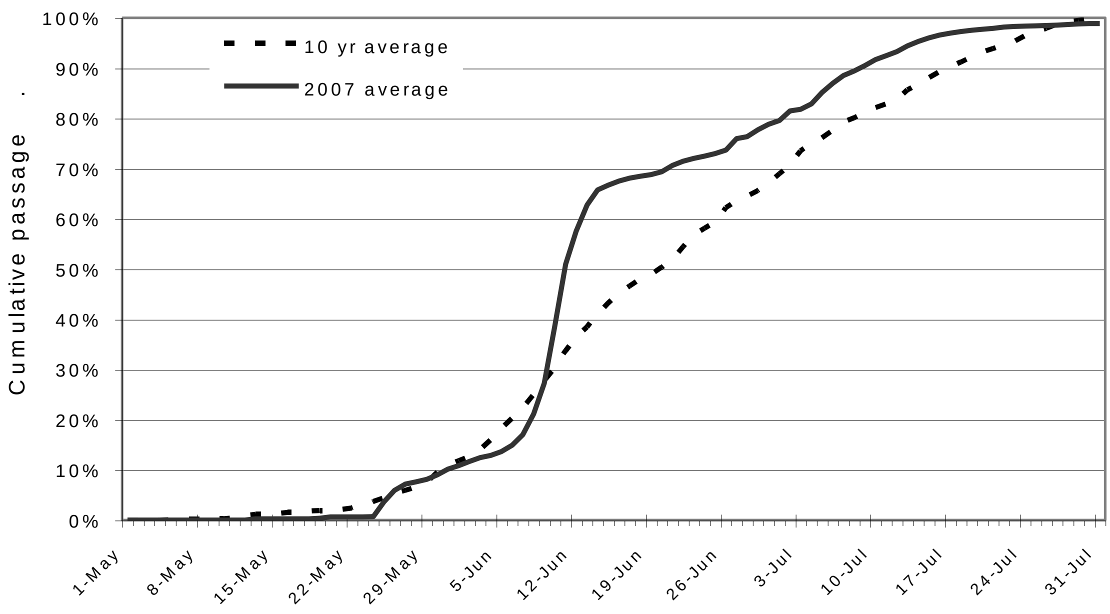

Figure 4. The 2007 cumulative distribution compared to the 10 year average (1998-2007) for subyearling Chinook salmon passing Lower Monumental Dam.

Table 2. Mean length of replicate groups of radio-tagged subyearling Chinook salmon (sample size, mean, range, and SD) released at Lower Monumental Dam to evaluate passage behavior and relative dam and spillway survival, 2007.

Release	Fish length (mm)							
	Forebay releases				Tailrace releases			
date	N	Mean	Range	SD	N	Mean	Range	SD
	Daytime releases							
6/12	20	116	106-138	7.0				
6/13	20	115	108-124	4.3	21	115	105-124	4.9
6/14	25	114	105-122	4.0	22	113	105-130	5.7
6/15	24	115	108-123	4.4	22	113	105-130	5.7
6/16	24	113	104-122	4.7	23	111	106-119	3.8
6/17	21	111	103-122	6.0	20	113	105-131	5.8
6/18	21	113	106-119	3.6	19	110	104-122	4.9
6/19					17	113	104-124	4.9
6/23	26	116	109-132	5.8				
6/24	26	112	105-124	4.8	27	116	108-142	6.7
6/25	25	113	106-124	4.6	28	115	105-128	6.8
6/26	27	117	112-127	4.6	26	117	108-129	6.0
6/27	28	117	102-141	8.4	25	118	105-136	7.0
6/28	26	118	108-129	5.3	26	117	107-137	6.4
6/29	28	117	107-131	5.5	26	120	111-131	5.3
6/30	26	117	108-129	4.6	28	119	106-131	6.2
7/1	21	115	106-121	3.6	23	118	106-135	6.0
7/2	24	117	111-130	4.8	22	121	113-129	4.3
7/3	23	120	114-124	3.1	22	121	113-129	7.3
7/4					14	121	115-129	3.9
7/5					14	122	115-131	5.2
subtotal	435	115	102-141	4.8	425	116	104-145	5.6
	Nighttime releases							
6/12	19	113	104-121	5.2				
6/13	21	115	107-124	4.9	22	116	106-129	5.7
6/14	25	115	109-122	3.9	24	116	106-125	5.3
6/15	21	113	104-126	5.3	22	112	106-118	3.4
6/16	21	113	105-121	4.4	19	112	107-120	4.2
6/17	22	113	105-138	7.2	19	111	105-118	3.8
6/18	22	112	104-126	5.6	19	113	106-122	4.7
6/19					19	113	106-122	4.1
6/23	26	117	108-130	6.1				
6/24	28	114	104-125	5.9	26	115	105-129	6.5
6/25	27	115	104-137	7.6	27	116	105-134	6.4
6/26	25	117	103-136	8.2	25	115	103-132	7.6
6/27	26	116	104-142	7.6	26	118	108-130	6.3
6/28	25	118	107-128	5.1	25	119	109-140	7.0
6/29	27	121	111-132	5.8	25	119	109-134	6.5
6/30	27	117	106-129	5.5	25	118	111-132	5.3
7/1	21	122	111-134	6.8	23	115	106-123	4.7
7/2	23	118	111-136	4.8	22	120	109-136	6.6
7/3	24	121	112-135	5.7	23	122	115-130	4.2
7/4					14	121	115-125	2.8
7/5					14	120	112-126	3.5
subtotal	430	116	103-142	5.9	419	116	103-140	5.2
Total	865	116	102-142	5.4	844	116	103-145	5.4

Table 3. Sample size and mean fish length (and range of length) by tagging date for river-run subyearling Chinook salmon collected at the Lower Monumental Dam smolt monitoring facility, 2007.

			Fish length (mm)	
Collection date	Release date	N	Mean	Range
6/10	6/12	200	106	60-125
6/11	6/13	200	108	80-130
6/12	6/14	200	104	85-125
6/13	6/15	200	104	65-130
6/14	6/16	176	102	70-130
6/15	6/17	200	103	80-120
6/16	6/18	191	104	70-125
6/17	6/19	173	105	75-140
6/18	6/23	134	106	60-135
6/19	6/24	81	107	65-135
6/23	6/25	187	109	75-130
6/24	6/26	158	110	75-135
6/25	6/27	154	111	80-135
6/26	6/28	170	115	95-135
6/27	6/29	200	113	95-135
6/28	6/30	73	111	90-125
6/29	7/1	200	114	65-140
6/30	7/2	152	113	80-135
7/1	7/3	115	113	95-135
7/2	7/4	171	113	75-135
7/3	7/5	53	111	100-125
Total/Overall		3,932	108	60-140

Table 4. Mean weight of radio-tagged subyearling Chinook salmon replicates released at Lower Monumental Dam to evaluate passage behavior and survival, 2007.

Release date	Fish weight (g)							
	Forebay releases				Tailrace releases			
	N	Mean	Range	SD	N	Mean	Range	SD
	Daytime releases							
6/12	20	14	10-24	3.5				
6/13	20	14	10-19	2.1	21	14	10-16	1.9
6/14	25	13	10-16	1.8	22	13	10-23	2.8
6/15	24	14	11-18	1.9	22	13	10-22	2.5
6/16	24	13	10-17	1.7	23	12	10-14	1.2
6/17	21	12	10-17	2.4	20	13	11-21	2.3
6/18	21	13	11-16	1.4	19	12	10-17	1.9
6/19					8	13	10-22	3.8
6/23	26	15	11-22	2.8				
6/24	26	13	11-18	1.9	27	14	10-30	3.6
6/25	24	13	10-18	1.9	28	14	10-19	2.7
6/26	27	15	12-19	2.0	25	15	10-26	3.3
6/27	28	16	11-26	3.9	25	15	10-24	3.2
6/28	26	15	11-22	2.6	26	15	11-24	2.9
6/29	28	15	11-20	2.3	26	15	12-20	2.0
6/30	26	15	11-21	2.2	28	16	12-20	2.3
7/1	21	13	10-16	1.7	23	15	11-25	3.3
7/2	24	14	12-19	1.9	22	16	13-19	2.1
7/3	23	16	14-12	1.2	22	16	12-33	4.5
7/4					14	16	14-20	2.0
7/5					14	18	15-22	2.5
subtotal	434	14	10-26	2.1	415	14	10-33	2.7
	Nighttime releases							
6/12	19	13	10-16	1.7				
6/13	21	13	11-18	1.9	22	14	11-20	2.6
6/14	25	13	10-16	1.7	24	14	10-17	2.0
6/15	21	13	11-18	1.8	22	12	10-15	1.3
6/16	21	13	10-16	1.7	19	12	10-16	1.7
6/17	22	13	10-27	3.5	19	12	11-15	1.1
6/18	0				0			
6/19					18	13	11-17	1.5
6/23	26	15	11-22	2.6				
6/24	28	13	10-18	2.3	26	14	11-21	2.6
6/25	27	14	10-24	3.0	26	14	11-22	2.7
6/26	24	15	11-24	3.3	0			
6/27	26	14	10-29	3.7	26	15	12-24	3.3
6/28	25	15	12-22	2.3	25	15	12-24	3.2
6/29	27	17	12-22	2.8	25	16	12-24	2.9
6/30	27	14	11-20	2.1	24	15	11-22	2.7
7/1	21	16	12-26	3.7	23	13	10-17	2.0
7/2	23	15	12-25	2.5	22	16	12-26	3.0
7/3	24	16	12-22	2.3	23	17	14-23	2.4
7/4					14	16	13-18	1.5
7/5					14	15	12-18	1.6
subtotal	407	14	10-29	2.5	372	14	10-26	2.2
Total	841	14	10-29	2.3	787	14	10-33	2.5

Project Operations

No specific project operations were requested for this study. During the 11 June through 8 July study period, average spill was 19.2 kcfs or 50% of total discharge (Table 5). Spill occurred throughout the study period except for short periods of time when it was interrupted to allow fish transportation barges to safely cross the river from

Table 5. Average daily conditions during releases and passage of radio-tagged hatchery subyearling Chinook salmon at Lower Monumental Dam, 2007.

Date	Spill (kcfs)	Powerhouse (kcfs)	Total discharge (kcfs)	Total discharge range (kcfs)	Tailwater elevation (ft msl)	Water temperature (°C)
6/11	23.1	28.0	51.1	38.8-79.0	438.1	15.8
6/12	23.1	39.9	63.0	53.3-78.8	438.7	15.9
6/13	23.0	32.0	55.0	39.3-70.1	438.2	16.2
6/14	24.0	27.3	51.3	33.8-67.8	438.1	16.4
6/15	23.3	24.4	47.7	33.9-57.3	437.8	16.3
6/16	22.8	18.9	41.7	33.9-53.1	437.6	15.7
6/17	22.8	22.6	45.3	34.2-58.0	437.9	15.8
6/18	23.1	15.5	38.6	34.2-49.7	437.5	15.8
6/19	23.0	12.0	35.1	34.1-36.9	437.1	15.5
6/20	23.1	19.0	42.0	34.8-56.6	437.6	15.5
6/21	17.1	16.1	33.2	28.3-52.2	437.6	15.4
6/22	17.1	27.0	44.2	34.7-55.8	437.8	15.7
6/23	17.1	20.5	37.6	33.4-44.7	437.4	16.4
6/24	17.1	16.1	33.2	28.6-36.3	437.4	16.3
6/25	17.1	17.4	34.5	28.4-37.0	437.3	16.6
6/26	15.9	12.2	28.1	23.1-32.6	437.3	16.8
6/27	16.9	12.2	29.2	26.7-34.1	437.4	17.0
6/28	17.1	15.0	32.1	28.4-36.5	437.5	16.9
6/29	17.1	18.6	35.7	32.7-36.4	437.5	17.2
6/30	17.1	15.6	32.7	28.6-35.7	437.2	18.0
7/1	17.2	15.9	33.1	28.6-36.7	437.4	18.2
7/2	17.1	11.6	28.7	28.4-28.9	437.3	18.0
7/3	17.1	15.9	33.0	28.5-48.7	437.3	18.3
7/4	17.1	13.4	30.6	28.3-36.9	437.2	18.9
7/5	17.1	15.0	32.1	28.5-48.9	437.5	19.1
7/6	17.1	16.6	33.7	28.8-45.0	437.3	19.0
7/7	16.8	16.6	33.4	24.0-36.8	437.4	19.2
7/8	17.2	21.4	38.5	32.9-44.3	437.8	19.6
Average	19.2	19.2	38.4	23.1-79.0	437.6	17.0

the navigation lock to the barge loading area. Spill ranged from 11.8 to 25.2 kcfs, powerhouse flow ranged from 11.1 to 56.0 kcfs, and total river flow ranged from 23.1 to 79.0 kcfs. Tailwater elevation ranged from 436.2 to 440.0 ft msl, and water temperature ranged from 15.8 to 19.6°C (Table 5). Average total river flow during the study in 2007 was lower than during the same period in 2006 (68.8 kcfs), and lower than the 10-year average (62.8 kcfs). The only year in the last 10 years that had a lower average total river flow was 2001 (31.6 kcfs). Spill from 11 to 20 June was to the gas cap, while spill from 21 June though the end of the study was 17.0 kcfs. The spill pattern used in 2007 is shown in Appendix C.

Migration Behavior and Passage Distribution

Forebay and tailrace behavior and timing, passage distribution and metrics, and passage survival results were based on fish that approached Lower Monumental Dam from 13 June through 4 July. Because of the low number of fish that approached the dam from 19 June through 23 June, data from these days were pooled into one release group for analysis.

Forebay Behavior and Timing

Of the 860 radio-tagged treatment fish released above Lower Monumental Dam, 641 were detected entering the forebay. Of these 641 fish, 92% were first detected approaching the spillway, and 8% were first detected approaching the powerhouse.

Forebay residence time was calculated for 520 fish, each with detections on the forebay entrance transect, a passage-route receiver, and a known passage route. Fish that were not detected in all three areas were not included in the analysis of forebay residence timing, but were included in survival estimates. Passive water-particle transport timing through the forebay was not used to further evaluate forebay residence timing because this was beyond the objectives of the study. Median forebay residence timing of treatment fish was 2.7 h through the spillway, 3.6 h through the bypass system, and 2.6 h through the turbines. Of the 520 fish used in this evaluation, 474 (91%) passed through the spillway, 36 (7%) through the JBS, and 9 (2%) through turbine units (Table 6). Forebay residence time is also presented by treatment group without consideration to passage route in Table 7.

Table 6. Forebay residence in hours for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2007. Numbers of fish passing via each route are shown in parentheses. Forebay residence time is not shown for fish that passed through the turbines because of the low number of fish (n = 9) that passed via that route.

	Forebay residence (h)		
Percentile	Bypass (n = 36)	Spillway (n = 474)	Overall (n = 520)
Minimum	0.4	0.3	0.3
10^{th}		0.8	0.8
20^{th}	2.0	1.2	1.2
30^{th}		1.7	1.8
40^{th}		2.4	2.5
50^{th} (median)	4.7	3.5	3.6
60^{th}		5.1	5.2
70^{th}		7.2	7.4
80^{th}	15.7	12.5	12.7
90^{th}		21.0	21.7
Maximum	51.8	141.5	141.5
Mean	10.0	8.9	9.0
Mode	N/A	1.3	1.1

Table 7. Forebay residence time for all passage routes combined for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2007. Residence time is shown by forebay entry date for the 10th, 50th (median), and 90th percentiles. Fish entering from 19 to 23 June were pooled with the 21 June group.

Forebay		Forebay residence time (h)		
entry date	n	10th	50th	90th
13 June	35	1.1	3.0	8.9
14 June	25	0.5	2.5	8.4
15 June	24	1.4	4.5	13.7
16 June	29	1.3	3.9	12.7
17 June	21	1.0	2.6	10.0
18 June	24	1.0	2.7	7.2
21 June	41	1.5	7.0	43.2
24 June	19	0.5	1.4	8.3
25 June	26	0.6	3.2	12.3
26 June	26	1.3	7.6	24.7
27 June	31	0.9	6.3	18.3
28 June	44	0.5	4.3	32.4
29 June	36	1.0	3.6	23.9
30 June	37	0.8	3.4	22.3
1 July	21	0.8	5.3	33.0
2 July	24	0.6	5.0	56.0
3 July	19	0.6	2.4	9.0
4 July	37	1.0	5.1	28.3
Total/mean	519	0.9	4.1	20.7
SE		0.1	0.4	3.2
95% CI		0.7-1.1	3.3-4.9	13.9-27.5

Passage Distribution and Metrics

Of the 860 radio-tagged treatment fish released, 641 (75%) were detected at or below Lower Monumental Dam, while 219 were not detected after release. Of the 579 (67%) fish that passed the dam, 520 (90%) passed through the spillway, 39 (7%) through the JBS, 10 (2%) through the turbines, and 10 (2%) through an undetermined route (Figure 5). The remaining 62 (7%) fish entered the forebay but were not recorded as passing the dam. Figure 6 illustrates the percentage of time each spillbay was open during the study period and the percentage of fish that passed through each spillbay.

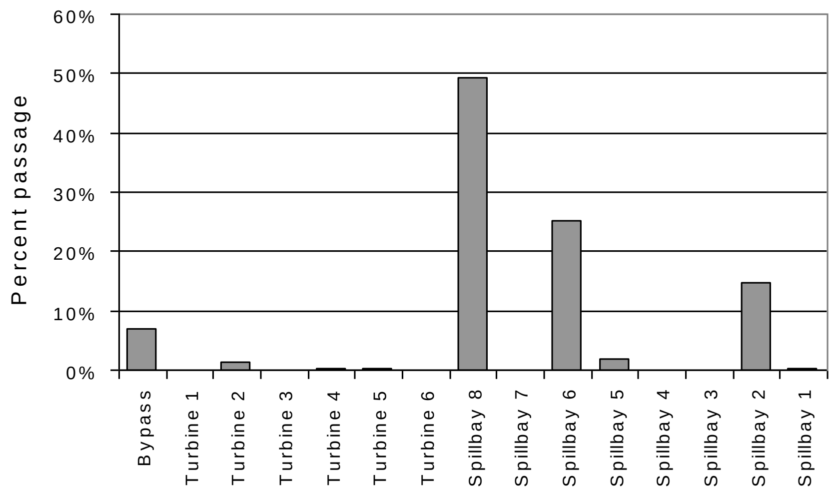

Figure 5. Passage route distribution of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2007.

Figure 6. Percent time individual spillbays were open and passage distribution for radio-tagged river-run subyearling Chinook salmon at Lower Monumental Dam, 2007.

Fish passage efficiency at Lower Monumental Dam was 0.982 (95% CI, 0.971-0.993). Spill efficiency was 0.914 (0.890-0.937), and spill effectiveness was 1.84:1 (1.75-1.93). Fish guidance efficiency was 0.796 (0.681-0.911), but the very low numbers of fish available to estimate FGE need to be considered when evaluating this result (Table 8).

Table 8. Fish passage metrics by passage date for river-run subyearling Chinook salmon at Lower Monumental Dam, 2007.

Passage date	n	Spill passage efficiency	Fish passage efficiency	Spill effectiveness	n	Fish guidance efficiency
12-13 June	39	0.821	0.974	2.10	7	0.857
14 June	28	1.000	1.000	2.14	0	
15 June	30	0.933	0.933	1.91	2	0.000
16 June	20	0.800	1.000	1.46	4	1.000
17 June	29	0.931	0.966	1.85	2	0.500
18 June	30	0.967	0.967	1.62	1	0.000
19-23 June	44	0.977	1.000	1.93	1	1.000
24 June	25	0.840	0.960	1.63	4	0.750
25 June	39	0.949	0.974	1.91	2	0.500
26 June	37	0.919	1.000	1.62	3	1.000
27 June	36	0.917	1.000	1.58	3	1.000
28 June	41	0.902	1.000	1.69	4	1.000
29 June	42	0.881	0.976	1.84	5	0.800
30 June	38	0.921	1.000	1.76	3	1.000
1 July	22	0.955	1.000	1.84	1	1.000
2 July	25	1.000	1.000	1.68	0	
3 July	27	0.926	0.963	1.78	2	0.500
4-5 July	17	0.706	0.941	1.26	5	0.800
Total/mean		0.914	0.982	1.84	49	0.796
SE		0.018	0.005	0.05		0.086
95% CI		0.876-0.951	0.971-0.993	1.75-1.93		0.681-0.911

Tailrace Behavior and Timing

Tailrace egress and timing was calculated for 546 radio-tagged, river-run subyearling Chinook salmon. Median tailrace egress time was 13 minutes overall, 11 minutes for fish that had passed through the spillway (n = 499), and 46 minutes for those that passed through the JBS (n = 36). Only 10 fish passed through the turbines, so we did not calculate median tailrace egress time for these fish (Table 9). The longer egress time for fish that passed through the JBS was expected and was due to the greater distance fish had to travel through the JBS prior to detection in the tailrace. Tailrace egress time for fish that passed through the JBS was calculated as the time from PIT-tag detection at the JBS exit to first detection on a tailrace radiotelemetry exit transect. By using PIT-tag detections from the JBS exit, which is the farthest downstream detection location in the bypass system, travel time through the bypass system was excluded. This provided a truer picture of tailrace egress time for fish that passed via the JBS. Table 10 presents tailrace egress time by percentile for fish overall and for fish that passed via the spillway and JBS.

Table 9. Tailrace egress timing in minutes for radio-tagged, river-run subyearling Chinook salmon passing through the bypass and spillway at Lower Monumental Dam, 2007.

	Tailrace egress time (min)		
Percentile	Bypass (n = 36)	Spillway (n = 499)	Overall (n = 546)
Minimum	9.7	1.3	1.3
10th		4.7	4.8
20th	13.7	5.6	5.8
30th		6.6	6.9
40th		8.2	8.8
50th (median)	45.6	11.2	13.1
60th		17.3	21.8
70th		32.3	38.4
80th	99.2	65.4	73.2
90th		226.9	241.4
Maximum	3718.0	10,673.6	10,673.6
Mean	193.5	305.4	299.0
Mode	n/a	6.3	6.3

Table 10. Tailrace egress time for spillway passage of radio-tagged river-run subyearling Chinook salmon at Lower Monumental Dam, 2007. Egress time is shown by forebay entry date for the 10^{th}, 50^{th} (median) and 90^{th} percentiles. These percentiles are also shown for passage through individual spillbays 2, 6, and 8.

		Tailrace egress time (min)		
Forebay entry date	n	10^{th}	50^{th} (median)	90^{th}
12-13 June	39	4.2	7.7	50.8
14 June	28	4.4	7.5	74.9
15 June	25	4.4	9.5	352.8
16 June	20	5.2	10.3	22.1
17 June	25	5.0	12.6	2,320.9
18 June	28	4.7	8.1	99.4
19-23 June	30	4.4	8.3	123.5
24 June	22	4.8	14.6	42.5
25 June	33	4.5	9.7	520.7
26 June	33	5.1	22.2	121.4
27 June	25	9.9	45.3	235.0
28 June	36	6.4	34.6	830.0
29 June	36	4.9	11.1	361.1
30 June	34	4.6	15.3	581.2
1 July	18	5.2	25.3	6,314.5
2 July	19	5.9	47.0	528.2
3 July	24	5.3	11.0	70.2
4-5 July	22	7.4	50.1	549.2
Total/mean	497	5.3	19.5	733.2
SE		0.3	3.5	351.6
95% CI		4.7-6.0	12.1-26.8	-8.5-1,475.0
Individual spillbay passage				
spillbay 2	70	11.5	30.1	1,829.5
spillbay 6	139	5.5	10.3	226.9
spillbay 8	278	4.4	8.5	159.9

Detection Probability

Detection probabilities at Burr Canyon for treatment and reference groups were 0.528 (95% CI, 0.494-0.562) and 0.932 (0.914-0.949), respectively. The difference in detection probabilities between treatment and reference groups was due to the large number of treatment fish that were never detected at either the forebay entry line or the dam.

Estimated Survival

Overall estimated relative dam survival (forebay BRZ to tailrace) at Lower Monumental Dam was 0.762 (95% CI, 0.690-0.841), and relative concrete survival (all fish passing the dam) was 0.845 (0.807-0.883). Relative survival estimates for the dam, concrete, spillway, and spillbay 8 are shown by forebay entry date in Table 11. The estimate of relative concrete survival based on detections at Ice Harbor Dam rather than Burr Canyon was somewhat lower at 0.642 (0.495-0.834). Detection histories of fish used in survival analysis are shown in Appendix D.

Table 11. Subyearling Chinook salmon relative point survival estimates by forebay entry date at Lower Monumental Dam, 2007. Dam survival includes approximately 500 m of forebay from the boat restricted zone deadline to the concrete.

	Dam survival		Concrete survival		Spillway survival		Spillbay 8 survival	
Date	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
6/13	0.841	0.059	0.876	0.058	0.882	0.059	0.917	0.069
6/14	0.887	0.083	0.865	0.090	0.893	0.089	0.989	0.088
6/15	0.826	0.094	0.890	0.098	0.872	0.104	0.838	0.156
6/16	0.897	0.096	0.851	0.087	0.899	0.086	0.924	0.099
6/17	0.675	0.100	0.806	0.103	0.806	0.103	0.885	0.122
6/18	0.955	0.070	0.884	0.089	0.868	0.094	0.964	0.100
6/21	0.677	0.078	0.905	0.047	0.903	0.048	0.987	0.013
6/24	0.814	0.097	0.846	0.106	0.833	0.110	0.833	0.152
6/25	0.801	0.087	0.995	0.078	0.984	0.083	1.006	0.088
6/26	0.821	0.084	0.836	0.097	0.826	0.100	0.990	0.082
6/27	0.581	0.092	0.738	0.094	0.711	0.099	0.871	0.103
6/28	0.672	0.085	0.771	0.078	0.726	0.085	0.781	0.112
6/29	0.752	0.076	0.778	0.077	0.745	0.085	0.864	0.094
6/30	0.785	0.093	0.818	0.094	0.824	0.097	0.756	0.123
7/1	0.532	0.123	0.748	0.127	0.777	0.130	0.914	0.133
7/2	1.094	0.744	1.026	0.399	1.026	0.399	1.068	0.400
7/3	0.831	0.094	0.867	0.100	0.867	0.100	0.867	0.123
7/4	0.515	0.105	0.760	0.096	0.722	0.106	0.855	0.148
Overall geomean	0.762	0.126	0.845	0.107	0.838	0.110	0.903	0.123
SE	0.036		0.018		0.020		0.019	
95% CI	0.690-0.841		0.807-0.883		0.797-0.882		0.862-0.945	

Overall estimated route-specific survival through the spillway was 0.838 (0.797-0.882), and relative survival through spillbay 8 was 0.903 (0.862-0.945). Survival through spillbay 8 was higher than through the other spillbays. Pooled relative survival was 0.697 (0.586-0.829) for spillbay 2 and 0.779 (0.700-0.867) for spillbay 6. The point estimate of relative survival for all spillbays except spillbay 8 (fish that passed through spillbays 1, 2, 5, and 6) was 0.760 (0.678-0.853). Insufficient numbers of fish passed through the turbines to enable us to estimate survival with precision through this route.

Diel Passage Behavior

We released radio-tagged fish twice per day in an attempt to have equal numbers of fish passing Lower Monumental Dam throughout the diel period. However, the sample sizes were not large enough, either to detect meaningful differences in survival or passage metrics between day and night releases or to identify diel trends in passage behavior. The percentage of fish entering the forebay during daylight hours was very close to the percent of the diel period designated as daytime. Daytime hours were designated as from 0400 to 1900, or 67% of a 24-h day, and we recorded 70% of the fish entering the forebay during those hours (Figure 7). The hours when dam passage was observed were also very close to the percentage of time designated as daytime. We observed 68% of fish passing the dam during daytime hours (Figure 8).

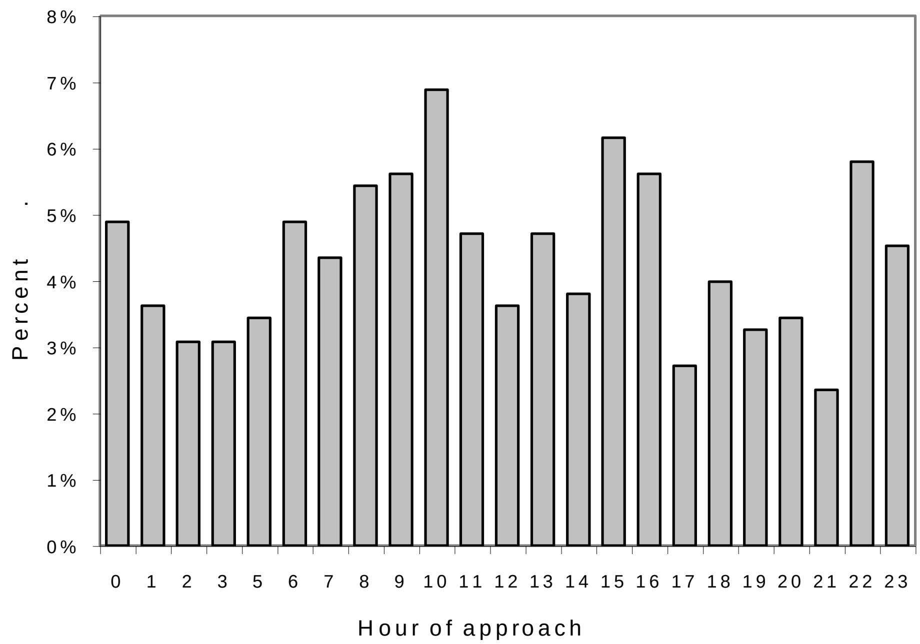

Figure 7. Percentage of radio-tagged subyearling Chinook salmon entering the forebay of Lower Monumental Dam by hour, 2007.

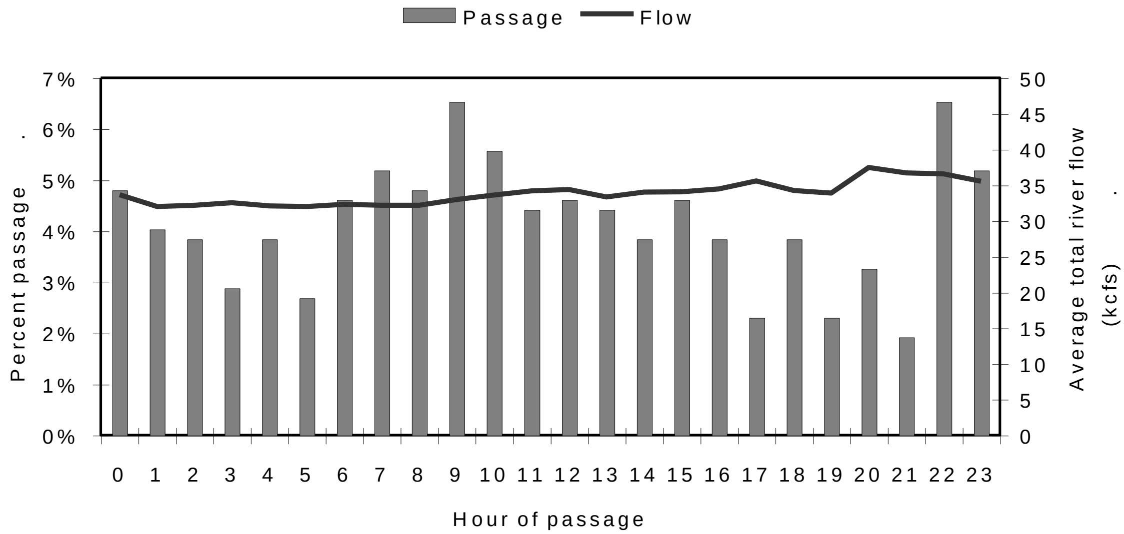

Figure 8. Percentage of radio-tagged subyearling Chinook salmon passing Lower Monumental Dam and average total river flow by hour, 2007.

The higher percentage of spill in 2007 resulted in a greater proportion of first approaches to the spillway (93%) and a lower proportion of first approaches to the powerhouse (7%) compared to observations in 2005 and 2006. Proportions of fish that first approached the spillway were 84% in 2006 and 90% in 2005. The average total river flow spilled was 32% in 2006 and 59% in 2005. Locations of first approaches to Lower Monumental Dam are presented in Figure 9. As we have seen in the past, the highest percentage of fish first approached the dam at spillbay 8 (35%).

In 2006, there was a marked difference in approach by diel period that was not observed in 2007. Powerhouse approach was higher in 2006 at night even though a higher proportion of flow went through the spillway at night (Absolon et al. 2008). Approach to the spillway and powerhouse by diel period were similar for day and nighttime (Figure 10).

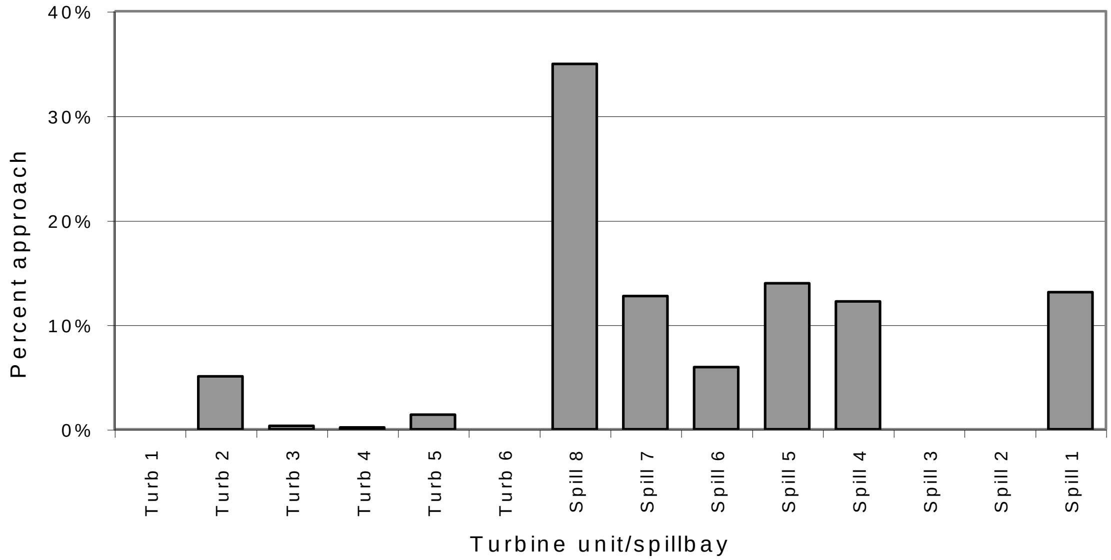

Figure 9. Percentages of radio-tagged subyearling Chinook salmon first approaching Lower Monumental Dam turbine units and spillbays, combined day and night releases, 2007.

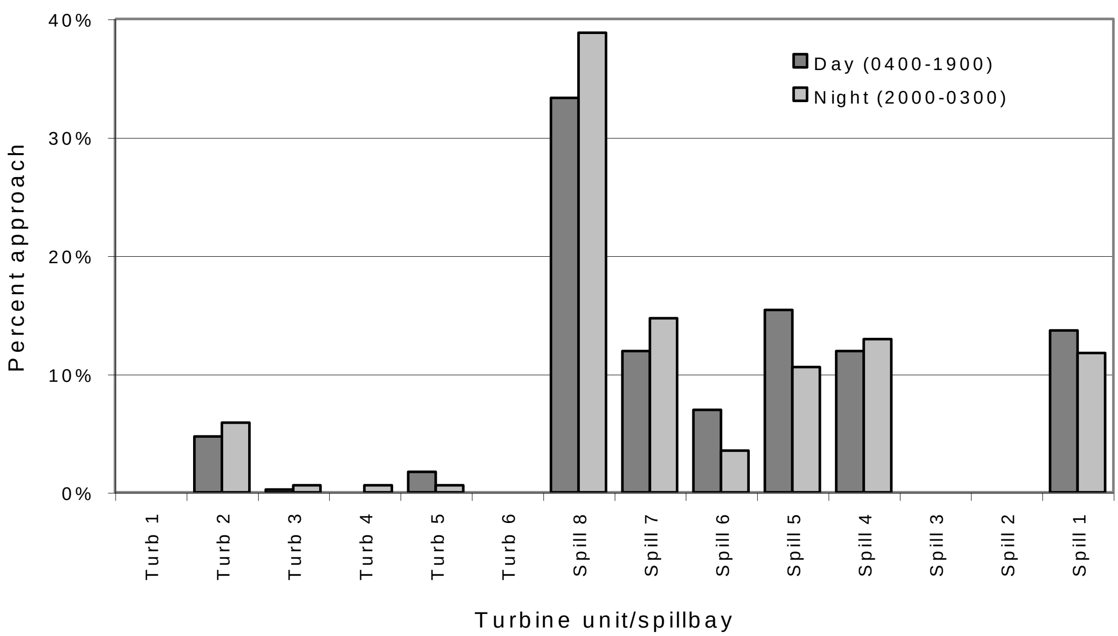

Figure 10. Percentages of radio-tagged subyearling Chinook salmon first approaching Lower Monumental Dam turbine units and spillbays by diel period, 2007.

Avian Predation

After avian nesting colonies on Crescent, Badger, and Foundation Islands had been abandoned for the season, an effort was initiated to recover radio tags that had been deposited on the colonies. Radio tags were collected by physically walking the island looking for visible tags. Radio-tag serial numbers were used to identify the individual tagged fish. PIT tags were also "recovered" in a thorough search using the mobile PIT-tag detection system described by Ryan et al. (2001). Information was provided on PIT-tag detections and physical recovery of radio transmitters at Crescent, Badger, and Foundation Islands by NMFS (S. Sebring, NMFS, personal communication).

There were 24 radio and 39 PIT tags found on islands in the mid-Columbia River, representing approximately 3.7% of the fish we released into the Snake River. We consider this 3.7% as a minimum estimate of avian predation because not all of the tags from fish consumed by birds were deposited on the island, and not all tags deposited on the islands were recovered. There were 22 and 41 tags recovered from treatment and reference groups, respectively; these represented 2.6% of the treatment fish and 4.9% of the reference fish.

Of the 63 radio and PIT tags recovered from bird colonies, one was from a fish not detected after release in the forebay of Lower Monumental Dam. The remaining 62 were from fish in both treatment and control releases that had all been detected at the primary survival line at Burr Canyon. Forty three of these fish were detected on at least one of the Ice Harbor Dam arrays, and of those, 21 were detected on at least one array downstream from Ice Harbor Dam.

An additional 4 PIT tags were recovered on East Sand Island in the Columbia River estuary. These tags were all from fish detected on at least one of the survival lines, and these fish were included in the survival estimates. However, they were not included in the avian predation information we obtained, which included recoveries only from colonies within the study area (Crescent, Badger, and Foundation Islands).

DISCUSSION

During 2007, we began testing after 57% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and finished when 85% of these fish had passed. We were able to begin tagging earlier during the juvenile migration this year because of the smaller tag that was available. To minimize the potential effects of tag weight on fish, we needed to tag fish with a minimum weight of about 10 g with the tag used in this study. This compared to a 12-g minimum fish size required for the tags available in 2006 (Absolon et al. 2008).

During the 2007 study period, 50% of total river flow was passed as spill. This compared to 32% that was spilled during the 2006 study period. In 2006, total river flow averaged 50.6 kcfs, while in 2007, total river flow averaged just 38.7 kcfs during the study. The volume of spill was also higher in 2007 compared to 2006 (19.5 and 16.1 kcfs, respectively). The much lower total river flow and the higher spill volume account for the higher spill percentage in 2007. Powerhouse flow averaged 19.3 kcfs in 2007 and 34.4 kcfs in 2006.

In all three study years (2005-2007), spillway passage reflected approach percentages. In 2007, spillway passage for treatment fish was 91.4%. This was higher than the 81.4% spillway passage in 2006 and slightly higher than the 90.0% spillway passage in 2005 (Absolon et al 2007). The trend toward higher proportions of fish passing through the spillway also reflected the increases in average proportions of total river flow spilled each year. Spill efficiency also reflected this pattern, with increasing proportions of fish approaching and passing via the spillway. Spill efficiency in 2007 was 0.914. This was the same as the proportion of fish that passed via the spillway, and was higher than spill efficiency observed either in 2006 (0.814) or 2005 (0.883). A summary of passage metrics and observed flow conditions for all three years of the study is presented in Table 12.

As observed in 2005 and 2006, the greatest proportion of fish passing via the spillway passed through spillbay 8 (54%; Figure 11), though this was less than the proportion that passed spillway 8 in 2006 (66%). The spill pattern used in 2007 increased spill in bay 2 and reduced it in bay 6 from the pattern used in 2006, at spill volumes less than 23.0 kcfs. This resulted in a change in spillway passage toward spillbay 2, with 16% passage in 2007 compared to 4% in 2006. The proportion of fish passing through spillbay 6 did not appear to have been affected by the spill pattern change, with 25% passage in 2006 and 28% in 2007. However, with the 2007 spill pattern, we believe a

Table 12. Summary of passage metrics and flow conditions for subyearling Chinook salmon radio tag studies from 2005-2007. Passage metrics include 95% confidence intervals in parentheses.

	2005	2006	2007
Average spill (%)	59	32	50
Average spill volume (kcfs)	20.9	16.1	19.5
Average total river flow (kcfs)	37	50.6	38.7
Average spillway passage (%)	88	82	91
Average bypass passage (%)	8	12	7
Average turbine passage (%)	2	7	2
Fish passage efficiency	0.955 (0.921-0.990)	0.947 (0.925-0.968)	0.982 (0.971-0.993)
Spill efficiency	0.874 (0.831-0.916)	0.820 (0.754-0.886)	0.914 (0.876-0.951)
Spill effectiveness	1.53 (1.44-1.58)	2.58 (2.39-2.77)	1.84 (1.75-1.93)
Fish guidance efficiency	0.832 (0.709-0.954)	0.645 (0.480-0.810)	0.796 (0.681-0.911)
Median forebay residence time (h)	3.0	2.7	1.1
Median tailrace egress time (min)	2	11	13

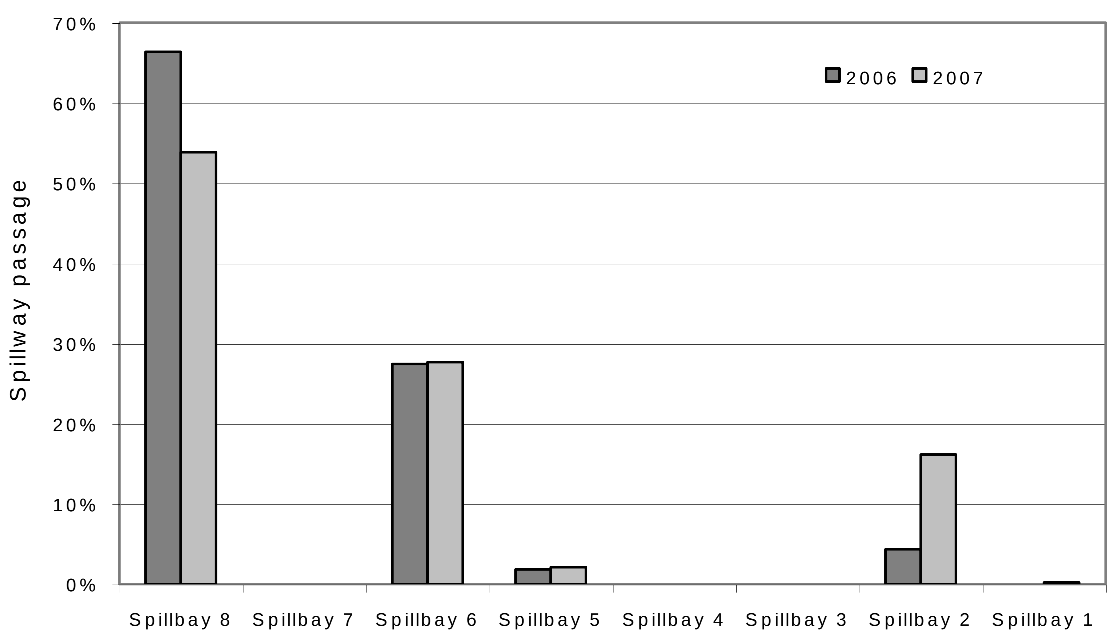

Figure 11. Percentage of radio-tagged subyearling Chinook salmon passing through each spillbay at Lower Monumental Dam, in 2006 and 2007.

similar percentage of fish that would have passed through spillbay 6 under the 2006 spill pattern instead passed through spillbay 2, and were "replaced" with fish that would have passed through spillbay 8, resulting in little difference between the two years.

In addition to the higher percentage of fish passing though spillbay 8, relative survival from passage in spillbay 8, at 0.903 (95% CI, 0.862-0.945), was higher than from any other spillbay or from the spillway as a whole. Relative survival was 0.779 (0.700-0.867) through spillbay 6 and 0.697 (0.568-0.829) through Spillbay 2. Overall spillway survival was 0.838 (0.797-0.882), and relative survival for all spillbays other than spillbay 8 was 0.760 (0.678-0.853).

Relative survival estimates of dam, concrete, spillway, spillbay 8, and spillbay 6 were each lower in 2007 than in 2006 (Table 13). Dam, concrete, and spillway survival point estimates in 2007 were closer to those observed in 2005, when river flow and spill percentages were similar (Tables 12 and 13). Factors that likely contributed to the lower estimates in 2007 include lower total river flow, lower tailwater elevation, and the change in spill pattern. The fact that all estimates of survival decreased in 2007 may indicate a cause of mortality specific to Lower Monumental Dam. Survival was evaluated in a similar study at Ice Harbor Dam in 2006 and 2007. In 2007, the Ice Harbor study was conducted during the same period, and fish were collected and tagged at the same location at Lower Monumental Dam. However, in contrast to the results found here, the evaluations at Ice Harbor Dam resulted in survival estimates similar to those of the previous year (Ogden et al. 2008). This would suggest that the relatively low forebay entry rate was not due to the condition of the tagged fish.

The higher survival through spillbay 8 than through other bays was similar to results in 2006. The spill pattern used in 2007 resulted in a higher percentage of spillway passage through spillbay 2, which has had lower survival rates than spillbay 8 in previous annual evaluations of survival. While additional passage through spillbay 2 could have contributed to lower estimates of spillway, dam, and concrete survival, it would not explain the lower estimate of survival through spillbay 8.

Mean average daily tailwater elevation was lower by 0.4 ft msl in 2007, which provided less water over the flow deflectors, and may have contributed to lower spillway survival. Lower total river flow during the 2007 study probably resulted in longer forebay residence and tailrace egress times. Median forebay residence time was 3.6 h in 2007. This was longer than either the 2.7 h seen in 2006 or the 3.0 h in 2005. Tailrace egress was also longer in 2007, increasing to 13 min from 11 min in 2006 and 2 min in 2005. Again, these slower egress times were probably related to lower total river flow and the tailrace conditions that occur at low river flows. The effect of longer forebay residence and tailrace egress timing on survival is unknown.

Table 13. Relative survival estimates for subyearling Chinook salmon through passage routes at Lower Monumental Dam, 2005-2007.

	2005			2006			2007		
Route	Point estimate	95% CI	Method	Point estimate	95% CI	Method	Point estimate	95% CI	Method
Dam	0.722	0.668-0.780	geomean	0.896	0.888-0.904	geomean	0.762	0.690-0.841	geomean
Concrete	0.862	0.752-0.988	geomean	0.943	0.936-0.950	geomean	0.845	0.807-0.883	geomean
Spillway	0.905	0.760-1.077	geomean	0.943	0.918-0.968	geomean	0.838	0.797-0.882	geomean
Spillbay 8				0.970	0.976-0.995	geomean	0.903	0.862-0.945	geomean
Spillbay 6				0.909	0.828-0.998	geomean	0.779	0.700-0.867	pooled
Spillbay 2				n/a			0.697	0.586-0.829	pooled
All but 8				n/a			0.760	0.678-0.853	geomean
JBS				n/a			0.949	0.750-1.149	pooled
Turbines				n/a			n/a		

Spill effectiveness in 2007 was 1.84:1, which was lower than the 2.58:1 observed in 2006 and higher than the 1.53:1 observed in 2005. Spill effectiveness, within the spill range that has occurred over the last 3 years, has been lower with higher spill percentages. This is may be due to the effect of diminishing returns of efficiency at these spill percentages, though it should be noted that spill efficiency has been higher at higher spill percentages.

At 0.982, fish passage efficiency was higher in 2007 than in either 2005 or 2006, when point estimates were 0.962 and 0.935, respectively. This was probably related to the high spill percentage and low total river flow during the 2007 study.

As occurred in previous years, a substantial proportion of treatment fish were not detected at the forebay entrance array after release. Twenty five percent of the treatment fish that were released 9 km upstream from Lower Monumental Dam were not detected after release. In previous years, the percentage of undetected fish has risen markedly after 4 July. To prevent such an occurrence in 2007, we released all replicates prior to 4 July. Therefore, we anticipated higher detection rates at the forebay entry line than observed in 2005 and 2006 (Absolon et al. 2007, 2008). Nevertheless, a large percentage of study fish were never detected at the forebay entry line.

Entry line detection rates may have been influenced by low river flows. Total river flow was only 62% of the 10-year average during the study period, and 2007 was the second lowest flow year recorded during this period over the last 10 years. However, several other factors may have contributed to the large percentage of non-detected fish.

These factors may include predation, water temperature, hydraulic conditions and tag life. Fish may also have adopted a “reservoir-type” life history strategy, wherein they overwinter in reservoirs and complete their migration the following spring, at age 1 (Conner et al. 2005). From 2005 and 2006 releases, we observed very few, if any, PIT-tag detections the following spring. Fish that delayed migration longer than the pre-determined tag life period of 10 d would not be detected on downstream telemetry arrays if they passed the dam after this period. However, the PIT-tags of these fish could potentially have been detected if they passed downstream projects while PIT detection systems were operational.

Hydraulic conditions in the Snake River upstream from Lower Monumental Dam may also contribute to delays in migration. Stratification and upstream surface flows were found to develop in July and to extend from Lower Monumental Dam several kilometers upstream, possibly delaying the migration of subyearling Chinook salmon (Cook et al. 2007). However, because our releases were completed by 4 July 2007, this was not likely to have been an important factor influencing the lower-than-expected detections of treatment fish at the entry line.

Temperatures above 20°C have been shown to increase predation (Vigg and Burley 1991), disrupt physiological processes (Mesa et al. 2002), reduce levels of smoltification, and decrease growth (Marine and Cech 2004) of subyearling Chinook salmon. These factors might have contributed to a decrease in detections of treatment fish; however, in 2007, average daily river temperature did not surpass 20°C until 10 July, well after treatment releases had been completed.

The total level of both piscivorous and avian predation on study fish is unknown, but predation almost certainly combined with other factors to account for the relatively large percentage of fish not detected after release. Predation was also likely higher this year due to the lower river flow and the resultant longer travel times as indicated by the longer forebay residence. Avian predation, as determined by radio and PIT-tag recoveries, was much higher in 2007 than in 2006. There were 63 tags recovered this year compared with 18 tags recovered in 2006 during a similar recovery effort. The study was conducted about a week earlier in the year in 2007 than in 2006, but it is not known whether this timing change may have influenced the higher rates of avian predation.

Our study fish were collected from the same site as study fish used at Ice Harbor Dam, and the same personnel tagged fish for both studies on any given day. Yet at Ice Harbor Dam, a much higher percentage of treatment fish (87%) were detected at the forebay entry line (D. Ogden, NOAA Fisheries, personal communication). This percentage was similar to those observed at Ice Harbor Dam in previous studies for subyearling Chinook salmon released prior to 4 July. Considering this result, we are confident that the condition of fish released at Lower Monumental Dam was not a factor in the lower-than-expected detection rate at the entry line. Also, because detection probability at the entry line was high, similar to previous years, we do not believe that missed detections contributed significantly to the lower detection rate.

Overall, during 2007 we found that a large percentage of radio-tagged subyearling Chinook salmon passed Lower Monumental Dam through spillbay 8, the location where the RSW will be installed prior to the 2008 migration. The lower river flows during the study this year probably contributed to the lower survival estimates observed. Survival through spillbay 8 was again higher than the other spillbays and the spillway as a whole. A summary of the 2007 Lower Monumental Dam passage behavior and survival study is presented in Appendix E.

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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 juvenile 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.

Of the 860 radio-tagged subyearling Chinook salmon released above Lower Monumental Dam, 619 were detected at either the entry line upstream from the dam or at the dam. Of these 619 fish, 454 (52.8% of those released) were detected either at or below the Burr Canyon survival transect. Of the 833 radio-tagged subyearling Chinook salmon released into the tailrace of Lower Monumental Dam, 776 (93.2% of those released) were detected either at or below Burr Canyon. The detection probability for fish used in survival analysis at Burr Canyon was 0.727 overall. This detection probability was lower than expected, and it had the effect of widening confidence intervals about the survival estimates; however, it was not so low as to indicate a violation of the model assumption.

Radiotelemetry detection probability at Burr Canyon was almost 100%, with only 10 fish (0.8%) detected downstream that were not detected at Burr Canyon. With detection probabilities at or near 100% for all fish, there was no disparity between detection probabilities of treatment and reference groups (Appendix Table A1).

Appendix Table A1. Detections at and below Burr Canyon and detection probabilities at Burr Canyon for evaluating survival of hatchery subyearling Chinook salmon passing Lower Monumental Dam, 2007.

Release group	Detection at Burr Canyon	Detection at or below Burr Canyon	Probability of detecting fish at Burr Canyon	Detection probability based on number of fish releases
Treatment	451	454	0.993	0.528
Reference	769	776	0.991	0.932
Totals	1,220	1,230	0.992	0.727

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, Burr Canyon and the forebay of Ice Harbor 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 grouped at the BRZ by day were "paired" with tailrace fish grouped by release day with the same pairings used in the survival analyses. Confidence intervals (95%) and t-tests were constructed for statistical comparison. However, the reasonableness of the assumption was evaluated based on the biological size of these differences.

Test of homogeneity of arrival distributions at Burr Canyon was statistically significant for the 10^{th} and 20^{th} percentiles (Appendix table A2a). However, the difference in average passage timing was only 0.116 and 0.117 days (2.8 h) for these percentiles. At the Ice Harbor Dam forebay, arrival distributions are shown for only the 10^{th}, 50^{th} (median) and 90^{th} percentiles (Appendix table A2b) due to the lower numbers of fish reaching Ice Harbor Dam. Potential differences in arrival timing of treatment and reference fish could not be determined due to the large 95% confidence intervals.

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 A2a. Test of homogeneity of arrival timing at Burr Canyon for treatment and reference groups of radio-tagged hatchery subyearling Chinook salmon used for estimating dam survival at Lower Monumental Dam, 2007. The passage date of treatment fish at Lower Monumental Dam was paired with the release date of reference fish. Burr Canyon observations were grouped by date since nearly all fish were detected in less than 3 d. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Passage date	Passage date difference at Burr Canyon (days)								
	10th	20th	30th	40th	50th	60th	70th	80th	90th
6/13	-0.159	-0.130	-0.089	-0.092	-0.087	-0.090	-0.154	-0.093	-0.019
6/14	0.066	-0.016	-0.034	-0.095	-0.111	-0.123	-0.146	-0.239	-0.104
6/15	0.109	0.221	0.019	0.020	-0.034	-0.059	0.038	0.096	0.562
6/16	-0.042	-0.011	-0.093	-0.092	0.025	0.076	0.045	-0.034	0.062
6/17	0.301	0.274	0.158	0.265	0.420	0.450	0.420	0.164	0.058
6/18	0.198	0.173	0.027	0.118	0.018	0.027	-0.041	-0.058	-0.153
6/19	-0.024	-0.072	-0.292	-0.081	-0.098	-0.144	-0.003	0.011	0.083
6/20	0.226	0.366	0.428	0.426	0.522	0.509	0.563	0.661	0.731
6/24	0.051	0.016	0.006	0.073	0.027	-0.045	-0.006	0.043	0.113
6/25	0.177	0.239	0.246	0.306	0.295	0.234	0.210	-0.026	-0.010
6/26	0.243	0.290	0.190	0.203	0.238	0.261	0.165	0.095	0.063
6/27	0.042	0.016	-0.101	-0.032	-0.055	-0.019	-0.076	-0.127	-0.043
6/28	0.172	0.144	0.056	0.085	0.162	0.096	0.120	-0.004	0.124
6/29	0.111	0.087	-0.028	-0.043	-0.052	-0.034	-0.024	-0.041	0.026
6/30	0.179	0.056	0.060	0.019	0.141	0.140	-0.049	-0.157	0.068
7/1	0.197	0.231	0.204	0.243	0.216	0.231	0.163	0.056	0.004
7/2	0.198	0.267	0.211	0.208	0.177	0.147	-0.056	-0.125	-0.015
7/3	0.003	-0.061	-0.076	-0.079	-0.054	0.015	-0.128	-0.061	-0.022
7/4	0.182	0.118	0.004	-0.031	-0.112	-0.135	-0.300	-0.361	0.037
Mean difference (days)									
	0.117	0.116	0.047	0.075	0.086	0.081	0.039	-0.011	0.082
SE	0.027	0.033	0.037	0.036	0.043	0.043	0.047	0.047	0.049
P	0.000	0.002	0.222	0.054	0.059	0.077	0.413	0.824	0.107
Lower 95% CI	0.061	0.047	-0.031	-0.002	-0.004	-0.010	-0.059	-0.109	-0.020
Upper 95% CI	0.173	0.185	0.126	0.151	0.176	0.172	0.137	0.088	0.185

Appendix Table A2b. Test of homogeneity of arrival timing at Ice Harbor Dam for treatment and reference groups of radio-tagged hatchery subyearling Chinook salmon used for estimating dam survival at Lower Monumental Dam, 2007. The passage date of treatment fish at Lower Monumental Dam was paired with the release date of reference fish. Ice Harbor observations were grouped by date since nearly all fish were detected in less than 3 d. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

	Passage date difference at Ice Harbor Dam (days)		
Entry date	10th	50th	90th
6/13	-0.960	-0.703	1.572
6/14	-1.304	-0.038	-0.676
6/15	-0.094	1.087	1.256
6/16	-0.097	0.059	-1.091
6/17	1.295	0.888	-0.277
6/18		0.266	
6/19			
6/20			
6/24		0.172	
6/25		-0.220	
6/26		-0.104	
6/27		-0.944	
6/28	-0.022	-0.326	-0.346
6/29		0.162	
6/30	0.487	0.990	1.452
7/1	0.532	-0.353	1.024
7/2			
7/3		-0.165	
7/4			
Mean difference (days)	-0.020	0.051	0.364
SE	0.294	0.150	0.378
P	0.947	0.737	0.363
Lower 95% CI	-0.715	-0.271	-0.529
Upper 95% CI	0.674	0.374	1.257

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

River-run hatchery subyearling Chinook salmon were collected at both the Lower Monumental and Little Goose Dam smolt monitoring collection facilities from 11 June to 3 July. Only hatchery-origin subyearling Chinook salmon, not previously PIT-tagged, without any visual signs of disease or injuries, and weighing 10 g or more were used. The tagging period encompassed the passage period between the 57th and 85th percentile based on the 10-year average subyearling Chinook salmon smolt index at Lower Monumental Dam. Overall mean length of study fish was 115 mm and 116 mm for fish released upstream and downstream from Lower Monumental Dam, respectively (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 109 mm. Mean overall weight of both treatment and control fish was 14 g.

The study was conducted after the midpoint of the juvenile migration, 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 first downstream detection array used to estimate survival at Burr Canyon was 18 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 did release 11 tagged fish that had died prior to release at the reference release location and none of those fish were detected at the Burr Canyon detection array.

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

All transmitters were checked prior to implantation into a fish and again prior to release, to ensure that the transmitter was functioning properly. Tags not functioning properly prior to implantation were not used in the study. Several tags were held out of each days tagging to evaluate tag performance. Of the 47 tags that were held to evaluate tag performance, all but one tag ran at least 4 days, and 85% of the tags ran at least 9 days. Therefore, we are confident this assumption was met.

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.

APPENDIX B

Telemetry Data Processing and Reduction Flowchart

Data Collection and Storage

Data from radiotelemetry 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 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.

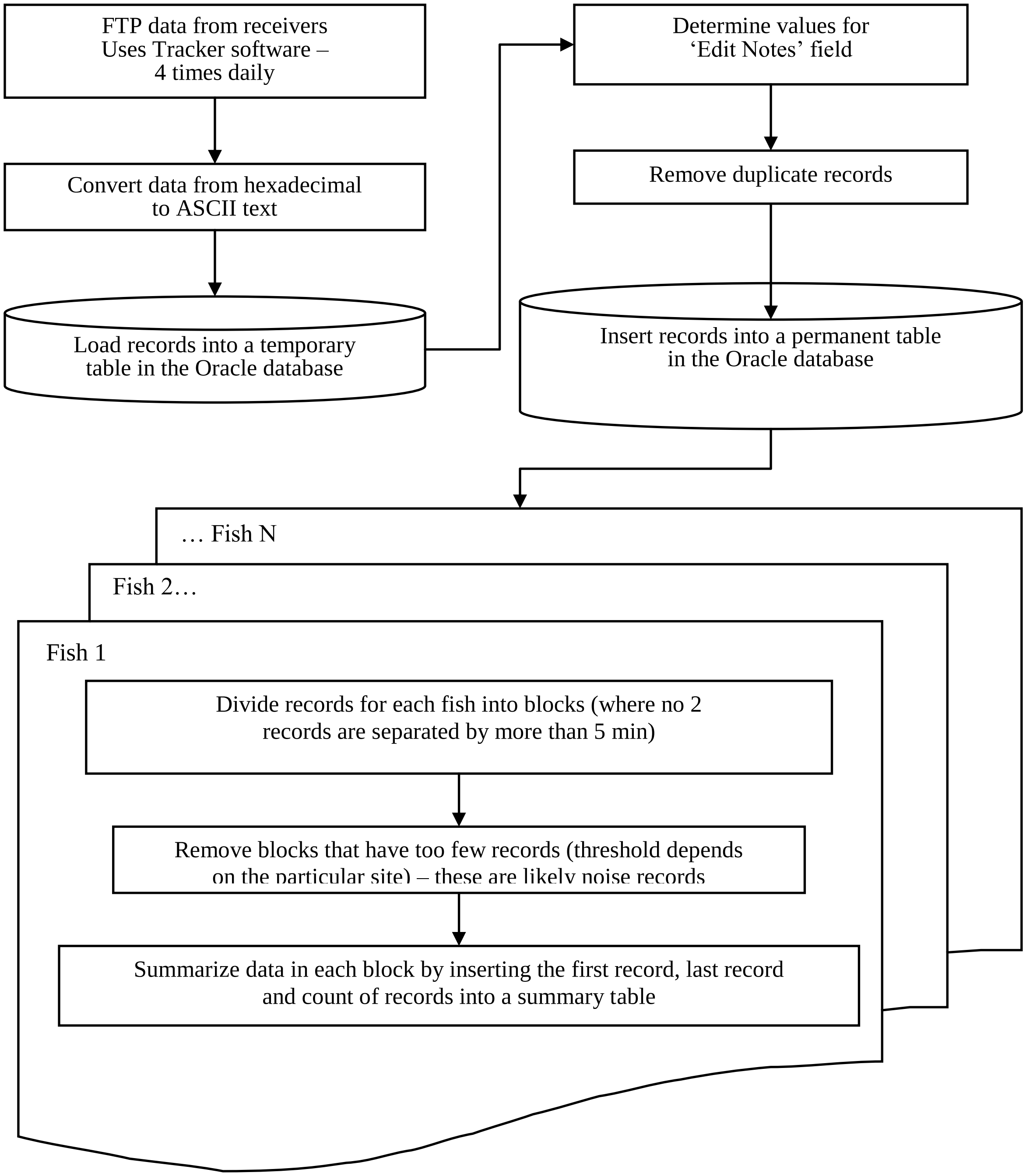
Lt start time: assigned to records occurring prior to the time at tag was activated (its start time).

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, 2007.

APPENDIX C

Spill Pattern

Lower Monumental Dam spill pattern for 2007.

Spill bay/stops								Total	
1	2	3	4	5	6	7	8	Stops	Spill
0	0	0	0	0	0	0	4	4	6.2
0	1	0	0	0	0	0	4	5	7.3
0	2	0	0	0	0	0	4	6	9.0
0	2	0	0	0	0	0	5	7	10.7
0	2	0	0	0	1	0	5	8	11.8
0	3	0	0	0	1	0	5	9	13.6
0	3	0	0	0	2	0	5	10	15.3
0	3	0	0	0	3	0	5	11	17.1
0	3	0	0	0	4	0	5	12	18.7
0	3	0	0	1	4	0	5	13	19.8
0	3	0	0	1	4	0	5	14	21.5
1	3	0	0	1	5	0	5	15	22.6
1	2	0	1	1	5	0	6	16	23.6
1	1	1	1	1	6	0	6	17	24.7
1	1	1	1	2	6	0	6	18	26.4
1	1	1	2	2	6	0	6	19	28.1
1	1	1	2	5	5	0	5	20	29.8
2	1	1	2	5	5	0	5	21	31.5
2	1	2	2	5	5	0	5	22	33.2
2	2	2	2	5	5	0	5	23	34.9
3	2	2	2	5	5	0	5	24	36.7
3	3	2	2	5	5	0	5	25	38.5
3	3	2	2	5	5	1	5	26	39.6
3	3	2	2	5	5	2	5	27	41.3
3	3	2	3	5	5	2	5	28	43.1
3	3	3	3	5	5	2	5	29	44.9
3	3	3	3	5	5	2	6	30	46.6
3	3	3	3	5	6	2	6	31	48.3
3	3	3	3	6	6	2	6	32	50.0
3	3	3	3	6	6	3	6	33	51.8
3	3	3	3	6	6	4	6	34	53.4
3	3	3	3	6	6	5	6	35	55.1
3	3	3	3	6	6	6	6	36	56.8
3	3	3	4	6	6	6	6	37	58.4
3	3	4	4	6	6	6	6	38	60.0
3	4	4	4	6	6	6	6	39	61.6
4	4	4	4	6	6	6	6	40	63.2
4	4	4	5	6	6	6	6	41	64.9

APPENDIX D

Detection Histories

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 2007. 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 (860)			
	0	0	406
	1	0	275
	0	1	3
	1	1	176
Reference group (833)			
	0	0	57
	1	0	442
	0	1	7
	1	1	327

Appendix Table D2. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival in 2007. 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 concrete survival estimates		
	Primary survival array	Post primary array	n
Treatment group (569)			
	0	0	125
	1	0	269
	0	1	3
	1	1	172
Reference group (833)			
	0	0	57
	1	0	442
	0	1	7
	1	1	327

Appendix Table D3. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival in 2007. 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 spillway survival estimates		
	Primary survival array	Post primary array	n
Treatment group (519)			
	0	0	116
	1	0	241
	0	1	2
	1	1	160
Reference group (833)			
	0	0	57
	1	0	442
	0	1	7
	1	1	327

Appendix Table D4. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillbay 8 passage survival in 2007. 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 spillbay 8 survival estimates		
	Primary survival array	Post primary array	n
Treatment group (280)			
	0	0	46
	1	0	141
	0	1	1
	1	1	92
Reference group (833)			
	0	0	57
	1	0	442
	0	1	7
	1	1	327

Appendix Table D5. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillbay 6 passage survival in 2007. 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 spillbay 6 survival estimates		
	Primary survival array	Post primary array	n
Treatment group (144)			
	0	0	37
	1	0	59
	0	1	0
	1	1	48
Reference group (833)			
	0	0	57
	1	0	442
	0	1	7
	1	1	327

Appendix Table D6. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillbay 2 passage survival in 2007. 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 spillbay 2 survival estimates		
	Primary survival array	Post primary array	n
Treatment group (84)			
	0	0	31
	1	0	36
	0	1	1
	1	1	16
Reference group (833)			
	0	0	57
	1	0	442
	0	1	7
	1	1	327

APPENDIX E

Study Summary

Year: 2007
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 and Little Goose Dam smolt monitoring facilities

Fish size:	Length	Weight
	median:	median: 14 g
	range: 102-145 mm	range: 10-33 g

Tag: Type: Advanced Telemetry Systems
Weight (g): 0.665 in air   Volume (mm^3): 203

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

Survival estimates:

Type	Value	SE	Replicate size	No. of replicates	Analytical model
dam	0.762	0.036	mean 31 (range 21-41)	18	CJS
concrete	0.845	0.018	mean 28 (range 19-44)	18	CJS
spillway	0.838	0.020	mean 25 (range 17-38)	18	CJS
Spillbay 8	0.903	0.019	mean 14 (range 9-21)	18	CJS
Spillbay 6	0.779	0.042	132	pooled	CJS
Spillbay 2	0.697	0.061	70	pooled	CJS
spillbays not 8	0.760	0.041	mean 14 (range 7-19)	15	CJS
JBS	0.949	0.100	39	pooled	CJS
Passage metrics					
FPE	0.982	0.005	mean 32 (range 17-44)	18	
SPE	0.914	0.018	mean 32 (range 17-44)	18	
spill efficiency	1.84	0.050	mean 32 (range 17-44)	18	
FGE	0.796	0.086	49	pooled	

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

Environmental/operating conditions

Daily operations/conditions	mean	range
spill (%)	50	12-38
total river flow (kcfs)	38.4	23.1-79.0
water temperature (°C)	18.9	15.8-19.6