Passage Behavior and Survival for Radio-tagged Subyearling Chinook Salmon at Lower Monumental Dam, 2006

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EXECUTIVE SUMMARY

This study was designed to collect supplementary data on subyearling Chinook salmon behavior and survival at Lower Monumental Dam during 2006. These data were collected in anticipation of installation of a removable spillway weir at the dam prior to the 2007 outmigration.

River-run subyearling Chinook salmon were collected and surgically tagged with a radio tag and PIT tag at Lower Monumental Dam from 21 June through 12 July. Data from fish reaching the forebay entry line from 22 June through 4 July were used in the analysis. These dates ecompassed the 85th through 93rd percentiles of the cumulative subyearling Chinook salmon passage index at Lower Monumental Dam. Data from fish reaching the entry line after 4 July were not used in the analysis because detection rates at the entry line from these groups were much lower than groups released before this date. We released 1,143 and 959 radio-tagged fish into the forebay and tailrace of Lower Monumental Dam, respectively. Releases were made during both daytime and nighttime throughout the study period.

Of the 1,143 fish released into the forebay, only 735 were used in the evaluation of relative survival. This was due to the large number of fish released after 2 July, which were not detected at any of the telemetry arrays. The fate of these fish is unknown, but may include 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. Similar results were noted in 2004 at Ice Harbor Dam with fish released for a passage behavior and survival study (for fish released after about 4 July), and also in July 2005 at Lower Monumental Dam for subyearling Chinook salmon released for a similar study.

Relative spillway passage survival was estimated at 0.943 (95% CI, 0.936-0.950) and relative dam survival at 0.896 (0.888-0.904). Passage route distribution was estimated at 81.4% through the spillway, 12.1% through the juvenile bypass system, 6.5% through turbines, and less than 0.5% through an unknown passage route. Spill efficiency was estimated at 0.820 (95% CI, 0.754-0.886), fish guidance efficiency at 0.645 (0.480-0.810), and fish passage efficiency at 0.947 (0.925-0.968). Median overall forebay residence time was 2.7 h (range 0.2-139.8 h), and median tailrace egress time was 10.9 min (range 2.8-9,448.8 min).

CONTENTS

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). Human activities that have contributed to the decline and loss of 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. From 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 provides 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. In 2003, after these modifications were complete, annual radiotelemetry studies were initiated to evaluate spillway survival during juvenile salmonid migration (Hockersmith et al. 2004, 2005, 2007, 2008; Absolon et al. 2007). The present study was initiated by the USACE Walla Walla District to collect additional baseline data to supplement data collected through 2005. This data will assist in evaluation of the removable spillway weir (RSW) after its deployment in spillbay 8 prior to the 2007 juvenile migration.

No specific operating conditions were requested during this study, and passage metrics were evaluated under the extant flow conditions. A bulk spill pattern, with spill limited by the "gas cap" was used through 20 June, with most flow directed through spillbays 7 and 8. This "gas cap" was generally found to be 25-40 kcfs, and was generally 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, the spill volume was 17 kcfs.

This study was conducted with the same telemetry equipment and personnel used during evaluation of yearling Chinook salmon and steelhead passage at Lower Monumental Dam in spring 2006 (Hockersmith et al. 2008). Telemetry equipment was located at the same sites as during the evaluation at the dam in 2005, with the exception that the main telemetry array used in determining passage survival was moved 8 km downstream from Windust Park to a location near Burr Canyon.

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). The primary telemetry array was moved approximately 8 km downstream from the Windust Park location used in previous years. This was done to further ensure that fish that died in the area of the dam would not reach the survival line and be incorrectly treated as live fish, so that this potential bias was effectively eliminated. Additional data was obtained from telemetry receivers located at Ice Harbor Dam (rkm 537).

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were collected at the Lower Monumental Dam smolt collection facility. We chose fish that did not have any gross injury or deformity and were of sufficient size for tagging. Fish selected for tagging were at least 105 mm long (fork length) or weighed at least 12 g. This size criteria ensured a tag burden of less than 7.5% of the 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 after they were processed, until the target number of fish were 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 according to the passage index.

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 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 measured 16 mm in length. The potting of the tag was ground down lengthwise to reduce weight. One end of the tag measured 6 mm in diameter, while the other end measured 4.2 mm, bringing the volume of the tag to 400 mm^3. Tags weighed 0.96 g in air and 0.4 g in water.

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

Fish were surgically implanted with a radio transmitter using techniques described by Adams et al. (1998). A PIT tag was also inserted with the radio transmitter during the surgical procedure for additional validation of telemetry detections and to potentially add data from PIT-tag detections 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

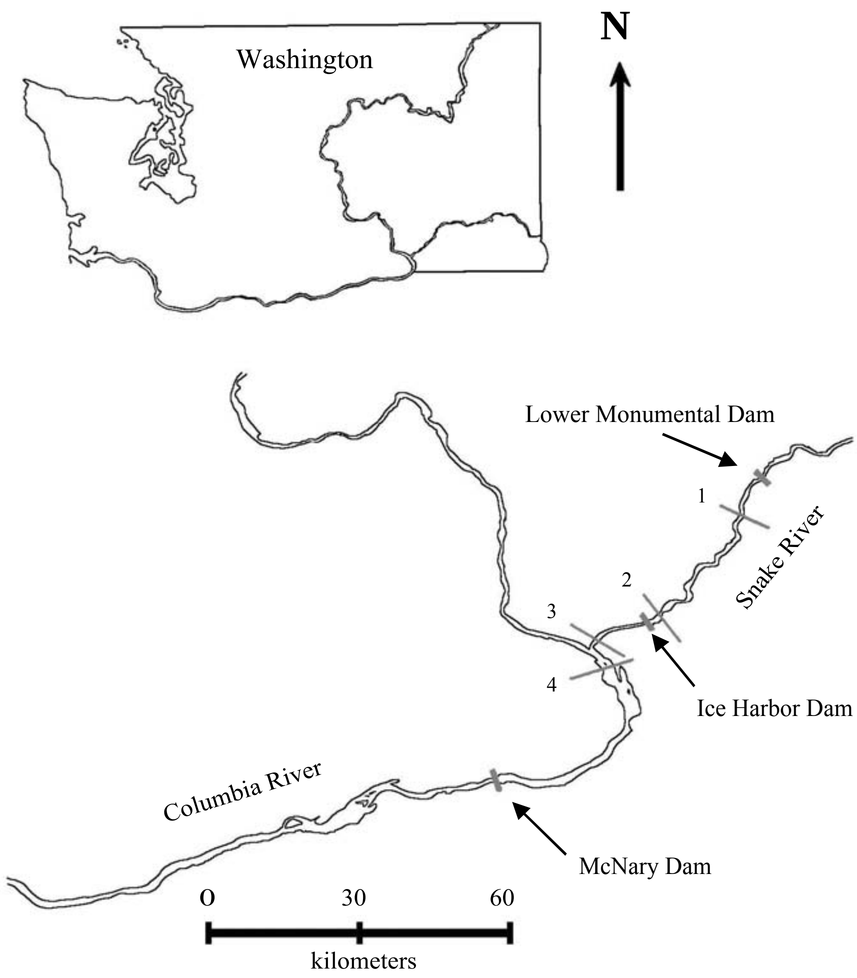

Figure 1. Study area showing location of radiotelemetry transects used for estimating subyearling Chinook salmon survival at Lower Monumental Dam (rkm 589) in 2006. Transects included: 1= Burr Canyon (rkm 571), 2 = forebay of Ice Harbor Dam (538), 3 = Sacajawea State Park (rkm523), and 4 = Burbank railroad bridge (rkm 520). The forebay, tailrace, and all routes of passage at Lower Monumental and Ice Harbor Dams were also monitored.

30.5 cm of the container to allow an exchange of water during holding. All holding tanks were supplied with flow-through ambient temperature water during tagging and holding, and were aerated with oxygen during transport to release locations. 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). Release groups were transferred from 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 so that arrival time at the forebay entry line would be spread over the diel period. Reference fish were released to the tailrace over a period of 6-7 h, both during the day and at night.

For releases of treatment fish, median start time was 0917 PDT for daytime releases and 2059 for nighttime releases. For daytime releases of reference fish, median start time was 1018 and median end time was 1500. For nighttime releases of reference fish, median start time was 2212 and median end time was 0314. We released 20 groups of approximately 58 fish per group during both day and night. A total of 1,143 radio-tagged fish were released 9 km upstream and a total of 959 radio-tagged fish were released 1 km downstream from Lower Monumental Dam (Figure 2). These were the same release locations used in the spring 2006 evaluation of Hockersmith et al. (2008).

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 survvial array near Burr Canyon (Figure 1). Underwater dipole or multiple-element aerial antennas were used to monitor entrance into the forebay, approach and passage through the dam, and exit from the tailrace. Underwater antennas were used to monitor passage routes (Figures 2 and 3), including 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 between detections was less than or equal to 5 min. When that difference became greater than 5 min, the last detection time was recorded and a new line of data was created.

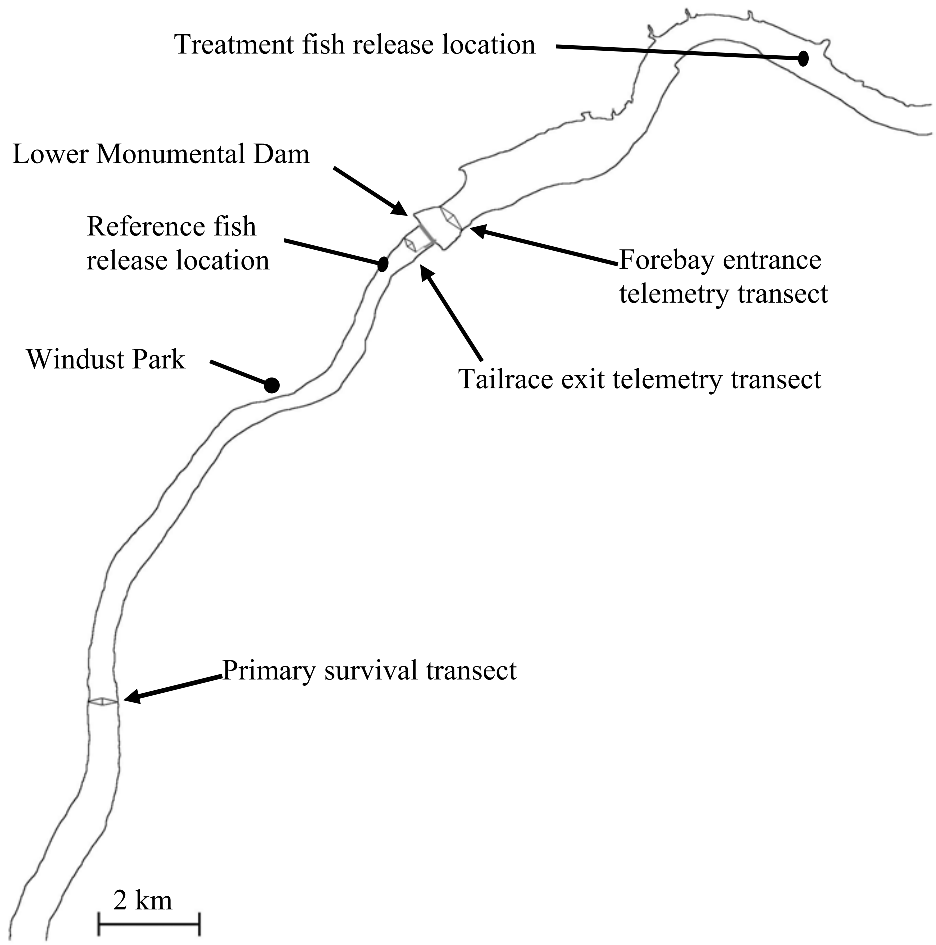

Figure 2. The Lower Snake River and Lower Monumental Dam (rkm 589) showing release locations for treatment (rkm 598) and reference groups (rkm 587) of radio-tagged subyearling Chinook salmon, 2006. Also shown are radiotelemetry transects used to detect fish entering the forebay (rkm 590), leaving the tailrace (rkm 589), and the location of the primary survival transect (rkm 571).

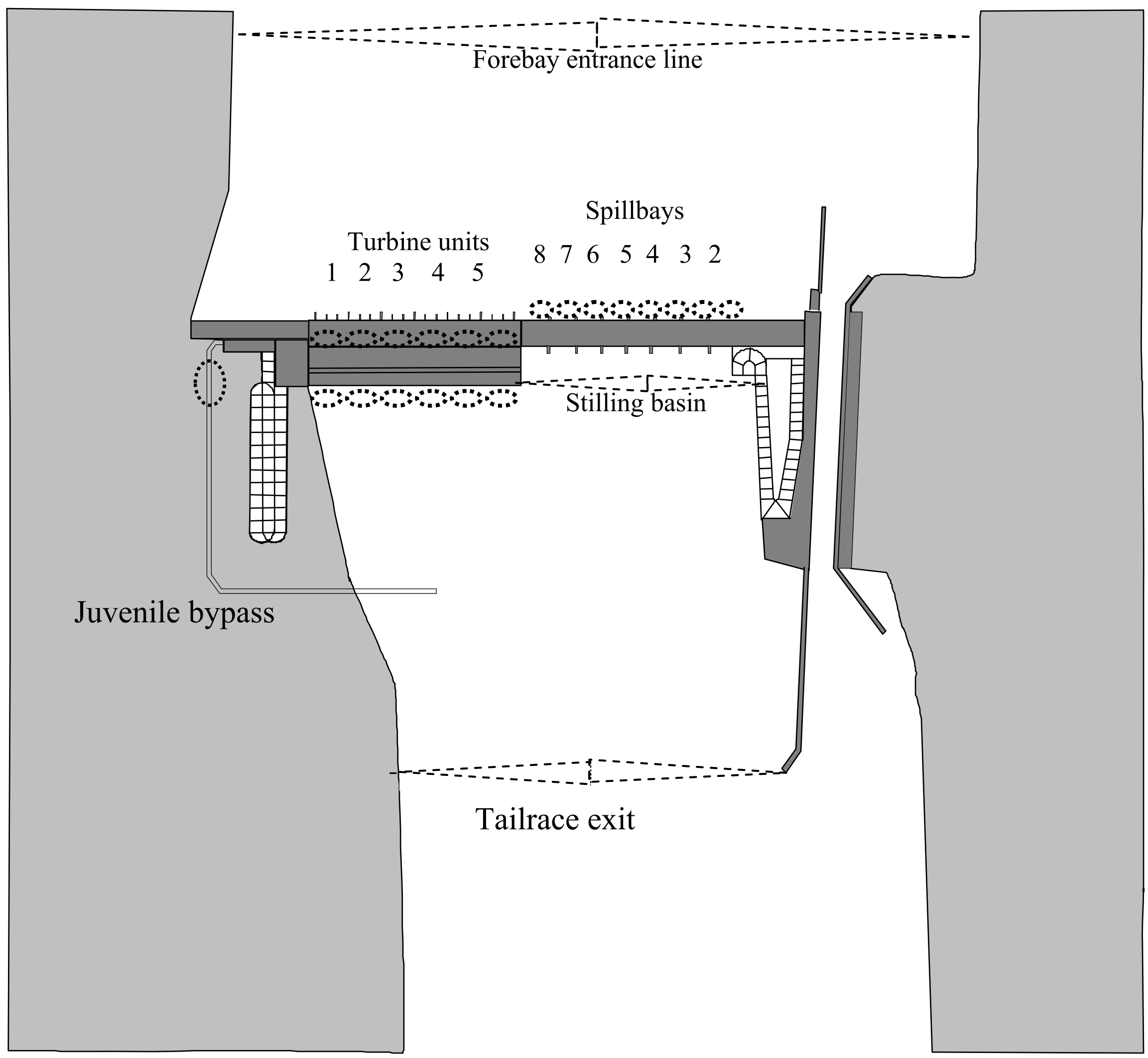

Figure 3. Plan view of Lower Monumental Dam showing approximate radiotelemetry detection zones in 2006 (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas).

Table 1. Fixed-site telemetry receivers for evaluating passage behavior and survival of radio-subyearling Chinook salmon at Lower Monumental Dam, 2006.

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

All compressed data were combined and loaded to a database where automated queries and algorithms were used to remove erroneous data (Appendix B). On the cleaned data set, detailed detection histories were created for each radio-tagged fish. These detection histories were used to calculate arrival time in the forebay, forebay approach 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 line 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 Lower Monumental Dam, detected on the forebay entry line, detected again in a passage route, and detected a third time in the immediate tailrace on either the stilling-basin or tailrace-exit telemetry receivers (Figure 3). Forebay residence time for individual fish was measured as the time between first detection on the forebay entrance line to the last detection in a passage route. Detections on the stilling basin and/or tailrace exit receivers were used to confirm passage.

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 in the stilling basin, tailrace exit transect, or at 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 spillbay. Similarly, turbine passage was assigned to fish last detected in a turbine intake prior to detection in the draft tube and tailrace. Passage through the JBS was assigned to fish detected in the bypass pipe 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 located upstream (treatment) and downstream (reference) of Lower Monumental Dam (Figure 2). Treatment replicate groups were formed by grouping daily detections of radio-tagged fish as they entered the forebay of Lower Monumental Dam. Reference replicates were grouped by day of release 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 includes survival from the immediate forebay, approximately 500 m upstream of the face of the dam, to the tailrace release location, approximately 1 km downstream.

Concrete survival was defined as survival of treatment fish from the upstream face of the dam to the tailrace reference release location approximately 1 km downstream of the dam relative to that of the 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 if certain assumptions are met (Zabel et al. 2002; Smith et al. 2003), in particular, that detection and survival probabilities downstream from detection sites were not conditional on radiotelemetry detection at upstream sites.

Relative survival estimates were then expressed as the ratio of survival estimates for treatment fish to those of reference fish using geometric means (Muir et al. 2001). A primary assumption made when using a paired-release study design is that treatment and reference groups have similar survival probabilities in the reach that is common to both groups (Burnham et al. 1987); that is, groups are mixed temporally upon detection at the primary detection array. Evaluation of this and other assumptions required for our study design are reported in Appendix A.

Passage Behavior and Timing

Forebay residence 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 of the primary dewatering structure. Fish that were detected on the fish screen antennas could then be assigned a passage route by their subsequent detection on either the bypass system antenna, indicating bypass passage, or detection on the draft tube antennas, indicating turbine passage.

Fish Passage Metrics

Fish-passage metrics including; spill efficiency, spill effectiveness, fish guidance efficiency (FGE), and fish passage efficiency (FPE) were also evaluated at Lower Monumental Dam using radiotelemetry detections in the locations used for passage route evaluation. 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 using an average ± 1.96 standard error of the 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 21 d from 21 June through 11 July. The number of fish tagged each day was not weighted to the passage index. Tagging occurred after 85% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and was completed when 93% of these fish had passed (Figure 4). Information on fish condition, size, and timing of the migration is reported by the Fish Passage Center (www.fpc.org).

Overall mean fork length was 118 mm (range 104-152 mm) for treatment fish and 118 mm (range 103-148 mm) for reference fish (Table 2). A total of 10 treatment fish did not have a length recorded at the time of tagging. Mean length of the run at large sampled at the Lower Monumental Dam smolt collection facility was 110 mm (Monty Price, WDFW, personal communication; Table 3). Overall mean weight was 15.3 g (range 11.5–27.9 g) for treatment fish and 15.4 g (range 11.5-32.1 g) for reference fish (Table 4). A total of eight treatment fish did not have a weight recorded at the time of tagging. During the study period, handling and tagging mortality for subyearling Chinook salmon held for a minimum of 24 h after tagging was 1.8%

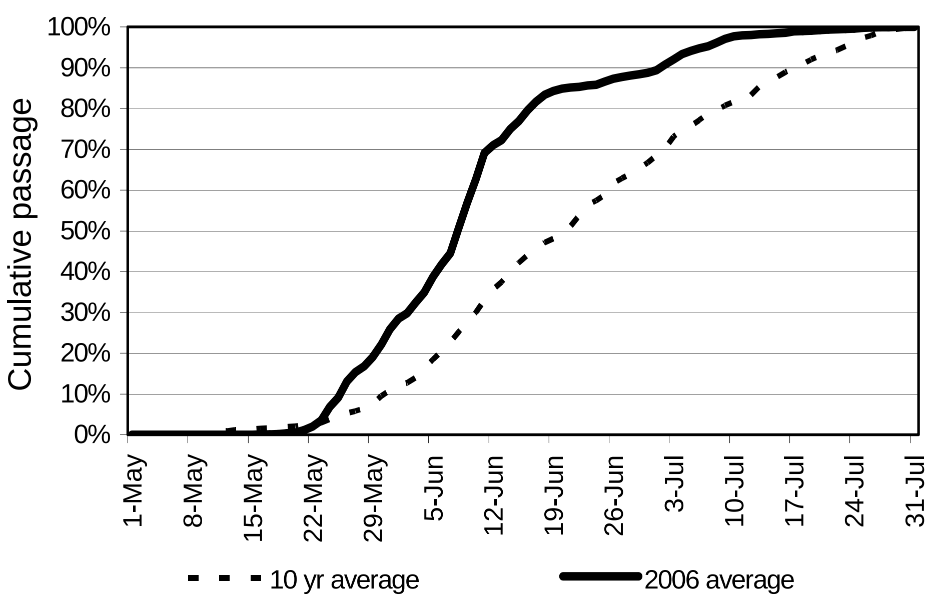

Figure 4. Cumulative distribution in 2006 compared to the 10-year average (1997-2006) for Chinook salmon passing Lower Monumental Dam.

Table 2. Length of radio-tagged subyearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2006.

	Forebay				Tailrace			
	Length (mm)				Length (mm)			
Release date	N	Mean	Range	SD	N	Mean	Range	SD
				Daytime releases				
6/21	32	117	108-152	7.6				
6/22	27	116	108-127	5.8	25	115	105-128	5.9
6/23	27	113	105-123	4.7	24	112	105-117	3.5
6/24	27	115	105-123	4.9	23	114	107-128	4.5
6/25	25	115	107-128	4.5	24	120	109-137	7.8
6/26	28	117	105-140	7.8	26	117	107-130	5.8
6/27	27	116	104-126	5.2	24	118	107-130	6.0
6/28	29	118	105-132	6.2	25	117	106-131	6.5
6/29	29	119	109-136	7.3	26	120	112-134	6.5
6/30	29	119	109-135	6.5	26	119	110-136	6.6
7/1	28	121	108-140	7.1	25	123	108-148	7.8
7/2	27	122	111-140	5.7	26	122	111-138	6.8
7/3	29	122	109-142	8.7	25	119	111-135	6.4
7/4	29	118	109-129	4.7	23	119	110-142	6.9
7/5	29	118	110-126	5.0	25	117	111-124	3.4
7/6	28	117	108-126	4.7	27	118	109-133	5.4
7/7	30	117	110-136	4.8	26	117	109-134	5.3
7/8	28	116	108-134	5.6	25	116	109-124	3.9
7/9	30	115	109-123	3.8	25	116	108-127	5.6
7/10	30	118	108-136	5.9	26	117	108-128	4.9
7/11					27	116	108-126	4.5
subtotal	568	117	104-152	5.8	503	118	105-148	5.7
				Nighttime releases				
6/21	31	116	111-126	4.1				
6/22	24	113	106-123	4.4	23	116	107-131	5.8
6/23	21	115	108-123	4.1	20	113	103-123	5.0
6/24	28	114	106-124	4.8	24	114	107-130	5.7
6/25	26	116	108-127	5.1	24	117	107-132	7.5
6/26	26	117	108-134	6.3	24	117	105-135	8.2
6/27	30	119	110-132	5.9	24	118	107-137	6.6
6/28	30	118	104-135	8.2	25	117	107-128	5.7
6/29	26	120	108-132	7.0	23	121	109-133	5.9
6/30	30	119	113-128	4.4	23	124	110-144	9.2
7/1	29	125	111-143	7.4	24	122	111-136	6.0
7/2	30	121	110-136	5.3	24	120	111-130	4.5
7/3	30	119	111-128	5.2	24	120	109-133	5.8
7/4	29	120	108-134	6.3	24	118	112-132	5.2
7/5	29	120	109-140	7.3	24	121	112-132	5.1
7/6	28	120	113-134	5.2	25	120	108-136	5.5
7/7	29	120	112-132	5.3	25	119	111-142	6.4
7/8	30	118	106-128	5.3	23	117	110-127	4.8
7/9	29	115	107-123	4.0	25	117	111-131	4.0
7/10	30	118	109-129	5.1	24	117	108-125	5.2
7/11					23	118	110-127	5.6
subtotal	565	118	104-143	5.5	475	118	103-144	5.9
Total	1,133	118	104-152	5.7	978	118	103-148	5.8

Table 3. Length of subyearling Chinook salmon from the smolt monitoring facility sample at Lower Monumental Dam, 2006. River-run fish including clipped and unclipped.

Collection date	Release date	N	Mean (mm)	Range (mm)
6/19	6/21	158	105	90-130
6/20	6/22	126	104	85-125
6/21	6/23	191	104	90-120
6/22	6/24	168	106	90-130
6/23	6/25	200	108	65-130
6/24	6/26	147	110	90-130
6/25	6/27	193	109	75-130
6/26	6/28	182	112	95-130
6/27	6/29	183	113	60-140
6/28	6/30	163	117	90-135
6/29	7/1	143	115	85-135
6/30	7/2	200	113	65-140
7/1	7/3	200	112	90-140
7/2	7/4	200	112	70-140
7/3	7/5	200	112	85-135
7/4	7/6	200	109	75-130
7/5	7/7	174	109	85-130
7/6	7/8	177	107	70-135
7/7	7/9	200	110	60-140
7/8	7/10	200	110	80-135
7/9	7/11	200	108	70-145
7/10	7/12	185	109	85-150
Totals		3,990	110	60-150

Table 4. Mean weight of radio-tagged subyearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2006.

Release date	Forebay Weight (g) N	Mean	Range	SD	Tailrace Weight (g) N	Mean	Range	SD
Daytime releases								
6/21	32	14.7	12.0-18.5	1.8				
6/22	27	14.1	11.6-18.8	2.3	25	14.4	11.7-21.0	2.3
6/23	27	13.2	11.8-17.0	1.5	24	12.8	11.5-15.5	0.9
6/24	27	14.4	11.9-18.5	2.0	23	14.2	12.0-19.6	1.9
6/25	25	14.2	12.1-19.7	1.9	23	17.0	12.7-25.5	3.9
6/26	28	15.3	12.3-21.6	2.5	26	15.4	12.1-21.5	2.4
6/27	29	14.8	12.7-18.7	1.6	24	15.4	12.5-21.3	2.5
6/28	29	16.2	12.4-23.0	2.6	25	15.4	11.9-20.5	2.4
6/29	29	16.1	12.1-25.1	3.5	26	15.9	12.2-21.7	2.8
6/30	29	15.7	12.3-21.3	2.4	26	15.6	12.2-22.9	3.0
7/1	28	16.9	12.7-27.9	3.4	25	16.8	12.5-25.4	3.0
7/2	27	16.8	12.7-27.4	2.8	26	16.4	12.8-23.6	2.7
7/3	29	17.7	12.4-27.6	4.2	25	15.9	12.6-23.9	3.0
7/4	29	14.9	12.4-18.8	1.7	23	15.6	12.6-29.2	3.6
7/5	29	15.7	12.5-20.8	2.0	25	14.8	12.5-17.6	1.5
7/6	28	14.9	12.1-18.7	2.0	27	14.8	12.0-22.6	2.7
7/7	30	14.7	12.2-25.1	2.5	26	14.6	12.2-20.1	1.9
7/8	28	14.9	12.2-25.4	2.7	25	14.4	12.2-17.8	1.6
7/9	30	14.0	12.2-17.4	1.4	25	14.8	12.4-20.6	2.0
7/10	30	15.7	12.2-23.1	2.4	26	14.8	12.4-20.4	1.8
7/11					27	15.0	12.2-20.5	2.0
subtotal	570	15.2	11.6-27.9	2.4	502	15.2	11.5-29.2	2.4
Nighttime releases								
6/21	31	13.8	12.0-18.1	1.6				
6/22	24	13.3	11.5-16.0	1.3	24	14.5	11.9-21.4	2.3
6/23	21	14.2	11.9-17.6	1.8	20	13.9	11.7-18.0	1.6
6/24	28	14.0	11.9-16.7	1.4	24	13.9	12.2-19.4	1.9
6/25	27	15.4	12.4-25.7	3.2	24	15.4	12.0-21.2	2.7
6/26	26	15.6	12.4-22.5	2.5	24	15.5	12.3-25.4	3.3
6/27	30	15.9	12.6-22.7	2.4	24	16.3	12.2-26.4	3.3
6/28	30	15.8	12.4-21.9	2.7	25	15.8	12.4-21.4	2.3
6/29	26	16.0	12.8-22.3	2.9	22	16.0	12.3-20.2	2.2
6/30	29	16.2	13.3-24.3	2.5	23	18.3	12.3-32.1	5.2
7/1	29	18.0	13.0-25.2	3.1	24	17.2	12.5-24.4	3.0
7/2	30	16.4	13.4-22.7	2.2	23	16.2	12.4-20.5	1.6
7/3	30	15.7	12.0-20.4	2.5	24	15.6	12.8-19.8	2.0
7/4	29	15.9	12.3-21.7	2.2	24	15.3	12.8-22.8	2.7
7/5	29	15.7	12.2-27.5	3.3	24	16.4	12.9-21.4	2.2
7/6	28	16.1	13.3-19.9	2.0	25	15.8	12.9-22.5	2.5
7/7	29	15.1	12.5-18.8	2.1	25	15.7	12.6-27.3	3.0
7/8	30	15.2	12.3-19.7	1.9	23	15.3	12.8-19.0	1.8
7/9	29	14.8	12.8-18.4	1.4	25	15.0	12.5-21.6	1.9
7/10	30	15.7	12.9-20.1	2.2	24	15.1	12.7-19.7	2.1
7/11					23	16.3	13.3-22.7	2.6
subtotal	565	15.4	11.5-27.5	2.3	474	15.7	11.7-32.1	2.5
Total	1,135	15.3	11.5-27.9	2.3	976	15.4	11.5-32.1	2.5

Project Operations

No special project operations were requested for this study. During the study period (21 June-12 July), spill averaged 16,100 ft^3/s, or 32% of total project discharge (Table 5). Spill occurred throughout the study period except for short periods to allow fish transportation barges to safely cross the river from the navigation lock to the barge loading area. Spill ranged from 0 to 21.8 kcfs, powerhouse flow ranged from 11.2 to 77.6 kcfs, and total river flow ranged from 21.7 to 94.5 kcfs. Tailwater elevation ranged from 436.3 to 440.7 ft msl, and water temperature ranged from 15.6 to 21.4°C (Table 5). The spill pattern used in 2006 is shown in Appendix C.

Table 5. Average daily conditions during releases and passage of radio-tagged hatchery subyearling Chinook salmon at Lower Monumental Dam, 2006.

Date	Spill (kcfs)	Powerhouse (kcfs)	Total discharge (kcfs)	Total discharge range (kcfs)	Tailwater elevation (ft msl)	Water temperature (°C)
6/21	17.1	49.2	66.4	47.9-84.2	438.8	15.7
6/22	17.3	47.6	64.9	39.2-94.5	438.7	15.8
6/23	16.9	41.5	58.4	29.5-79.8	438.4	16.1
6/24	16.6	42.3	58.9	40.9-69.8	438.4	16.4
6/25	17.0	39.0	56.0	43.0-68.8	438.3	16.8
6/26	16.7	41.5	58.1	33.1-85.8	438.4	17.3
6/27	16.0	38.9	54.8	30.0-81.3	438.2	17.8
6/28	14.9	35.5	50.5	28.3-70.9	438.1	18.0
6/29	14.9	39.9	54.8	25.1-75.4	438.3	18.5
6/30	14.3	37.0	51.4	25.0-69.9	438.0	18.7
7/1	14.4	26.6	41.0	25.9-50.7	437.9	18.7
7/2	14.9	30.0	44.8	29.7-50.2	438.0	19.3
7/3	15.2	30.8	46.1	44.4-47.6	438.0	19.7
7/4	15.3	26.2	41.5	21.7-45.1	437.7	20.0
7/5	16.8	30.0	46.7	28.1-64.1	438.1	20.4
7/6	16.0	27.3	43.3	29.1-58.8	437.9	20.5
7/7	16.9	29.8	46.7	28.1-67.8	438.1	20.8
7/8	16.6	27.6	44.2	30.9-60.8	437.7	20.9
7/9	17.0	30.0	47.0	29.5-54.8	437.9	20.7
7/10	16.8	28.6	45.4	28.3-64.6	438.0	20.7
7/11	16.9	28.6	45.5	28.5-70.9	437.8	21.1
7/12	16.7	29.1	45.8	28.1-67.4	438.0	21.2
Average	16.1	34.4	50.6	21.7-94.5	438.1	18.9

Migration Behavior and Passage Distribution

Forebay and tailrace behavior and timing, passage distribution and metrics, and passage survival results are based on fish that approached Lower Monumental Dam from 21 June through 4 July. Treatment fish released later in the study (4-11 July), had much lower detection and survival rates, and much higher standard errors in survival rates, than those detected at the forebay entry line earlier in the study. We observed a small decrease in survival rate for control fish after 4 July (Figure 5). Because these differences were due to behavioral factors (holdover behavior) unrelated to dam passage, we feel including these data would bias our results.

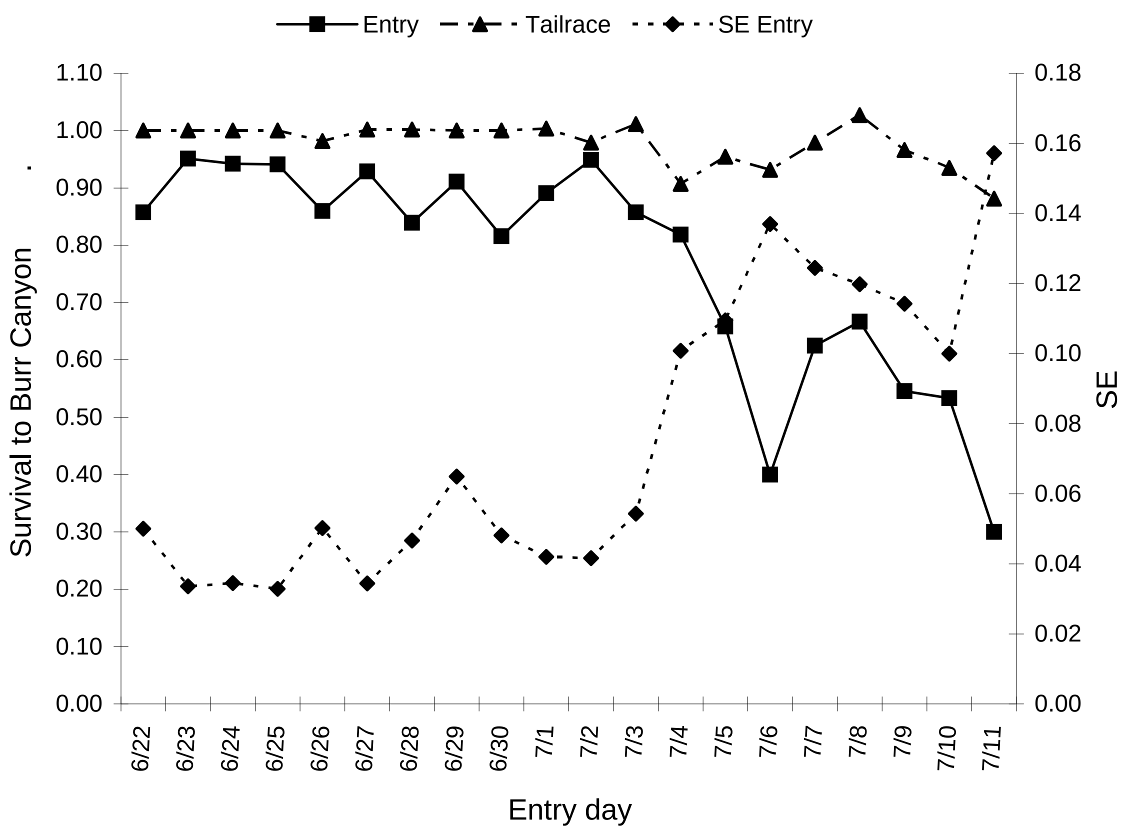

Figure 5. Survival to Burr Canyon telemetry line for subyearling Chinook salmon detected at the entry line, released into the tailrace and detected at Burr Canyon and the standard error (SE) of survival of treatment fish detected at the entry line, 2006.

Forebay Behavior and Timing

Of the 1,143 radio-tagged treatment fish released above Lower Monumental Dam, 752 were detected entering the forebay. Of these 752 fish, 84% were first detected approaching the spillway and 16% were first detected approaching the powerhouse.

Forebay residence times were calculated for 680 fish, each with detections on both the forebay entrance transect, a passage-route receiver, and a known passage route. Median forebay residence timing of treatment fish was 3.6 h through the bypass system, 2.7 h through the spillway, and 2. 6 h through the turbines. Of these fish, 554 (81.5%) passed through the spillway, 80 (11.8%) passed through the JBS, and 46 (6.8%) passed 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 time in hours for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2006. Number (n) of fish passing by each route is shown in parentheses.

	Forebay residence time (h)			
Percentile	Bypass (n = 80)	Spillway (n = 554)	Turbine (n = 46)	Overall (n = 680)
Minimum	0.4	0.2	0.5	0.2
10th	0.8	0.5		0.6
20th	1.3	0.8	0.9	0.8
30th	1.9	1.2		1.3
40th	2.6	1.8		1.8
50th (median)	3.6	2.7	2.6	2.7
60th	5.5	3.5		3.8
70th	7.1	5.6		5.9
80th	12.6	11.6	9.4	11.5
90th	17.8	19.6		18.2
Maximum	33.2	106.2	139.8	139.8
Mean	6.7	8.0	7.6	7.8
Mode	n/a	1.2	n/a	2.7

Table 7. Forebay residence timing for all passage routes combined, by entry date, for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2006. Represented are the 10th, 50th (median) and 90th percentile passage times and the number (n) of fish in each group. Times are presented in h:mm:ss format.

Entry date	n	10th	50th	90th
6/22	38	0:39:07	3:10:26	26:13:55
6/23	40	1:04:31	6:00:51	39:40:28
6/24	47	0:50:03	2:42:28	17:26:08
6/25	50	0:46:31	2:59:40	19:57:30
6/26	53	0:46:58	3:05:39	26:29:04
6/27	52	0:42:14	3:38:24	23:00:23
6/28	58	0:38:59	2:36:12	22:03:36
6/29	20	1:21:41	4:22:27	15:08:19
6/30	62	0:36:45	3:03:06	14:20:56
7/1	53	0:28:47	2:00:35	15:14:50
7/2	36	0:29:55	3:16:05	17:12:40
7/3	39	0:27:12	1:45:00	17:24:12
7/4	21	0:24:13	0:51:34	4:16:20
Total/mean	569	0:42:51	3:02:30	19:52:57
se		0:04:27	0:20:51	2:18:12
95% CI				
lower		0:33:09	2:17:04	14:51:50
upper		0:52:32	3:47:56	24:54:04

Passage Distribution and Metrics

Of the 1,143 radio-tagged treatment fish released, 802 (70%) were detected at or below Lower Monumental Dam, while 341 were not detected after release. Of the 739 (65%) fish that passed the dam, 598 (81%) passed through the spillway, 89 (12%) through the JBS, 48 (7%) through turbines and 4 (<1%) through an undetermined route (Figure 6). The remaining 63 (8%) fish entered the forebay but were not recorded as passing the dam. Figure 7 illustrates the percentage of time each spillbay was open during the study period and the percentage of fish that passed through each spillbay.

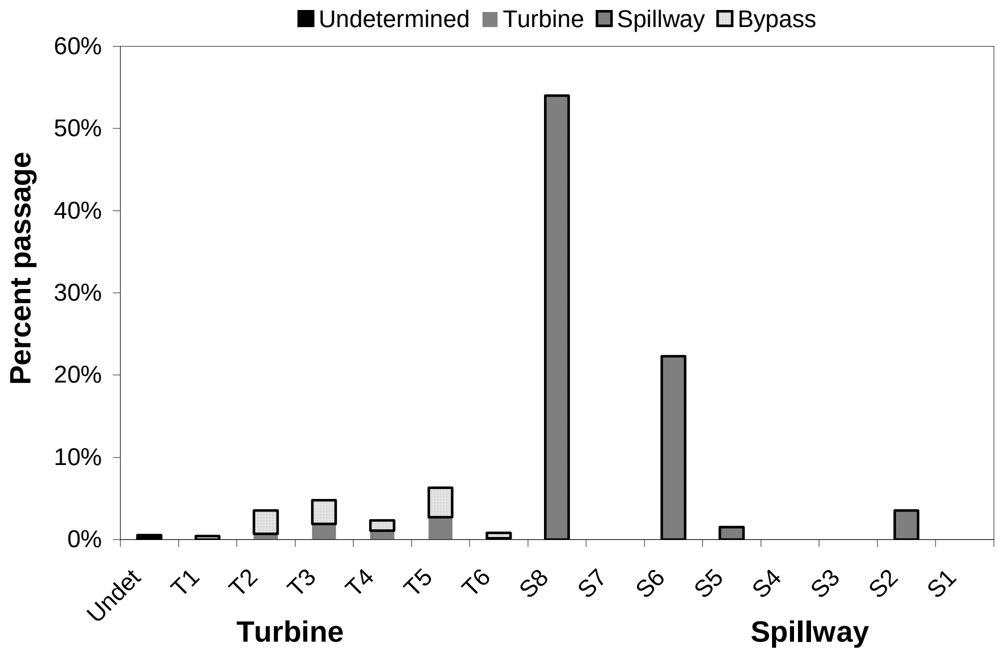

Figure 6. Passage route distribution of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2006.

Figure 7. Percent time individual spillbays were open and passage distribution for radio-tagged river-run subyearling Chinook salmon at Lower Monumental Dam, 2006.

Fish passage efficiency at Lower Monumental Dam was 0.947 (95% CI, 0.925-0.968), spill efficiency was 0.820 (0.754-0.886), and spill effectiveness was 2.58:1 (2.39-2.77). Fish guidance efficiency was 0.645 (0.480-0.810), but the very low numbers of fish available to estimate FGE needs to be considered when evaluating this result (Table 8).

Table 8. Fish passage metrics by forebay entry date for river-run subyearling Chinook salmon at Lower Monumental Dam, 2006. SPE = spill passage efficiency, FPE = fish passage efficiency, FGE = fish guidance efficiency, and n = number of fish per group.

Entry date	n	SPE	FPE	Spill effectiveness	n	FGE
6/22	38	0.711	0.947	2.45	11	0.818
6/23	40	0.675	0.950	2.09	13	0.846
6/24	47	0.766	0.851	0.69	11	0.364
6/25	50	0.900	0.980	2.94	5	0.800
6/26	53	0.648	0.926	2.04	19	0.789
6/27	52	0.796	0.907	2.44	10	0.600
6/28	58	0.914	0.966	2.83	5	0.600
6/29	20	0.700	0.950	2.33	6	0.833
6/30	62	0.919	0.968	3.14	5	0.600
7/1	53	0.943	0.962	2.62	3	0.333
7/2	36	0.865	0.973	2.67	4	1.000
7/3	39	0.872	0.974	2.69	5	0.800
7/4	21	0.952	0.952	2.61	1	0.000
Total/mean	569	0.820	0.947	2.58	98	0.645
se		0.030	0.010	0.09		0.076
95% CI						
lower		0.754	0.925	2.39		0.480
upper		0.886	0.968	2.77		0.810

Tailrace Behavior and Timing

Tailrace egress and timing was calculated for 631 radio-tagged, river-run subyearling Chinook salmon. Median tailrace egress time was 11 minutes overall, 9 minutes for fish that passed through the spillway (n = 520), 29 minutes for those that passed through the JBS (n = 69), and 14 minutes for those that passed through the turbines (n = 42; Table 9). The longer egress time for fish that passed through the JBS was expected and was due to the greater distance fish passing through the JBS had to travel prior to detection in the tailrace. Table 10 presents the 10^{th}, 50^{th} (median), and 90^{th} percentiles of tailrace passage by treatment group for fish that passed via the spillway and also by spillbay passage route.

Table 9. Tailrace egress times in minutes for radio-tagged, river-run subyearling Chinook salmon passing through the bypass and spillway at Lower Monumental Dam, 2006.

	Tailrace egress time (min)			
Percentile	Bypass (n = 69)	Spillway (n = 520)	Turbine (n = 42)	Overall (n =631)
Minimum	10	3	7	3
10^{th}		5		5
20^{th}	17	6	10	6
30^{th}		6		7
40^{th}		7		9
50^{th} (median)	29	9	14	11
60^{th}		11		14
70^{th}		16		20
80^{th}	81	27	24	39
90^{th}		73		80
Maximum	955	9,449	143	9,449
Mean	19	6	n/a	6
Mode	75	72	25	69

Table 10. Tailrace egress timing for radio-tagged river-run subyearling Chinook salmon that passed Lower Monumental Dam through the spillway by forebay entry date and also by spillbay passage route, 2006. Represented are the 10th, 50th (median) and 90th percentile passage times and the number (n) of fish in each group. Times are presented as h:mm:ss.

Entry date	n	10th	50th (median)	90th
6/22	27	0:04:46	0:6:37	0:30:12
6/23	27	0:04:55	0:10:52	10:19:43
6/24	35	0:05:32	0:08:37	1:29:04
6/25	43	0:05:32	0:13:37	1:15:59
6/26	35	0:05:08	0:10:04	1:47:44
6/27	43	0:05:06	0:08:51	1:08:23
6/28	53	0:05:13	0:08:34	21:02:18
6/29	14	0:05:44	0:09:45	1:00:43
6/30	55	0:05:42	0:10:19	3:20:18
7/1	48	0:05:26	0:08:01	9:04:55
7/2	31	0:05:35	0:11:31	2:05:53
7/3	32	0:05:34	0:09:01	6:41:44
7/4	19	0:06:18	0:22:17	4:24:33
Total/mean	462	0:05:26	0:10:37	4:56:16
se		0:00:07	0:01:05	1:36:35
95% CI				
lower		0:05:11	0:08:15	1:25:50
upper		0:05:40	0:12:59	8:26:43
Spillbay	n	10th	50th (median)	90th
2	15	0:17:00	1:03:10	64:53:50
6	138	0:06:42	0:16:38	3:08:20
8	309	0:05:02	0:07:36	1:42:09

Detection Probability

Detection probabilities at Burr Canyon were 0.590 (95% CI, 0.561-0.620) for treatment groups overall and 0.943 (0.928-0.958) for reference groups. The large difference in detection probability between the two groups is due to the large number of treatment fish released after 4 July and never detected at either the forebay entry line or the dam. For fish released from 22 June to 4 July, detection probabilities at Burr Canyon were 0.746 (0.715-0.777) for treatment and 0.975 (0.963-0.988) for reference groups. These probabilities were used in survival estimates. The exclusion of treatment fish released later in the study resulted in notably higher detection probabilities. This further illustrated the problems encountered by releasing subyearling fish later in the migration season. Detection histories of groups used in survival estimates are shown in Appendix D.

Estimated Survival

Relative survival was estimated using the ratio of survival estimates for treatment fish to those of reference fish, using the geomean for both estimates. Overall relative dam survival (forebay BRZ to tailrace) was 0.896 (95% CI, 0.867-0.926) at Lower Monumental Dam. Relative concrete survival (all fish passing the dam) was 0.941 (0.918-0.964). Relative survival estimates for dam, concrete, spillbay 6, and spillbay 8 passage are shown by forebay entry date in Table 11. Relative concrete survival estimates derived from detections at Ice Harbor Dam were the same as those derived from detections at Burr Canyon at 0.940 (0.844-1.047). Detection histories of fish used in survival analysis are shown in Appendix D. Relative survival was estimated at 0.943 (0.918-0.968) through the spillway overall, 0.970 (0.946-0.995) through spillbay 8, and 0.909 (0.828-0.998) through spillbay 6. Insufficient numbers of fish passed through the turbines and juvenile bypass system (powerhouse) to allow precise estimates of survival through either of these routes.

Table 11. Relative survival estimates by forebay entry date for subyearling Chinook salmon at Lower Monumental Dam, 2006. Dam survival includes approximately 500 m of forebay from the BRZ deadline to the concrete. Spillbay 6 estimates are pooled over several days.

	Relative dam survival		Relative concrete survival		Relative survival through spillbay 6		Relative survival through spillbay 8	
Date	Estimate	SE	Est.	SE	Est.	SE	Est.	SE
6/22	0.857	0.050	0.917	0.046			0.941	0.057
6/23	0.951	0.034	0.963	0.036	0.918	0.039	1.000	0.000
6/24	0.942	0.035	1.004	0.004			1.008	0.010
6/25	0.941	0.033	0.949	0.029			1.000	0.000
6/26	0.876	0.050	0.978	0.035			1.019	0.021
6/27	0.927	0.034	0.943	0.031			0.998	0.002
6/28	0.837	0.047	0.878	0.046	0.872	0.045	0.919	0.044
6/29	0.911	0.065	0.949	0.039			0.952	0.047
6/30	0.815	0.048	0.889	0.043			0.914	0.047
7/1	0.888	0.042	0.890	0.041			0.927	0.039
7/2	0.969	0.042	0.971	0.041			1.022	0.022
7/3	0.848	0.054	0.961	0.030	0.938	0.049	0.989	0.012
7/4	0.902	0.101	0.949	0.079			0.928	0.103
Geomean	0.896	0.049	0.941	0.038	0.909	0.045	0.970	0.031
SE	0.013		0.011		0.020		0.011	
95% CI								
lower	0.867		0.918		0.828		0.946	
upper	0.926		0.964		0.998		0.995	

Diel Passage Behavior

We released radio-tagged fish both during daytime and nighttime hours in an attempt to provide an equal distribution of fish passing Lower Monumental Dam throughout the daily 24-h period. However, sample sizes were not large enough to allow meaningful analyses of survival or passage metrics between daytime and nighttime releases or of trends in data during the study period.

The percentage of fish entering the forebay was higher during daytime hours. Daytime hours were designated as 0300 to 1900 PST, which is 67% of a 24-h day. We recorded 83% of the fish entering the forebay during those hours (Figure 8). The percentage of dam passage was also higher during the day than at night, with 76% of the fish passing the dam during designated daylight hours (Figure 9). Also shown in Figure 9 is the average total river flow by hour during the study period to allow a comparison between river flow and passage hour.

The location of first approach to Lower Monumental Dam is presented in Figure 10. As we have seen in the past, the highest percentage of fish approached the dam at spillbay 8, with spillbays 7 and 6 also seeing high numbers of approaching fish. Of the total number of treatment fish approaching Lower Monumental Dam, 57% approached these three spillbays.

We did see a difference in approach by diel period. There was a shift toward the powerhouse for fish that approached during the night (Figure 11). This occurred in spite of a higher percentage and volume of flow passing through the powerhouse during daytime hours (Table 12).

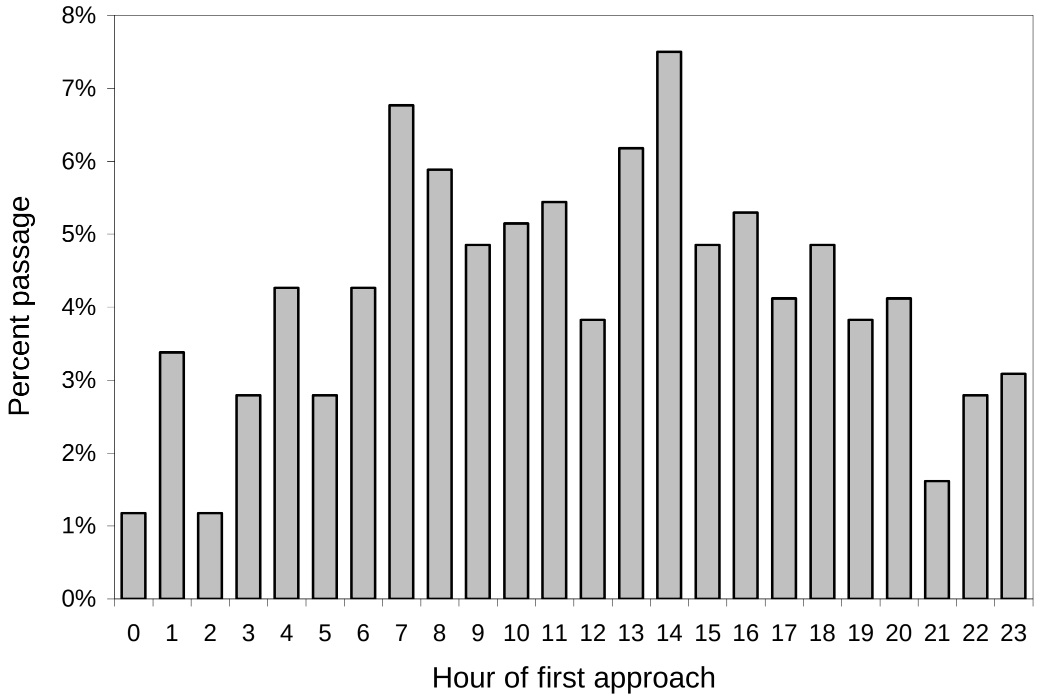

Figure 8. Percentage of radio-tagged subyearling Chinook salmon entering the forebay of Lower Monumental Dam by hour, 2006.

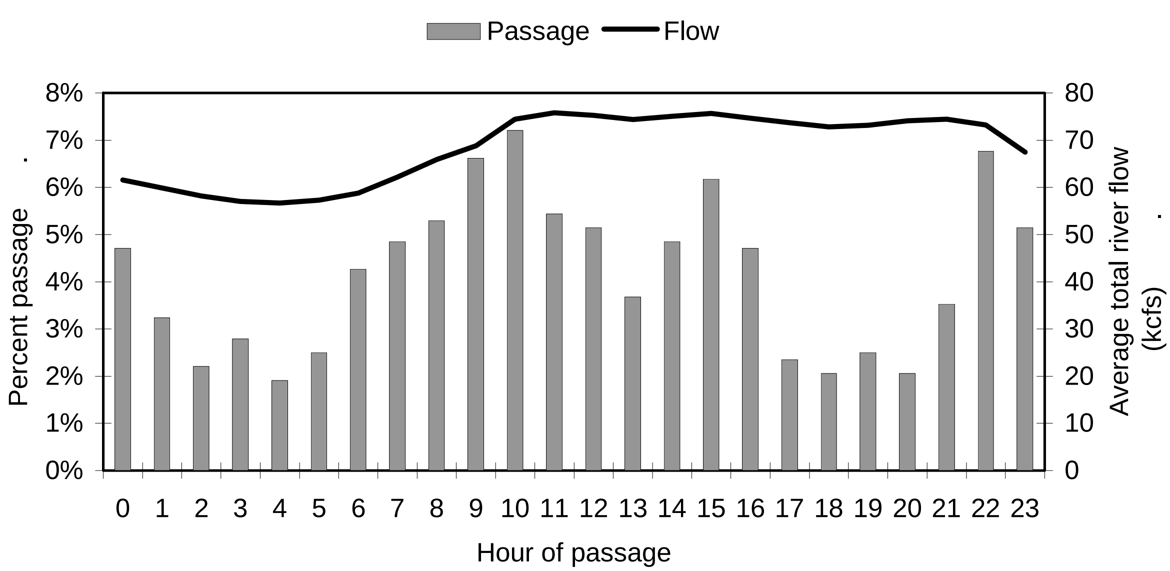

Figure 9. Percentage of radio-tagged subyearling Chinook salmon passing Lower Monumental Dam and average total river flow by hour, 2006.

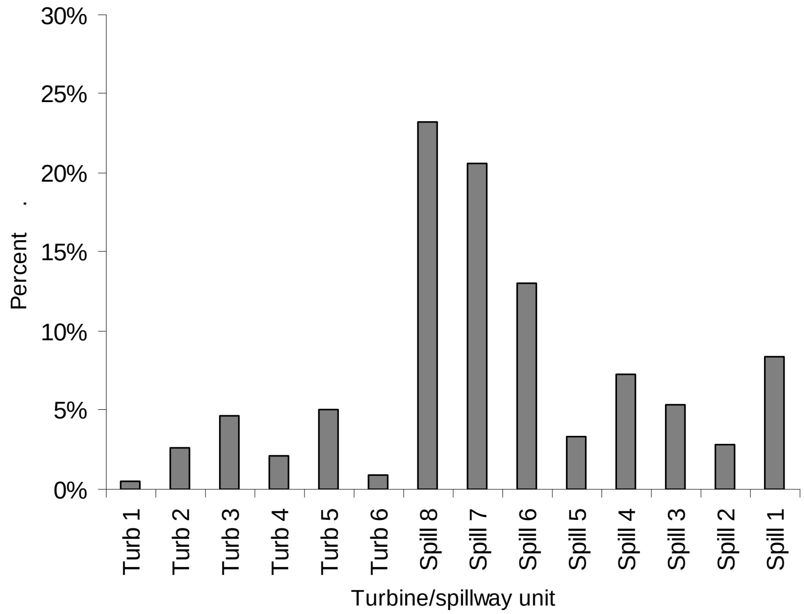

Figure 10. Percentages of radio-tagged subyearling Chinook salmon first approaching Lower Monumental Dam turbine units and spillbays, combined day and night releases, 2006.

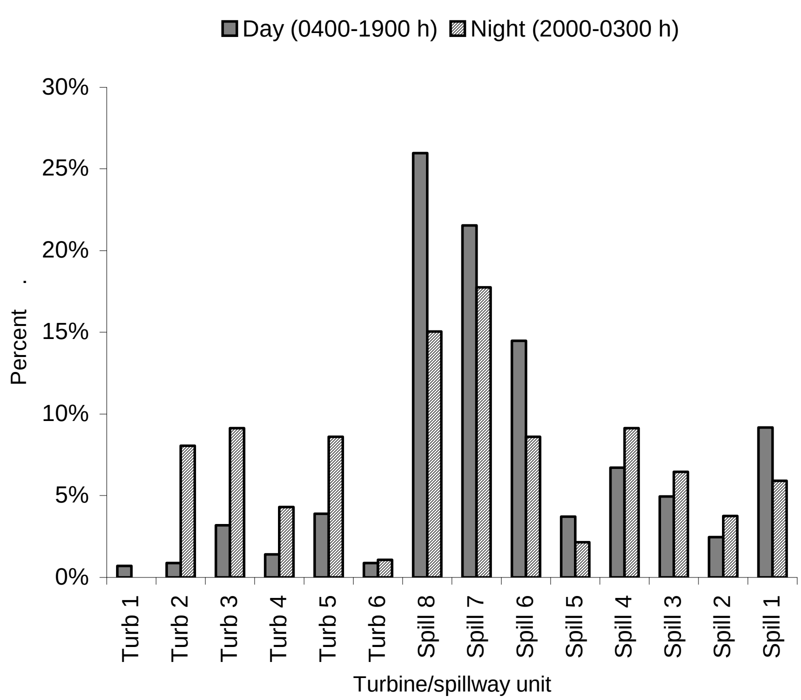

Figure 11. Percentages of radio-tagged subyearling Chinook salmon first approaching Lower Monumental Dam turbine units and spillbays by day or night, 2006.

Table 12. Median volume, percentage of flow, and percentage of fish approaching and passing Lower Monumental Dam spillway and powerhouse during day and nighttime diel periods, 2006.

		Spillway				Powerhouse			
Diel	Total flow (ft^3)	Volume (ft^3)	Spill (%)	Approach (%)	Passage (%)	Volume (ft^3)	Spill (%)	Approach (%)	Passage (%)
Day	61.0	16.0	27.7	89	94	44.9	73.7	11	6
Night	49.0	15.8	34.3	69	86	33.2	67.8	31	14

Avian Predation

When avian nesting colonies had been abandoned at Crescent and Foundation Islands for the season, a recovery effort was initiated for radio tags that had been deposited by piscivorous birds. Radio tags were collected by physically walking the island looking for visible tags. Radio-tag serial numbers were used to identify individual tagged fish. PIT tags were “recovered” by a thorough search with a detection system as described in Ryan et al. (2001). PIT-tag detections and physical recovery of radio transmitters at Crescent and Foundation Islands were provided by NOAA Fisheries and Real Time Research Inc. (B. Ryan, NOAA Fisheries, personal communication; A. Evans, Real Time Research Inc., personal communication).

There were 18 PIT tags recovered, representing approximately 0.8% of the fish we released into the Snake River. This 0.8% should be considered a minimum estimate of predation because of the probability that not all radio tags from fish consumed by birds were deposited on the islands, and not all tags deposited on the islands were recovered. Nine tags were recovered from both the treatment and reference groups, which represented 0.8% of treatment and 0.9% of reference fish. One PIT tag from our study was also recovered on East Sand Island in the Columbia River estuary. However, that tag was not included as a mortality in terms of dam passage, since the fish had survived through the study area and had continued to migrate several hundred kilometers downstream.

DISCUSSION

During 2006, our tagging coincided with the period between the 85th and 93rd passage percentiles of the juvenile subyearling Chinook salmon population at Lower Monumental Dam. We had planned to begin tagging on June 12, which would have coincided with the 71st passage percentile of the juvenile migration; however, at that time, there were insufficient numbers of subyearling Chinook available that were large enough for tagging. We would have preferred to tag and release fish over a broader and more representative portion of the migrating juvenile population, but tags used for this study required a minimum fish body weight of about 12 g to minimize potential tag effects. Due to the smaller size of migrating target fish in 2006, we had to wait until the later part of June for a sufficient number of large enough fish to become available.

During the 2006 study, 32% of total river flow was passed as spill. This compares to 59% of total river flow spilled during our 2005 study of subyearling Chinook salmon (Absolon 2007). While the population passage percentiles of study fish during the 2006 study were similar to those during 2005, the study was conducted 2 weeks earlier in the year. Therefore, river flows during the study were much higher during 2006 with average total river flows of 37 kcfs during the 2005 study and 51 kcfs during the 2006 study. While the volume of spill was higher in 2005 than 2006 (21 and 16 kcfs, respectively), most additional flow passed through the powerhouse in 2006. Powerhouse flow averaged 16 kcfs in 2005 and 34 kcfs in 2006.

Increased flow to the powerhouse probably accounted for the increased percentage of fish that first approached the powerhouse in 2006. In 2005, 90% of study fish first approach the dam at the spillway, and only 10% first approached at the powerhouse (Absolon 2007). That pattern shifted in 2006, with 84 and 16% of first approaches at the spillway and powerhouse, respectively. The percentage of fish passing the spillway also dropped from 90.0% in 2005 to 81.4% in 2006. This resulted in a lower spill efficiency in 2006 (0.814) than in 2005 (0.883). However, spill effectiveness was higher in 2006 (2.58:1) than in 2005 (1.53:1). Fish passage efficiency (FPE) was higher in 2005; the point estimate was 0.935 in 2006 and 0.962 in 2005. This was due to the higher percentage of spill that year. Forebay residence time was slightly shorter in 2006 (2.7 h) compared to the 3.0 h noted in 2005, and was likely due to higher total river flow in 2006. This higher flow had the opposite effect on tailrace egress timing, which increased from 2 min in 2005 to 11 min in 2006.

We noted again this year that a substantial percentage of passage through the available spillway routes occurred through spillbay 8. While spillbays 2, 6, and 8 were each open during 98% of the study period, only 4% of treatment fish passed through spillbay 2, while 27% passed through spillbay 6, and 66% through spillbay 8. In addition to the higher proportion of passage through spillbay 8, relative survival was also higher through that bay. Relative survival was 0.970 (95% CI, 0.946-0.995) through spillbay 8 vs. 0.909 (0.828-0.998) through spillbay 6. Too few fish passed through the other spillbays to develop survival estimates for those bays. Overall spillway survival was 0.943 (0.918-0.968).

A substantial proportion (35%) of treatment fish released upstream from Lower Monumental Dam after 4 July were never detected at the forebay entrance array. For fish released from the beginning of the study on 22 June to 4 July, 82% were detected at the forebay entrance array. In contrast, for fish released near the end of the study, from 5 to 10 July, only 36% were detected in the forebay.

Similar results were observed in studies of subyearling Chinook salmon both at Lower Monumental Dam in 2005 (Absolon et al. 2007) and at Ice Harbor Dam in 2004 (Ogden et al. 2005). In both of these previous evaluations of passage and survival, large proportions of fish released after about 4 July were never detected after release. Several factors may have contributed to this occurrence, including increasing water temperature and predation. 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).

Fish that delayed migration longer than the 10-d predetermined tag life would not be detected if they did later migrate downstream past the dam and detection arrays. These fish could possibly be interrogated by their PIT tag as they passed downstream projects. In this study, none of the treatment fish which that not detected entering the forebay were later interrogated by downstream PIT tag detection systems.

Temperatures above 20°C have been shown to increase predation vulnerability of Pacific salmon (Vigg and Burley 1991). In subyearling Chinook salmon, these higher temperatures have also been shown to disrupt physiological processes (Mesa et al. 2002) and reduce levels of smoltification and growth rates (Marine and Cech 2004). In 2006, average daily river temperature exceeded 20°C on July 4 and remained over 20°C for the remainder of the study. This is an additional factor that may have contributed to the high percentage of treatment fish not detected after 4 July.

Overall, we found that a large percentage of radio-tagged subyearling Chinook salmon passed Lower Monumental Dam through spillway 8 during 2006. Spillway 8 is the location planned for installation of the RSW prior to the 2008 migration. Passage through this spillway has resulted in high survival and little delay in either the forebay or tailrace. A summary of the 2006 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 these survival estimates (treatment survival divided by reference survival) were calculated to determine relative survival. Evaluation of critical model and biological assumptions of the study are detailed below.

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

Of the 1,143 radio-tagged subyearling Chinook salmon released above Lower Monumental Dam, 802 were detected at either the entry line upstream of the dam or at the dam. Of these 802 fish, 657 (57.5% of those released) were detected either at or below the Burr Canyon survival transect. Of the 959 radio-tagged subyearling Chinook salmon released into the tailrace of Lower Monumental Dam, 904 (94.3% of those released) were detected either at or below Burr Canyon. The detection probability for fish used in survival analysis at Burr Canyon was 0.753 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 12 fish (0.8%) detected downstream that were not detected at Burr Canyon. With detection probabilities at or near 100% for all fish, there was little or 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, 2006.

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 released
Treatment	653	657	0.994	0.575
Reference	896	904	0.991	0.943
Totals	1,549	1,561	0.992	0.753

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}, 40^{th}, 80^{th}, and 90^{th} percentiles (Appendix Table A2a). However, the largest difference in average passage timing was only 0.15 days (for the 20^{th} percentile, and not significant). At the Ice Harbor Dam forebay, arrival distributions were unmixed for all percentiles (Appendix Table A2b), but the largest difference between arrival times for treatment and reference groups was only 0.21 days (10^{th} percentile).

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. 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 (α = 0.05).

	Passage timing difference at Burr Canyon (d)								
Entry date	10th	20th	30th	40th	50th	60th	70th	80th	90th
6/22	0.03	0.03	0.04	0.11	0.14	0.14	0.10	0.02	0.22
6/23	-0.52	0.07	-0.03	0.04	0.12	0.11	0.14	0.17	0.04
6/24	0.09	0.16	0.11	-0.01	0.02	0.11	0.19	0.27	0.03
6/25	0.03	0.11	0.21	0.01	0.00	0.06	0.13	0.20	0.05
6/26	0.04	0.13	0.23	-0.03	0.00	0.11	0.28	0.48	0.32
6/27	0.14	0.24	0.24	0.04	0.04	0.13	0.10	0.27	0.14
6/28	0.19	0.20	0.21	0.04	0.08	0.09	0.14	0.06	-0.14
6/29	0.08	0.14	0.13	-0.04	-0.02	0.00	0.11	0.26	0.27
6/30	0.15	0.19	0.14	0.01	0.04	0.05	0.10	0.06	-0.02
7/1	0.14	0.12	-0.01	-0.06	-0.01	0.02	-0.01	-0.25	-0.19
7/2	0.11	0.13	-0.03	0.00	0.01	0.04	0.05	-0.06	0.02
7/3	0.19	0.14	0.01	-0.03	0.01	0.05	0.19	0.06	0.05
7/4	0.03	0.22	-0.01	0.04	0.02	0.00	-0.04	-0.26	-0.16
Mean									
difference (d)	0.05	0.15	0.09	0.01	0.03	0.07	0.11	0.10	0.05
SE	0.05	0.02	0.03	0.01	0.01	0.01	0.02	0.06	0.04
P	0.306	0.000	0.007	0.516	0.033	0.000	0.000	0.114	0.290
95% CI									
Lower	-0.06	0.11	0.03	-0.02	0.00	0.04	0.06	-0.03	-0.05
Upper	0.16	0.18	0.16	0.04	0.06	0.10	0.16	0.23	0.15

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. 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 timing difference at Ice Harbor Entry (d)								
Entry date	10th	20th	30th	40th	50th	60th	70th	80th	90th
6/22	0.29	0.00	-0.42	0.19	-0.33	-0.41	-0.38	-0.71	-1.17
6/23	-0.34	-0.52	-0.38	-0.35	-0.61	-0.83	-1.52	-1.84	-0.43
6/24	-0.43	-0.36	-0.19	-0.15	0.50	0.46	0.88	0.57	0.34
6/25	0.35	0.44	0.20	0.47	0.54	0.94	0.91	0.10	-0.40
6/26	-0.59	-0.14	-0.11	-0.16	0.35	0.44	0.34	0.19	0.92
6/27	-0.49	-0.37	-0.58	0.03	0.05	0.13	0.12	0.45	0.70
6/28	1.00	0.65	0.46	0.11	0.04	-0.11	-0.41	-0.12	-0.49
6/29	0.17	0.23	0.88	0.50	0.51	0.24	0.27	0.48	0.77
6/30	-1.91	-0.20	-0.38	0.00	0.14	0.06	0.04	0.08	0.14
7/1	-0.62	-0.03	0.00	0.02	0.12	-0.02	-0.03	-0.03	-0.40
7/2	-0.14	0.26	-0.17	-0.42	-0.23	-0.15	-0.19	0.02	0.31
7/3	-0.08	-0.10	0.08	0.11	0.12	-0.09	-0.10	-0.04	-0.42
7/4	0.01	0.31	0.27	0.35	0.08	0.07	0.10	0.65	0.40
Mean									
difference (d)	-0.21	0.01	-0.03	0.05	0.10	0.06	0.00	-0.02	0.02
SE	0.19	0.10	0.11	0.08	0.09	0.12	0.17	0.18	0.17
P	0.283	0.886	0.815	0.501	0.316	0.649	0.983	0.933	0.902
95% CI									
Lower	-0.62	-0.19	-0.27	-0.12	-0.11	-0.20	-0.37	-0.41	-0.35
Upper	0.20	0.22	0.22	0.23	0.30	0.32	0.37	0.38	0.40

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

River-run hatchery subyearling Chinook salmon were collected at Lower Monumental Dam smolt monitoring collection facility from 21 June to 11 July. Only hatchery-origin subyearling Chinook salmon not previously PIT tagged, without any visual signs of disease or injuries, and weighing approximately 12 g or more were used. The tagging period encompassed the passage period between the 85^{th} and 93^{rd} percentile based on the 10-year average subyearling Chinook salmon smolt index at Lower Monumental Dam. Overall mean length of study fish was 118 mm for fish released both above and below Lower Monumental Dam, respectively (Table 2). The overall mean length of river-run subyearling Chinook salmon collected at the Smolt Monitoring Facility during the study period was 110 mm. Mean overall weight of treatment and control fish was 15.3 and 15.4 g, respectively.

The study was conducted during the later part 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. (1998) 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 16 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 100 tags that were held to evaluate tag performance, 2 tags shut off after 7 days, and all other tags ran for at least 10 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 which 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 process 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.

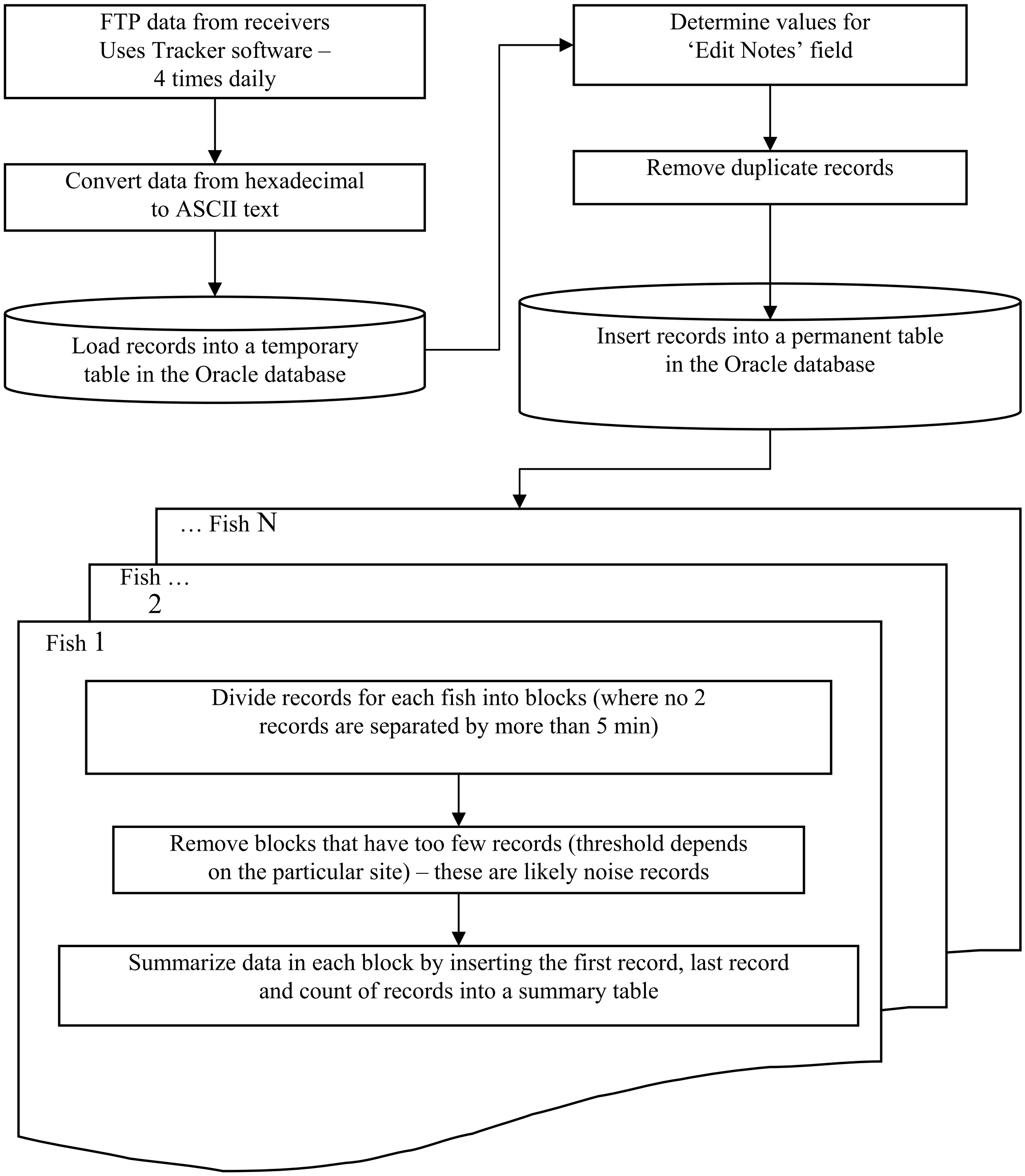
Lt start time: assigned to records occurring prior to the time at tag was activated (its start time).

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, 2006.

APPENDIX C

Spill Pattern

Lower Monumental Dam spill pattern for 2006.

Spill bay/stops								Total	
1	2	3	4	5	6	7	8	Stops	Spill
0	1	0	0	0	0	0	1	2	2.2
0	1	0	0	0	0	0	2	3	3.9
0	1	0	0	0	0	0	3	4	5.7
0	1	0	0	0	0	0	4	5	7.3
0	1	0	0	0	0	0	5	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	2	0	0	0	2	0	5	9	13.5
0	2	0	0	0	3	0	5	10	15.3
0	2	0	0	0	4	0	5	11	16.9
0	2	0	0	1	4	0	5	12	18.0
0	2	0	0	1	5	0	5	13	19.7
1	2	0	0	1	5	0	5	14	20.8
1	1	1	1	1	5	0	5	15	21.3
1	1	1	1	1	5	0	6	16	23.0
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

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 2006. The primary survival array was 16 km downstream from Lower Monumental Dam; arrays downstream from the primary array are shown in Figure 1. Detection histories recorded as: 1, detected; 0, not detected.

	Dam passage detection history		
	Primary survival array	Post primary array	n
Treatment group (n = 1,113)			
	0	0	456
	1	0	149
	0	1	4
	1	1	504
Reference group (n = 959)			
	0	0	55
	1	0	269
	0	1	8
	1	1	627

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 2006. The primary survival array was 16 km downstream from Lower Monumental Dam; arrays downstream from the primary array are shown in Figure 1. Detection histories recorded as: 1, detected; 0, not detected.

	Concrete passage detection history		
	Primary survival array	Post primary array	n
Treatment group (n = 734)			
	0	0	79
	1	0	147
	0	1	4
	1	1	504
Reference group (n = 959)			
	0	0	55
	1	0	269
	0	1	8
	1	1	627

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 2006. The primary survival array was 16 km downstream from Lower Monumental Dam; arrays downstream from the primary array are shown in Figure 1. Detection histories recorded as: 1, detected; 0, not detected.

	Spillway passage detection history		
	Primary survival array	Post primary array	n
Treatment group (n = 598)			
	0	0	62
	1	0	109
	0	1	3
	1	1	424
Reference group (n = 959)			
	0	0	55
	1	0	269
	0	1	8
	1	1	627

Appendix Table D4. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental to evaluate spillbay 8 passage survival in 2006. The primary survival array was 16 km downstream from Lower Monumental Dam; arrays downstream from the primary array are shown in Figure 1. Detection histories recorded as: 1, detected; 0, not detected.

	Spillbay 8 detection history		
	Primary survival array	Post primary array	n
Treatment group (n = 397)			
	0	0	27
	1	0	69
	0	1	1
	1	1	300
Reference group (n = 959)			
	0	0	55
	1	0	269
	0	1	8
	1	1	627

APPENDIX E

Summary Page

Year: 2006

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: 118 mm	median: 15.3 g
range: 103-152 mm	range: 11.5-32.1 g

Tag: Type: Advanced Telemetry Systems
Weight (g): 0.96 in air   Volume (mm^3): 400

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	0.896	0.013	mean 44 (range 21-62)	13	CJS
concrete	0.941	0.011	mean 44 (range 27-56)	13	CJS
spillway	0.943	0.011	mean 36 (range 20-55)	13	CJS
spillbay 8	0.970	0.011	mean 24 (range 9-43)	13	CJS
spillbay 6	0.901	0.016	mean 48 (range 35-59)	3	CJS
Passage metrics					
FPE	0.947	0.010	mean 32 (range 20-62)	13	
SPE	0.820	0.030	mean 32 (range 20-62)	13	
spill effectiveness	2.58	0.090	mean 32 (range 20-62)	13	
FGE	0.645	0.076	mean 8 (range 1-9)	13	

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

Environmental/operating conditions

Daily operations/conditions	mean	range
spill (%)	32	26-38
total river flow (kcfs)	50.6	41.0-66.4
water temperature (°C)	18.9	15.7-21.2