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Fish Ecology Division

Northwest Fisheries Science Center

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Seattle, Washington

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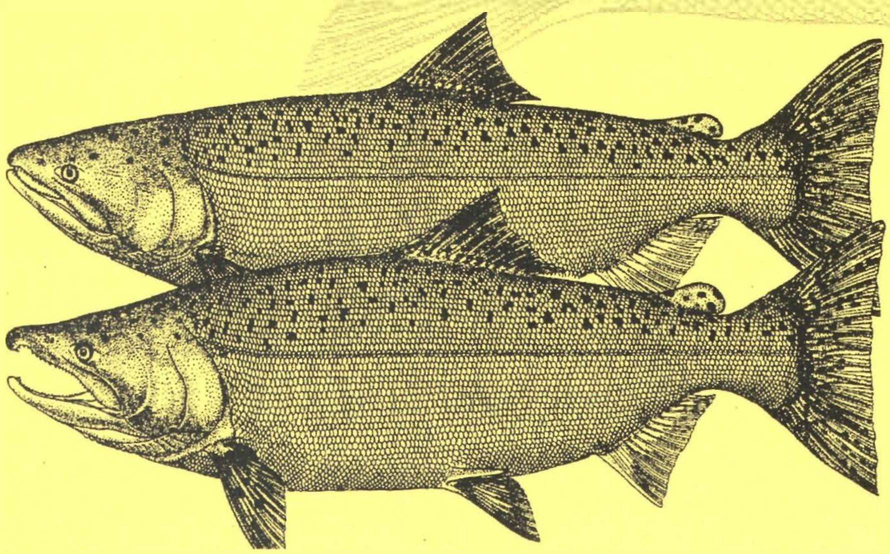

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Report of research by

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to

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Walla Walla, Washington 99362-1876
Contract W68SBV80438584

March 2010

EXECUTIVE SUMMARY

This study was designed to evaluate passage behavior and survival of subyearling fall Chinook salmon with the newly installed removable spillway weir (RSW) at Lower Monumental Dam. For these evaluations, river-run subyearling Chinook salmon were collected from 6 June through 1 July 2008. Fish were collected primarily at Little Goose Dam, with additional fish collected at Lower Monumental Dam. Study fish were surgically tagged with both a radio tag and passive integrated transponder (PIT) tag and released either 42 km upstream from the dam (treatment) or 1.25 km below the dam (reference). Evaluations of survival were based on detections at Ice Harbor Dam, 52 km downstream from Lower Monumental Dam.

Data from fish reaching the forebay entry line from 10 June through 3 July were used in the analysis, which included the 28th through the 84th percentiles of the cumulative subyearling Chinook salmon passage index at Lower Monumental Dam. We released 2,362 radio-tagged fish as treatment groups and 2,071 as control groups. Releases were made twice per day during the study period. Treatment fish were released 40 km upstream from Lower Monumental Dam, which was approximately 31 km farther upstream than in previous years.

Of the 2,362 fish released into the forebay, 1,650 were used in the evaluation of relative survival. The number of fish not detected after release was similar to what we observed in previous years, and was apparently not affected by the change in release site. The fate of the undetected fish was unknown, but likely included loss to predators, failure to move downstream to the detection arrays, or downstream movement delayed until after the life of the radio tag had expired.

Average total river flow was 106.4 kcfs during the study period, which was much higher than either 2006 (50.6 kcfs), 2007 (38.7 kcfs), or the 10-year average (65.4 kcfs). In the last 10 years, there has only been one year (1999) when the average total river flow was higher than in 2008.

Estimated relative dam survival was 0.879 (95% CI, 0.835-0.925), relative concrete survival was 0.932 (0.888-0.979), relative spillway survival was 0.920 (0.864-0.980), relative RSW survival was 0.974 (0.920-1.032), relative turbine survival was 0.960 (0.849-1.085), and relative bypass survival was 0.928 (0.866-0.994). All estimates were geometric means. Total spillway passage was estimated at 40.4% with 24% of fish passing through the RSW. Juvenile bypass passage was 46.2% and turbine passage was 13.4%. There were 63 fish (2.7% of fish released into forebay) that passed

the dam via an unknown route. Spill efficiency was estimated at 0.404 (95% CI, 0.380-0.428), fish guidance efficiency at 0.775 (0.749-0.802), and fish passage efficiency at 0.866 (0.849-0.883). Median overall forebay residence time was 2.3 h (range 0.3-139.2 h), and median tailrace egress time was 8.2 min (range 0.4-10,114.4 min).

CONTENTS

INTRODUCTION

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

Juvenile anadromous salmonids in the Columbia River Basin generally migrate in the upper 3 to 6 m of the water column (Johnson et al. 2000; Beeman and Maule 2006). However, at dams on the lower Columbia and Snake River, existing juvenile passage systems require fish to dive to depths of 15 to 18 m in order to enter a passage route. To provide a more surface-oriented passage route, engineers and biologists from the U.S. Army Corps of Engineers (USACE) and from state, tribal, and federal fishery agencies, developed a removable spillway weir (RSW).

The spillway weir was designed to be attached to the upstream face of a traditional spillway, and a prototype was installed at Lower Granite Dam on the Snake River in 2001. Initial evaluations indicated that the RSW reduced migrational delay, improved fish passage efficiency, and increased passage survival (Plumb et al. 2003, 2004). A second RSW was installed at Ice Harbor Dam in 2005.

At Lower Monumental Dam, a combination of voluntary spill and collection of fish for transport has been used to improve passage survival for migrating juvenile salmonids, pursuant to the National Marine Fisheries Service (NMFS) 2000 biological opinion (NMFS 2000). A more recent biological opinion calls for dam passage survival (through the concrete) of 96% for spring migrants and 93% for summer migrants at each project in the federal Columbia River hydropower system (NMFS 2008).

However, voluntary spill to achieve fish passage survival requirements can potentially result in dissolved gas levels that exceed state and federal limits. To reduce dissolved gas levels, the USACE added flow deflectors to the end bays of the spillway at Lower Monumental Dam in 2002. With the addition of flow deflectors, new spill patterns using all eight bays were developed prior to the 2003 juvenile salmonid migration. In 2003, radiotelemetry studies were initiated to evaluate spillway survival with the new spill patterns and flow deflectors (Hockersmith et al. 2004, 2005, 2007, 2008a,b; Absolon et al. 2007, 2008a,b). Prior to the 2008 juvenile salmonid migration, an RSW was installed at Lower Monumental Dam. The present study was initiated by USACE Walla Walla District to evaluate passage behavior and survival of subyearling fall Chinook salmon *O. tshawytscha* after installation of the RSW.

No specific operations were requested for this study, and thus passage metrics were evaluated under extant flow conditions. A bulk spill pattern, with spill not exceeding total dissolved gas limits "gas cap" was used through 20 June 2008, with most flow passing through spillbays 6 and 8. This "gas cap" was generally reached with spill levels of 25-40 kcfs, and was based on maintaining total dissolved gas levels below the mandated limits of 120% in the tailrace of Lower Monumental Dam or 115% in the forebay of Ice Harbor Dam. Spill was maintained at 17 kcfs from 21 June through 31 August.

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. in prep). Telemetry equipment was located at the same sites used during radiotelemetry evaluations in 2006 and 2007.

METHODS

Study Area

The primary study area included a 53-km reach of the Snake River extending from the forebay entrance line (0.5 km upstream from Lower Monumental Dam at river kilometer 590) to Ice Harbor Dam (rkm 537, Figure 1). Data were also obtained from telemetry receivers located at Burr Canyon (rkm 571), and several other sites as far downstream as the McNary Dam forebay at rkm 472.

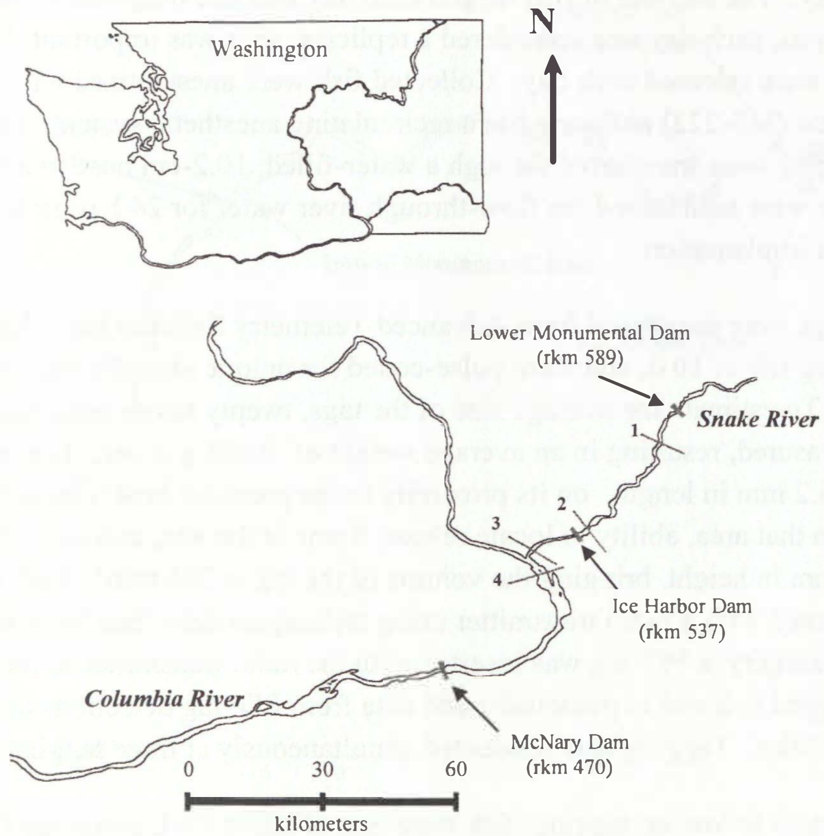

Figure 1. Study area and location of telemetry transects used to estimate survival of subyearling Chinook salmon at Lower Monumental Dam in 2008. Transect locations were 1 Burr Canyon (rkm 571), 2 forebay of Ice Harbor Dam (rkm 538), 3 Sacajawea State Park (rkm 523), and 4 Burbank railroad bridge (rkm 518). 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 Little Goose Dam smolt collection facility, with additional fish collected at the Lower Monumental Dam smolt collection facility. We tagged only fish that were not previously tagged with a passive integrated transponder (PIT), did not have any gross injury or deformity, and were at least 95 mm fork length or 10 g. The minimum size criteria were 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 was obtained each day. 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. Collected 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.,[1] had a predetermined tag life of 10 d, and were pulse-coded for unique identification of individual fish. To estimate the average size of the tags, twenty seven radio tags were weighed and measured, resulting in an average weight of 0.698 g in air. Tags measured an average of 13.2 mm in length, on its proximity to the previous boat release location, depth of water in that area, ability to locate release flume at the site, and nearby 5.4 mm width, and 3.7 mm in height, bringing the volume of the tag to 268 mm^3. Fish were surgically implanted with a radio transmitter using techniques described by Adams et al. (1998). During surgery, a PIT tag was inserted with the radio transmitter to facilitate data collection on tagged fish and to potentially add data from PIT-tag detections at downstream facilities. Tagging was conducted simultaneously at three tagging stations.

Immediately 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.

[1] 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 from the anesthetic and surgery and to determine post-tagging mortality. After the recovery period, radio-tagged fish were moved in the recovery containers from the holding area to release locations in the forebay and tailrace (Figure 2).

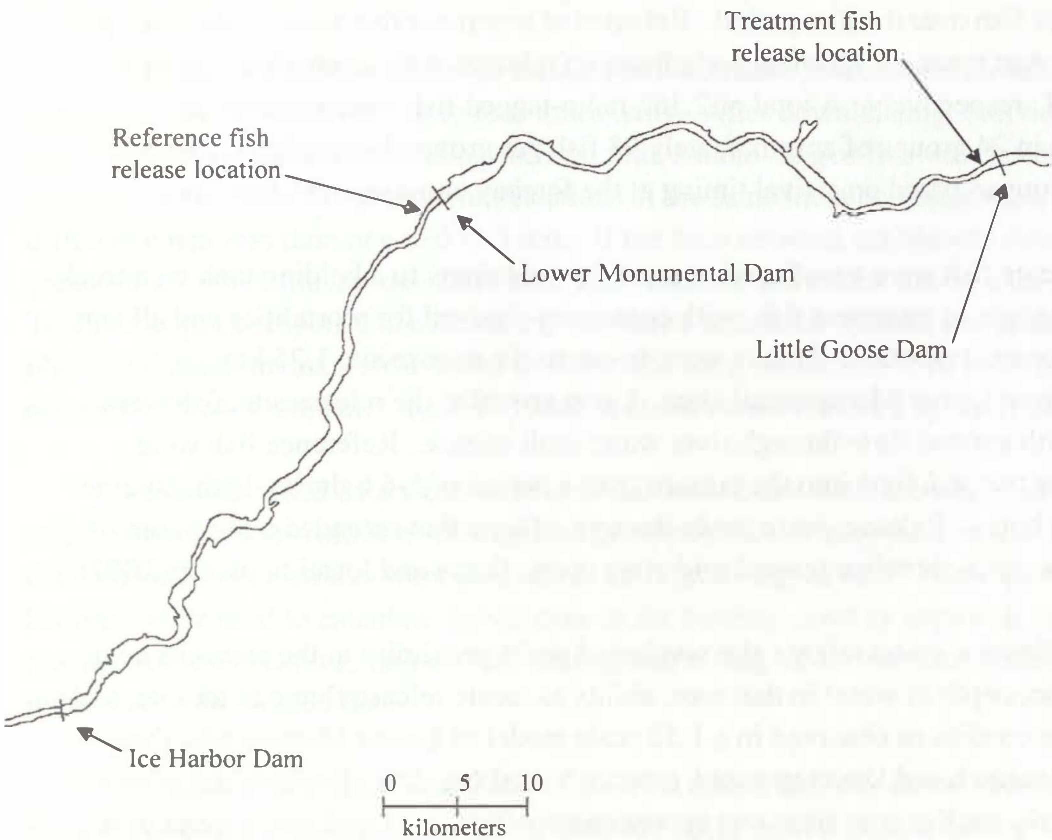

Figure 2. Lower Snake River and Ice Harbor (rkm 537), Lower Monumental (rkm 589), and Little Goose Dams (rkm 635) showing release locations for treatment (rkm 631) and reference groups (rkm 587) of radio-tagged subyearling Chinook salmon, 2008.

Treatment groups were released twice per day about 42 km upstream from Lower Monumental Dam at approximately rkm 631 (Figure 2). To release fish, the holding containers were first transferred from the holding tank to a similar tank mounted on a truck. During this transfer, all containers were checked for any mortalities, and all tags were checked to confirm they operated properly. The tank on the truck was filled with river water prior to the transfer of containers, and was aerated with oxygen during transport to the release area. At the release area, containers were again transferred to a tank mounted on an 8.5- by 2.4-m barge. On the barge, the tank was supplied with flow-through river water during transport to the release location, and fish were released mid-channel using water-to-water transfer methods.

Treatment fish were released over brief intervals. Travel time to the forebay entry line distributed fish over the diel period. Releases of treatment fish were made twice per day. Median start times for morning and afternoon releases were approximately 1010 and 1400 PDT, respectively. A total of 2,362 radio-tagged fish were released as treatment fish in 24 groups of approximately 98 fish per group. For analysis, treatment fish were regrouped based on arrival timing at the forebay entrance detection line.

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

The reference group release site was based on its proximity to the previous boat release location, depth of water in that area, ability to locate release flume at the site, and nearby tailrace conditions observed in a 1:55 scale model of Lower Monumental Dam at the USACE Research and Development Center in Vicksburg, MS. For daytime releases of reference fish, median start time was approximately 0830 PDT and median end time 1510. For nighttime releases of reference fish, median start time was approximately 2030 and median end time was 0400. A total of 2,071 radio-tagged reference fish were released in 24 groups of approximately 86 fish.

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 at Ice Harbor Dam (Figure 1). Receivers using dipole or multiple-element aerial antennas were positioned to determine forebay entrance, dam approach, route of passage, tailrace egress and downstream detection. The locations of fixed sites at Lower Monumental Dam are summarized in Table 1 and Figure 3. An additional transect was established approximately 2 km upstream from Lower Monumental Dam to collect information on upstream entry above the immediate forebay. We did not use a double array (Skalski et al. 2002) for evaluating routes of passage because based on past experience with a single array, the proportion of fish with undetermined passage routes has typically been less than 3%.

Telemetry data was retrieved through an automated process that downloaded 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. To allow a quick response to address any problems within the system, automated cell phone and email messages were sent to electronic shop personnel when problems occurred. In addition, daily logs of system operation were received by study personnel.

All compressed data were combined and loaded to a database where automated scripts were used to remove erroneous data (Appendix B). Using the cleaned data set, detailed detection histories were created for each radio-tagged fish. These detection histories were used to calculate arrival time in the forebay, forebay approach pattern, passage route and timing, tailrace exit timing, and timing of downstream detections for individual radio-tagged fish.

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, either on 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.

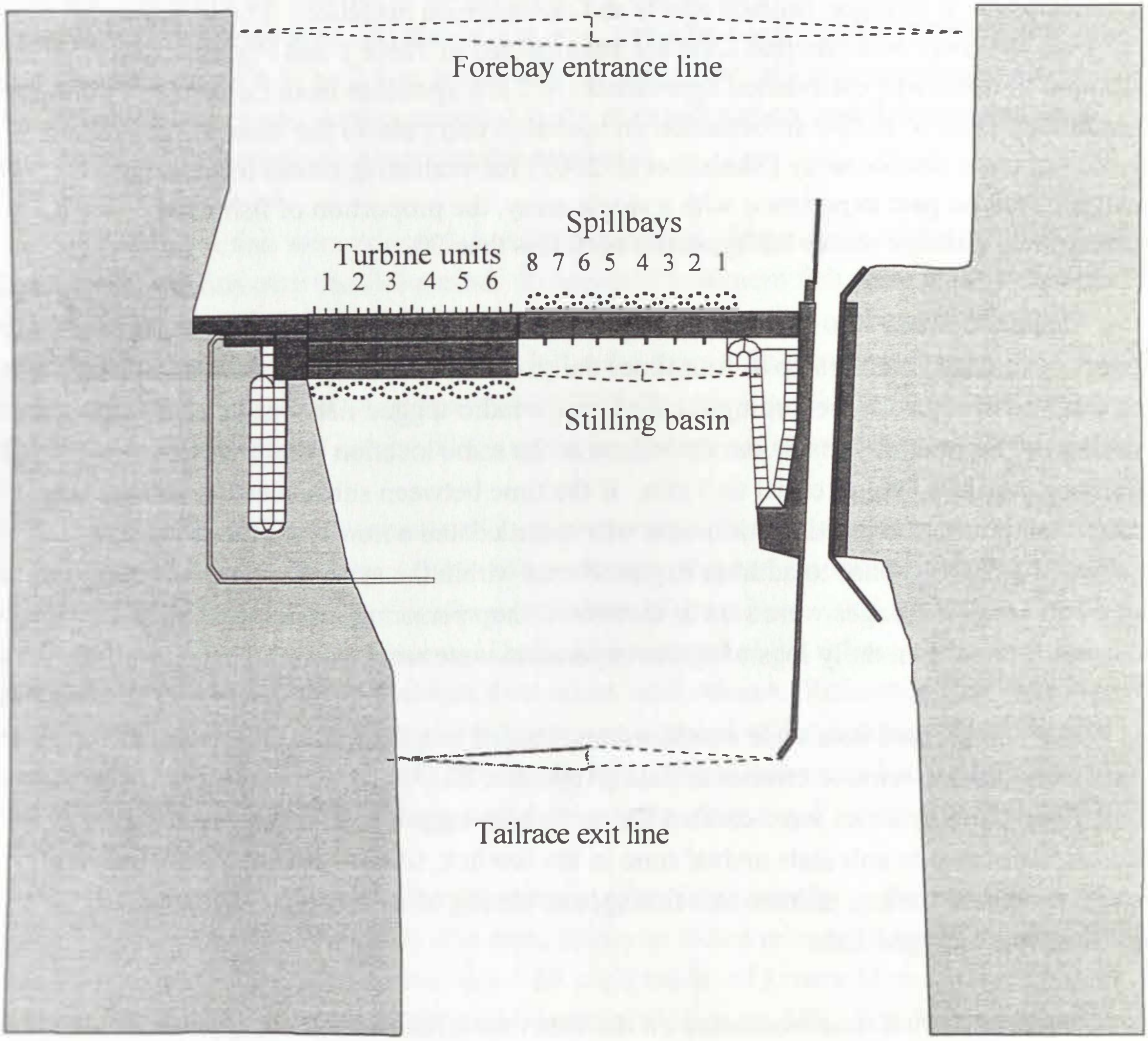

Figure 3. Plan view of Lower Monumental Dam showing approximate radio-telemetry detection zones in 2008 (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas). The RSW is located in Spillbay 8.

Table 1. Fixed-site telemetry receivers for evaluating passage behavior and survival of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2008.

Site description	Type of monitoring	Antenna type
Forebay (2 k upstream)		
north shore	Upstream entry	3-element Yagi
south shore	Upstream entry	3-element Yagi
Forebay (500 m upstream)		
north shore	Entrance line and residence time	3-element Yagi
mid channel	Entrance line and residence time	3-element Yagi
south shore	Entrance line and residence time	3-element Yagi
Turbine units 1-6	Approach and passage	Stripped coax
Spillbays 1-7	Approach and passage	Underwater dipole
RSW	Approach and passage	Tuned loop
Draft tube units 1-6	Project passage	Underwater dipole
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	2-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 was required on the stilling basin, tailrace exit line, or at the transect near Burr Canyon (Figures 1 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 juvenile bypass system 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 to estimate relative survival where groups of radio-tagged fish were released at one of two sites: upstream (treatment) and downstream (reference) from Lower Monumental Dam (Figure 2). Treatment groups were formed by grouping daily detections of radio-tagged fish 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 relative 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 relative 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 radio-telemetry 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. 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 time was defined as the time from last detection on a passage route to last 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 detected on fish-screen antennas could then be assigned a passage route by their subsequent detection on either the bypass system antenna, which indicated bypass passage, or draft tube antennas, which indicated turbine passage.

Fish Passage Metrics

Fish-passage metrics evaluated were spill efficiency, spill effectiveness, fish guidance efficiency (FGE), and fish passage efficiency (FPE). These evaluations were based on radiotelemetry detections at the same locations used for passage route evaluations. Spill efficiency was estimated as the number of fish passing the dam via the spillway divided by the total number of fish passing the dam. Spill effectiveness was estimated as the proportion of fish passing the dam via the spillway divided by the proportion of water spilled. Efficiency for the RSW was estimated as the number of fish passing through the RSW divided by the total number of fish passing the dam. Effectiveness for the RSW was estimated as the proportion of fish passing the dam via the RSW divided by the proportion of water passing through the RSW. Fish guidance efficiency was estimated as the number of fish passing the dam through the JBS divided by the total number of fish passing the dam through the powerhouse (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 treatment groups formed by daily detection in the forebay. For some metrics, there were only enough fish to get pooled estimates, so confidence intervals were based on assumed binomial distributions.

Avian Predation

Predation by Caspian terns *Hydroprogne caspia*, double-crested cormorants *Phalacrocorax aurtius* and gulls *Larus* spp. was evaluated by physical recovery of radio transmitters and by PIT-tag detection on Crescent, Badger, and Foundation Islands in the McNary Dam reservoir. Radio transmitters and PIT tags were recovered on nesting colonies during fall 2008 after the birds had abandoned their nesting colonies. Radio 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 also "recovered" in a thorough search using the mobile PIT-tag detection system described by Ryan et al. (2001). PIT-tag detections and recovery of radio transmitters were provided by NOAA Fisheries (S. Sebring and N. Dumdei, NOAA Fisheries, personal communication) and Real Time Research (A. Evans, Real Time Research, personal communication). There is an ongoing monitoring effort to detect PIT tags from active avian colonies in the region conducted by NOAA Fisheries and by the Columbia Bird Research group.

RESULTS

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were tagged at Lower Monumental Dam and released over a period of 26 d from 8 June through 3 July 2008. Tagging began after 28% of the general population of juvenile subyearling Chinook salmon had passed Lower Monumental Dam and was completed when 84% of these fish had passed the project (Figure 4). Fish condition information and data on the size and timing of the juvenile migration are reported on the Fish Passage Center website (www.fpc.org).

Overall mean fork length was 108 mm (range 96-135 mm) for treatment fish and 108 mm (range 95-144 mm) for reference fish (Table 2). Mean length of the run at large sampled at the Little Goose smolt collection facility was 105 mm over the course of the study (A. Dowdy, ODFW, personal communication; Table 3). Overall mean weight was 13 g (range 10-27 g) for treatment fish and 13 g (range 10-35 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 1.1% (49 fish). Fish that died during the post-tagging recovery period were released with their live cohorts to verify the assumption that dead fish are not detected on downstream survival arrays.

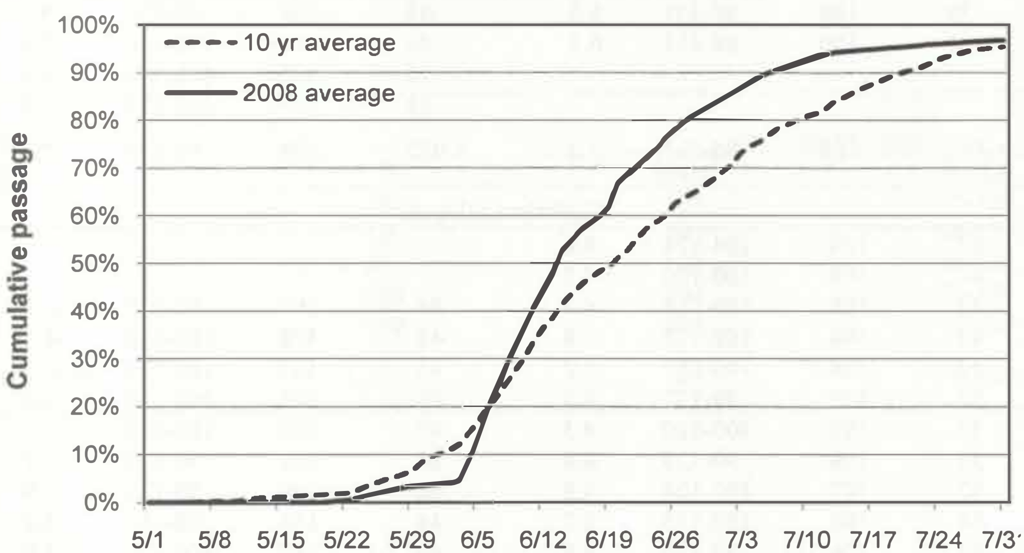

Figure 4. Cumulative distribution of subyearling Chinook salmon passing Lower Monumental Dam, during 2008 compared to the 10-year average (1999-2008).

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, 2008.

Release date	Fish length (mm)							
	Forebay releases				Tailrace releases			
	N	Mean	Range	SD	N	Mean	Range	SD
	Daytime releases							
6/8	43	109	101-119	4.4				
6/9	44	108	103-117	4.0				
6/10	44	107	99-124	5.0	42	108	102-117	4.2
6/11	44	108	102-115	3.0	44	108	99-124	4.4
6/12	53	106	101-114	3.9	44	107	100-117	4.2
6/13	53	107	98-123	5.4	44	105	100-119	4.2
6/14	51	109	100-127	6.0	43	108	99-117	4.7
6/15	53	107	96-126	5.2	44	106	99-113	3.8
6/16	53	106	99-121	4.7	45	107	99-114	4.2
6/17	53	106	100-118	4.1	44	105	99-116	4.6
6/18	53	108	100-127	5.8	45	108	100-120	4.8
6/19	53	106	99-116	4.5	44	109	99-125	6.4
6/20	53	108	100-123	5.4	44	106	99-116	4.9
6/21	53	109	102-125	4.5	44	109	102-132	5.9
6/22	53	110	102-122	5.2	43	109	102-123	5.0
6/23	53	108	101-127	5.9	45	108	98-120	5.0
6/24	53	108	102-118	3.6	44	108	101-123	4.8
6/25	52	110	98-125	6.3	43	109	102-126	6.3
6/26	53	110	100-128	6.1	44	108	102-124	5.1
6/27	52	110	99-125	6.1	44	109	102-124	5.4
6/28	44	111	100-130	6.0	42	109	100-120	5.1
6/29	45	109	97-130	5.6	44	107	98-127	6.0
6/30	39	109	98-125	6.6	44	108	99-124	5.5
7/1	35	109	98-131	6.7	44	110	102-130	7.0
7/2					35	108	100-144	9.9
7/3					33	110	100-137	9.0
Subtotal	1,182	108	96-131	5.2	1,032	108	98-144	5.4
	Nighttime releases							
6/8	43	110	104-124	4.6				
6/9	44	108	100-120	4.7				
6/10	43	108	100-118	4.4	44	107	98-132	6.3
6/11	43	108	102-117	3.8	43	108	102-120	4.2
6/12	53	108	100-119	5.2	43	107	100-114	3.4
6/13	52	105	99-122	4.9	42	106	100-116	4.3
6/14	51	107	100-120	4.5	45	107	101-118	4.3
6/15	53	108	99-123	4.8	44	106	99-122	5.2
6/16	52	107	101-124	4.8	44	109	99-124	5.6
6/17	54	106	100-115	3.7	44	106	98-115	4.0
6/18	53	106	97-120	4.9	44	107	100-121	4.9
6/19	53	108	100-124	5.6	45	108	100-122	4.5
6/20	53	109	98-122	5.7	44	106	100-122	5.1
6/21	51	109	100-124	5.4	42	107	95-116	4.2

Table 2. Continued.

Release date	Forebay releases N	Mean	Range	SD	Tailrace releases N	Mean	Range	SD
	Fish length (mm)							
	Nighttime releases (Continued)							
6/22	52	110	101-124	4.9	45	108	101-120	4.6
6/23	53	108	98-120	5.3	44	108	100-123	4.5
6/24	53	108	100-117	4.2	44	109	101-118	4.0
6/25	53	109	101-123	4.9	45	110	99-126	6.3
6/26	53	110	99-126	7.3	45	107	100-126	6.3
6/27	53	109	102-128	5.4	45	111	103-133	6.4
6/28	44	111	102-135	7.2	44	109	101-129	6.1
6/29	44	109	98-122	5.9	43	107	98-125	6.2
6/30	40	109	98-125	5.4	45	109	102-119	4.6
7/1	36	110	98-129	6.0	44	110	100-129	6.7
7/2					35	109	102-127	6.7
7/3					35	107	99-125	5.5
Subtotal	1,179	108	97-135	5.2	1,038	108	95-133	5.2
Total	2,361	108	96-135	5.2	2,070	108	95-144	5.3

Table 3. Sample size and mean fish length (and range of length) by collection week for combined hatchery and wild river-run subyearling Chinook salmon collected at the Little Goose Dam smolt monitoring facility, 2008.

Collection week	N	Fish length (mm) Mean	Range
6/1	46	101	75-120
6/8	190	107	90-125
6/15	357	103	70-125
6/22	428	104	75-130
6/29	330	108	75-130
Total/overall	1,351	105	70-130

Table 4. Mean weight of radio-tagged subyearling Chinook salmon replicates released at Lower Monumental Dam to evaluate passage behavior and survival, 2008.

Release date	Fish weight (g)							
	Forebay releases				Tailrace releases			
	N	Mean	Range	SD	N	Mean	Range	SD
	Daytime releases							
6/8	43	14	11-17	1.7				
6/9	44	13	11-17	1.5				
6/10	44	13	10-20	1.9	42	13	10-16	1.5
6/11	44	13	10-15	1.4	44	13	10-19	1.6
6/12	53	12	10-16	1.4	44	13	10-17	1.6
6/13	53	13	10-19	2.1	44	13	10-18	1.7
6/14	51	13	11-22	2.4	43	13	10-17	1.7
6/15	53	12	10-20	2.1	44	13	10-16	1.7
6/16	53	12	10-18	1.7	42	12	10-15	1.5
6/17	53	13	10-19	1.8	42	12	10-18	2.1
6/18	52	12	10-20	2.2	45	13	10-17	1.7
6/19	53	12	10-16	1.6	44	13	10-19	2.4
6/20	53	13	10-20	2.1	44	13	10-18	1.8
6/21	52	13	11-20	1.8	43	13	10-20	2.3
6/22	52	13	11-18	1.7	43	13	10-18	1.8
6/23	53	13	10-20	2.2	45	13	10-17	1.8
6/24	53	13	11-17	1.5	43	13	11-19	1.8
6/25	42	13	10-19	2.3	43	13	10-20	2.4
6/26	53	14	11-23	2.5	43	13	10-21	2.2
6/27	50	14	10-22	2.7	44	13	11-19	2.1
6/28	43	14	10-26	2.7	42	14	10-19	2.2
6/29	45	13	10-22	2.3	44	14	11-23	2.7
6/30	38	13	10-21	2.7	44	13	10-20	2.1
7/1	35	14	10-25	2.9	44	14	10-24	3.0
7/2					35	14	10-35	5.6
7/3					33	15	10-29	4.3
Subtotal	1,165	13	10-26	2.0	1,024	13	10-35	2.2
	Nighttime releases							
6/8	43	14	11-20	2.0				
6/9	44	13	10-17	1.8				
6/10	43	13	10-22	2.2	44	13	10-25	2.5
6/11	43	13	10-17	1.5	43	13	10-18	1.7
6/12	53	13	10-18	1.8	42	13	11-17	1.3
6/13	52	13	10-20	2.1	42	13	10-17	1.7
6/14	51	12	10-18	1.7	45	13	10-19	1.9
6/15	53	13	10-19	1.9	42	13	10-19	2.1
6/16	52	12	10-19	1.9	44	13	10-18	2.1
6/17	54	12	10-18	1.8	42	12	10-16	1.6
6/18	53	12	10-18	1.8	44	12	10-19	1.8
6/19	53	13	10-20	2.1	44	13	10-18	1.8
6/20	53	13	10-19	2.2	44	13	10-18	2.1
6/21	51	13	10-18	1.9	42	12	10-15	1.2
6/22	52	14	10-18	2.0	45	13	10-16	1.5
6/23	53	13	10-18	2.0	44	13	10-19	1.8
6/24	53	13	10-17	1.7	44	14	10-17	1.8

Table 4. Continued.

Release date	Forebay releases N	Mean	Range	SD	Tailrace releases N	Mean	Range	SD
	Fish weight (g)							
	Nighttime releases (continued)							
6/25	53	13	10-18	1.9	45	13	10-21	2.4
6/26	53	14	10-21	2.8	45	13	11-22	2.6
6/27	53	13	11-20	2.0	45	15	12-26	2.8
6/28	44	15	10-27	3.4	44	13	10-23	2.6
6/29	44	13	10-18	2.2	43	14	10-22	2.8
6/30	40	13	10-21	2.2	45	13	10-18	1.8
7/1	36	14	10-23	2.7	44	14	10-22	3.0
7/2					35	13	10-21	2.6
7/3					35	13	11-20	2.1
Subtotal	1,179	13	10-27	2.1	1,032	13	10-26	2.1
Total	2,344	13	10-27	2.1	2,056	13	10-35	2.1

Project Operations

No specific project operations were requested for this study. During the 9 June through 9 July study period; average spill was 25.5 kcfs or 24% of total discharge (Table 5). Spill occurred throughout the study period except for short periods when it was interrupted to allow fish transport barges to safely cross the river from the navigation lock to the barge loading area. Average daily spill ranged from 14.6 to 51.7 kcfs, powerhouse flow ranged from 42.5 to 111.2 kcfs, and total river flow ranged from 60.0 to 135.6 kcfs. Tailwater elevation ranged from 438.7 to 443.1 ft msl, and water temperature ranged from 11.0 to 17.2°C (Table 5).

Average total river flow during the study in 2008 (106.4 kcfs) was much higher than during the same period in previous study years and higher than the 10-year average (65.4 kcfs). Average total river flow was 71.4 and 39.7 kcfs in 2006 and 2007, respectively. The only year in the last 10 years that had higher average total river flow was 1999 (110.0 kcfs). Spill from 9 to 20 June was to the gas cap, while spill from 21 June though 31 August was 17.0 kcfs, except for periods where additional spill occurred due to flows in excess of powerhouse capacity. The spill pattern used in 2008 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, 2008.

Date	Spill (kcfs)	Powerhouse (kcfs)	Total discharge (kcfs)	Total discharge range (kcfs)	Tailwater elevation (ft msl)	Water temperature (°C)
6/9	30.6	86.3	116.9	85.8-135.0	441.9	11.0
6/10	40.1	78.1	118.2	86.6-133.0	441.7	11.2
6/11	51.7	66.7	118.4	95.8-140.1	441.4	11.4
6/12	46.8	73.2	120.0	86.6-144.6	441.6	11.5
6/13	39.6	82.3	121.9	108.4-129.1	441.8	11.8
6/14	22.4	92.0	114.4	99.5-122.8	441.6	12.3
6/15	21.7	88.4	110.1	92.8-128.8	441.4	12.3
6/16	20.7	93.7	114.4	99.3-134.7	441.6	12.1
6/17	28.3	94.9	123.2	109.3-134.7	442.1	11.9
6/18	43.4	89.4	132.8	99.4-171.0	442.3	12.4
6/19	36.2	92.3	128.5	111.5-161.4	442.2	13.2
6/20	19.4	106.6	126.0	99.3-134.7	442.5	13.8
6/21	17.4	109.6	127.0	124.3-130.9	442.5	14.2
6/22	24.6	106.9	131.5	110.7-163.5	442.7	14.4
6/23	24.4	111.2	135.6	117.8-163.1	443.1	14.1
6/24	22.2	108.1	130.3	108.0149.7	442.8	13.9
6/25	27.9	88.4	116.3	108.9-129.2	441.6	14.1
6/26	35.3	72.9	108.2	92.3-123.7	441.0	14.2
6/27	35.7	61.2	96.9	90.7-117.2	440.4	14.6
6/28	18.1	79.5	97.6	83.1-101.5	440.7	14.8
6/29	17.3	83.0	100.3	95.0-105.4	440.7	14.9
6/30	16.1	86.1	102.2	83.7-126.8	440.8	15.2
7/1	14.8	84.1	98.9	86.1-111.9	440.7	15.4
7/2	14.6	85.1	99.7	69.5-126.4	440.8	15.8
7/3	16.4	75.2	91.6	74.7-109.8	440.3	16.2
7/4	17.3	67.0	84.3	67.1-107.1	439.9	16.7
7/5	17.6	59.2	76.8	73.2-84.5	439.5	16.8
7/6	17.5	50.1	67.6	52.0-76.9	438.9	17.0
7/7	17.4	46.8	64.2	59.5-69.6	438.8	17.2
7/8	17.1	47.3	64.4	49.4-83.0	438.8	17.2
7/9	17.5	42.5	60.0	49.3-80.1	438.7	17.2
Average	25.5	80.9	106.4	49.3-171.0	441.1	14.2

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 10 June through 3 July.

Forebay Behavior and Timing

Of the 2,362 radio-tagged treatment fish released above Lower Monumental Dam, 1,891 were detected entering the forebay. Of these, 73 and 27% were first detected approaching the spillway and powerhouse, respectively.

Forebay residence time was calculated for 1,552 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 excluded from analyses of forebay residence timing, but were not excluded from survival estimates. Passive water-particle transport timing through the forebay was not used to further evaluate forebay residence timing because this was beyond the scope of the study. Median forebay residence timing of treatment fish was 1.3 h through the spillway, 6.0 h through the bypass system, and 1.2 h through the turbines. Of the 1,552 fish used in this evaluation, 636 (41%) passed through the spillway, 719 (46%) through the JBS, and 197 (13%) 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, 2008. Numbers of fish passing via each route are shown in parentheses.

	Forebay residence (h)			
Percentile	Turbine (n = 197)	Bypass (n = 719)	Spillway (n = 636)	Overall (n = 1,552)
Minimum	0.4	0.3	0.3	0.3
10th	0.7	1.3	0.7	0.8
20th	0.8	1.9	0.8	1.0
30th	0.8	2.7	0.9	1.3
40th	1.0	4.1	1.1	1.7
50th (median)	1.2	6.0	1.3	2.3
60th	1.3	8.9	1.7	3.4
70th	1.9	12.6	2.3	5.4
80th	3.1	16.6	3.5	9.6
90th	5.8	26.5	6.0	17.1
Maximum	76.3	139.2	108.1	139.2
Mean	3.1	11.4	3.1	6.9
Mode	0.8	1.3	0.8	0.8

Table 7. Forebay residence time for all passage routes combined for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2008. Residence time is shown by forebay entry date for the 10th, 50th (median), and 90th percentiles.

Forebay entry date	n	Forebay residence time (h)		
		10th	50th	90th
10 June	64	0.8	1.3	14.4
11 June	62	0.7	1.2	14.3
12 June	58	0.7	1.3	8.2
13 June	83	0.7	1.3	10.5
14 June	49	0.7	2.8	39.2
15 June	60	0.7	2.1	18.6
16 June	48	0.9	3.0	19.1
17 June	70	0.7	2.8	20.4
18 June	92	0.6	1.2	14.2
19 June	68	0.8	2.8	16.9
20 June	46	0.9	2.3	15.9
21 June	82	0.8	3.0	13.5
22 June	71	0.7	2.0	13.3
23 June	41	0.8	2.4	17.2
24 June	92	1.1	4.3	21.4
25 June	69	1.0	2.7	19.8
26 June	68	0.8	3.7	18.8
27 June	66	1.0	2.1	10.2
28 June	72	1.0	2.5	16.0
29 June	52	0.8	2.5	19.3
30 June	52	1.0	3.6	21.5
1 July	77	1.1	3.7	17.7
2 July	66	0.8	2.5	12.8
3 July	32	0.1	4.2	16.4
Total/mean	1,540	0.8	2.6	17.1
SE		0.04	0.2	1.2
95% CI		0.7-0.9	2.2-2.9	14.6-19.6

Passage Distribution and Metrics

Of the 2,362 radio-tagged treatment fish released, 471 (20%) were not detected entering the study area and 1,891 (80%) were detected at or below Lower Monumental Dam. Of the 1,687 (71%) fish that passed the dam, 410 (24%) passed through the RSW, 271 (16%) passed through the remaining spillbays, 780 (46%) through the JBS, 226 (13%) through the turbines, and 63 (3%) through an undetermined route (Figure 5). The remaining 141 fish (6%) 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.

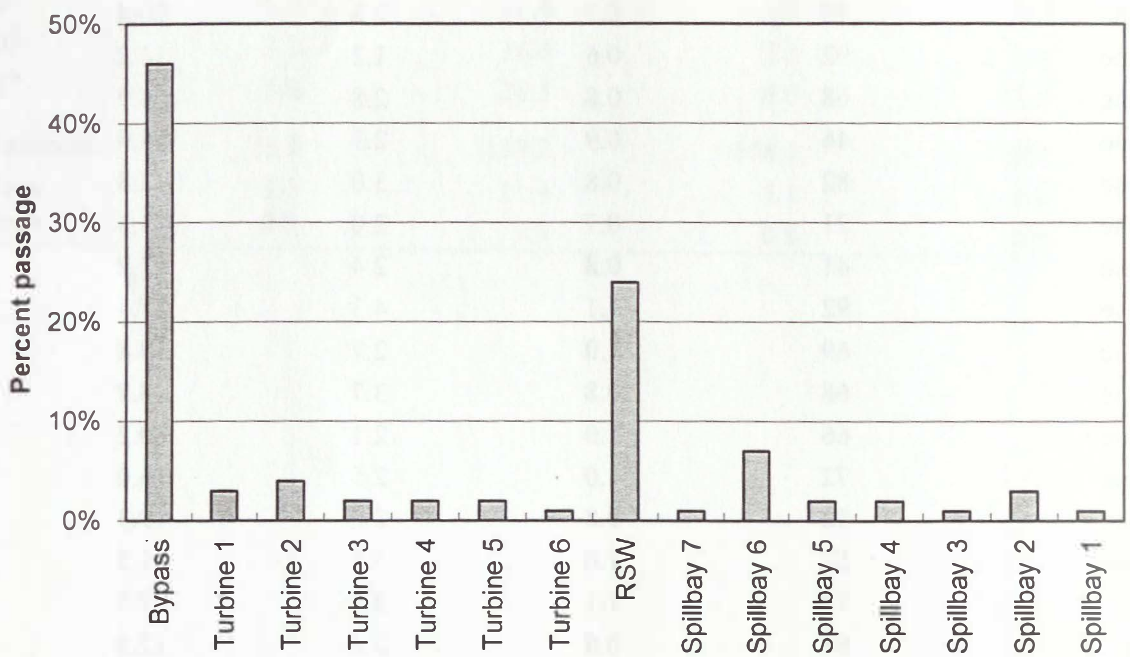

Figure 5. Passage route distribution of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2008.

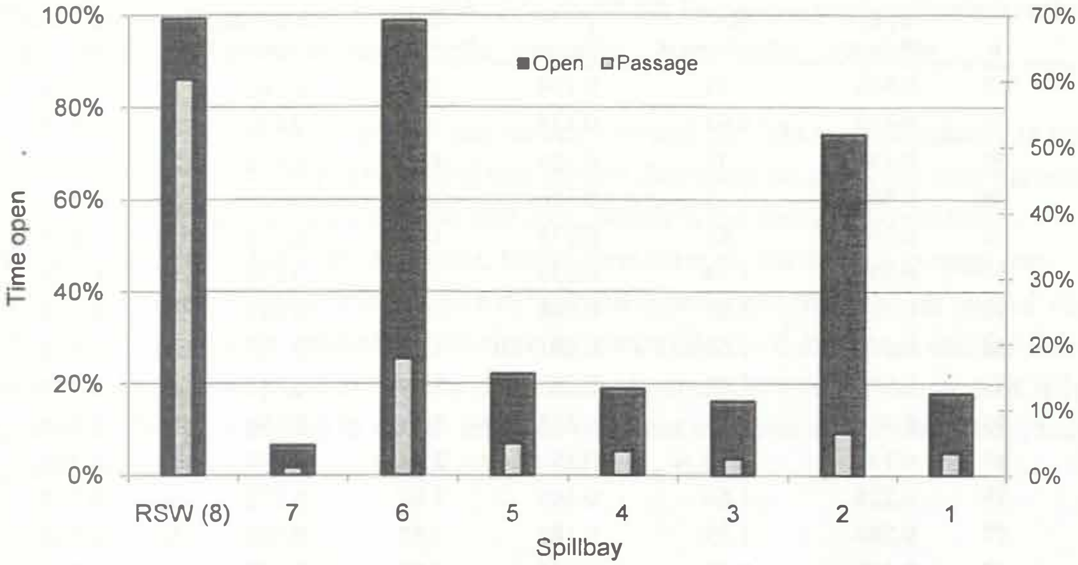

Figure 6. Percent time individual spillbays were open and passage distribution for radio-tagged river-run subyearling Chinook salmon at Lower Monumental Dam, 2008.

Passage metrics at Lower Monumental Dam were calculated by pooling data for all releases, resulting in the following point estimates and 95% CIs (Table 8). Fish passage efficiency was 0.866 (0.849-0.883), spill efficiency was 0.404 (0.380-0.428), spill effectiveness was 1.46:1 (1.37-1.54), RSW efficiency was 0.235 (0.189-0.281), RSW effectiveness was 3.33 (3.30-3.36), and fish guidance efficiency was 0.775 (0.749-0.802).

Table 8. Fish passage metrics by passage date for river-run subyearling Chinook salmon at Lower Monumental Dam, 2008. Pooled estimates are presented at the bottom of the table.

Passage date	n	Spill efficiency	Spill effectiveness	RSW efficiency	RSW effectiveness	Fish passage efficiency	n	Fish guidance efficiency
6/9-10	65	0.385	1.28	0.154	2.63	0.708	37	0.568
6/11	78	0.410	0.94	0.115	2.01	0.846	42	0.810
6/12	57	0.526	1.35	0.228	4.08	0.825	27	0.630
6/13	100	0.380	1.17	0.110	1.97	0.770	59	0.661
6/14	44	0.364	1.86	0.273	4.62	0.773	28	0.643
6/15	67	0.343	1.74	0.239	3.86	0.836	44	0.750
6/16	72	0.333	1.85	0.208	3.50	0.889	47	0.851
6/17	86	0.244	1.06	0.081	1.47	0.767	60	0.750
6/18	104	0.548	1.68	0.163	3.19	0.865	46	0.717
6/19	95	0.411	1.46	0.284	5.37	0.874	55	0.800
6/20	61	0.148	0.96	0.131	2.47	0.787	51	0.765
6/21	79	0.228	1.66	0.165	3.07	0.772	60	0.717
6/22	77	0.260	1.39	0.182	3.58	0.766	54	0.722
6/23	58	0.155	0.86	0.155	3.09	0.621	36	0.750
6/24	83	0.265	1.55	0.241	4.70	0.807	48	0.938
6/25	80	0.400	1.67	0.263	4.49	0.900	47	0.851
6/26	64	0.609	1.87	0.250	4.03	0.906	24	0.792
6/27	74	0.635	1.72	0.243	3.46	0.973	27	0.926
6/28	73	0.575	3.09	0.493	7.16	0.959	31	0.903
6/29	52	0.577	3.34	0.500	7.18	0.865	20	0.750
6/30	63	0.413	2.62	0.365	5.52	0.857	35	0.800
7/1	71	0.423	2.82	0.338	5.05	0.873	39	0.821
7/2	86	0.326	2.22	0.291	4.42	0.895	55	0.891
7/3-5	58	0.414	2.04	0.345	4.37	0.879	34	0.794
Pooled estimates								
Total no.	1,747						900	
Estimate		0.404	1.46	0.235	3.33	0.866		0.775
95% CI		0.380-0.428	1.37-1.54	0.189-0.281	3.30-3.36	0.849-0.883		0.749-0.802

Tailrace Behavior and Timing

Tailrace egress and timing was calculated for 1,459 radio-tagged, river-run subyearling Chinook salmon. Median tailrace egress time was 8 minutes overall, 6 minutes for fish that had passed through the spillway (n = 585), 9 minutes for those that passed through the JBS (n = 677), and 12 minutes for those that passed through turbine units (n = 195, Table 9).

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 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. The difference between the overall numbers of fish reported in Tables 9 and 10 is due to fish that were not detected on the entry line; tailrace egress by entry date could not be calculated for those fish.

Table 9. Tailrace egress timing in minutes for radio-tagged, river-run subyearling Chinook salmon passing through the turbines, bypass, and spillway at Lower Monumental Dam, 2008.

	Tailrace egress time (min)			
Percentile	Turbine (n = 195)	Juvenile bypass (n = 677)	Spillway (n = 585)	Overall (n = 1,459)
Minimum	3.9	0.4	0.4	0.4
10th	6.8	5.3	2.8	3.6
20th	8.7	6.4	3.6	5.0
30th	9.5	7.4	4.4	6.1
40th	10.6	8.2	5.1	7.2
50th (median)	11.5	9.1	5.9	8.2
60th	12.7	10.0	6.7	9.5
70th	14.5	11.3	7.8	11.1
80th	22.0	14.2	11.1	14.8
90th	642.0	132.0	40.9	91.7
Maximum	9,476.2	10,114.4	9,691.1	10,114.4
Mean	446.7	417.8	246.0	356.9
Mode	11.3	7.8	4.6	5.7

Table 10. Tailrace egress time for passage of radio-tagged river-run subyearling Chinook salmon through all routes combined at Lower Monumental Dam, 2008. Egress time is shown by forebay entry date for the 10th, 50th (median) and 90th percentiles. These percentiles are also shown for passage through the RSW and spillbays 1-7 combined.

		Tailrace egress time (min)		
Forebay entry date	n	10th	50th (median)	90th
6/9-10	65	4.8	9.6	119.4
6/11	41	3.3	10.8	88.9
6/12	43	4.2	8.4	77.3
6/13	77	4.4	8.9	68.8
6/14	47	3.3	8.9	515.3
6/15	56	5.1	8.0	57.8
6/16	41	4.1	7.1	40.9
6/17	64	4.8	8.9	98.3
6/18	86	3.5	8.7	107.6
6/19	59	4.5	8.1	119.6
6/20	41	5.6	8.2	550.2
6/21	70	4.1	7.7	1128.1
6/22	56	3.3	7.4	14.8
6/23	34	3.7	7.8	20.2
6/24	67	3.1	7.1	625.1
6/25	63	3.3	6.7	22.8
6/26	61	3.3	6.2	26.0
6/27	57	3.9	8.9	684.1
6/28	57	4.3	9.0	13.1
6/29	44	2.8	8.0	426.0
6/30	45	3.1	8.4	13.8
7/1	71	4.4	9.6	21.8
7/2	61	4.0	9.2	15.3
7/3-5	36	3.6	8.6	25.4
Total/mean	1342	3.9	8.3	203.4
SE		0.1	0.2	59.7
95% CI		3.6-4.3	7.9-8.8	79.9-326.8
Individual spillbay passage				
RSW (spillbay 8)	328	3.0	5.9	32.0
Spillbays 1-7 (combined)	217	2.5	6.0	49.8

Detection Probability and Estimated Survival

Detection probabilities at Burr Canyon for treatment and reference groups were 0.978 (95% CI, 0.970-0.985) and 0.988 (0.983-0.993), respectively. Overall detection probability for both groups combined was 0.984 (0.979-0.988).

Relative pool survival was estimated from the release location to both the forebay entry line and dam passage. The pooled estimates were 0.786 (0.750-0.816) and 0.768 (0.736-0.797) for entry line and passage, respectively.

Estimated relative dam survival (forebay BRZ to tailrace approximately 1 km downstream from the dam) at Lower Monumental Dam was estimated at 0.879 (95% CI, 0.835-0.925), and relative concrete survival (all passage routes combined to approximately 1 km downstream from the dam) was estimated at 0.932 (0.888-0.979).

Estimated relative survival through the RSW was 0.974 (0.920-1.032) and through the entire spillway including the RSW was 0.920 (0.864-0.980). Turbine relative survival was estimated at 0.960 (0.849-1.085) and through the bypass system was 0.928 (0.866-0.994).

Relative survival estimates for the dam, concrete, turbine spillway, RSW and bypass system are shown by forebay entry date in Table 11. Detection histories of fish used in survival analysis are shown in Appendix D.

Table 11. Subyearling Chinook salmon point estimates of relative survival by forebay entry date at Lower Monumental Dam, 2008. Dam survival includes approximately 500 m of forebay from the boat restricted zone deadline to the concrete.

Date	Dam survival		Concrete survival		Turbine survival	
	Estimate	SE	Estimate	SE	Estimate	SE
6/10	0.856	0.080	0.910	0.078	0.785	0.167
6/11	0.904	0.067	0.968	0.065	0.982	0.158
6/12	0.917	0.108	1.009	0.111	0.841	0.183
6/13	0.903	0.085	0.943	0.086	0.889	0.151
6/14	0.894	0.101	0.915	0.102	1.090	0.141
6/15	0.668	0.085	0.747	0.090	0.734	0.195
6/16	0.929	0.097	0.977	0.098	1.269	0.080
6/17	0.995	0.102	1.028	0.103	1.109	0.148
6/18	0.931	0.085	0.993	0.086	1.369	0.305
6/19	1.056	0.113	1.160	0.117	1.144	0.223
6/20	0.824	0.100	0.903	0.104	0.894	0.218
6/21	0.923	0.090	0.984	0.092	1.002	0.158
6/22	0.884	0.083	0.908	0.084	0.903	0.161
6/23	0.826	0.085	0.855	0.085	0.810	0.195
6/24	0.941	0.082	1.023	0.083	1.293	0.075
6/25	0.976	0.091	1.062	0.094	0.771	0.257
6/26	0.746	0.091	0.781	0.093	0.784	0.290
6/27	0.739	0.092	0.839	0.099	0.703	0.500
6/28	0.818	0.083	0.851	0.084	0.421	0.345
6/29	0.910	0.110	0.966	0.112		
6/30	1.049	0.116	1.069	0.117	1.159	0.272
7/1	0.677	0.080	0.709	0.082	1.208	0.059
7/2	0.947	0.118	0.947	0.118	1.579	0.135
7/3	0.920	0.145	0.971	0.149	1.139	0.344
Overall						
geomean	0.879	0.095	0.932	0.097	0.960	0.207
SE	0.022		0.022		0.057	
95% CI	0.835-0.925		0.888-0.979		0.849-1.085	

Table 11. Continued.

Date	Spillway survival		RSW survival		Bypass survival	
	Estimate	SE	Estimate	SE	Estimate	SE
6/10	0.897	0.109	0.935	0.176	0.987	0.112
6/11	0.993	0.084	1.018	0.128	0.916	0.093
6/12	1.101	0.139	1.165	0.284	0.961	0.187
6/13	0.918	0.106	0.992	0.156	0.972	0.124
6/14	0.788	0.161	0.817	0.173	0.920	0.142
6/15	0.796	0.139	0.816	0.157	0.718	0.120
6/16	0.846	0.141	0.816	0.171	1.027	0.129
6/17	0.843	0.176	1.049	0.243	1.050	0.143
6/18	0.869	0.105	1.027	0.190	1.146	0.103
6/19	1.091	0.145	1.161	0.166	1.234	0.138
6/20	1.006	0.215	0.958	0.237	0.907	0.121
6/21	1.039	0.146	1.028	0.169	0.971	0.112
6/22	0.865	0.143	0.903	0.161	0.934	0.105
6/23	0.810	0.195	0.810	0.195	0.794	0.120
6/24	0.999	0.129	1.034	0.130	1.085	0.096
6/25	1.100	0.118	1.157	0.128	1.075	0.112
6/26	0.839	0.112	0.898	0.160	0.707	0.161
6/27	0.901	0.117	1.101	0.158	0.731	0.149
6/28	0.906	0.102	0.948	0.105	0.815	0.123
6/29	1.054	0.131	1.111	0.133	0.992	0.180
6/30	1.251	0.139	1.242	0.142	0.850	0.159
7/1	0.673	0.118	0.745	0.130	0.690	0.118
7/2	0.936	0.170	0.948	0.175	0.880	0.138
7/3	0.760	0.191	0.912	0.208	1.194	0.197
Overall geomean	0.920	0.140	0.974	0.170	0.928	0.133
SE	0.028		0.027		0.031	
95% CI	0.864-0.980		0.920-1.032		0.866-0.994	

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 to detect meaningful differences either in survival or passage metrics between day and night releases. Small sample sizes also precluded identification of any diel trends in passage behavior.

The percentage of fish entering the forebay during daylight hours was lower than the percent of the diel period designated as daytime. Daytime hours were designated as from 0400 to 1900, or 67% of a 24-h period, and we recorded 59% of the fish entering the forebay during those hours (Figure 7). Thus the percentage of hours when dam passage was observed was also lower than the percentage of hours designated as daytime. We observed 54% of fish passing the dam during daytime hours (Figure 8).

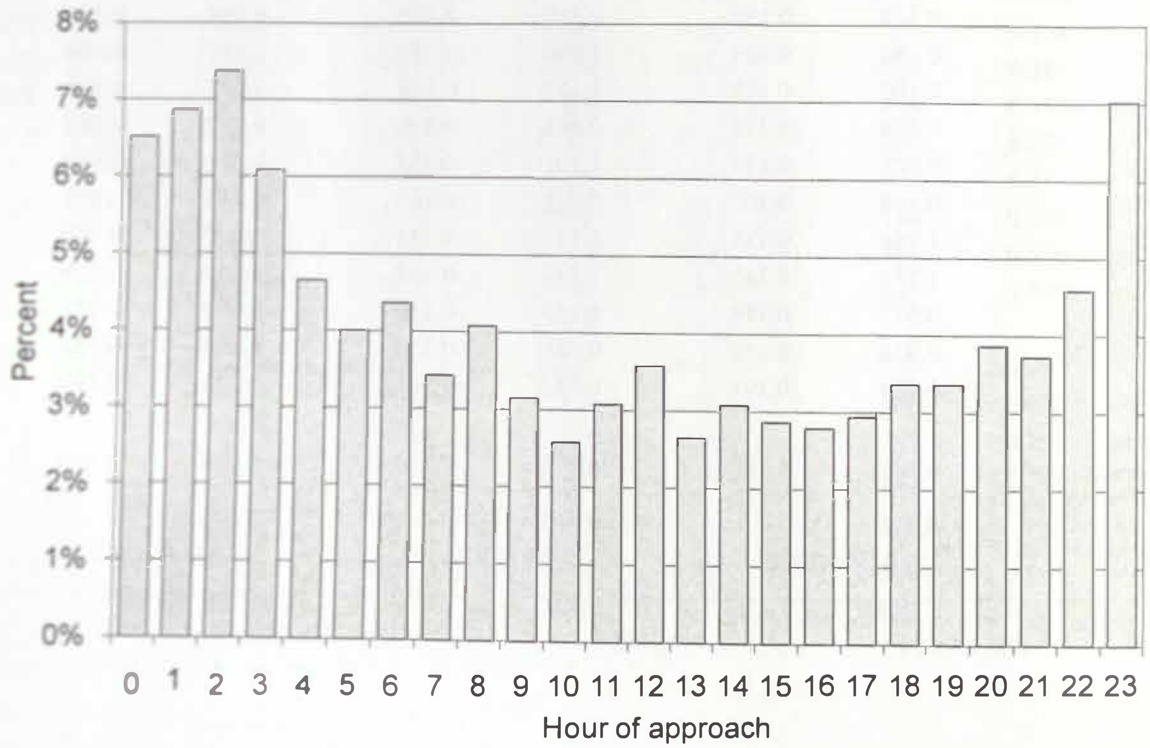

Figure 7. Percentage of radio-tagged subyearling Chinook salmon entering the forebay of Lower Monumental Dam by hour, 2008.

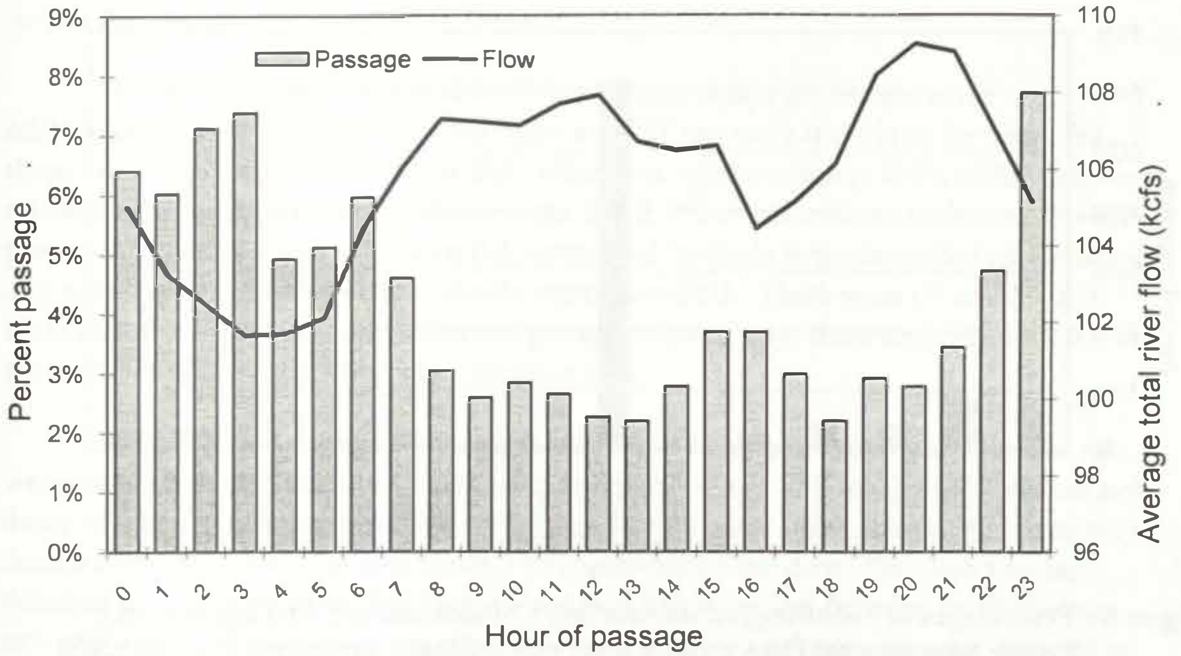

Figure 8. Percentage of radio-tagged subyearling Chinook salmon passing Lower Monumental Dam and average total river (DART 2008) flow by hour, 2008.

The spill percentage in 2008 was lower than in previous years of the study due to the much higher total river flow this year: the average spill percentage was 24% in 2008 compared to 31% in 2006 and 50% in 2007. This lower percentage of spill resulted in a greater proportion of fish first approaching the powerhouse than was observed in previous years. In 2008, first approach to the powerhouse was 27%, compared to 16% in 2006 and 7% in 2007. 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 (62%). This proportion was higher than we have seen in previous years of the study and was probably due to the location of the antennas on the RSW. The antennas on the RSW extended approximately 10 m farther out into the forebay compared to the other spillways, increasing the likelihood that fish would first be detected on those antennas.

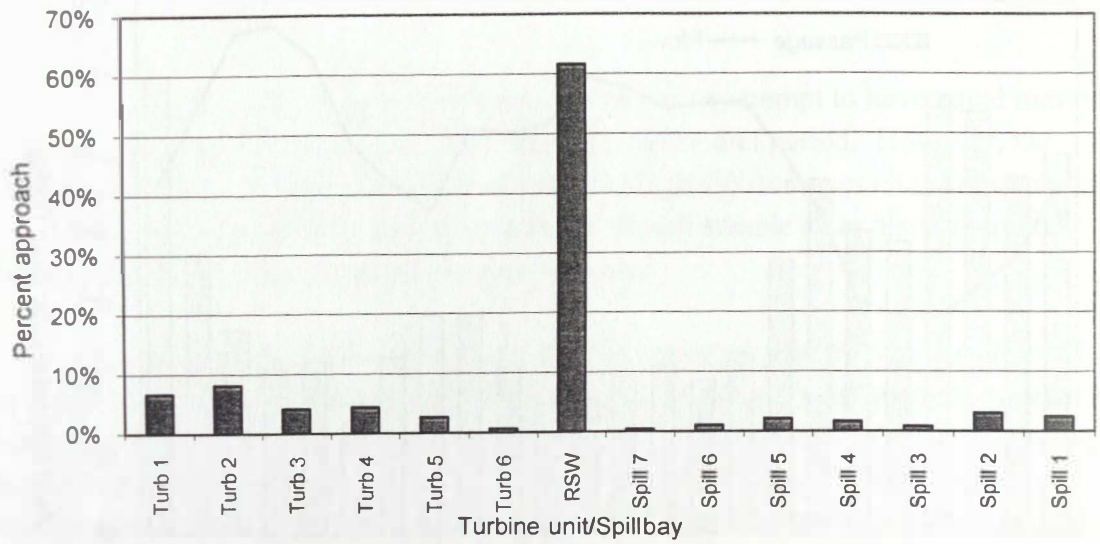

Figure 9. Percentages of radio-tagged subyearling Chinook salmon first approaching Lower Monumental Dam turbine units and spillbays, combined day and night releases, 2008.

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

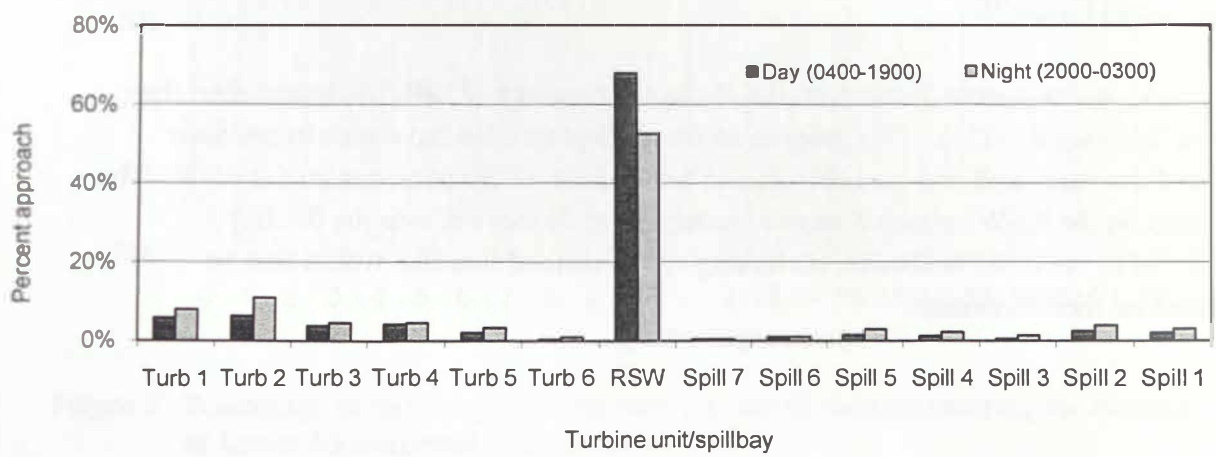

Figure 10. Percentages of radio-tagged subyearling Chinook salmon first approaching Lower Monumental Dam turbine units and spillbays by diel period, 2008.

Avian Predation

A total of 77 radio tags and 86 PIT tags were found on islands in the mid-Columbia River. Since both the radio and PIT tag were recovered for some fish, these totals represented 130 unique fish, which was approximately 2.9% of the fish we released into the Snake River. We consider this 2.9% as a minimum estimate of avian predation because not all tags from fish consumed by birds were deposited on the islands, and not all tags deposited on the islands were recovered. There were 61 and 69 tags recovered from treatment and reference groups, respectively; these represented 2.6% of the treatment fish and 3.3% of the reference fish.

Of the 61 unique tags from treatment groups recovered from bird colonies, 43 were detected at the Burr Canyon transect or downstream. Fourteen were from fish not detected after release in the forebay of Lower Monumental Dam, and one fish was only detected on the transect located about 2 km upstream of the dam. One fish was last detected at a passage route (Spillbay 4), and two fish were last detected on the tailrace exit receivers. All but one of the 69 unique tags from control releases were detected at Burr Canyon; the one fish that was not detected was never detected after release.

Comparison with 2006 and 2007 Lower Monumental Dam Results

During the 2008 study period, 24% of total river flow was passed as spill. This compared to 32 and 50% of total river flow that was spilled during the 2006 and 2007 study periods, respectively. Total river flow averaged 106 kcfs in 2008, compared with 51 kcfs in 2006 and 39 kcfs in 2007. The volume of spill was higher in 2008 (25 kcfs) than either 2006 (16 kcfs) or 2007 (19 kcfs), but the very high total river flow resulted in a lower spill percentage than the previous two years. The 10-year average for the study period is 65 kcfs.

In 2008, spillway passage for treatment fish was 40.4% and was much lower than the 82.0% seen in 2006 and 91.4% in 2007 (Absolon et al 2008a,b). This was due to the lower spill percentage and the higher total river flow, which resulted in a large increase in the number of fish passing the dam through the powerhouse, either through the turbines or the juvenile bypass system.

Spill efficiency also reflected this pattern, with reduced proportions of fish approaching and passing via the spillway. Spill efficiency in 2008 was 0.404. This was the same as the proportion of fish that passed via the spillway, and was much lower than spill efficiency observed either in 2006 (0.820) or 2007 (0.914). A summary of passage metrics and observed flow conditions for last three years of the study is presented in Table 12.

Table 12. Summary of passage metrics and flow conditions for subyearling Chinook salmon radio tag studies from 2006-2008. Passage metrics include 95% confidence intervals in parentheses.

	2006	2007	2008
Average spill (%)	32	50	24
Average spill volume (kcfs)	16.1	19.5	25.5
Average total river flow (kcfs)	50.6	38.7	106.4
Average spillway passage (%)	82	91	40
Average bypass passage (%)	12	7	46
Average turbine passage (%)	7	2	13
Fish passage efficiency	0.947 (0.925-0.968)	0.982 (0.971-0.993)	0.866 (0.849-0.883)
Spill efficiency	0.820 (0.754-0.886)	0.914 (0.876-0.951)	0.404 (0.380-0.428)
Spill effectiveness	2.58 (2.39-2.77)	1.84 (1.75-1.93)	1.46 (1.37-1.54)
RSW efficiency	n/a	n/a	0.24 (0.189-0.281)
RSW effectiveness	n/a	n/a	3.33 (3.30-3.36)
Fish guidance efficiency	0.645 (0.480-0.810)	0.796 (0.681-0.911)	0.775 (0.749-0.802)
Median forebay residence time (h)	2.7	3.6	2.3
Median tailrace egress time (min)	11	13	8

The greatest proportion of fish passing via the spillway passed through the RSW in Spillbay 8 (62%; Figure 11). This was similar to percentages that passed through Spillbay 8 prior to the installation of the RSW. In 2006 and 2007, Spillbay 8 passage was 66 and 54%, respectively. The spill pattern used in 2008 was similar to the pattern used in 2006 with an adjustment for flow through the RSW. At spill volumes less than 23.0 kcfs, the spill pattern used in 2007 increased spill in Spillbay 2 and reduced it in Spillbay 6 compared to the pattern used in 2006. This resulted in an increase in Spillway 2 passage to 16% in 2007 compared to 4% in 2006. In 2008, the shift in spill away from Spillbay 2 resulted in a decrease in passage to 6%.

Relative survival through the RSW was 0.974 (95% CI, 0.920-1.032). This was higher than the point estimate of relative survival for the spillway as a whole, including the RSW, which was 0.920 (0.864-0.980). In 2006 and 2007, estimated relative survival through Spillbay 8 was also higher than that estimated for the overall spillway (Absolon et al. 2008a,b). Estimated survival through the RSW in 2008 was higher than through other passage routes, but was the same as estimated through Spillbay 8 in 2006, prior to installation of the RSW (Table 13).

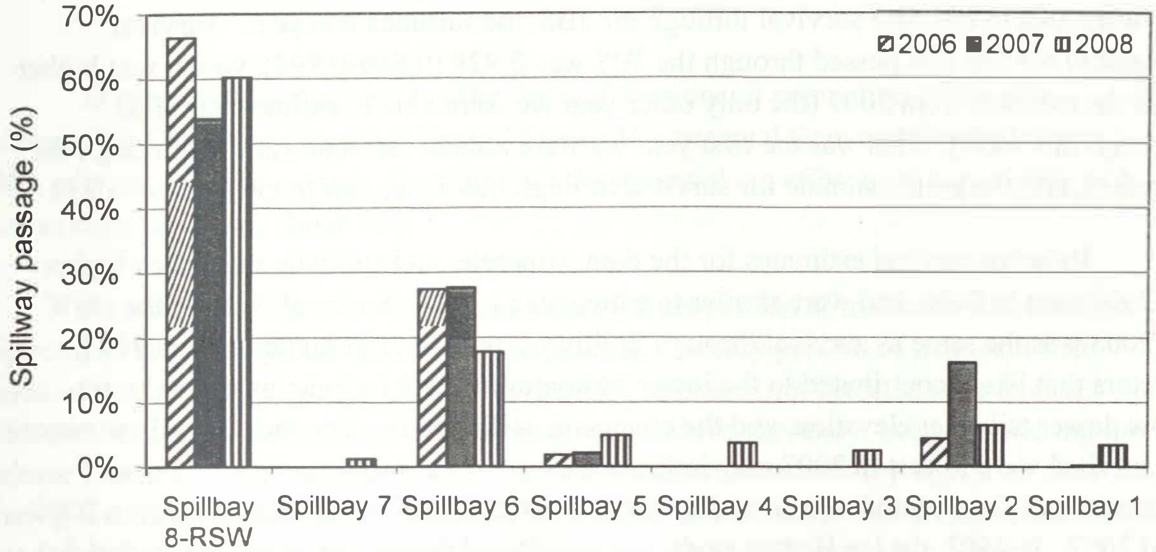

Figure 11. Percentage of radio-tagged subyearling Chinook salmon passing through each spillbay at Lower Monumental Dam, in 2006, 2007 and 2008.

Table 13. Relative survival estimates for subyearling Chinook salmon through passage routes at Lower Monumental Dam, 2006-2008.

	2006			2007			2008		
Route	Point estimate	95% CI	Method	Point estimate	95% CI	Method	Point estimate	95% CI	Method
Dam	0.896	0.888-0.904	geomean	0.762	0.690-0.841	geomean	0.879	0.835-0.925	geomean
Concrete	0.943	0.936-0.950	geomean	0.845	0.807-0.883	geomean	0.932	0.888-0.979	geomean
Spillway	0.943	0.918-0.968	geomean	0.838	0.797-0.882	geomean	0.920	0.864-0.980	geomean
Spillbay 8	0.970	0.976-0.995	geomean	0.903	0.862-0.945	geomean	see RSW below		
Spillbay 6	0.909	0.828-0.998	geomean	0.779	0.700-0.867	pooled	n/a		
Spillbay 2	n/a			0.697	0.586-0.829	pooled	n/a		
RSW	n/a			n/a			0.974	0.920-1.032	geomean
JBS	n/a			0.949	0.750-1.149	pooled	0.928	0.866-0.994	geomean
Turbines	n/a			n/a			0.960	0.849-1.085	geomean

Due to the increased number of fish passing the project through the powerhouse, we were able to estimate survival through the JBS and turbines this year. Survival estimated for fish that passed through the JBS was 0.928 (0.866-0.994), which was higher than the estimate from 2007 (the only other year we were able to estimate survival through this route). This was the first year we were able to estimate survival through the turbines, and the point estimate for survival through this route was 0.960 (0.849-1.085).

Relative survival estimates for the dam, concrete, and spillway were each higher in 2008 than in 2006, and were similar to estimates in 2007. Survival through the RSW in 2008 was the same as survival through Spillbay 8 in 2006, but higher than in 2007. 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 were lowest 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.

Mean average daily tailwater elevation was 441.1 ft msl in 2008. This was 3.0 and 3.5 ft higher than in 2006 and 2007, respectively. This provided more water depth over the flow deflectors than we have observed in previous years of the study.

Median forebay residence time in 2008 was 2.3 h, which was shorter than either 2006 or 2007, as would be expected with the very high levels of total river flow observed during the study this year. Median forebay residence time was 2.7 h in 2006 and 3.6 h in 2007. Tailrace egress was also shorter in 2008, at 8 min for all passage routes combined, compared to 11 and 13 min in 2006 and 2007, respectively.

Spill effectiveness in 2008 was 1.46:1, which was lower than both 2006 (2.58:1) and 2007 (1.84:1) and was likely influenced by the very high total river flow this year. The trend we saw in 2006 and 2007 was toward higher spill effectiveness during lower spill percentage. Spill percentage was lower in 2008 than either 2006 or 2007, but average total river flow was double that of 2006 and nearly three times higher than 2007. The much greater volume of water in 2008 seemed to negate the increase in spill effectiveness seen at lower spill volumes in 2006 and 2007.

The point estimate of spill efficiency was 0.404, which was much lower than the estimates of 0.935 and 0.982 in 2006 and 2007, respectively. In the past, spill efficiency has been higher at higher spill percentages. While spill percentage in 2008 was lower than observed the previous two years, total river flow was much higher.

DISCUSSION

During 2008, testing began after 28% of the general population of juvenile subyearling Chinook salmon had passed Lower Monumental Dam and finished when 84% of these fish had passed. To minimize the potential tag effects, we tagged fish with a minimum weight of about 10 g.

As occurred in previous years, a substantial proportion of treatment fish were not detected at the forebay entrance array after release. Twenty percent of treatment fish released 42 km upstream of Lower Monumental Dam were not detected after release. This percentage was lower than the previous two years of the study, even considering the release location farther upstream, and was likely a direct result of very high river flow during the study, which may have helped move fish downstream. Other factors that may have contributed to the percentage of non-detected fish include predation, water temperature, hydraulic conditions, and tag life.

It is also possible that some fish may 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). In previous study years, we have observed very few, if any, PIT-tag detections the following spring. The downstream telemetry arrays would not detect radio-tagged fish that delayed migration longer than the pre-determined tag life period of 10 d. 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 have contributed to delays in migration. Flow stratification with upstream directed 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 2008, 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 disrupt physiological processes (Mesa et al. 2002), reduce levels of smoltification, and decrease growth (Marine and Cech 2004) in subyearling Chinook salmon, as well as to increase predation on these fish (Vigg and Burley 1991). In 2008, water temperature did not rise above 20°C until August, which was well after the study period. Therefore, temperature was not likely a contributor to the number of non-detected fish during this study.

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. The much higher river flows, which reduced forebay residence times, may also have reduced predation this year, but the change in release location does not allow a comparison between study years.

Avian predation, as determined by radio and PIT-tag recoveries, was higher in 2008 than in 2006 or 2007. In 2006, tags from 0.8% of the total number of fish we released were recovered. That increased to 2.9% in 2007 and 3.7% in 2008. The study was conducted during the same general time period in 2007 and 2008, which was about a week earlier than in 2006.

Detection rates at the forebay entry line in 2008 were again lower than expected, but higher than those observed in previous study years, even with treatment fish being released approximately 33 km farther upstream. This was likely due to the very high river flows present during the study period. In previous years we have observed lower detection rates on the forebay entry line at Lower Monumental than at Ice Harbor Dam when the same collection of fish were tagged for each location by the same personnel. 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 forebay entry line was high, similar to previous years, we do not believe that missed detections contributed significantly to the lower detection rate.

Release of treatment groups farther upstream this year allowed us to estimate pool survival to the forebay entry line in addition to dam passage.

Overall, high river flows throughout the 2008 study period influenced the passage metrics compared to previous years. The high flow and lower spill percentage resulted in a lower proportion of fish passing the project via the spillway. The largest percentage of fish that passed through the spillway did so via the RSW, which also produced the highest point estimate of relative survival. The increased number of fish passing through the bypass system and turbine units allowed us to estimate survival through these routes with much higher precision than has been possible in the past. A summary table of results from the 2008 study of Lower Monumental Dam passage behavior and survival is presented in Appendix E.

ACKNOWLEDGEMENTS

We express our appreciation to all who assisted with this research. We thank the USACE (Walla Walla District) who funded this research. We particularly thank William Spurgeon (Lower Monumental Dam Project Biologist), George Melanson (Little Goose Project Biologist), and Ann Setter (Walla Walla USACE District Office) for their help coordinating research activities. Monty Price and the staff of the Washington Department of Fish and Wildlife at Lower Monumental Dam, and Annie Dowdy and the staff of the Oregon Department of Fish and Wildlife at Little Goose Dam provided valuable assistance with the collecting and sorting of study fish. Carter Stein and staff of the Pacific States Marine Fisheries Commission provided valuable assistance in PIT tag data acquisition.

For their ideas and assistance, we also thank, Steven Brewer, JoAnne Butzerin, Tyler Conrad, Scott Davidson, Doug Dey, Nathan Dumdei, John Ferguson, Josh Gifford, Wayne Henry, Byron Iverson, Bruce Jonasson, Mark Kaminski, Jesse Lamb, Pecca Maenpaa, Ron Marr, Bill Muir, Jeff Moser, Matthew Nesbit, Sean Newsome, Darren Ogden, Sam Rambo, Thomas Ruehle, Sam Rushing, Jim Simonson, Scott Telander, Bill Wassard, Alex Wentz, John Williams, and Galen Wolf of the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service.

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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 2,362 radio-tagged subyearling Chinook salmon released above Lower Monumental Dam, 1,891 were detected at either the entry line upstream from the dam or at the dam. Of these 1,891 fish, 1,576 (66.7% of those released) were detected either at or below the Burr Canyon transect. Of the 2,071 radio-tagged subyearling Chinook salmon released into the tailrace of Lower Monumental Dam, 2,007 (96.9% of those released) were detected either at or below Burr Canyon.

Radio-telemetry detection probability at Burr Canyon approached 100%, with only 59 fish (1.6%) detected downstream that were not detected at Burr Canyon. With detection probabilities at or near 100% for both groups, there was no disparity between detection probabilities of treatment and reference groups (Appendix Table A1).

Appendix Table A1. Detections at and below Burr Canyon and detection probabilities at Burr Canyon for evaluating survival of hatchery subyearling Chinook salmon passing Lower Monumental Dam, 2008.

Release group	Detection at Burr Canyon	Detection at or below Burr Canyon	Detection probability of fish at Burr Canyon	Observed proportion of fish released
Treatment	1,541	1,576	0.978	0.667
Reference	1,983	2,007	0.988	0.969
Totals	3,524	3,583	0.984	0.808

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 Ice Harbor Dam was statistically significant for all percentiles (Appendix table A2). The passage date of treatment fish at Lower Monumental Dam was paired with the release date of reference fish. Ice Harbor Dam observations were grouped by date since nearly all fish were detected in less than 3 d. Negative numbers indicate reference fish arriving later than treatment fish at Ice Harbor Dam. The difference in average passage timing was in the range of 0.2 days (4.8 h) for the 10 – 40th percentiles and rose to over 0.5 days for the 90th percentile of passage.

We believe differences of only a few hours in arrival distributions were unlikely to have been biologically meaningful and thus it is reasonable to conclude that the survival estimates were not significantly biased by violation of the assumption regarding mixing through the common reach.

Appendix Table A2. Test of homogeneity of arrival timing at Ice Harbor Dam for treatment and reference groups of radio-tagged hatchery subyearling Chinook salmon used for estimating dam survival at Lower Monumental Dam, 2008. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Passage date	Passage date difference at Ice Harbor Dam (days)								
	10th	20th	30th	40th	50th	60th	70th	80th	90th
6/10	-0.382	-0.315	-0.296	-0.203	-0.107	0.055	0.159	0.202	0.117
6/11	-0.088	-0.183	-0.183	-0.255	-0.341	-0.414	-0.382	-0.433	-0.472
6/12	0.157	0.074	-0.061	-0.025	-0.043	-0.111	-0.307	-0.710	-0.449
6/13	-0.364	-0.131	-0.163	-0.104	-0.246	-0.340	-0.458	-0.593	-1.255
6/14	-0.343	-0.388	-0.333	-0.398	-0.361	-0.536	-0.784	-1.049	-1.663
6/15	-0.389	-0.088	-0.104	-0.137	-0.335	-0.708	-0.567	-0.087	-0.670
6/16	-0.258	-0.063	-0.094	0.007	0.062	-0.183	-0.227	-0.158	-0.253
6/17	-0.037	0.055	0.021	-0.070	-0.046	-0.116	-0.041	-0.164	-0.337
6/18	-0.082	-0.007	-0.065	-0.102	-0.197	-0.406	-0.688	-0.792	-0.520
6/19	-0.338	-0.268	-0.223	-0.132	-0.026	-0.085	-0.177	-0.385	-0.704
6/20	-0.292	-0.280	-0.173	-0.046	-0.255	-0.245	-0.246	-0.423	-0.070
6/21	-0.065	-0.205	-0.160	-0.148	-0.284	-0.256	-0.307	-0.558	-0.751
6/22	-0.291	-0.276	-0.150	-0.198	-0.349	-0.347	-0.742	-0.833	-0.388
6/23	-0.355	-0.260	-0.307	-0.338	-0.448	-0.380	-0.688	-1.055	-1.132
6/24	0.151	-0.033	-0.200	-0.278	-0.252	-0.649	-0.857	-1.108	-0.918
6/25	-0.047	-0.098	-0.070	-0.148	-0.154	-0.215	-0.432	-0.648	-0.660
6/26	-0.747	-0.824	-0.715	-0.561	-0.568	-0.524	-0.398	-0.505	-0.578
6/27	-0.465	-0.412	-0.270	-0.314	-0.526	-0.702	-0.705	-0.713	-0.778
6/28	-0.476	-0.508	-0.460	-0.495	-0.499	-0.723	-0.778	-0.884	-0.638
6/29	-0.303	-0.393	-0.387	-0.309	-0.481	-0.727	-0.699	-0.776	-1.014
6/30	-0.152	-0.323	-0.270	-0.258	-0.316	-0.252	-0.426	-0.657	-0.821
7/1	-0.216	-0.186	-0.177	-0.237	-0.309	-0.294	-0.424	-0.387	-0.724
7/2	0.055	-0.005	-0.218	-0.181	-0.200	-0.057	-0.493	-0.271	-0.390
7/3	-0.128	-0.342	-0.170	-0.165	-0.037	0.091	0.193	0.113	0.749
7/4	0.026	0.050	-0.034	-0.179	-0.164	-0.191	-0.229	-0.075	0.187
Mean difference (days)									
	-0.217	-0.216	-0.210	-0.211	-0.259	-0.333	-0.428	-0.518	-0.565
SE	0.043	0.041	0.031	0.028	0.034	0.049	0.057	0.072	0.098
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95% CI									
Lower	-0.305	-0.301	-0.274	-0.268	-0.330	-0.433	-0.545	-0.666	-0.768
Upper	-0.129	-0.131	-0.147	-0.154	-0.189	-0.232	-0.311	-0.370	-0.363

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

River-run hatchery subyearling Chinook salmon were collected primarily at the Little Goose Dam smolt monitoring facility with additional fish collected at the Lower Monumental Dam facility from 6 June to 3 July. 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 28th and 84th percentile based on the 10-year average subyearling Chinook salmon smolt index at Lower Monumental Dam. Overall mean length of study fish was 108 mm for fish released both upstream and downstream from Lower Monumental Dam (Table 2). The overall mean length of river-run subyearling Chinook salmon collected at the Lower Monumental Dam Smolt Monitoring Facility during the study period was 105 mm (Table 3). Mean overall weight of both treatment and control fish was 13 g (Table 4).

The study encompassed just over 50% 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 was 18 km. The detection array used to estimate survival at Ice Harbor Dam was 52 km downstream of Lower Monumental Dam. 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 23 tagged fish that had died prior to release at the reference location and none of those fish were detected on a downstream 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 70 tags that were held to evaluate tag performance, all 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 radio-telemetry studies are stored in the Juvenile Salmon Radio Telemetry project, an interactive database maintained by staff of the Fish Ecology Division at the NOAA Fisheries Northwest Fisheries Science Center. This project tracks migration routes and passage of juvenile salmon and steelhead past dams within the Columbia and Snake Rivers using a network of radio receivers to record signals emitted from radio transmitters ("tags") implanted into the fish. Special emphasis is placed on routes of passage and on survival for individual routes at hydroelectric dams on the lower Columbia and Snake Rivers. The database includes observations of tagged fish and the locations and configurations of radio receivers and antennas.

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

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

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

The 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.

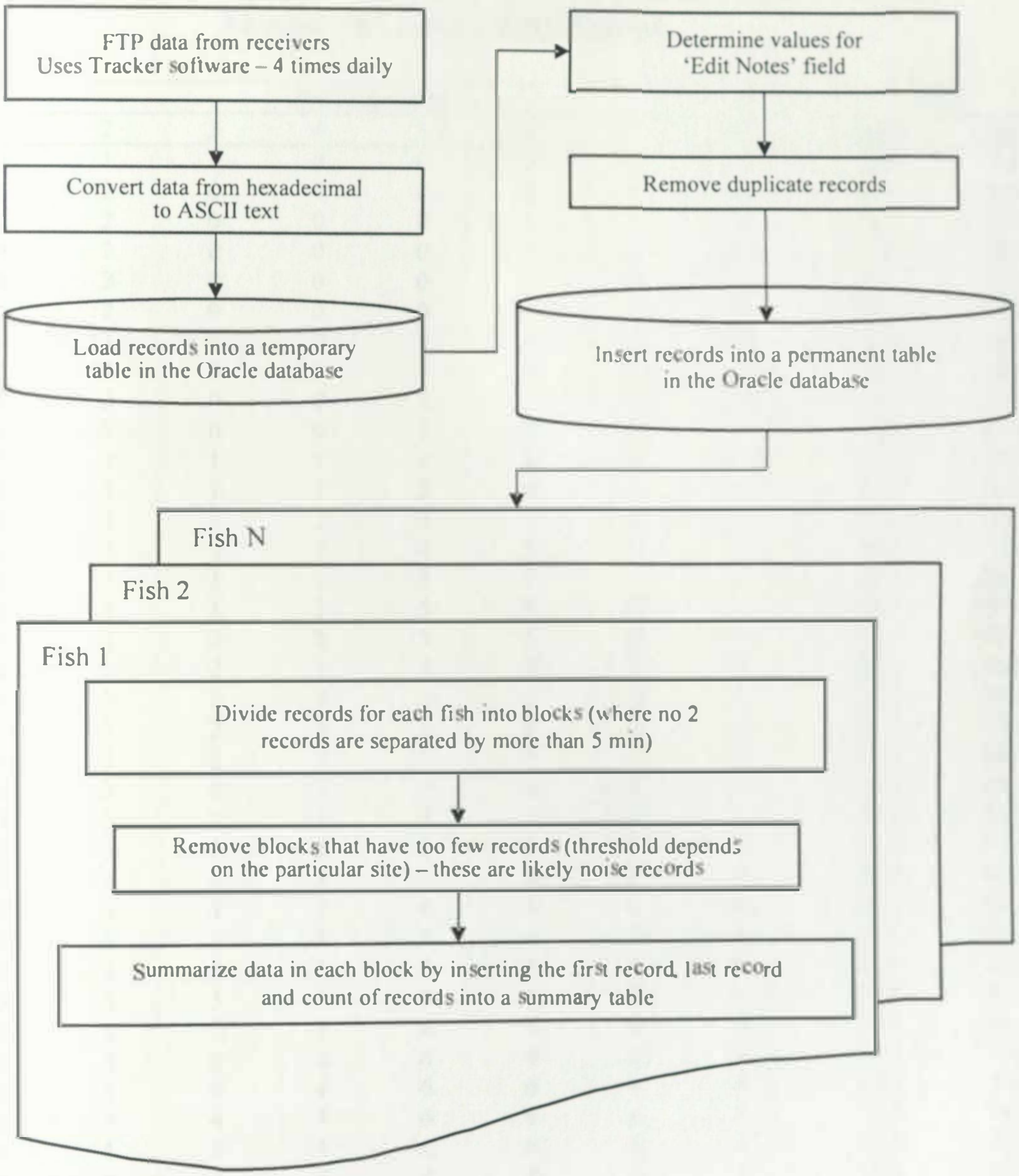
Lt start time: assigned to records occurring prior to the time at tag was activated (its start time).

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, 2008.

APPENDIX C

Spill Pattern

Appendix Table C1. Lower Monumental Dam spill pattern for 2008. RSW in Spillbay 8 has a flow equivalent of 4.5 stops at elevation 537.0 ft msl. Summer spill pattern is highlighted.

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

APPENDIX D

Detection 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 2008. The primary survival array was 16 km downstream from the dam; additional downstream arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection histories for dam survival estimates		
	Primary survival array	Post primary array	n
Treatment group (2,362)			
	0	0	786
	1	0	309
	0	1	35
	1	1	1,232
Reference group (2,071)			
	0	0	64
	1	0	418
	0	1	24
	1	1	1,565

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 2008. 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 (1,714)			
	0	0	262
	1	0	284
	0	1	28
	1	1	1,140
Reference group (2,071)			
	0	0	64
	1	0	418
	0	1	24
	1	1	1,565

Appendix Table D3. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate overall spillway passage survival in 2008. 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 (681)			
	0	0	70
	1	0	117
	0	1	12
	1	1	482
Reference group (2,071)			
	0	0	64
	1	0	418
	0	1	24
	1	1	1,565

Appendix Table D4. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate RSW passage survival in 2008. 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 RSW survival estimates		
	Primary survival array	Post primary array	n
Treatment group (410)			
	0	0	26
	1	0	71
	0	1	10
	1	1	303
Reference group (2,071)			
	0	0	64
	1	0	418
	0	1	24
	1	1	1,565

Appendix Table D5. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate bypass passage survival in 2008. 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 bypass survival estimates		
	Primary survival array	Post primary array	n
Treatment group (780)			
	0	0	76
	1	0	146
	0	1	15
	1	1	543
Reference group (2,071)			
	0	0	64
	1	0	418
	0	1	24
	1	1	1,565

Appendix Table D6. Detection histories of radio-tagged subyearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate turbine passage survival in 2008. 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 turbine survival estimates		
	Primary survival array	Post primary array	n
Treatment group (226)			
	0	0	22
	1	0	34
	0	1	4
	1	1	166
Reference group (2,071)			
	0	0	64
	1	0	418
	0	1	24
	1	1	1,565

APPENDIX E

Study Summary

Year: 2008
Study site: Lower Monumental Dam

Objectives of study:

Evaluation of:

- forebay residence time
- fish passage efficiency
- fish guidance efficiency
- project survival
- passage distribution
- spill effectiveness
- route specific 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: 108 mm	median: 13 g
	range: 95.2-144 mm	range: 10-35 g

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

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

Survival estimates:

Type	Value	SE	Replicate size	No. of replicates	Analytical model
dam	0.879	0.022	mean 69 (range 38-96)	24	CJS
concrete	0.932	0.022	mean 65 (range 36-91)	24	CJS
spillway	0.920	0.028	mean 26 (range 8-52)	24	CJS
RSW	0.974	0.027	mean 16 (range 5-36)	24	CJS
JBS	0.928	0.031	mean 28 (range 14-47)	24	CJS
turbines	0.960	0.057	mean 8 (range 2-16)	23	CJS
Passage metrics					
FPE	0.866	0.016	mean 73 (range 44-104)	24	
SPE	0.404	0.018	mean 73 (range 44-104)	24	
Spill effectiveness	1.46	0.140	mean 73 (range 44-104)	24	
FGE	0.775	0.019	mean 20 (range 24-60)	24	

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

Environmental/operating conditions

Daily operations/conditions	mean	range
Spill (%)	24	8.8-87.7
Total river flow (kcfs)	106	49.3-171.0
Water temperature (°C)	14.2	11.1-17.5