Passage behavior and survival for radio-tagged yearling chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006

Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
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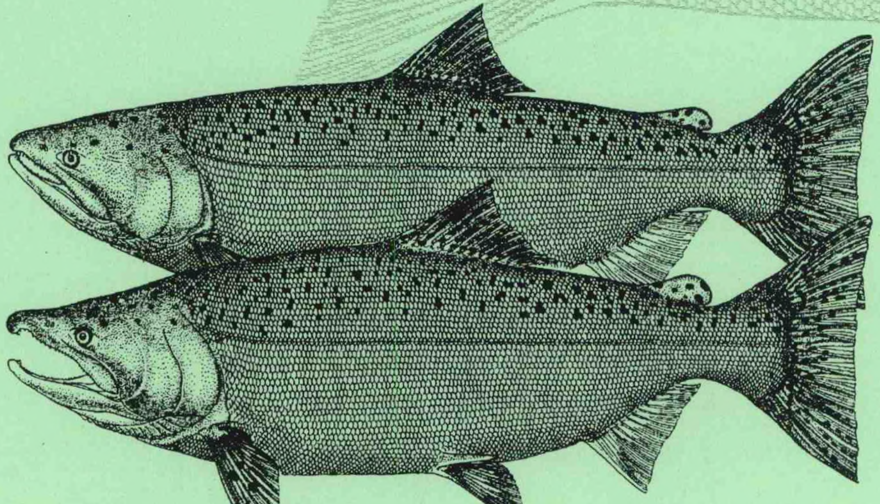
May 2008



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Report of research by

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EXECUTIVE SUMMARY

In 2006, NOAA Fisheries evaluated passage behavior and estimated relative survival for radio-tagged river-run hatchery yearling Chinook salmon *Oncorhynchus tshawytscha* and juvenile steelhead *O. mykiss* at Lower Monumental Dam on the Snake River. Fish were collected, PIT tagged, and surgically implanted with a radio transmitter at Lower Monumental Dam. Treatment groups were comprised of 1,398 yearling Chinook salmon and 1,171 juvenile steelhead released 7 km upstream from Lower Monumental Dam. The reference groups were comprised of 1,183 yearling Chinook salmon and 998 juvenile steelhead released into the tailrace of Lower Monumental Dam. Releases occurred during both daytime and nighttime operations for 26 d from 2 to 27 May. Project operations during the evaluation included bulk spill 24 h per day. River flow, percent spill, and tailwater elevation during releases averaged 139 kcfs, 26%, and 443 ft msl, respectively.

For yearling Chinook salmon, median forebay delay was 2.5 h overall. During passage, the largest proportion (26%) of yearling Chinook first approached Lower Monumental Dam near the middle of the dam in the vicinity of spillbay 8. Yearling Chinook passed the dam primarily through the spillway (58%); however, almost one-third passed through the JBS (30%), and 9% passed via the turbines. Passage routes for the remaining 3% were not determined. Within the spillway, the largest proportion (36%) of yearling Chinook passed through spillbay 8. For fish with a known passage route, fish guidance efficiency (FGE) was 77% and fish passage efficiency (FPE) was 91%. Median tailrace egress was 6 min overall, and spill efficiency was 2.31 to 1.

Relative survival was estimated from detections of treatment and reference groups at a series of downstream telemetry transects between Lower Monumental Dam on the lower Snake River and McNary Dam on the lower Columbia River. Relative dam survival for yearling Chinook salmon was 0.924 (95% CI, 0.905-0.942). Relative survival was 0.925 (0.898-0.953) for yearling Chinook passing through the spillway, 0.987 (0.974-1.000) for fish passing through the JBS, and 0.910 (0.857-0.964) for fish passing through turbines. Survival for fish passing through spillbay 8 was 0.940 (0.918-0.962).

For juvenile steelhead, median forebay delay was 5.5 h. The greatest proportion of steelhead (18%) first approached Lower Monumental Dam near the middle of the dam in the vicinity of spillbay 8. The proportion of steelhead passing through the spillway (49%) was slightly higher than that passing through the JBS (48%). Only 2% of juvenile steelhead passed via turbines (2%), and passage routes of the remaining 1% could not be determined.

Within the spillway, the largest proportion of steelhead (24%) passed through spillbay 8. For fish with a known passage route, FGE was 96% and FPE was 98%. Median tailrace egress was 6 minutes overall, and spill efficiency was 1.9 to 1.

Relative dam survival was 0.980 (95% CI, 0.956-1.005) for juvenile steelhead. Relative survival was 0.999 (0.971-1.027) for juvenile steelhead passing through the spillway, 1.010 (0.990-1.031) for those passing through the JBS, and 0.838 (0.661-1.015) for fish passing through turbines. Survival for juvenile steelhead passing through spillbay 8 was 1.000 (0.970-1.030).

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INTRODUCTION

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

The spillway has long been considered the safest passage route for migrating juvenile salmonids at Columbia and Snake River dams. Holmes (1952) reported survival estimates of 96 (weighted average) to 97% (pooled) for fish passing Bonneville Dam spillway during the 1940s. A review of 13 estimates of spillway mortality published through 1995 concluded that for fish passing via standard spillbays, mortality rates most likely range from 0 to 2% (Whitney et al. 1997). Similarly, recent survival studies of juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that survival was highest through spillways, followed by bypass systems, then turbines (Muir et al. 2001). Pursuant to the National Marine Fisheries Service (NMFS) 2000 Biological Opinion (NMFS 2000), 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.

Juvenile anadromous salmonids in the Columbia River Basin generally migrate in the upper 3 to 6 m of the water column (Johnson et al. 2000, Beeman and Maule 2006). However, juvenile fish passage routes at dams on the lower Columbia and Snake Rivers require fish to dive to depths of 15 to 18 m in order to enter a passage route. Engineers and biologists within the U.S. Army Corps of Engineers (USACE) developed a removable spillway weir (RSW) to provide surface-oriented spillway passage. The RSW uses a traditional spillway and is attached to the upstream face of the spillbay. In the lower Snake River, RSWs were installed at Lower Granite Dam in 2001 and Ice Harbor Dam in 2005. The RSW at Lower Granite Dam has reduced migrational delays, improved fish passage efficiency, and provided increased passage survival (Plumb et al. 2003, 2004).

An RSW is being designed and constructed for installation at Lower Monumental Dam in 2007. The proposed location for an RSW at Lower Monumental Dam is spillbay 8 because the majority of fish first approach the dam in this area (Hockersmith et al. 2005; Johnson et al. 1998). Hockersmith et al. (2006) estimated survival for juvenile salmon passing through spillbay 8 at 95.2%. Survival for juvenile steelhead volitionally passing Lower Monumental Dam has not previously been evaluated.

In 2006 we examined passage behavior and survival at Lower Monumental Dam during voluntary bulk spill for yearling Chinook salmon and juvenile steelhead. The goal of this study was to collect baseline data on passage behavior and survival for comparison to passage behavior and survival after installation of an RSW at Lower Monumental Dam. Results of this study will be used to inform management decisions for development and operation of an RSW at Lower Monumental Dam and to optimize survival and passage for juvenile salmonids. This study addressed research needs outlined in SPE-W-00-1 of the USACE, Northwestern Division, Anadromous Fish Evaluation Program.

METHODS

Study Area

The study area included a 119-km river reach from Lower Monumental Dam on the lower Snake River to McNary Dam on the lower Columbia River (Figure 1). Lower Monumental Dam is the second dam upstream from the mouth of the Snake River and is located in Washington State, 67 km above the confluence of the Snake and Columbia Rivers. Construction of Lower Monumental Dam was completed in 1969, and the dam is 1,155 m long and 34 m high. The powerhouse contains 6 Kaplan turbines capable of producing 810 megawatts of electricity. Total hydraulic capacity of the powerhouse is about 130 kcfs. The spillway is 174 m long and has eight 15- by 18-m tainter gates. Lake Herbert G. West, which extends 45 km upstream, is formed by the dam.

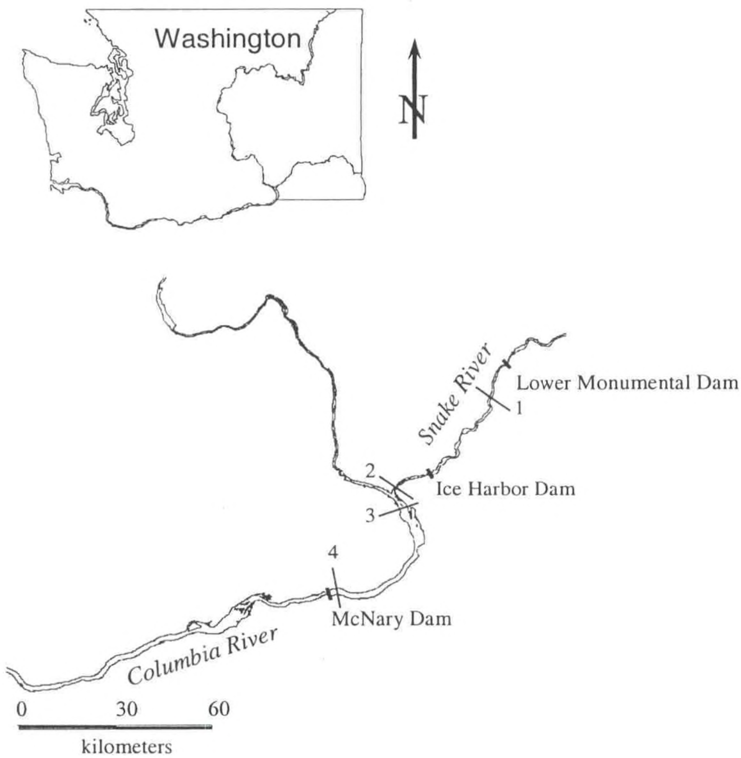

Figure 1. Detail of the study area showing locations of radiotelemetry transects used for estimating survival at Lower Monumental Dam in 2006. Transects included: 1 = primary survival array 16 km downstream from Lower Monumental Dam; 2 = mouth of the Snake River; 3 = Burbank/Finley Railroad Bridge and 4 = forebay of McNary Dam. The forebay, tailrace, and all routes of passage at Lower Monumental and Ice Harbor Dams were also monitored.

Fish Collection, Tagging, and Release

Radio tags were purchased from Advanced Telemetry Systems Inc.[1], had a user-defined shut-off after 10 d, and were pulse-coded for identification of individual fish. Each radio tag measured 13.2 mm in length by 6.2 mm in diameter, had a volume of 257 mm^3, and weighed 1.0 g in air. Each tag had a 30-cm long external antenna.

River-run, hatchery yearling Chinook salmon and juvenile steelhead were collected from the smolt collection facility at Lower Monumental Dam from 30 April to 26 May. We used only hatchery-origin yearling Chinook salmon and run of the river juvenile steelhead that were not previously PIT tagged, that had no visual signs of disease or injury, and that weighed 15 g or more. Fish were anesthetized with tricaine methanesulfonate (MS-222) and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were randomly selected from the daily smolt-monitoring sample and transferred through a water-filled, 10.2-cm hose to a 935-L holding tank. Following collection and sorting, fish were maintained via flow-through river water and held a minimum of 18 h prior to radio tagging.

Fish were surgically tagged with a radio transmitter using techniques described by Adams et al. (1998). A PIT tag was also inserted with the radio transmitter so that test fish could be separated by code in the fish collection system and returned to the river (Marsh et al. 1999). Surgical tagging was conducted simultaneously at four tagging stations. During a 4-h shift, approximately 160 fish were tagged.

Immediately following tagging, fish were placed into 9-L, aerated recovery containers (two fish per container) and held a minimum of 18-h for recovery and determination of post-tagging mortality. Fish holding containers were perforated with 1.3-cm holes in the top half of the container to allow exchange of water during holding. Recovery containers were then closed and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers. All holding tanks were supplied with flow-through water during tagging and holding and were aerated with oxygen during transport to release locations.

Release procedures followed those used in 2004 at Lower Monumental Dam during a study to evaluate passage and survival (Hockersmith et al. 2005). After a post-tagging recovery period, fish were transported in their recovery containers from the holding area to release locations (7 km upstream from Lower Monumental Dam or into the tailrace). Immediately prior to transport to release locations, the transmitters of all

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

tagged fish were checked to verify operation, and that the codes were recorded correctly in the database. To provide mixing of treatment and reference groups, treatment groups were released all at one time twice daily (daytime and nighttime periods), and reference release groups were released over a 4-h period twice daily (daytime and nighttime periods).

Treatment and reference groups were moved from holding tanks to a release tank using water-to-water transfer methods. Release tanks were mounted on an 8.5 × 2.4-m barge and transported either 7 km upstream (treatment) or approximately 1 km downstream (reference) from Lower Monumental Dam. Both treatment and reference groups were released from a boat in mid-channel. The reference group release location was determined from operations testing on a 1:55 scale model of Lower Monumental Dam at the USACE Research and Development Center in Vicksburg, MS. Specific operating conditions were not requested for release days, and project operations at Lower Monumental Dam included either voluntary or involuntary bulk spill for the duration of the study. Project operation data were collected every 5 min by the USACE.

Project operations assigned to treatment fish corresponded to conditions recorded at the time closest to the time of fish passage. For treatment fish that passed the dam with an undetermined passage time, project operations were assigned based on conditions closest to the time of first detection recorded in the tailrace. For treatment fish that did not pass the dam, project operations corresponded to conditions closest to the time of forebay entry. Operational conditions assigned to reference fish corresponded to conditions closest to time of release.

Telemetry Monitoring

Radiotelemetry receiver arrays were positioned to determine forebay entrance, dam approach, route of passage, tailrace exit, and downstream detection (Figure 1). The locations of fixed telemetry receiver sites at Lower Monumental Dam in 2006 are summarized in Table 1 and Figure 2. Based on past experience, we did not utilize a double array (Skalski et al. 2002) for evaluating routes of passage because the proportion of fish with undetermined passage routes has been typically less than 3%.

Table 1. Locations of fixed-site telemetry receivers for evaluating passage behavior and survival at Lower Monumental Dam, 2006.

Location	Number of receivers	Type of monitoring	Antenna type
Forebay	3	Entrance line and timing	3-element Yagi
Turbine units 1-6	6	Approach and passage location	Striped coax
Spillbays 1-8	8	Approach and passage location	Underwater dipole
Stilling basin	2	Project passage	Tuned loop
Juvenile bypass system	1	Bypass passage	Tuned loop
Turbine unit draft tubes	3	Project passage	Underwater dipole
Tailrace exit	2	Project passage and egress	3-element Yagi
Total receivers	25		

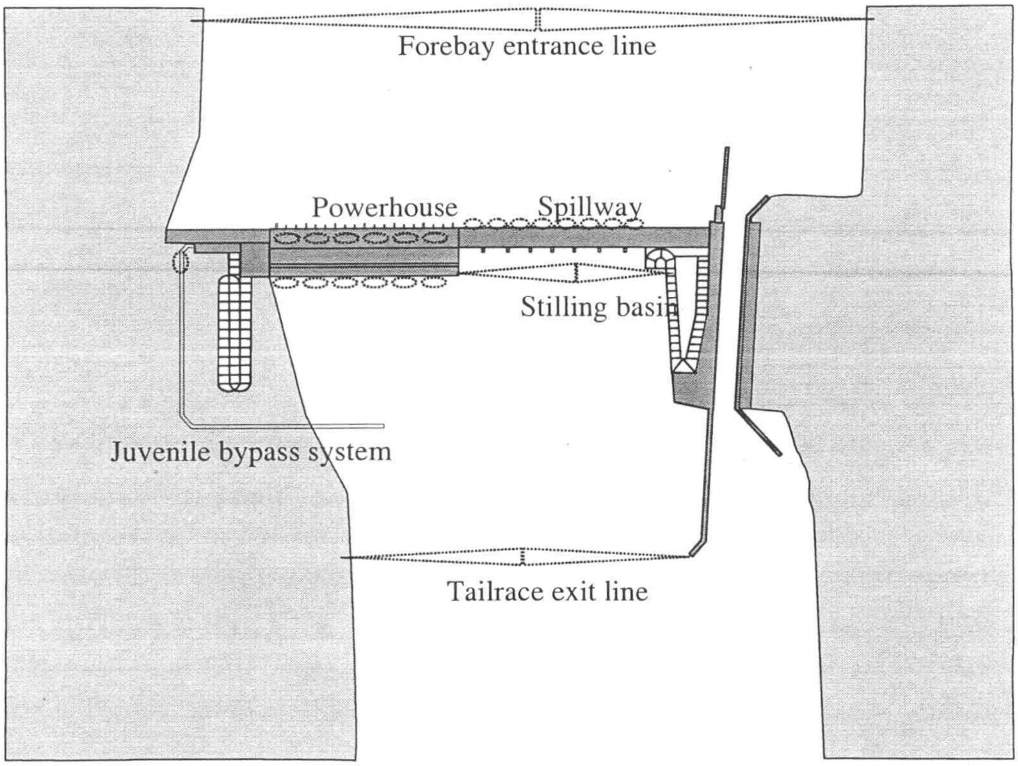

Figure 2. Lower Monumental Dam plan view showing approximate locations of detection zones for radiotelemetry receivers in 2006. Oval lines represent underwater antennas, and triangular lines represent aerial antennas.

Data Processing and Analysis

Telemetry data were retrieved through an automated process that downloaded networked telemetry receivers up to four times daily. Data processing and reduction are summarized in Appendix Figure C. After downloading, individual data files were compressed by recording the first time a radio-tagged fish was detected and counting the number of detections where the time difference between adjacent detections was less than or equal to 5 min. When the difference between adjacent detections became greater than 5 min, a new line of data was created. All compressed data were combined and loaded into a database, where automated queries and algorithms were used to remove erroneous data. On the cleaned data set, detailed detection histories were created for each radio-tagged fish. These detection histories were used to calculate arrival time in the forebay, forebay approach patterns, passage-route distribution and timing, tailrace exit timing, and timing of downstream detections for individual radio-tagged fish.

Forebay Residence Time

Forebay arrival time was based on the first time a fish was detected on the forebay entry line at the upstream end of the boat restricted zone (BRZ) at Lower Monumental Dam (approximately 500 m upstream from the face of the dam). Forebay residence time was determined for fish that had been released upstream from Lower Monumental Dam and detected entering the forebay, detected in a passage route, and detected in the immediate tailrace on either the stilling-basin, turbine draft tube, or tailrace-exit telemetry receivers (Figure 2). Forebay residence time for individual fish was calculated as the difference between the time of last detection in a passage route and the first detection on the forebay entrance line at the upstream end of the BRZ.

Overall forebay residence delay was characterized by constructing means and 95% confidence intervals (i.e. approximately the mean ±2 standard errors) for the 10th, 20th,..., 80th, 90th percentiles of the residence time distributions. Replicates used for comparisons among passage routes were formed by grouping fish by day of detection at the entrance to the BRZ. Confidence intervals were also constructed by route of passage (i.e., bypass, turbine, and spillway). Time in the bypass route was divided into gatewell and post-gatewell segments.

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

Approach and Passage Distribution

Approach patterns were established based on the first detection at either underwater dipole spillway antennas (Beeman et al. 2004) or on stripped coax underwater antennas (Knight et al. 1977) on the standard-length traveling screens. Route of passage through the dam was based on the last time a fish was detected on a passage-route antenna and was assigned only to fish that were subsequently detected in the tailrace on either the stilling-basin, turbine draft tube, or tailrace-exit telemetry receivers (Figure 2). Tailrace detections were used to validate passage because fish could be detected on a passage-route receiver while still in the forebay.

Spillway passage was assigned to fish that were detected in the tailrace of the dam after last being detected in the forebay on one of the eight antenna arrays that were deployed along each of the two pier noses on the sides of individual spillbays. Powerhouse passage was assigned to fish last detected in a turbine intake prior to detection in the tailrace of the dam. Fish passing via the powerhouse were further partitioned into either turbine or juvenile bypass system (JBS) passage based on the presence or absence of a detection in the JBS (either PIT-tag or telemetry detection). Fish that were assigned to powerhouse passage but that did not have a detection in the JBS were assigned to turbine passage. For analysis of passage-route distributions, we included only fish that had been released upstream from Lower Monumental Dam, detected entering the forebay, detected again in a passage route, and detected a third time in the immediate tailrace either on the stilling-basin, turbine draft tube, or tailrace-exit telemetry receivers.

Fish Passage Performance Metrics

Fish passage performance metrics included spill efficiency, spill effectiveness, fish passage efficiency (FPE), and fish guidance efficiency (FGE). These metrics were estimated as follows:

Spill efficiency: Number of fish passing the dam via the spillway divided by the total number of fish passing the dam.

Spill effectiveness: Proportion of fish passing the dam via the spillway divided by the proportion of water spilled.

FPE: Number of fish passing the dam through non-turbine routes divided by total number of fish passing the dam.

FGE: Number of fish passing the dam through the JBS divided by the total number of fish passing the dam through the powerhouse (turbines and JBS).

Tailrace Egress

For analysis of tailrace egress, we included only fish that had been released upstream from Lower Monumental Dam, detected entering the forebay, detected again in a passage route, and detected a third time in the immediate tailrace. Tailrace egress time for individual fish was calculated as the difference between time of last detection in a passage route and time of last detection on the tailrace-exit array.

Overall tailrace egress time was characterized by constructing 95% confidence intervals about the mean egress time for each 10-percentile increment (10th, 20th,...80th, 90th percentiles) of the distribution (i.e. means ± $t_{(0.05,\, n\text{-}1)}$ standard errors). Replicates were formed by grouping fish by passage day at Lower Monumental Dam. Similar intervals were constructed for tailrace egress time by route of passage (i.e., bypass, turbine, and spillway).

Survival Estimates

Survival estimates were based on detections of individual fish at Snake River telemetry transects 16 km downstream from Lower Monumental Dam, at Ice Harbor Dam, at the mouth of the Snake River, at Columbia River transects near Burbank, WA, and in the forebay of McNary Dam (Figure 1). Detection histories were evaluated independently for treatment and reference groups using the CJS single-release model (Cormack 1964; Jolly 1965; Seber 1965). Data were analyzed using the Survival with Proportional Hazards (SURPH) statistical software developed at the University of Washington (Smith et al. 1994).

Survival estimates followed the guidelines described by Peven et al. (2005). Dam survival was defined as survival of treatment fish through all passage routes combined relative to survival of tailrace-released reference fish. The "effect zone" (Peven et al. 2005) extended from the forebay entrance array to the tailrace control release location. The forebay entrance array was located at the upstream point of the BRZ, which is approximately 500 m upstream from the face of the dam. Therefore, dam survival included losses within the immediate forebay of the dam. The tailrace release location (reference fish) was approximately 1 km downstream from Lower Monumental Dam.

Concrete survival is a ratio of survival estimated for treatment fish, from release at the upstream face of the dam to approximately 1 km downstream, and that of reference fish, which are released in the tailrace. The effect zone extended from the exit of all passage routes to the tailrace release location. Concrete survival did not include any losses in the forebay.

Capture histories of treatment and reference groups were partitioned into three periods for survival estimation; detection at the primary survival line (16 km downstream from Lower Monumental Dam), at Ice Harbor Dam, and detection downstream from Ice Harbor Dam. Treatment groups for estimates of survival were comprised of fish released above Lower Monumental Dam and subsequently detected on the forebay entrance array 500 m upstream from the dam. For estimates of dam survival, treatment groups were formed based on the date of forebay entry. For estimates of concrete and route-specific survival, treatment groups were formed based on date of passage. Reference fish groups were based on release date. For estimates of relative survival, treatment fish that passed the the dam on day *i* were paired with reference fish that were released to the tailrace on the same day (i.e., day *i*). Relative survival was estimated at the ratio of survival estimates between treatment (numerator) and reference (denominator) fish groups.

Confidence intervals for estimates of relative survival were constructed using geometric mean of daily estimates of survival. Since geometric means were used, the ratios of proportions were assumed log-normally distributed (Snedecor and Cochran 1980). Thus, the geometric mean was assumed equivalent to the back-transformed arithmetic mean of the log-transformed estimates. Confidence intervals were of the form:

$$\left({}_e\log(\bar{x}) - t_{.05,n-1} \times SE,\ {}_e\log(\bar{x}) + t_{.05,n-1} \times SE\right)$$

where $\bar{x}$ was the geomean; t was the t-value, given $\alpha = 0.05$ and 25 degrees of freedom (i.e., approximately equal 2); and SE was the standard error of the geomean.

An assumption of the CJS model is that fish in all groups have equal probabilities of survival and detection downstream from the point of release (i.e., the tailrace of Lower Monumental Dam). This assumption is reasonable if release groups have similar passage distributions at downstream detection sites, in this case, at the primary survival array 16 km downstream from the dam. To evaluate this assumption, we compared differences between treatment and reference groups in temporal passage distribution at the primary survival array. Treatment fish were grouped by passage date and were "paired" with tailrace fish grouped by release date. Confidence intervals (95%) and *t*-tests were constructed for statistical comparison. Model assumptions and methods used to evaluate them are detailed in Appendix A.

Treatment fish were assumed to pass the dam through the location where they were last detected. We excluded from the analysis any fish that had not been detected on the forebay entrance array.

To provide continuity between analysis and interpretation of survival and passage behavior, we excluded any fish that did not meet the criteria for both passage behavior and survival analyses. These exclusions did not bias any of the estimated parameters, but decreased the precision of estimates, since the effect was to decrease sample size. At present, no formal analysis of adult returns of tagged fish used in this study is anticipated.

Avian Predation

Predation from the Caspian Tern *Hydroprogne caspia*, double-crested comorants *Phalacrocorax aurtius* and gulls *Larus* spp. was evaluated by physical recovery of radio transmitters and by PIT tag detection on Crescent and Foundation Islands in the McNary Dam Reservoir. Radio transmitters and PIT tags were recovered on nesting colonies during fall 2006 after the birds had abandoned their nesting colonies. Radio tag serial numbers were used to identify individual tagged fish. PIT tag detections and recovery of radio transmitters were provided by NMFS (B. Ryan, NOAA Fisheries, personal communication) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication). There is an ongoing monitoring effort to detect PIT tags from active avian colonies in the region conducted by NOAA Fisheries and by the Columbia Bird Research group.

RESULTS

Fish Collection, Tagging, and Release

Yearling Chinook salmon and juvenile steelhead were collected, radio tagged, and PIT tagged at Lower Monumental Dam for 26 d from l to 26 May. The 2006 study period encompassed the smolt passage index at Lower Monumental Dam between the 10th and 98th percentile for yearling Chinook salmon and between the 16th and 96th percentile for juvenile steelhead (Figure 3).

We released 1,398 radio-tagged yearling Chinook salmon 7 km upstream from Lower Monumental Dam and 1,183 yearling Chinook salmon into the tailrace. For yearling Chinook released above the dam, overall mean fork length was 148.6 mm (SD = 17.7) and overall mean weight was 25.3 g (SD = 6.9). For yearling Chinook released below the dam, overall mean fork length was 147.7 mm (SD = 13.6) and overall mean weight was 24.9 g (SD = 6.2; Tables 2 and 3).

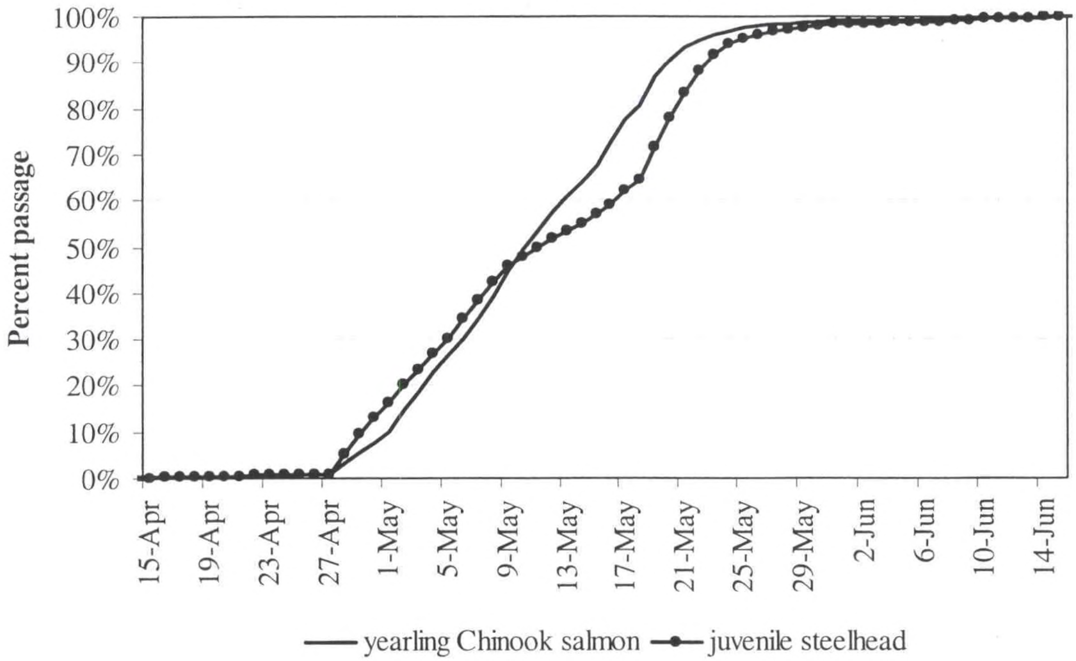

Figure 3. Cumulative passage distribution of hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam during 2006.

Table 2. Sample size, range, mean, and standard deviation (SD) of fork lengths for radio-tagged, yearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2006.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
1 May	56	122	198	142.7	10.2	---	---	---	---	---
2 May	58	128	176	146.3	11.0	47	120	176	145.0	9.5
3 May	54	130	211	149.4	13.4	47	124	168	147.3	10.4
4 May	57	124	242	155.2	20.7	47	130	184	149.1	10.4
5 May	57	123	285	153.8	29.2	47	125	284	156.5	26.4
6 May	56	122	244	151.6	22.1	47	119	243	148.8	20.7
7 May	57	124	265	154.0	24.4	47	115	260	147.8	21.7
8 May	51	126	272	151.2	20.6	49	130	278	155.0	24.7
9 May	56	125	292	152.5	27.9	47	124	165	148.2	10.5
10 May	54	124	289	154.6	26.2	51	128	190	152.2	11.9
11 May	57	117	217	142.3	13.8	48	114	168	142.3	10.6
12 May	79	127	166	146.7	9.0	23	125	165	143.4	9.6
13 May	57	131	291	151.0	20.7	47	124	181	149.3	12.2
14 May	58	128	172	146.4	8.7	47	131	169	145.6	8.1
15 May	56	134	168	147.6	8.4	47	128	159	145.2	7.4
16 May	56	128	173	148.2	9.6	48	130	232	149.1	14.4
17 May	55	130	182	145.9	9.9	46	132	164	146.5	7.0
18 May	56	127	156	141.3	6.8	51	120	160	138.4	9.5
19 May	57	133	163	148.1	6.9	46	130	166	146.6	7.8
20 May	59	127	161	144.6	8.5	45	131	164	145.9	7.2
21 May	29	122	286	149.2	28.6	74	126	189	147.9	9.3
22 May	56	126	161	146.9	8.4	46	130	170	148.3	8.8
23 May	55	127	182	145.9	10.1	46	126	180	145.3	9.3
24 May	55	126	298	156.5	30.8	48	134	209	151.1	13.9
25 May	57	125	176	146.1	10.5	47	123	186	147.0	11.5
26 May	---	---	---	---	---	45	126	165	147.4	9.7
Overall	1,398	117	298	148.6	17.7	1,183	114	284	147.7	13.6

Table 3. Sample size, range, mean, and standard deviation (SD) of weights for radio-tagged, yearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2006.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
1 May	56	18.5	36.2	26.5	4.1	---	---	---	---	---
2 May	58	18.5	49.9	26.8	6.6	47	18.5	47.8	27.2	6.3
3 May	54	16.5	86.6	29.0	10.9	47	16.4	45.4	25.7	6.0
4 May	57	17.7	80.3	30.0	11.3	47	16.8	48.3	26.1	6.6
5 May	57	15.5	61.4	28.7	10.3	47	15.8	60.8	28.4	9.8
6 May	56	15.6	66.6	27.0	10.3	47	15.2	72.2	25.0	11.1
7 May	57	15.0	70.5	28.7	10.5	47	15.2	56.8	26.2	8.8
8 May	51	15.5	41.5	24.1	6.0	49	15.6	60.6	25.3	7.8
9 May	56	15.9	43.4	24.1	6.4	47	16.0	33.5	23.5	5.0
10 May	54	15.0	50.7	24.7	7.2	51	15.1	53.4	25.7	7.2
11 May	57	15.5	39.7	24.4	4.9	48	17.5	42.2	24.5	5.1
12 May	79	15.8	42.4	25.0	5.4	23	15.3	40.5	24.2	5.5
13 May	57	18.0	34.1	23.2	4.0	47	15.9	47.0	24.4	5.8
14 May	58	16.4	42.5	23.6	4.8	47	16.8	32.1	22.8	3.4
15 May	56	15.2	34.2	23.0	4.4	47	16.0	32.3	23.0	4.0
16 May	56	16.8	44.7	25.0	5.2	48	16.1	37.3	24.5	4.4
17 May	55	15.5	37.3	23.7	4.5	46	17.5	34.3	24.0	3.9
18 May	56	16.7	33.6	24.4	3.7	51	15.2	40.9	23.1	5.1
19 May	57	17.5	33.9	24.7	3.7	46	16.9	36.9	24.5	4.5
20 May	59	15.1	36.2	23.4	4.4	45	16.7	32.2	24.1	3.7
21 May	29	15.7	44.4	24.0	6.4	74	16.1	39.9	25.3	4.7
22 May	56	16.9	33.4	24.7	4.0	46	18.1	36.8	25.2	4.6
23 May	55	16.5	42.5	22.8	4.8	46	16.9	42.9	23.6	5.3
24 May	55	18.1	37.0	25.4	4.7	48	19.7	59.6	25.9	6.6
25 May	57	15.3	44.5	24.8	6.1	47	15.1	35.5	24.4	4.8
26 May	---	---	---	---	---	45	18.2	37.4	26.2	5.3
Overall	1,398	15.0	86.6	25.3	6.9	1,183	15.1	72.2	24.9	6.2

We released 1,171 radio-tagged juvenile steelhead 7 km upstream from Lower Monumental Dam and 998 steelhead into the tailrace. For juvenile steelhead released upstream from the dam, overall mean fork length was 220.7 mm (SD = 21.5) and overall mean weight was 87.7 g (SD = 27.4; Tables 4 and 5). For juvenile steelhead released below Lower Monumental Dam, overall mean fork length was 220.1 mm (SD = 22.4) and overall mean weight was 87.3 g (SD = 29.8; Tables 4 and 5).

Table 4. Sample size, range, mean, and standard deviation (SD) of fork lengths for radio-tagged, juvenile steelhead released at Lower Monumental Dam to evaluate passage behavior and survival, 2006.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
1 May	43	127	262	210.4	22.5	---	---	---	---	---
2 May	47	124	288	213.5	28.2	36	178	247	205.2	17.1
3 May	46	185	261	213.8	15.9	40	159	247	211.5	18.2
4 May	47	166	260	225.9	22.5	40	163	257	213.0	20.1
5 May	47	179	248	216.4	17.1	40	172	272	217.5	20.0
6 May	48	180	274	221.1	23.1	40	172	261	222.6	23.8
7 May	46	177	270	223.3	18.2	39	190	286	224.6	22.1
8 May	44	178	273	221.8	19.5	44	166	265	221.0	22.5
9 May	47	162	260	221.8	23.0	40	168	262	217.5	22.7
10 May	46	179	265	221.5	18.0	38	178	256	221.4	16.4
11 May	47	172	264	225.6	20.2	39	196	267	228.3	16.9
12 May	68	195	273	227.4	18.6	20	191	268	225.6	18.9
13 May	46	194	256	223.1	16.6	40	173	263	222.9	21.0
14 May	47	158	285	220.6	28.6	39	173	263	216.1	23.7
15 May	48	169	268	215.4	24.0	40	172	263	218.8	23.9
16 May	46	169	262	216.5	21.4	40	174	265	223.0	23.3
17 May	48	179	271	222.5	21.8	40	188	279	225.0	20.2
18 May	48	191	254	224.9	17.4	40	190	264	231.9	18.0
19 May	47	169	277	225.9	23.7	40	190	277	228.1	20.4
20 May	48	171	270	217.4	20.1	40	191	299	225.6	21.8
21 May	24	181	252	220.0	19.5	64	153	296	213.3	28.4
22 May	48	187	254	219.2	16.2	39	182	274	225.0	23.4
23 May	48	178	269	225.1	21.7	40	175	262	219.3	20.3
24 May	49	173	262	220.6	22.7	40	169	247	214.5	22.2
25 May	48	156	290	219.4	24.1	40	179	276	221.2	21.6
26 May	---	---	---	---	---	40	153	296	215.4	28.2
Overall	1,171	124	290	220.7	21.5	998	153	299	220.1	22.4

Table 5. Sample size, range, mean, and standard deviation (SD) of weights for radio-tagged, juvenile steelhead released at Lower Monumental Dam to evaluate passage behavior and survival, 2006.

	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
1 May	43	46.4	167.3	78.6	25.6	---	---	---	---	---
2 May	47	37.6	185.1	77.2	30.3	36	43.3	121.0	68.5	21.3
3 May	46	45.3	132.2	76.4	18.3	40	39.9	120.7	77.6	22.4
4 May	47	38.1	143.5	94.1	28.9	40	29.1	137.1	76.2	24.3
5 May	47	40.2	124.3	78.1	21.0	40	34.2	154.5	80.2	26.3
6 May	48	42.5	177.8	88.0	32.5	40	40.6	161.2	89.6	30.5
7 May	46	38.1	166.7	88.7	25.7	39	49.6	211.1	88.8	31.6
8 May	44	43.5	166.5	90.0	25.2	44	35.5	173.0	89.5	33.3
9 May	47	34.4	146.8	91.6	29.4	40	34.2	153.0	85.8	29.1
10 May	46	45.7	155.6	90.3	24.4	38	38.3	136.9	88.1	21.0
11 May	47	38.5	161.4	92.3	26.4	39	56.3	155.1	95.1	24.6
12 May	68	54.2	159.1	93.3	25.3	20	52.6	154.5	93.3	24.4
13 May	46	50.7	135.3	89.2	21.1	40	38.8	146.0	88.5	25.9
14 May	47	30.0	211.1	92.8	36.9	39	35.5	152.7	86.8	31.6
15 May	48	35.3	182.0	82.9	30.9	40	38.1	150.6	88.3	30.2
16 May	46	33.8	143.1	83.9	26.4	40	33.9	165.4	92.4	31.9
17 May	48	42.3	157.7	90.0	27.2	40	50.7	195.0	92.4	29.8
18 May	48	49.9	123.4	87.8	20.6	40	52.8	165.7	100.7	26.2
19 May	47	35.3	186.6	92.8	31.4	40	48.0	170.0	94.5	29.8
20 May	48	37.7	154.2	83.7	25.4	40	51.2	228.4	95.8	32.0
21 May	24	44.4	151.2	90.1	27.0	64	25.1	210.5	82.1	36.5
22 May	48	56.5	133.6	87.9	20.8	39	46.0	161.4	95.2	31.5
23 May	48	44.5	165.9	96.2	28.2	40	41.6	153.7	86.4	24.9
24 May	49	38.4	155.8	90.4	28.0	40	37.3	124.6	82.2	25.2
25 May	48	25.4	187.7	83.4	31.0	40	47.5	155.3	85.4	26.8
26 May	---	---	---	---	---	40	26.7	279.3	83.1	42.6
Overall	1,171	25.4	211.1	87.7	27.4	998	25.1	279.3	87.3	29.8

Post-tagging mortality was 0.4% (10 fish) for yearling Chinook salmon and 0.6% (12 fish) for juvenile steelhead. Fish that died during the post-tagging holding period were released in the planned location to verify the assumption that dead fish are not detected on downstream survival arrays (Appendix Table A18). Treatment fish were released between 0849 and 1052 and between 2021 and 0118 PDT. Reference fish were released between 1000 and 1559 and between 2101 and 0348 PDT. Fifty-nine yearling Chinook salmon and 34 juvenile steelhead were excluded from the analysis because they were not detected entering the forebay.

Project Operations

During our study period, project discharge averaged 139 kcfs, or approximately 130% of the previous 10-year average (1996-2005) of 107 kcfs at Lower Monumental Dam (Figure 4). Project operations included either voluntary or involuntary bulk spill throughout the study period. Median gate opening and percent time individual spillbays were open during bulk spill are presented in Figures 5 and 6. Daily project operations during the study averaged 139.2 kcfs total project discharge, 100.9 kcfs powerhouse discharge, 38.3 kcfs spillway discharge (26.3% of total project discharge), and tailwater elevation of 442.8 ft msl (Table 6 and Figure 7). Water temperature during tagging, post-tagging recovery, and releases ranged from 11.0 to 14.1°C and averaged 12.3°C.

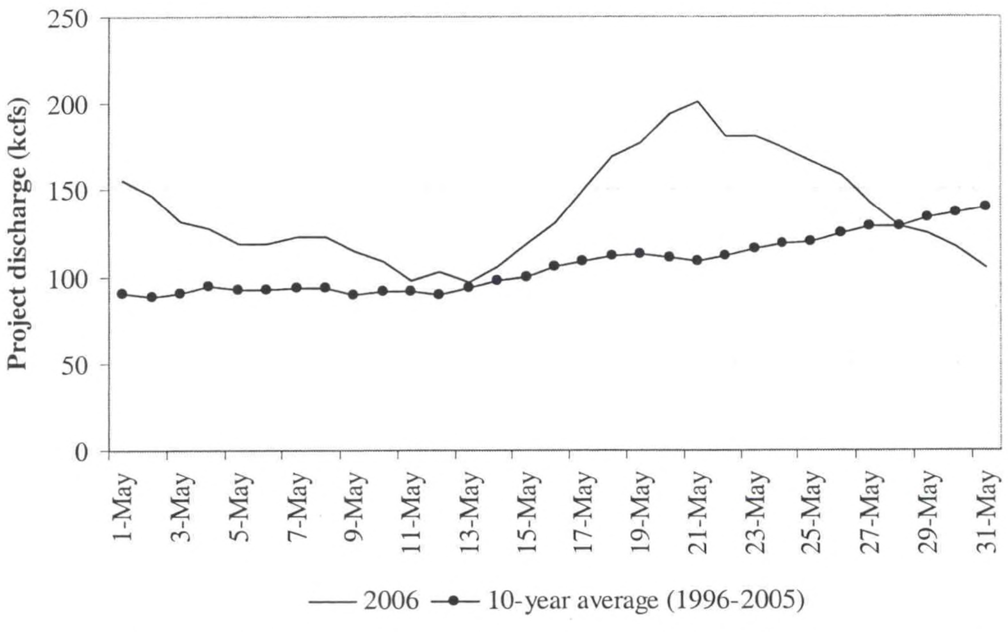

Figure 4. Daily and 10-year average (1996-2005) project discharge during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead for evaluating passage and survival at Lower Monumental Dam, 2006.

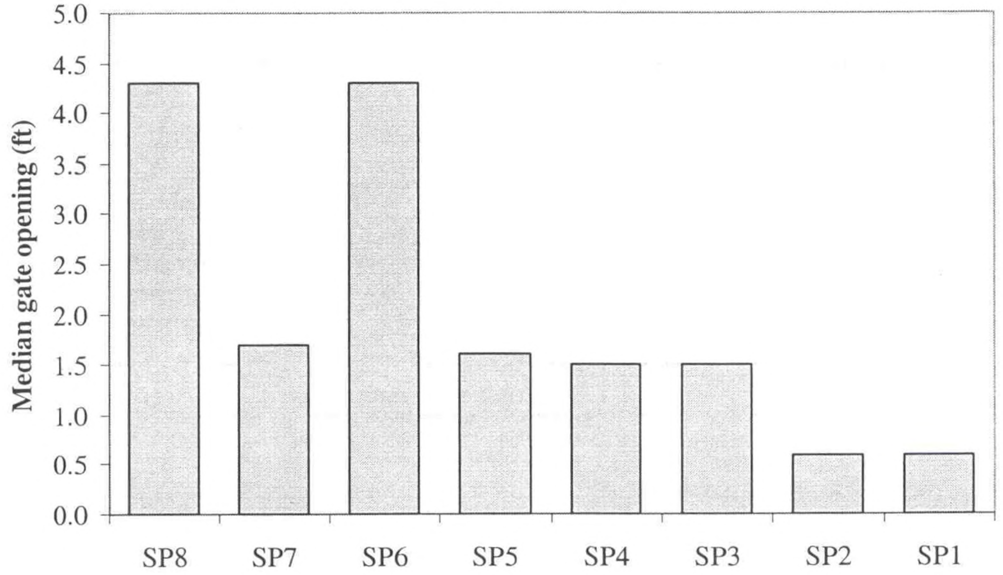

Figure 5. Median spillbay gate opening during passage of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006.

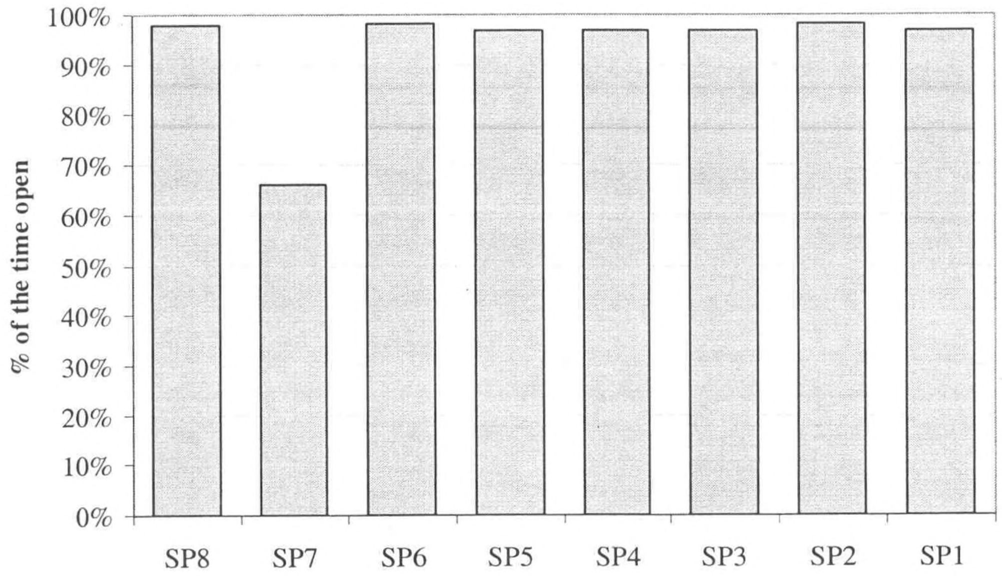

Figure 6. Percent of the time individual spillbays were open during passage of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006.

Secchi disk measurements in the forebay of Lower Monumental Dam during releases averaged 0.5 m and ranged from 0.3 to 0.6 m (Table 6). Visible depth in the forebay of Lower Monumental Dam during 2006 was 71% of the previous 10-year average (1996-2005) of 0.7 m (Figure 8).

Table 6. Average daily conditions during evaluation of passage and survival of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006.

Release date	Total discharge (kcfs)	Powerhouse (kcfs)	Spill (kcfs)	Spill (%)	Water temperature (°C)	Tailwater (ft msl)	Secchi depth (m)
1 May	154.8	115.8	39.0	25.2	11.0	443.9	0.5
2 May	146.4	113.8	32.6	22.3	11.4	443.4	0.5
3 May	131.4	108.7	22.8	17.3	11.7	442.5	0.3
4 May	127.4	104.5	22.9	18.0	11.7	442.3	0.3
5 May	118.1	96.0	22.1	18.7	11.6	441.8	0.3
6 May	118.2	97.2	21.0	17.8	11.5	441.7	0.3
7 May	122.6	102.0	20.6	16.8	11.3	442.1	--
8 May	122.6	100.3	22.3	18.2	11.2	442.0	0.6
9 May	115.0	89.9	25.1	21.8	11.4	441.5	0.6
10 May	108.9	81.2	27.8	25.5	11.8	441.0	0.6
11 May	97.6	71.6	26.0	26.6	12.3	440.2	0.6
12 May	102.5	79.1	23.4	22.8	12.4	440.6	0.6
13 May	96.9	74.3	22.6	23.4	12.2	440.4	0.6
14 May	105.5	84.1	21.5	20.3	12.2	441.0	0.6
15 May	118.2	98.0	20.2	17.1	12.2	441.8	0.6
16 May	130.1	104.9	25.1	19.3	12.6	442.4	0.6
17 May	149.7	111.5	38.2	25.5	13.1	443.5	0.6
18 May	169.4	114.8	54.6	32.2	13.7	444.4	0.6
19 May	176.9	116.2	60.8	34.3	14.1	444.8	0.6
20 May	193.3	116.8	76.5	39.6	13.7	445.7	0.6
21 May	200.9	114.8	86.2	42.9	13.0	446.0	0.3
22 May	180.6	114.2	66.4	36.8	12.5	445.1	0.3
23 May	180.8	112.0	68.8	38.1	12.3	444.9	0.3
24 May	173.7	113.2	60.6	34.9	12.3	444.7	0.3
25 May	166.0	113.7	52.3	31.5	12.2	444.4	0.3
26 May	158.5	114.2	44.3	28.0	12.4	444.0	0.3
27 May	142.0	98.9	43.2	30.4	12.6	442.9	0.3
28 May	128.5	94.8	33.7	26.2	12.6	442.2	0.3
29 May	124.1	92.6	31.5	25.4	12.8	442.1	0.3
30 May	116.3	79.4	36.8	31.7	13.0	441.3	0.6
Average	139.2	100.9	38.3	26.3	12.3	442.8	0.5

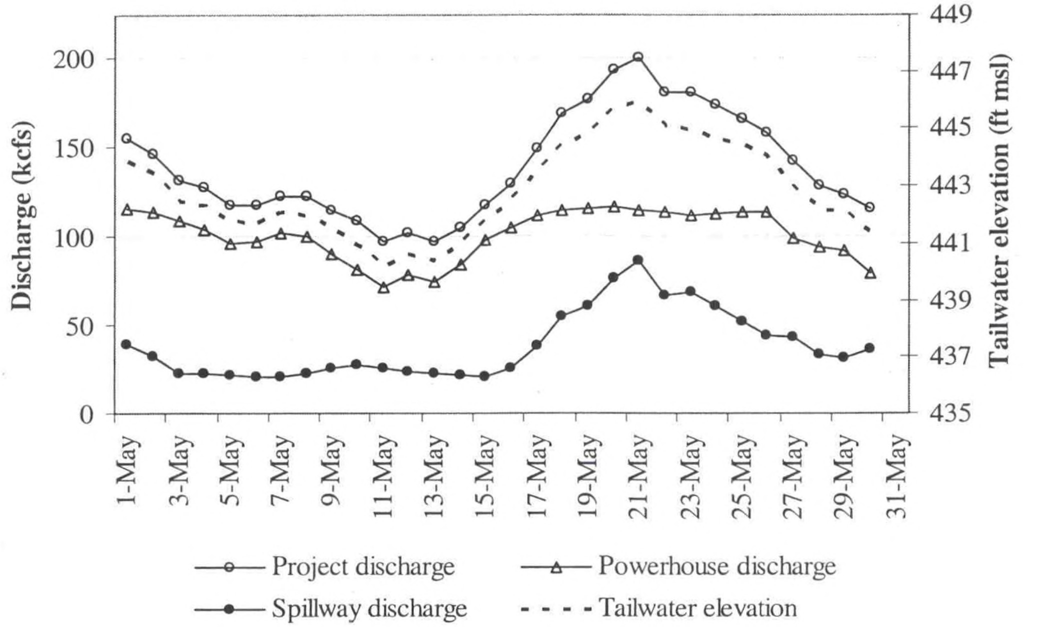

Figure 7. Average project discharge, powerhouse discharge, spillway discharge, and tailwater elevation by date during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006.

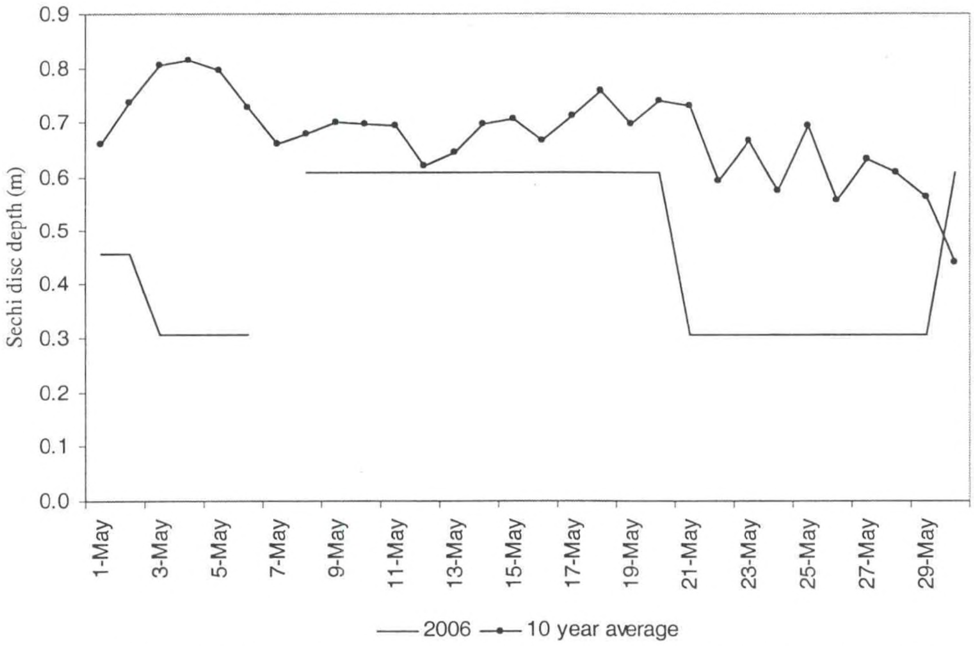

Figure 8. Daily and 10-year average (1996-2005) turbidity in the forebay of Lower Monumental Dam during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead for evaluating passage and survival at Lower Monumental Dam, 2006. Turbidity was measured by the visible depth of a Secchi disk below the surface.

Forebay Residence Time

Of the 1,438 radio-tagged yearling Chinook salmon released above Lower Monumental Dam, 1,379 (96%) were detected on the forebay entrance line at the upstream end of the BRZ. Yearling Chinook salmon entering the forebay of Lower Monumental Dam had a bimodal distribution with peak numbers at approximately 0200 and 1400 (Figure 9). Median forebay residence time was 2.5 h (95% CI 1.6-3.3) and ranged from 0.3 to 183.9 h (Table 7). Median forebay residence time of yearling Chinook salmon that passed through the JBS (5.6 h; 95% CI 3.0-8.1) was significantly longer (3.7 h) than that of fish passing through the spillway (1.9 h; 95% CI 1.3-2.6) or turbines (1.2 h, 95% CI 0.0-3.0; $P = 0.002$).

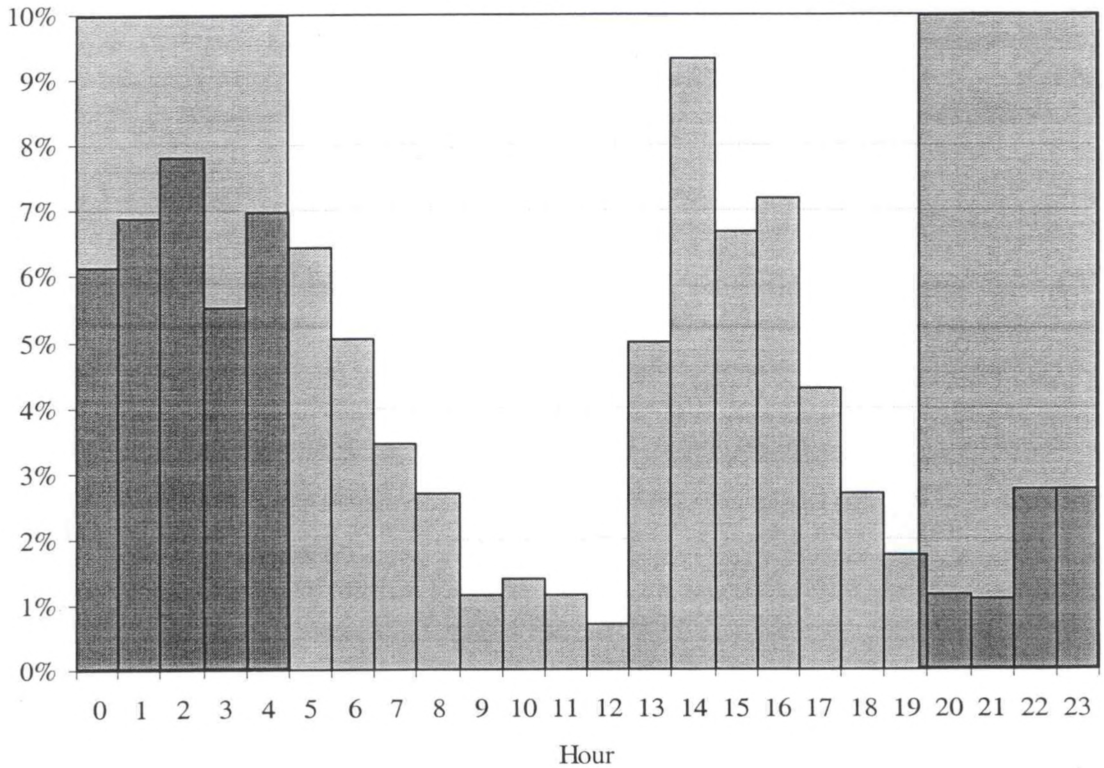

Figure 9. Hour of first detection for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam and detected in the forebay of Lower Monumental Dam. Shaded areas indicate night-time hours.

Table 7. Sample size, percentile distribution, minimum, mean, median, mode, and maximum forebay residence time (elapsed time in hours from first detection on the forebay entry line to time of passage) by passage route and overall for radio-tagged hatchery yearling Chinook salmon at Lower Monumental Dam, 2006.

	Forebay residence time (h)			
Passage percentile	JBS	Spillway	Turbine	Overall
n	399	787	119	1,305
10th	0.8	0.6	0.5	0.6
20th	1.0	0.8	0.6	0.8
30th	1.7	1.0	0.8	1.1
40th	3.4	1.4	0.9	1.5
50th	5.6	1.9	1.2	2.5
60th	8.0	3.0	2.5	4.0
70th	12.7	4.5	5.6	6.5
80th	18.3	7.6	7.8	11.0
90th	29.8	14.8	14.2	20.2
95th	41.2	22.1	25.7	29.5
Minimum	0.4	0.3	0.4	0.3
Mean	12.3	5.5	8.3	7.8
Median	5.6	1.9	1.2	2.5
Mode	0.78	0.57	0.53	0.57
Maximum	183.9	105.9	158.8	183.9

Of the 1,190 radio-tagged juvenile steelhead released above Lower Monumental Dam, 1,156 (97%) were detected on the forebay entrance line at the upstream end of the BRZ. Juvenile steelhead entering the forebay of Lower Monumental Dam had a trimodal distribution, with peak numbers at approximately 0000, 0400, and 1600 (Figure 10). Median forebay residence time was 5.5 h (95% CI 3.5-7.6) and ranged from 0.01 to 184.1 h (Table 8). Median forebay residence time of juvenile steelhead that passed through the JBS (10.2 h; 95% CI 7.5-12.9) was significantly longer (8.1 h) than that of fish that passed through the spillway (2.1 h ; 95% CI 0.6-3.7; $P < 0.001$). Only 25 juvenile steelhead passed through the turbines.

Median gatewell residence time was 0.3 h for yearling Chinook salmon and 2.9 h for juvenile steelhead (Table 9). For yearling Chinook salmon that passed via the JBS, median gatewell residence time accounted for 6% of forebay residence time. For juvenile steelhead that passed via the JBS, median gatewell residence time accounted for 29% of forebay residence time.

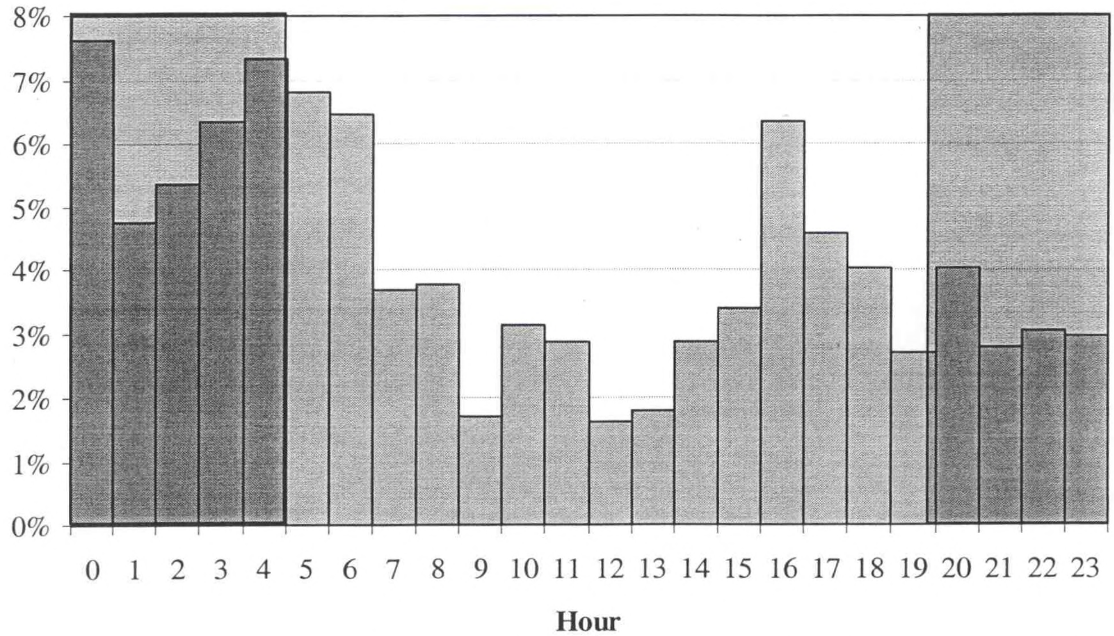

Figure 10. Hour of first detection for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam and detected in the forebay of Lower Monumental Dam. Shaded areas indicate night-time hours.

Table 8. Sample size, percentile distribution, minimum, mean, median, mode, and maximum forebay residence time (elapsed time in hours from first detection on the forebay entry line to time of passage) by passage route and overall for radio-tagged juvenile steelhead at Lower Monumental Dam, 2006.

	Forebay residence time (h)			
Passage percentile	JBS	Spillway	Turbine	Overall
n	540	528	25	1093
10th	1.3	0.6	1.0	0.7
20th	2.4	0.7	1.2	1.1
30th	4.0	1.0	1.2	1.7
40th	6.5	1.4	1.6	2.9
50th	10.2	2.1	3.7	5.5
60th	15.2	3.7	4.7	9.1
70th	20.1	7.7	18.2	14.7
80th	28.0	12.9	29.1	21.1
90th	45.0	22.2	112.5	34.6
95th	66.3	32.9	148.3	54.8
Minimum	0.1	0.2	0.6	0.1
Mean	19.1	8.0	28.6	14.0
Median	10.2	2.1	3.7	5.5
Mode	1.03	1.68	N/A	0.60
Maximum	172.2	110.5	184.1	184.1

Table 9. Sample size, percentile distribution, minimum, mean, median, mode, and maximum gatewell residence time (elapsed time in hours from first detection in the gatewell to time of passage) for radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006.

	Gatewell residence time (h)	
Passage percentile	Yearling Chinook salmon	Juvenile steelhead
n	394	545
10th	0.0	0.1
20th	0.0	0.3
30th	0.1	0.6
40th	0.2	1.3
50th	0.3	2.9
60th	0.5	5.8
70th	1.7	10.8
80th	5.5	19.0
90th	12.6	30.6
95th	21.5	52.3
Minimum	0.0	0.0
Mean	5.6	11.9
Median	0.3	2.9
Mode	0.0	0.2
Maximum	180.1	171.8

Approach and Passage-Route Distribution

A total of 1,379 yearling Chinook salmon entered the forebay of Lower Monumental Dam, and 98% of these fish (1,349) subsequently passed the dam. The remaining 30 fish were not observed in the tailrace or downstream from the dam and were assumed to have not passed the dam. Fifty-nine percent of the yearling Chinook salmon first approached the spillway portion of the dam, with the majority of these (26%) approaching at spillbay 8 (Figure 11). Yearling Chinook passed the dam primarily through the spillway (58%); however, almost one-third passed through the JBS (30%), and 9% passed via the turbines. The remaining 3% passed through undetermined routes. Undetected fish may have passed the dam through the adult fish ladder or navigation lock, since these were not monitored. They may also have passed during very brief periods when individual receivers were being downloaded or during brief periods of electronic failure. The greatest proportion of yearling Chinook passed through spillbay 8 (36%; Figure 12).

A total of 1,156 juvenile steelhead entered the forebay of Lower Monumental Dam, 98% of these fish (1,133) subsequently passed the dam. The remaining 23 fish were not observed in the tailrace or downstream from the dam, and they were assumed not to have passed the dam. Fifty-five percent of the juvenile steelhead first approached the spillway portion of the dam, with the majority of these (18%) approaching at spillbay 8 (Figure 13). The proportion of steelhead passing through the spillway (49%) was slightly higher than that passing through the JBS (48%). Only 2% of juvenile steelhead passed via turbines (2%), and passage routes of the remaining 1% could not be determined. Undetected fish may have passed the dam through the adult fish ladder, navigation lock, or during short interruptions to the monitoring system described above. The largest proportion of juvenile steelhead passed through spillbay 8 (24%; Figure 14).

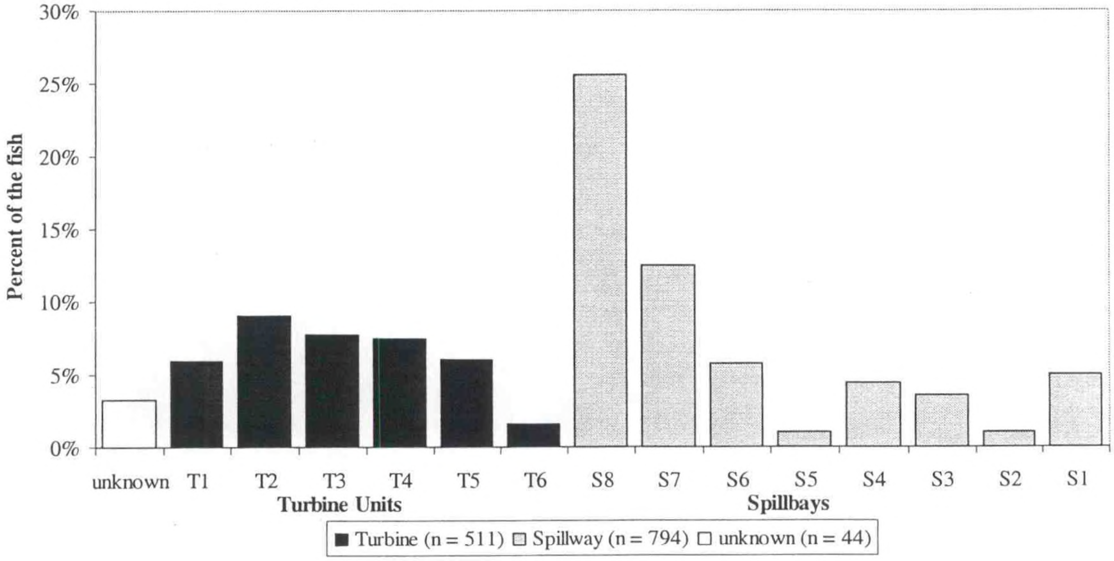

Figure11. Horizontal approach distribution for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam based on first detection at individual turbine intakes or spillbays, 2006.

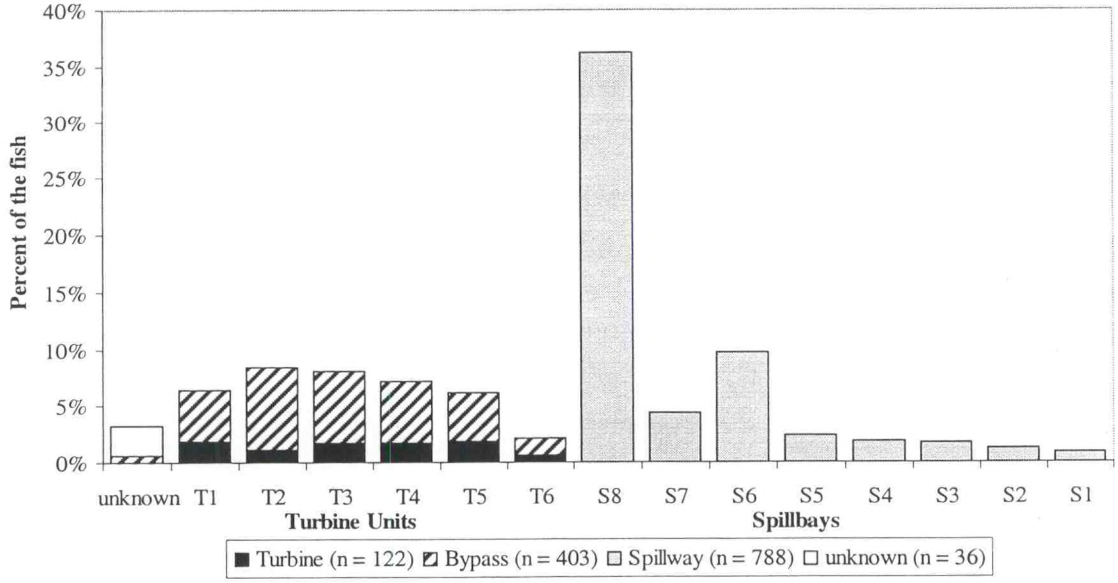

Figure 12. Passage distribution for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam, 2006.

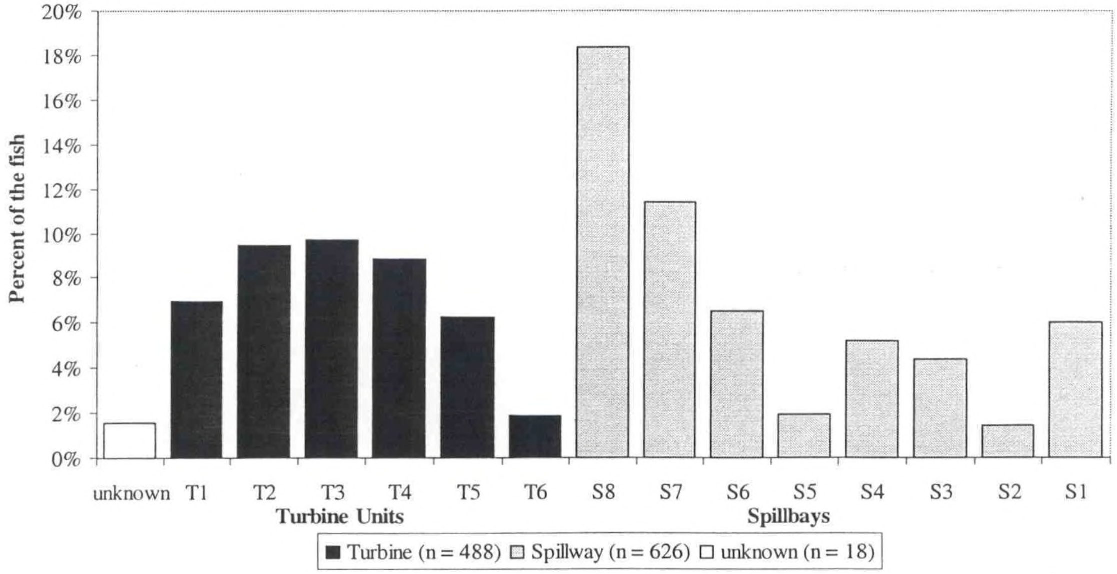

Figure13. Horizontal approach distribution for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam based on first detections at either individual turbine intakes or spillbays, 2006.

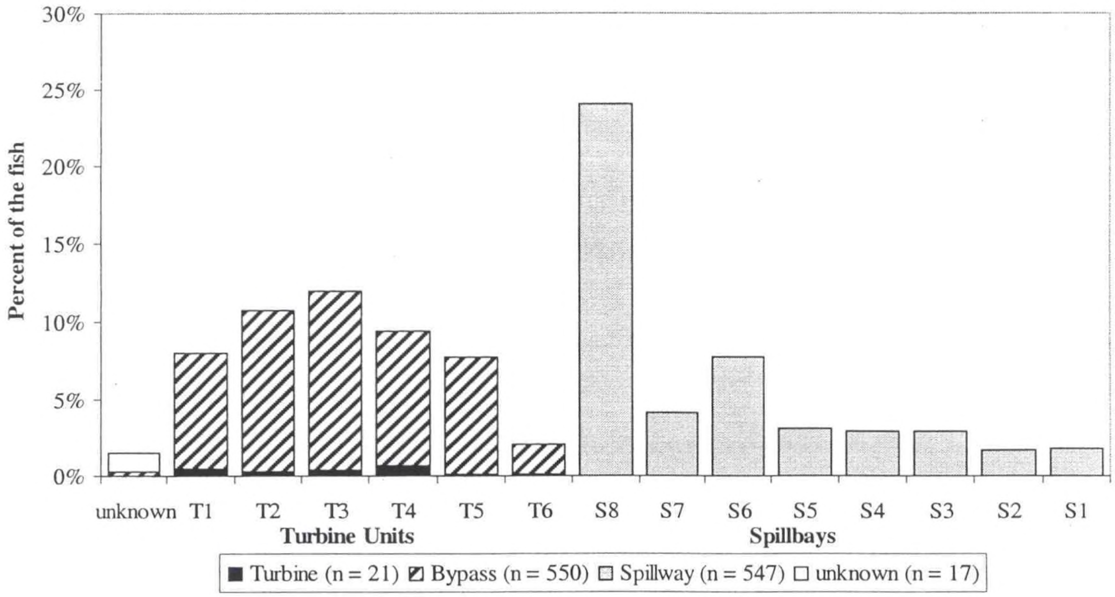

Figure 14. Passage distribution for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam, 2006.

Fish Passage Performance Metrics

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

	Yearling Chinook Salmon		Steelhead	
		95% CI		95% CI
FGE	0.768	0.731-0.804	0.963	0.947-0.979
FPE	0.907	0.891-0.923	0.981	0.973-0.989
Spill Efficiency	0.600	0.573-0.627	0.489	0.459-0.519
Spill effectiveness (mean spill of 26%)	2.31 to 1	2.204-2.412	1.88 to 1	1.767-1.997

Tailrace Egress

Overall median tailrace egress time was 6.0 min (95% CI, 5.7-6.4) for yearling Chinook salmon and ranged from 1 to 8,053 min (Table 10). Median tailrace egress time was longer for yearling Chinook that passed through the powerhouse (JBS; 7.0 min; 95% CI, 6.0-8.0: turbines; 9.7 min, 95% CI, 9.1-10.2) than for those that passed through the spillway (5.1 min; 95% CI, 4.8-5.4; $P<0.001$). This was probably related to the proximity of the powerhouse and a strong clockwise eddy that forms in the tailrace during spill.

Overall median tailrace egress for juvenile steelhead was 6.2 min (95% CI, 5.5-7.0) and ranged from 2 to 6,772 min (Table 11). Median tailrace egress time was significantly longer for juvenile steelhead passing through the JBS (7.1 min; 95% CI, 6.4-7.8) than for those passing through the spillway (5.0 min; 95% CI, 4.6-5.3; $P < 0.001$). The longer egress times for JBS passage was likely related to the proximity of the powerhouse and a strong clockwise eddy. Tailrace egress was not evaluated for steelhead that passed through turbines because there were not enough of these fish for meaningful analysis.

Table 10. Sample size, distribution, minimum, mean, median, mode, and maximum tailrace egress time (elapsed time from last detection in a passage route to last detection in the tailrace) by passage route and overall for radio tagged hatchery yearling Chinook salmon at Lower Monumental Dam, 2006.

	Tailrace egress time (min)			
Passage percentile	JBS	Spillway	Turbine	Overall
n	366	717	108	1,191
10th	5.7	3.6	6.9	3.9
20th	6.0	4.1	7.3	4.6
30th	6.3	4.4	8.0	5.0
40th	6.6	4.8	8.9	5.5
50th	7.0	5.1	9.7	6.0
60th	7.3	5.4	10.2	6.6
70th	7.9	5.9	11.2	7.2
80th	9.2	6.7	12.3	8.4
90th	12.4	9.0	14.3	11.9
95th	111.8	19.8	18.5	21.1
minimum	1.3	1.9	4.9	1.3
mean	110.7	35.6	45.4	59.6
median	7.0	5.1	9.7	6.0
mode	6.7	5.0	6.9	5.0
maximum	8053.5	3342.2	3746.2	8053.5

Table 11. Sample size, percentile distribution, minimum, mean, median, mode, and maximum tailrace egress time (elapsed time in minutes from last detection in a passage route to last detection in the tailrace) by passage route and overall for radio-tagged juvenile steelhead at Lower Monumental Dam, 2006.

	Tailrace egress time (min)			
Passage percentile	JBS	Spillway	Turbine	Overall
n	483	525	15	1,023
10th	5.7	3.7	7.6	3.9
20th	6.1	4.0	8.7	4.5
30th	6.4	4.3	9.4	5.1
40th	6.8	4.6	10.2	5.7
50th	7.1	5.0	10.7	6.2
60th	7.5	5.3	10.8	6.8
70th	8.3	5.8	11.7	7.3
80th	9.5	6.7	12.7	8.7
90th	13.1	9.8	14.8	12.2
95th	20.9	53.2	28.6	35.0
minimum	3.0	3.1	6.8	2.1
mean	63.3	42.1	13.7	51.6
median	7.1	5.0	10.7	6.2
mode	6.3	3.9	N/A	3.9
maximum	6224.3	6772.2	58.7	6772.2

Survival Estimates

Detection Probability

Detection histories used for survival estimates are presented in Appendix Tables A1-A12. Detection probabilities at the primary survival array, 16 km downstream from Lower Monumental Dam, are presented for each species in Appendix Table A13. Daily survival estimates for paired treatment and reference fish groups are presented in Appendix Tables B1-B11.

Project Survival

For yearling Chinook salmon, relative dam survival (~500 m upstream to 1 km downstream from the dam) was estimated at 0.924 (geomean; SE = 0.009; 95% CI, 0.905-0.942; Table 12). Relative concrete survival (upstream face of the dam to approximately 1 km downstream) for yearling Chinook salmon was estimated at 0.943 (geomean; SE = 0.009; 95% CI, 0.925-0.961).

For juvenile steelhead, relative dam survival was estimated at 0.980 (geomean; SE = 0.012; 95% CI, 0.956-1.005; Table 13). Relative concrete survival was estimated at 1.001 for juvenile steelhead (geomean; SE = 0.010; 95% CI, 0.980-1.023).

Route-Specific Survival

For radio-tagged yearling Chinook salmon, relative survival (treatment/reference) was estimated at 0.925 (SE = 0.013; 95% CI, 0.898-0.953) for fish passing via the spillway, 0.987 (SE = 0.006; 95% CI, 0.974-1.000) for those passing via the JBS, and 0.910 (SE = 0.017; 95% CI, 0.857-0.964) for those passing via turbines at Lower Monumental Dam (Table 12). For yearling Chinook salmon passing through spillbay 8, relative survival was estimated at 0.940 (SE = 0.011; 95% CI, 0.918-0.962).

For radio-tagged juvenile steelhead passing Lower Monumental Dam, relative survival was estimated at 0.999 (SE = 0.013; 95% CI, 0.971-1.027) for fish passing via the spillway, 1.010 (SE = 0.009; 95% CI, 0.990-1.031) for fish passing via the JBS, and 0.838 (pooled; SE = 0.017; 95% CI, 0.661-1.015) for those passing via turbines at Lower Monumental Dam (Table 13). For juvenile steelhead passing through spillbay 8 at Lower Monumental Dam, survival was estimated at 1.000 (SE = 0.014; 95% CI, 0.970-1.030).

Table 12. Sample sizes and mean estimates of survival for radio-tagged, hatchery yearling Chinook salmon passing (treatment) Lower Monumental Dam relative to fish released into the tailrace (reference), 2006. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
	n	Survival	n	Survival	
Project survival					
Dam survival	1,353	0.924 (0.009)	1,136	1.000 (0.000)	0.924 (0.009)
Concrete survival	1,295	0.943 (0.009)	1,136	1.000 (0.000)	0.943 (0.009)
Route specific survival					
Spillway survival	788	0.925 (0.013)	1,136	1.000 (0.000)	0.925 (0.013)
JBS survival	385	0.987 (0.006)	1,136	1.000 (0.000)	0.987 (0.006)
Turbine survival	122	0.910 (0.017)	1,136	1.000 (0.000)	0.910 (0.017)
Spillbay 8	488	0.940 (0.011)	1,136	1.000 (0.000)	0.940 (0.011)

Table 13. Sample sizes and mean estimates of survival for radio-tagged, hatchery juvenile steelhead passing (treatment) Lower Monumental Dam relative to fish released into the tailrace (reference), 2006. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
	n	Survival	n	Survival	
Project survival					
Dam survival	1,087	0.955 (0.007)	967	0.975 (0.008)	0.980 (0.012)
Concrete survival	1,053	0.976 (0.006)	967	0.975 (0.008)	1.001 (0.010)
Route specific survival					
Spillway survival	532	0.971 (0.009)	967	0.975 (0.008)	0.999 (0.013)
JBS survival	503	0.984 (0.006)	967	0.975 (0.008)	1.010 (0.009)
Turbine survival	18	0.838 (0.089)	967	0.975 (0.008)	1.010 (0.009)
Spillbay 8	269	0.972 (0.010)	967	0.975 (0.008)	1.000 (0.014)

Avian Predation

A total of 82 tags from yearling Chinook salmon released at Lower Monumental Dam during 2006 were recovered from avian colonies on Crescent or Foundation Island in the McNary Dam Reservoir, Columbia River (Table 14). The majority of these fish (70-76%) were last detected between Ice Harbor Dam and the mouth of the Snake River. No tags from yearling Chinook salmon were last detected above our primary survival line (16 km downstream from Lower Monumental Dam) prior to being recovered from Crescent Island.

A total of 195 tags from juvenile steelhead released at Lower Monumental Dam during 2006 were recovered from avian colonies on Crescent or Foundation Island (Table 15). The majority of these fish (50-52%) were last detected between Ice Harbor Dam and the mouth of the Snake River. Only one tag from a juvenile steelhead was last detected above our primary survival line (16 km downstream from Lower Monumental Dam) prior to being recovered from Crescent Island.

Table 14. Number and percent of radio tags from yearling Chinook salmon recovered from avian colonies on Crescent or Foundation Island. Yearling Chinook were released to evaluate passage behavior and survival at Lower Monumental Dam, 2006. Recoveries are grouped by location of the last telemetry detection.

	Yearling Chinook salmon tags recovered on avian colonies			
	Treatment		Reference	
Last location of telemetry detection	n	(%)	n	(%)
Lower Monumental Dam forebay	0	0.0	N/A	N/A
Ice Harbor Dam pool	1	0.1	1	0.1
Ice Harbor forebay	0	0.0	1	0.1
Ice Harbor Dam to Snake River mouth	32	2.3	28	2.4
McNary Dam pool	3	0.2	5	0.4
McNary Dam forebay	6	0.4	5	0.4
Total	42	3.0	40	3.4

Table 15. Number and percentage of radio tags from juvenile steelhead recovered from avian colonies on Crescent or Foundation Island. Steelhead were released to evaluate passage behavior and survival at Lower Monumental Dam, 2006. Recoveries are grouped by location of the last telemetry detection.

	Juvenile steelhead tags recovered on avian colonies			
	Treatment		Reference	
Last location of telemetry detection	n	(%)	n	(%)
Lower Monumental Dam forebay	1	0.1	N/A	N/A
Ice Harbor Dam pool	14	1.2	6	0.6
Ice Harbor forebay	3	0.3	3	0.3
Ice Harbor Dam to Snake River mouth	55	4.7	44	4.4
McNary Dam pool	15	1.3	12	1.2
McNary Dam forebay	22	1.9	20	2.0
Total	110	9.4	85	8.5

DISCUSSION

This radiotelemetry study provides the first year of volitional passage behavior and survival evaluations for steelhead, and the second year of these evaluations for yearling Chinook salmon. For both species, the largest proportions of radio-tagged fish approached and passed Lower Monumental Dam in the thalweg of the river, near spillbay 8. These horizontal distribution patterns were similar to those observed by Johnson et al. (1998) using hydroacoustics, where smolts approached Lower Monumental at the midpoint of the thalweg.

Median forebay delay was more than twice as long for juvenile steelhead (5.5 h) as for yearling Chinook salmon (2.5 h) overall. However, for fish that passed via the spillway, median forebay delay was similar between juvenile steelhead and yearling Chinook salmon (2.1 vs. 1.9 h).

We observed spill effectiveness of 2.3:1 for yearling Chinook salmon and 1.9:1 for juvenile steelhead. These were similar to the 1.9:1 reported by Johnson et al. (1998), and higher than the 1:1 ratio of spilled fish to spilled water expected by the regional spill program. Our observations of spill efficiency of 60% for yearling Chinook salmon and 49% for juvenile steelhead were lower than the 69% observation by Johnson et al. (1998) at Lower Monumental Dam. The lower spill efficiency we observed was likely due to a 13% lower average spill proportion of the river in 2006 than in 1997 (26% in 2006 and 39% in 1997 (Johnson et al. 1998)).

Snake River flows in spring 2006 at Lower Monumental Dam averaged 139 kcfs, or 130% of the previous 10-year average of 107 kcfs. These higher flows may have influenced the predator/prey dynamics for our radio-tagged fish resulting in higher survival due to above-average water turbidity (Gregory and Levings 1998).

The high flow and spill conditions that prevailed during the 2006 spring migration led to higher-than-normal survival for PIT-tagged fish migrating through the lower Snake River (Faulkner et al. 2007). Under moderate to low flow and spill levels, our survival estimates would likely have been lower. For yearling Chinook salmon passing during periods of spill, we observed similar median forebay residence times between a high flow year (2006) and a low flow year (2004) (Hockersmith et al. 2005) (2.5 vs. 2.2 h, respectively). In 2004, Hockersmith et al. (2005) reported longer forebay residence times and lower survival during periods of no spill than during periods of spill. The relationships between survival and increased exposure time to predators for juvenile salmonids have been described previously by Vigg and Burley (1991).

Potential positive effects of spill likely go beyond those directly measured as dam survival. Smith et al. (2002) found a strong inverse relationship between travel time and spill exposure in the Snake River for yearling Chinook salmon. Positive effects of spill on a season-wide basis have also been demonstrated (Zabel et al. 2002). Analysis based on early data (1973-1979) suggested that increases in spill had a direct impact on increasing survival (Sims and Ossiander 1981). Zabel et al. (2002) reported lower survival through the hydropower system in 1993 and 1994, when spill occurred only in excess of powerhouse capacity, than after spill was prescribed at all dams in the 1995 Biological Opinion (NMFS 1995).

In general, among the various passage routes (spillway, bypass, or turbine) at lower Snake River dams, spillway passage is considered to provide the highest survival for juvenile salmonids (Muir et al. 2001). Higher survival for spillway passage is attributed to reductions in passage time and exposure to predators in the forebay and tailrace (Beamesderfer et al. 990; Vigg and Burley 1991). However, spillway survival tends to be more variable than either bypass or turbine survival.

A reanalysis of juvenile salmonid survival studies by Bickford and Skalski (2000) found high variability among spillway survival estimates. This is not surprising, since hydraulic conditions in the stilling basin and immediate tailrace can be highly variable across a range of project operations and total river flows. Relationships between juvenile salmonid spillway survival and project operations (project and powerhouse discharge, spill volume, spill pattern, spillbay gate opening, and tailwater elevation) in the lower Snake and Columbia River Basins are not well understood. In addition, the indirect effects of spill operations on predation of smolts passing hydroelectric dams (i.e., increased vulnerability of smolts due to delay, structures, back-eddies, or disorientation) remain critical uncertainties.

Previous evaluations of spillway survival at Lower Monumental Dam have also shown considerable variation across species, runs, and years; this variation may have been species- or run-specific, or it may be related to differences in project operations. Long and Ossiander (1974) reported spillway passage survival of 97 to 110% for coho salmon *O. kistuch* released into spillbays with flow deflectors. Estimated survival of steelhead was 98% for releases into a spillbay with a flow deflector and 76% for releases into a spillbay without a flow deflector (Long et al. 1972). For subyearling Chinook salmon released into a spillbay with a flow deflector, survival estimates were 83 to 84% (Long et al 1972). For yearling Chinook salmon, Muir et al. (1995) estimated survival at 93% for releases into a spillbay with a flow deflector (spillbay 7) and 98% for releases into a spillbay without a flow deflector (spillbay 8) at Lower Monumental Dam. In 2005, Hockersmith et al. (2006) estimated survival for yearling Chinook salmon released directly into spillbays 7 and 8 at 93% and 95%, respectively.

Hockersmith et al. (2004) estimated survival for fish released directly into spillbays 4 and 7 to be 90%. During this study, the total river flow could be partitioned into two distinctly different conditions (average 76 and 150 kcfs). Hockersmith et al. (2004) observed significantly higher spillway survival (0.987 vs. 0.834) for fish released during periods of higher total river flow, powerhouse discharge, and tailwater elevation. However, because these variables were highly correlated among themselves, their relative importance with regard to spillway survival could not be determined. They reported that spillway survival at Lower Monumental Dam appears to be related to tailrace conditions, such as depth of submergence of the flow deflectors, or the hydraulic conditions near the deflector, since survival was significantly higher during periods of higher total river flow and tailwater elevation.

In 2006, our estimate of relative survival for yearling Chinook salmon passing through the spillway (93%) was within the range of previously reported estimates (90 to 98%). Similarly, our estimate of relative survival for yearling Chinook salmon passing through spillbay 8 in 2006 (94%) was close to the range of previously reported estimates for spillbay 8 (95 to 98%).

In 2006, our estimate of bypass survival for yearling Chinook salmon was higher than previously reported for volitionally passage at Lower Monumental Dam (99% vs. 92%) (Hockersmith et al. 2005). Tailrace egress for individual passage routes, as well as overall, was much shorter in 2006 than in 2004 (overall 6 minutes vs. 10 minutes) (Hockersmith et al. 2005). Higher flows in 2006 relative to 2004 probably resulted in better tailrace egress conditions.

To increase the proportion of fish passing through the spillway, engineers and biologists within the USACE have developed a RSW to provide surface-oriented spillway passage. RSWs were installed at Lower Granite Dam in 2001 and Ice Harbor Dam in 2005. At both projects, the RSWs reduced migrational delays, improved FPE, and provided increased passage survival while spilling either similar or less water (Plumb et al. 2003, 2004; Axel et al. 2007; Ogden et al. 2007). An RSW is being developed for installation at Lower Monumental Dam in 2007. The goal of this study was to collect baseline data on passage behavior and survival for comparison to passage behavior and survival after installation of an RSW at Lower Monumental Dam.

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APPENDIX A

Evaluation of Study Assumptions

We used the CJS single-release model (Cormack 1964, Jolly 1965, Seber 1965) to estimate survival of radio-tagged juvenile Chinook salmon 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 1,353 radio-tagged yearling Chinook salmon released above Lower Monumental Dam and detected on the forebay entrance array, 1,253 (92.6% of those released) were detected either at or below our primary survival line 16 km downstream from Lower Monumental Dam. Of the 1,136 radio-tagged yearling Chinook salmon released into the tailrace of Lower Monumental Dam, 1,136 (100% of those released) were detected either at or below our primary survival line 16 km downstream from Lower Monumental Dam. Capture histories for survival analysis of yearling Chinook salmon are presented in Appendix Tables A1-A6.

Of the 1,087 radio-tagged steelhead released above Lower Monumental Dam and detected on the forebay entrance array, 1,038 (95.9% of those released) were detected either at or below our primary survival line 16 km downstream from Lower Monumental Dam. Of the 967 radio-tagged steelhead released into the tailrace of Lower Monumental Dam, 938 (97.4% of those released) were detected either at or below our primary survival line 16 km downstream from Lower Monumental Dam. Capture histories for survival analysis of juvenile steelhead are presented in Appendix Tables A7-A13.

The detection probability for fish used in survival analysis was greater than 0.963 overall (Appendix Table A14). Thus, radiotelemetry detection probability at our primary array was very near 100%, with few fish detected downstream that were not detected at the primary array. With detection probabilities at or near 100% for all fish, there was likely no disparity between detection probabilities of treatment and reference groups.

Appendix Table A1. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate dam passage survival in 2006. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (1,353)	0	0	100
	1	0	33
	0	1	2
	1	1	1,218
Reference group (1,136)	0	0	0
	1	0	17
	0	1	3
	1	1	1,116

Appendix Table A2. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate concrete passage survival in 2006. The primary survival array was 16 km downstream from the dam, and detectins downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (1,295)	0	0	72
	1	0	32
	0	1	1
	1	1	1,190
Reference group (1,136)	0	0	0
	1	0	17
	0	1	3
	1	1	1,116

Appendix Table A3. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillway passage survival in 2006. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (788)	0	0	56
	1	0	16
	0	1	1
	1	1	715
Reference group (1,136)	0	0	0
	1	0	17
	0	1	3
	1	1	1,116

Appendix Table A4. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival in 2006. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (385)	0	0	5
	1	0	12
	0	1	0
	1	1	368
Reference group (1,136)	0	0	0
	1	0	17
	0	1	3
	1	1	1,116

Appendix Table A5. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate turbine passage survival in 2006. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (122)	0	0	11
	1	0	4
	0	1	0
	1	1	107
Reference group (1,136)	0	0	0
	1	0	17
	0	1	3
	1	1	1,116

Appendix Table A6. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillbay 8 passage survival in 2006. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (488)	0	0	29
	1	0	8
	0	1	0
	1	1	451
Reference group (1,136)	0	0	0
	1	0	17
	0	1	3
	1	1	1,116

Appendix Table A7. Detection histories of radio-tagged juvenile steelhead 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 the dam and detections downstream from the primary array are shown in Figure 1. Detection histories recorded as: 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (1,087)	0	0	49
	1	0	11
	0	1	37
	1	1	990
Reference group (967)	0	0	25
	1	0	28
	0	1	0
	1	1	914

Appendix Table A8. Detection histories of radio-tagged juvenile steelhead 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 the dam and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (1,053)	0	0	25
	1	0	35
	0	1	10
	1	1	983
Reference group (967)	0	0	25
	1	0	28
	0	1	0
	1	1	914

Appendix Table A9. Detection histories of radio-tagged juvenile steelhead 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 the dam and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (532)	0	0	14
	1	0	17
	0	1	2
	1	1	499
Reference group (967)	0	0	25
	1	0	28
	0	1	0
	1	1	914

Appendix Table A10. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate JBS passage survival in 2006. The primary survival array was 16 km downstream from the dam and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (503)	0	0	8
	1	0	17
	0	1	7
	1	1	471
Reference group (967)	0	0	25
	1	0	28
	0	1	0
	1	1	914

Appendix Table A11. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate turbine passage survival in 2006. The primary survival array was 16 km downstream from the dam, and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (18)	0	0	3
	1	0	1
	0	1	1
	1	1	13
Reference group (967)	0	0	25
	1	0	28
	0	1	0
	1	1	914

Appendix Table A12. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate spillbay 8 passage survival in 2006. The primary survival array was 16 km downstream from the dam and detections downstream from the primary array are shown in Figure 1. Detection histories are 1 = detected; 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (269)	0	0	6
	1	0	8
	0	1	1
	1	1	254
Reference group (967)	0	0	25
	1	0	28
	0	1	0
	1	1	914

Appendix Table A13. Detections at the primary survival array and below, and the resulting detection probabilities at the primary survival array 16 km downstream from the dam. These probabilities satisfied assumptions of the CJS model used in evaluating survival of yearling Chinook salmon and juvenile steelhead passing Lower Monumental Dam, 2006.

Release group	Detection at primary array and below	Detection below primary array	Detection probability
Yearling Chinook salmon			
Treatment	1,218	1,220	0.998
Reference	1,116	1,119	0.997
Totals	2,334	2,339	0.998
Juvenile steelhead			
Treatment	990	1,027	0.964
Reference	914	914	1.000
Totals	1,904	1,941	0.981

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

The difference in passage distribution of treatment and reference groups at the primary survival line (16 km downstream from the dam) were examined to determine if groups were evenly mixed and travel together through downstream reaches (Appendix Tables A14 and A15). Mixing was compared for specific percentiles (10th, 50th, 90th) of the passage distribution with t tests for differences in passage distributions (Tables A16 and A17). For mixing analysis the date of passage of treatment fish at Lower Monumental Dam was paired with the release date of reference fish.

Tests of homogeneity in passage distributions at the primary survival line were similar between treatment and reference groups used to calculate relative survival estimates (Appendix Tables A16 and A17). The overall survival estimates were not biased regarding mixing through the common reach.

Appendix Table A14. Differences in passage timing at the primary survival line (16 km downstream from the dam) between treatment and reference groups in hours for radio tagged hatchery yearling Chinook salmon used for estimating survival at Lower Monumental Dam in 2006. Standard errors are in parenthesis.

		Percentile								
Date	n	10th	20th	30th	40th	50th	60th	70th	80th	90th
3 May	77	-10.0	-7.4	-6.0	0.4	4.1	5.7	4.6	2.0	1.7
4 May	88	3.3	4.9	6.2	2.3	2.0	4.3	4.8	3.9	1.9
5 May	76	1.6	3.0	3.8	-4.5	-3.2	-3.5	1.9	2.8	-0.5
6 May	93	1.5	3.5	5.1	-0.9	4.1	4.2	5.3	4.9	1.0
7 May	93	2.3	3.1	3.6	-2.4	-0.5	5.6	5.6	6.1	1.7
8 May	110	2.3	3.4	6.1	1.3	3.2	3.4	3.5	5.1	-0.9
9 May	106	1.2	1.7	3.1	-0.8	1.3	4.5	3.6	0.1	0.0
10 May	90	2.6	5.3	5.6	0.7	3.8	4.5	4.5	5.8	1.2
11 May	78	3.9	3.3	4.6	-1.7	1.3	3.1	2.4	2.5	3.8
12 May	94	3.6	5.1	8.8	4.5	5.5	4.1	4.7	5.9	1.9
13 May	94	1.9	4.4	5.4	6.4	1.6	6.2	7.8	8.5	7.9
14 May	94	-8.5	-6.3	-5.7	-5.0	-4.4	-2.8	-4.9	-4.1	0.1
15 May	97	3.0	3.6	3.2	-4.5	-4.1	2.4	3.6	2.1	-1.2
16 May	105	1.8	2.0	2.8	-3.0	1.1	2.8	3.1	-1.7	-1.1
17 May	111	1.2	3.2	-4.4	-0.6	0.6	2.0	2.6	-0.5	-0.8
18 May	89	1.3	3.1	5.1	-3.2	-1.1	4.3	6.2	9.2	9.3
19 May	106	1.6	3.2	3.4	4.1	3.1	2.8	4.3	5.4	7.8
20 May	101	3.7	4.8	6.3	10.5	3.4	3.2	3.6	5.9	-0.3
21 May	98	0.4	0.1	-0.5	-8.2	2.1	1.7	0.1	-0.5	-5.8
22 May	93	-0.9	-1.0	-1.2	-8.0	-6.1	2.0	1.8	5.0	-0.5
23 May	92	0.7	0.9	0.6	-6.8	-4.4	0.6	3.5	1.5	-0.3
24 May	95	0.3	0.1	1.3	-2.8	2.2	2.1	1.9	2.9	-1.8
25 May	82	0.3	-0.2	-0.9	-8.0	-6.8	0.8	1.3	0.6	-6.4
26 May	88	-0.3	-0.3	-0.7	-7.8	-8.3	-6.4	2.5	6.9	4.9
27 May	98	-0.9	-1.1	-7.1	-8.3	-8.1	-6.0	-6.9	-5.7	2.0
Mean		0.7 (0.7)	1.7 (0.6)	1.9 (0.9)	-1.9 (1.0)	-0.3 (0.8)	2.1 (0.7)	2.9 (0.6)	3.0 (0.7)	1.0 (0.7)

Appendix Table A15. Differences in passage timing at the primary survival line (16 km downstream from the dam) between treatment and reference groups in hours for radio tagged juvenile steelhead used for estimating survival at Lower Monumental Dam in 2006. Standard errors are in parenthesis.

		Percentile								
Date	n	10th	20th	30th	40th	50th	60th	70th	80th	90th
3 May	53	-10.5	-9.8	-7.6	-7.4	-3.3	-2.2	-3.1	-2.6	-16.8
4 May	64	1.2	1.6	-5.6	-3.5	-2.6	4.7	4.4	-0.7	0.5
5 May	80	3.1	3.4	3.9	-5.4	-6.3	0.8	0.3	-1.4	-1.1
6 May	80	0.5	1.7	1.9	2.3	6.1	6.1	2.3	1.2	8.5
7 May	88	1.5	0.9	-5.6	0.9	2.8	5.3	5.4	-0.9	-0.4
8 May	83	2.1	2.6	0.3	-3.0	-2.0	1.5	2.9	4.2	-0.9
9 May	89	1.4	1.6	-2.1	-5.0	2.4	0.0	0.2	0.4	0.1
10 May	81	1.6	3.6	4.1	-2.3	-0.2	0.3	3.2	2.0	-2.5
11 May	72	1.2	3.6	5.9	1.4	3.2	5.3	1.4	-0.4	0.3
12 May	74	1.9	2.4	2.7	1.9	4.0	3.8	5.8	0.8	0.2
13 May	67	0.2	1.4	2.5	-0.4	2.5	6.9	6.6	5.3	9.5
14 May	89	-9.1	-9.2	-9.7	-8.4	-6.6	-6.5	-4.6	-0.7	-0.8
15 May	82	0.2	0.1	1.0	-3.5	-3.0	-2.7	-0.5	1.8	-0.1
16 May	84	1.6	2.8	2.0	0.7	3.6	3.9	3.4	0.1	0.3
17 May	92	1.5	3.6	5.0	2.0	1.7	3.8	0.2	-0.6	-1.7
18 May	63	1.1	3.0	3.7	-4.4	-1.6	2.4	3.0	5.2	3.1
19 May	94	0.1	1.1	2.1	4.2	10.6	6.2	7.2	6.8	6.3
20 May	86	-0.5	2.0	6.5	7.5	3.9	3.9	5.4	-0.5	-0.9
21 May	95	-0.1	-0.5	-1.2	-8.6	-4.4	1.2	3.2	3.0	-1.6
22 May	79	0.2	0.4	0.4	-7.8	-5.6	0.5	-1.0	-4.5	-2.6
23 May	84	0.3	0.6	-1.2	-5.9	-1.8	-0.4	-4.3	-3.1	-1.6
24 May	72	-0.6	0.0	-9.0	-8.7	-8.2	-1.0	0.6	-1.4	-2.5
25 May	83	1.5	1.4	3.7	-2.7	-0.2	0.8	2.9	3.3	-0.5
26 May	77	2.9	3.5	5.7	-0.3	2.3	3.1	3.9	-1.9	-0.9
27 May	87	-0.6	0.7	-5.8	-6.6	-8.4	-4.1	-6.8	-6.1	-1.3
Mean		0.1 (0.6)	0.9 (0.7)	0.1 (1.0)	-2.5 (0.9)	-0.4 (0.9)	1.7 (0.7)	1.7 (0.7)	0.4 (0.6)	-0.3 (0.9)

Appendix Table A16. Mean difference and tests of homogeneity of passage timing at the primary survival line (16 km downstream from the dam) for treatment groups and reference groups of radio tagged hatchery yearling Chinook salmon used for estimating survival at Lower Monumental Dam in 2006. Significant differences in passage timing among tests was determined for α = 0.05.

Passage percentile	Mean difference in timing (hours)	*t*	df	*P*
10th	0.7	1.10	25	0.238
50th	-0.3	-0.37	25	0.718
90th	1.0	1.39	25	0.178

Appendix Table A17. Mean difference and tests of homogeneity of passage timing at the primary survival line (16 km downstream from the dam) for treatment groups and reference groups of radio tagged steelhead used for estimating survival at Lower Monumental Dam in 2006. Significant differences in passage timing among tests was determined for α = 0.05.

Passage percentile	Mean difference in timing (hours)	*t*	df	*P*
10th	0.1	0.16	25	0.871
50th	-0.4	-0.47	25	0.674
90th	-0.3	-0.32	25	0.749

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

River run, hatchery yearling Chinook salmon and juvenile steelhead were collected at the Lower Monumental Dam smolt collection facility from 1 to 26 May. Only fish not previously PIT tagged, without any visual signs of disease or injuries, and 15 g or larger were used. Tagging comprised the period between the 10th and 98th passage percentile for yearling Chinook salmon and between the 16th and 96th passage percentile for juvenile steelhead at Lower Monumental Dam in 2006 (Figure 3). Overall mean fork lengths for yearling Chinook salmon were 148.6 mm (SD = 17.7) and 147.7 mm (SD = 13.6) for fish released into the forebay and tailrace of Lower Monumental Dam, respectively (Table 2). Overall mean fork lengths for juvenile steelhead were 220.6 mm (SD = 21.5) and 220.1 mm (SD = 22.4) for fish released into the forebay and tailrace of Lower Monumental Dam, respectively (Table 4).

A4. The tag and/or tagging method do not significantly affect the subsequent behavior or survival of the marked individual.

Assumption A4 was not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have previously been evaluated by Adams et al. (1998) and Hockersmith et al. (2003). 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.

In 2006, we conducted a very limited test of the assumption that fish that die as a result of passing through a passage route are not subsequently detected at a downstream array that is used to estimate survival for that passage route because past studies at Lower Monumental Dam have not observed a violation of this assumption. We released 8, 2, 6, and 6 dead radio tagged hatchery yearling Chinook salmon and juvenile steelhead into the forebay and the tailrace of Lower Monumental Dam to test Assumption A5 (Appendix Table A18). Forebay releases were 7 km upstream from the forebay entrance array. The distance between release at Lower Monumental Dam and the first downstream telemetry array used to estimate survival was 16 km. Similar to past findings, no dead radio tagged fish were detected at any downstream telemetry arrays.

Appendix Table A18. Numbers of dead fish released and subsequent detections downstream from release locations. These releases were used to test the study assumption that fish that die as a result of passing through a passage route at Lower Monumental Dam are not subsequently detected on downstream survival arrays.

	Dead fish releases					
	Yearling Chinook salmon			Juvenile steelhead		
	Forebay	Tailrace	Overall	Forebay	Tailrace	Overall
Number released	8	2	10	6	6	12
Proportion of total released (%)	0.6	0.2	0.4	0.5	0.6	0.6
Number detected below release site	0	0	0	0	0	0

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

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish and prior to release, to ensure that the transmitter was functioning properly. Of 4,889 tags allocated for the evaluation of Lower Monumental Dam spillway survival 31 (0.6%) could not be activated and were therefore not used. A total of 4,750 tags were implanted in either hatchery yearling Chinook salmon of juvenile steelhead of which 6 (0.1%) were not working 24 h after tagging. Of the live fish released with functional tags, a total of 10 fish (0.4% of those released) (3 yearling Chinook salmon and 7 juvenile steelhead) released upstream from Lower Monumental Dam were subsequently detected at downstream PIT tag detection facilities and not detected on any radiotelemetry arrays. The transmitters in these fish likely malfunctioned. All fish with tags that were known to be not functioning properly were excluded from the study.

In addition, a total of 108 radio transmitters throughout the study were tested for tag life by allowing them to run in river water and checking them daily to determine if they functioned for the predetermined period of time. Seven tags (6.5%) failed prior to the preprogrammed shut down after 10 d (Appendix Table A19). Of these, no tags failed in less than 7 d. The maximum travel time from release to our primary survival array was 7.3 d for forebay releases and 4.8 d for tailrace released fish (Appendix Table A20). Although we documented transmitter failures during our study, the short travel times to our survival line and the relatively low failure rate were such that they would not have significantly changed our findings.

Appendix Table A19. Transmitter battery life testing (in days).

Tags (n)	Tags (%)	Tag life (d)
0	0.0	1
0	0.0	2
0	0.0	3
0	0.0	4
0	0.0	5
0	0.0	6
1	0.9	7
1	0.9	8
5	4.6	9
101	93.5	10

Appendix Table A20. Travel time from release to detection at the primary survival array for radio tagged, hatchery yearling Chinook salmon and juvenile steelhead released into the forebay and the tailrace of Lower Monumental Dam, 2006.

	Travel time (d) to primary survival array by release location and species			
	Yearling Chinook salmon		Juvenile steelhead	
Percentile	Forebay	Tailrace	Forebay	Tailrace
10	0.3	0.0	0.4	0.1
20	0.3	0.0	0.5	0.1
30	0.4	0.1	0.6	0.1
40	0.5	0.1	0.7	0.1
50	0.6	0.1	0.8	0.1
60	0.7	0.1	1.1	0.1
70	0.9	0.1	1.3	0.1
80	1.1	0.1	1.6	0.1
90	1.5	0.1	2.2	0.3
Max	7.3	0.6	8.0	4.8
Time > 7 d	1 (0.1%)	0 (0.0%)	4 (0.4%)	0 (0.0%)
n	1,273	1,131	1,091	941

APPENDIX B

Treatment and Reference Groups Formed for Survival Estimates

Appendix Table B1. Daily dam survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2 May	22	0.955 (0.044)			0.955 (0.044)
3 May	60	0.900 (0.039)	31	1.000 (0.000)	0.900 (0.039)
4 May	51	0.863 (0.048)	46	1.000 (0.000)	0.863 (0.048)
5 May	45	0.956 (0.031)	44	1.000 (0.000)	0.956 (0.031)
6 May	57	0.965 (0.024)	45	1.000 (0.000)	0.965 (0.024)
7 May	52	0.962 (0.027)	44	1.000 (0.000)	0.962 (0.027)
8 May	53	0.962 (0.026)	49	1.000 (0.000)	0.962 (0.026)
9 May	54	0.926 (0.036)	48	1.000 (0.000)	0.926 (0.036)
10 May	44	0.977 (0.023)	46	1.000 (0.000)	0.977 (0.023)
11 May	49	0.816 (0.055)	48	1.000 (0.000)	0.816 (0.055)
12 May	45	0.911 (0.042)	46	1.000 (0.000)	0.911 (0.042)
13 May	60	0.900 (0.039)	41	1.000 (0.000)	0.900 (0.039)
14 May	76	0.947 (0.026)	30	1.000 (0.000)	0.947 (0.026)
15 May	56	0.911 (0.038)	47	1.000 (0.000)	0.911 (0.038)
16 May	58	0.966 (0.024)	49	1.000 (0.000)	0.966 (0.024)
17 May	57	0.947 (0.030)	46	1.000 (0.000)	0.947 (0.030)
18 May	53	0.943 (0.032)	37	1.000 (0.000)	0.943 (0.032)
19 May	55	0.910 (0.039)	49	1.000 (0.000)	0.910 (0.039)
20 May	57	0.983 (0.017)	52	1.000 (0.000)	0.983 (0.017)
21 May	53	0.962 (0.026)	46	1.000 (0.000)	0.962 (0.026)
22 May	50	0.920 (0.038)	45	1.000 (0.000)	0.920 (0.038)
23 May	54	0.815 (0.053)	49	1.000 (0.000)	0.815 (0.053)
24 May	59	0.864 (0.045)	43	1.000 (0.000)	0.864 (0.045)
25 May	48	0.875 (0.048)	47	1.000 (0.000)	0.875 (0.048)
26 May	44	0.955 (0.031)	47	1.000 (0.000)	0.955 (0.031)
27 May	41	0.927 (0.041)	61	1.000 (0.000)	0.927 (0.041)
Overall	1,353	0.924 (0.009)	1,136	1.000 (0.000)	0.924 (0.009)

Appendix Table B2. Daily concrete survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2 May	12	0.917 (0.080)			0.917 (0.080)
3 May	52	0.902 (0.042)	31	1.000 (0.000)	0.902 (0.042)
4 May	45	0.911 (0.042)	46	1.000 (0.000)	0.911 (0.042)
5 May	34	0.971 (0.029)	44	1.000 (0.000)	0.971 (0.029)
6 May	51	0.959 (0.028)	45	1.000 (0.000)	0.959 (0.028)
7 May	48	0.979 (0.021)	44	1.000 (0.000)	0.979 (0.021)
8 May	62	0.984 (0.016)	49	1.000 (0.000)	0.984 (0.016)
9 May	60	0.950 (0.028)	48	1.000 (0.000)	0.950 (0.028)
10 May	46	0.957 (0.030)	46	1.000 (0.000)	0.957 (0.030)
11 May	35	0.857 (0.059)	48	1.000 (0.000)	0.857 (0.059)
12 May	42	1.000 (0.000)	46	1.000 (0.000)	1.000 (0.000)
13 May	60	0.883 (0.041)	41	1.000 (0.000)	0.883 (0.041)
14 May	66	0.955 (0.026)	30	1.000 (0.000)	0.955 (0.026)
15 May	53	0.925 (0.036)	47	1.000 (0.000)	0.925 (0.036)
16 May	55	1.000 (0.000)	49	1.000 (0.000)	1.000 (0.000)
17 May	67	0.970 (0.021)	46	1.000 (0.000)	0.970 (0.021)
18 May	58	0.912 (0.038)	37	1.000 (0.000)	0.912 (0.038)
19 May	59	0.950 (0.029)	49	1.000 (0.000)	0.950 (0.029)
20 May	51	0.980 (0.019)	52	1.000 (0.000)	0.980 (0.019)
21 May	53	0.981 (0.019)	46	1.000 (0.000)	0.981 (0.019)
22 May	50	0.960 (0.028)	45	1.000 (0.000)	0.960 (0.028)
23 May	52	0.827 (0.053)	49	1.000 (0.000)	0.827 (0.053)
24 May	56	0.929 (0.034)	43	1.000 (0.000)	0.929 (0.034)
25 May	38	0.921 (0.044)	47	1.000 (0.000)	0.921 (0.044)
26 May	40	1.000 (0.000)	47	1.000 (0.000)	1.000 (0.000)
27-29 May	50	0.940 (0.034)	61	1.000 (0.000)	0.940 (0.034)
Overall	1,295	0.943 (0.009)	1,136	1.000 (0.000)	0.943 (0.009)

Appendix Table B3. Daily spillway survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2-3 May	21	0.857 (0.076)	31	1.000 (0.000)	0.857 (0.076)
4 May	22	0.818 (0.082)	46	1.000 (0.000)	0.818 (0.082)
5 May	24	0.958 (0.041)	44	1.000 (0.000)	0.958 (0.041)
6 May	27	0.926 (0.050)	45	1.000 (0.000)	0.926 (0.050)
7 May	18	0.944 (0.054)	44	1.000 (0.000)	0.944 (0.054)
8 May	29	1.000 (0.000)	49	1.000 (0.000)	1.000 (0.000)
9 May	30	0.967 (0.033)	48	1.000 (0.000)	0.967 (0.033)
10 May	36	0.944 (0.038)	46	1.000 (0.000)	0.944 (0.038)
11 May	26	0.846 (0.071)	48	1.000 (0.000)	0.846 (0.071)
12 May	28	1.000 (0.000)	46	1.000 (0.000)	1.000 (0.000)
13 May	50	0.880 (0.046)	41	1.000 (0.000)	0.880 (0.046)
14 May	51	0.941 (0.033)	30	1.000 (0.000)	0.941 (0.033)
15 May	44	0.909 (0.043)	47	1.000 (0.000)	0.909 (0.043)
16 May	35	1.000 (0.000)	49	1.000 (0.000)	1.000 (0.000)
17 May	41	1.000 (0.000)	46	1.000 (0.000)	1.000 (0.000)
18 May	35	0.853 (0.061)	37	1.000 (0.000)	0.853 (0.061)
19 May	44	0.932 (0.038)	49	1.000 (0.000)	0.932 (0.038)
20 May	36	1.000 (0.000)	52	1.000 (0.000)	1.000 (0.000)
21 May	42	0.976 (0.024)	46	1.000 (0.000)	0.976 (0.024)
22 May	36	0.944 (0.038)	45	1.000 (0.000)	0.944 (0.038)
23 May	31	0.774 (0.075)	49	1.000 (0.000)	0.774 (0.075)
24 May	27	0.926 (0.050)	43	1.000 (0.000)	0.926 (0.050)
25 May	20	0.850 (0.080)	47	1.000 (0.000)	0.850 (0.080)
26-28 May	35	0.963 (0.036)	108	1.000 (0.000)	0.963 (0.036)
Overall	788	0.925 (0.013)	1,136	1.000 (0.000)	0.925 (0.013)

Appendix Table B4. Daily juvenile bypass system (JBS) survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n		n	Survival	Relative survival
2-3 May	33	0.938 (0.043)	31	1.000 (0.000)	0.938 (0.043)
4 May	18	1.000 (0.000)	46	1.000 (0.000)	1.000 (0.000)
5-6 May	23	1.000 (0.000)	89	1.000 (0.000)	1.000 (0.000)
7 May	23	1.000 (0.000)	44	1.000 (0.000)	1.000 (0.000)
8 May	29	1.000 (0.000)	49	1.000 (0.000)	1.000 (0.000)
9 May	22	0.9555 (0.044)	48	1.000 (0.000)	0.9555 (0.044)
10-12 May	28	0.964 (0.035)	140	1.000 (0.000)	0.964 (0.035)
13-15 May	26	0.962 (0.038)	118	1.000 (0.000)	0.962 (0.038)
16-17 May	34	1.000 (0.000)	95	1.000 (0.000)	1.000 (0.000)
18-19 May	28	1.000 (0.000)	86	1.000 (0.000)	1.000 (0.000)
20-22 May	31	1.000 (0.000)	143	1.000 (0.000)	1.000 (0.000)
23-24 May	33	1.000 (0.000)	92	1.000 (0.000)	1.000 (0.000)
25-26 May	36	1.000 (0.000)	94	1.000 (0.000)	1.000 (0.000)
27-29 May	21	1.000 (0.000)	61	1.000 (0.000)	1.000 (0.000)
Overall	385	0.987 (0.006)	1,136	1.000 (0.000)	0.987 (0.006)

Appendix Table B5. Daily turbine passage survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n		n	Survival	Relative survival
2-7 May	33	0.941 (0.040)	210	1.000 (0.000)	0.941 (0.040)
8-16 May	30	0.938 (0.043)	404	1.000 (0.000)	0.938 (0.043)
17-23 May	34	0.882 (0.055)	324	1.000 (0.000)	0.882 (0.055)
24-29 May	25	0.880 (0.065)	198	1.000 (0.000)	0.880 (0.065)
Overall	122	0.910 (0.017)	1,136	1.000 (0.000)	0.910 (0.017)

Appendix Table B6. Daily estimates of survival through spillbay 8 for yearling Chinook salmon passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Date	n		n	Survival	
2-3 May	17	0.941 (0.057)	31	1.000 (0.000)	0.941 (0.057)
4 May	18	0.889 (0.074)	46	1.000 (0.000)	0.889 (0.074)
5 May	23	0.957 (0.043)	44	1.000 (0.000)	0.957 (0.043)
6 May	17	0.882 (0.078)	45	1.000 (0.000)	0.882 (0.078)
7 May	11	0.909 (0.087)	44	1.000 (0.000)	0.909 (0.087)
8 May	22	1.000 (0.000)	49	1.000 (0.000)	1.000 (0.000)
9 May	29	0.966 (0.034)	48	1.000 (0.000)	0.966 (0.034)
10 May	28	0.964 (0.035)	46	1.000 (0.000)	0.964 (0.035)
11 May	11	0.909 (0.087)	48	1.000 (0.000)	0.909 (0.087)
12 May	21	1.000 (0.000)	46	1.000 (0.000)	1.000 (0.000)
13 May	38	0.868 (0.055)	41	1.000 (0.000)	0.868 (0.055)
14 May	27	0.889 (0.061)	30	1.000 (0.000)	0.889 (0.061)
15 May	33	0.970 (0.030)	47	1.000 (0.000)	0.970 (0.030)
16 May	28	1.000 (0.000)	49	1.000 (0.000)	1.000 (0.000)
17 May	26	1.000 (0.000)	46	1.000 (0.000)	1.000 (0.000)
18 May	23	0.864 (0.073)	37	1.000 (0.000)	0.864 (0.073)
19 May	20	0.900 (0.067)	49	1.000 (0.000)	0.900 (0.067)
20 May	15	1.000 (0.000)	52	1.000 (0.000)	1.000 (0.000)
21 May	14	1.000 (0.000)	46	1.000 (0.000)	1.000 (0.000)
22 May	17	0.882 (0.078)	45	1.000 (0.000)	0.882 (0.078)
23 May	16	0.875 (0.083)	49	1.000 (0.000)	0.875 (0.083)
24 May	9	1.000 (0.000)	43	1.000 (0.000)	1.000 (0.000)
25 May	10	0.900 (0.095)	47	1.000 (0.000)	0.900 (0.095)
26-28 May	15	1.000 (0.000)	108	1.000 (0.000)	1.000 (0.000)
Overall	488	0.940 (0.011)	1,136	1.000 (0.000)	0.940 (0.011)

Appendix Table B7. Grouping, samples sizes, and estimated dam survival for juvenile steelhead passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		Relative survival
Date	n	Survival	n	Survival	
3 May	48	0.959 (0.029)	26	0.962 (0.038)	0.997 (0.049)
4 May	41	0.976 (0.024)	37	0.865 (0.056)	1.128 (0.078)
5 May	34	0.971 (0.029)	39	1.000 (0.000)	0.971 (0.029)
6 May	34	0.971 (0.029)	42	1.000 (0.000)	0.971 (0.029)
7 May	42	0.976 (0.024)	40	1.000 (0.000)	0.976 (0.024)
8 May	50	0.901 (0.043)	36	1.000 (0.000)	0.901 (0.043)
9 May	45	0.978 (0.022)	44	1.000 (0.000)	0.978 (0.022)
10 May	36	0.944 (0.038)	42	0.905 (0.045)	1.044 (0.067)
11 May	32	0.938 (0.043)	38	1.000 (0.000)	0.938 (0.043)
12 May	42	1.001 (0.001)	39	0.949 (0.035)	1.055 (0.039)
13 May	41	0.981 (0.025)	31	1.000 (0.000)	0.981 (0.025)
14 May	61	0.934 (0.032)	26	1.000 (0.000)	0.934 (0.032)
15 May	43	0.930 (0.039)	39	0.974 (0.025)	0.955 (0.047)
16 May	47	1.000 (0.000)	42	0.976 (0.024)	1.024 (0.025)
17 May	51	0.963 (0.027)	42	0.952 (0.033)	1.011 (0.045)
18 May	39	0.872 (0.054)	30	1.000 (0.000)	0.872 (0.054)
19 May	45	0.978 (0.022)	38	1.000 (0.000)	0.978 (0.022)
20 May	43	1.000 (0.000)	48	0.896 (0.044)	1.116 (0.055)
21 May	49	0.980 (0.020)	36	1.000 (0.000)	0.980 (0.020)
22 May	41	0.951 (0.034)	41	0.976 (0.024)	0.975 (0.042)
23 May	51	0.902 (0.042)	42	0.952 (0.033)	0.947 (0.055)
24 May	39	0.949 (0.035)	36	0.972 (0.027)	0.976 (0.046)
25 May	41	1.000 (0.000)	42	1.000 (0.000)	1.000 (0.000)
26 May	43	0.955 (0.032)	39	1.000 (0.000)	0.955 (0.032)
27 May-1 June	36	0.889 (0.052)	52	1.000 (0.000)	0.889 (0.052)
Overall	1,087	0.956 (0.028)	967	0.975 (0.015)	0.980 (0.039)

Appendix Table B8. Grouping, samples sizes, and estimated concrete survival for juvenile steelhead passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

Date	Treatment n	Treatment Survival	Reference n	Reference Survival	Relative survival
3 May	29	0.971 (0.029)	26	0.962 (0.038)	0.962 (0.038)
4 May	33	0.970 (0.030)	37	0.865 (0.056)	0.865 (0.056)
5 May	36	1.000 (0.000)	39	1.000 (0.000)	1.000 (0.000)
6 May	36	0.972 (0.027)	42	1.000 (0.000)	1.000 (0.000)
7 May	44	0.932 (0.038)	40	1.000 (0.000)	1.000 (0.000)
8 May	44	1.001 (0.001)	36	1.000 (0.000)	1.000 (0.000)
9 May	47	0.979 (0.021)	44	1.000 (0.000)	1.000 (0.000)
10 May	42	0.976 (0.024)	42	0.905 (0.045)	0.905 (0.045)
11 May	28	0.966 (0.035)	38	1.000 (0.000)	1.000 (0.000)
12 May	33	0.971 (0.030)	39	0.949 (0.035)	0.949 (0.035)
13 May	34	1.000 (0.000)	31	1.000 (0.000)	1.000 (0.000)
14 May	63	0.971 (0.022)	26	1.000 (0.000)	1.000 (0.000)
15 May	44	0.977 (0.023)	39	0.974 (0.025)	0.974 (0.025)
16 May	41	1.000 (0.000)	42	0.976 (0.024)	0.976 (0.024)
17 May	53	1.000 (0.001)	42	0.952 (0.033)	0.952 (0.033)
18 May	38	0.871 (0.055)	30	1.000 (0.000)	1.000 (0.000)
19 May	54	1.000 (0.000)	38	1.000 (0.000)	1.000 (0.000)
20 May	43	1.000 (0.000)	48	0.896 (0.044)	0.896 (0.044)
21 May	59	1.000 (0.000)	36	1.000 (0.000)	1.000 (0.000)
22 May	40	0.950 (0.035)	41	0.976 (0.024)	0.976 (0.024)
23 May	47	0.915 (0.041)	42	0.952 (0.033)	0.952 (0.033)
24 May	37	1.000 (0.000)	36	0.972 (0.027)	0.972 (0.027)
25 May	39	1.000 (0.000)	42	1.000 (0.000)	1.000 (0.000)
26 May	38	1.002 (0.002)	39	1.000 (0.000)	1.000 (0.000)
27-29 May	46	0.978 (0.022)	52	1.000 (0.000)	1.000 (0.000)
Overall	1,048	0.976 (0.017)	967	0.975 (0.015)	0.975 (0.015)

Appendix Table B9. Grouping, samples sizes, and estimated spillway survival for juvenile steelhead passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2-4 May	28	1.000 (0.000)	63	0.905 (0.037)	1.105 (0.045)
5-7 May	35	0.971 (0.028)	121	1.000 (0.000)	0.971 (0.028)
8-9 May	36	1.000 (0.000)	80	1.000 (0.000)	1.000 (0.000)
10 May	26	0.962 (0.038)	42	0.905 (0.045)	1.063 (0.068)
11 May	19	0.947 (0.051)	38	1.000 (0.000)	0.947 (0.051)
12 May	20	0.953 (0.049)	39	0.949 (0.035)	1.004 (0.064)
13 May	23	1.000 (0.000)	31	1.000 (0.000)	1.000 (0.000)
14 May	30	0.933 (0.046)	26	1.000 (0.000)	0.933 (0.046)
15 May	19	0.947 (0.051)	39	0.974 (0.025)	0.972 (0.058)
16 May	17	1.000 (0.000)	42	0.976 (0.024)	1.024 (0.025)
17 May	21	1.000 (0.000)	42	0.952 (0.033)	1.050 (0.036)
18 May	22	0.866 (0.074)	30	1.000 (0.000)	0.866 (0.074)
19 May	41	1.000 (0.000)	38	1.000 (0.000)	1.000 (0.000)
20 May	29	1.000 (0.000)	48	0.896 (0.044)	1.116 (0.055)
21 May	51	1.000 (0.000)	36	1.000 (0.000)	1.000 (0.000)
22 May	24	0.958 (0.041)	41	0.976 (0.024)	0.982 (0.048)
23 May	33	0.909 (0.050)	42	0.952 (0.033)	0.955 (0.062)
24-25 May	32	1.000 (0.000)	78	0.987 (0.013)	1.013 (0.013)
26-29 May	26	1.000 (0.000)	91	1.000 (0.000)	1.000 (0.000)
Overall	532	0.971 (0.022)	967	0.975 (0.015)	1.010 (0.030)

Appendix Table B10. Grouping, samples sizes, and estimated juvenile bypass system survival for juvenile steelhead passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2-3 May	34	0.971 (0.029)	26	0.962 (0.038)	1.009 (0.050)
4 May	33	0.970 (0.030)	37	0.865 (0.056)	1.121 (0.081)
5 May	36	1.000 (0.000)	39	1.000 (0.000)	1.000 (0.000)
6 May	36	0.972 (0.027)	42	1.000 (0.000)	0.972 (0.027)
7 May	44	0.932 (0.038)	40	1.000 (0.000)	0.932 (0.038)
8 May	44	1.001 (0.001)	36	1.000 (0.000)	1.001 (0.001)
9 May	47	0.979 (0.021)	44	1.000 (0.000)	0.979 (0.021)
10 May	42	0.976 (0.024)	42	0.905 (0.045)	1.079 (0.060)
11 May	28	0.966 (0.035)	38	1.000 (0.000)	0.966 (0.035)
12 May	33	0.971 (0.030)	39	0.949 (0.035)	1.023 (0.049)
13 May	34	1.000 (0.000)	31	1.000 (0.000)	1.000 (0.000)
14 May	63	0.971 (0.022)	26	1.000 (0.000)	0.971 (0.022)
15 May	44	0.977 (0.023)	39	0.974 (0.025)	1.003 (0.035)
16 May	41	1.000 (0.000)	42	0.976 (0.024)	1.024 (0.025)
17 May	53	1.000 (0.001)	42	0.952 (0.033)	1.050 (0.036)
18 May	38	0.871 (0.055)	30	1.000 (0.000)	0.871 (0.055)
19 May	54	1.000 (0.000)	38	1.000 (0.000)	1.000 (0.000)
20 May	43	1.000 (0.000)	48	0.896 (0.044)	1.116 (0.055)
21 May	59	1.000 (0.000)	36	1.000 (0.000)	1.000 (0.000)
22 May	40	0.950 (0.035)	41	0.976 (0.024)	0.974 (0.043)
23 May	47	0.9159 (0.041)	42	0.952 (0.033)	0.961 (0.054)
24 May	37	1.000 (0.000)	36	0.972 (0.027)	1.029 (0.029)
25 May	39	1.000 (0.000)	42	1.000 (0.000)	1.000 (0.000)
26 May	38	1.002 (0.002)	39	1.000 (0.000)	1.002 (0.002)
27-29 May	46	0.978 (0.022)	52	1.000 (0.000)	0.978 (0.022)
Overall	1,053	0.976 (0.017)	967	0.975 (0.015)	1.001 (0.030)

Appendix Table B11. Grouping, samples sizes, and estimated spillbay 8 survival for juvenile steelhead passing Lower Monumental Dam, 2006. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2-4 May	22	1.000 (0.000)	63	0.905 (0.037)	1.105 (0.045)
5-7 May	28	0.964 (0.035)	121	1.000 (0.000)	0.964 (0.035)
8-9 May	27	1.000 (0.000)	80	1.000 (0.000)	1.000 (0.000)
10 May	17	1.000 (0.000)	42	0.905 (0.045)	1.105 (0.055)
11 May	7	1.000 (0.000)	38	1.000 (0.000)	1.000 (0.000)
12 May	10	0.900 (0.095)	39	0.949 (0.035)	0.949 (0.106)
13 May	14	1.000 (0.000)	31	1.000 (0.000)	1.000 (0.000)
14 May	17	0.941 (0.057)	26	1.000 (0.000)	0.941 (0.057)
15 May	12	1.000 (0.000)	39	0.974 (0.025)	1.026 (0.027)
16 May	12	1.000 (0.000)	42	0.976 (0.024)	1.024 (0.025)
17 May	9	1.000 (0.000)	42	0.952 (0.033)	1.050 (0.036)
18 May	9	0.889 (0.105)	30	1.000 (0.000)	0.889 (0.105)
19 May	20	1.000 (0.000)	38	1.000 (0.000)	1.000 (0.000)
20 May	8	1.000 (0.000)	48	0.896 (0.044)	1.116 (0.055)
21 May	15	1.000 (0.000)	36	1.000 (0.000)	1.000 (0.000)
22 May	9	0.889 (0.105)	41	0.976 (0.024)	0.911 (0.110)
23 May	9	0.889 (0.105)	42	0.952 (0.033)	0.933 (0.115)
24-25 May	13	1.000 (0.000)	78	0.987 (0.013)	1.013 (0.013)
26-28 May	11	1.000 (0.000)	91	1.000 (0.000)	1.000 (0.000)
Overall	269	0.972 (0.026)	967	0.972 (0.016)	1.000 (0.041)

APPENDIX C: Telemetry Data Processing and Reduction

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 processes in this database fall into three main categories or stages in the flow of data from input to output: loading, validation, and summarization. These are explained below and summarized in Appendix Figure C.

The loading process consists of copying data files from their initial locations to the database server, converting the files from their original format into a format readable by SQL, and having SQL read the files and stores the data in preliminary tables.

Data Validation

During the validation process, the records stored in the preliminary tables are analyzed. We determine the study year, site identifier, antenna identifier, and tag identifier for each record, flagging them as invalid if one or more of these identifiers cannot be determined. Records are flagged by storing brief comments in the edit notes field. Values of edit notes associated with each record are as follows:

Null: denotes a valid observation of a tag

Not Tagged: denotes an observation of a channel code combination that was not in use at the time. Such values are likely due to radio frequency noise being picked up at an antenna.

Noise Record: denotes an observation where the code is equal to 995, 997, or 999. These are not valid records, and relate to radio frequency noise being picked up at the antenna.

Beacon Record: hits recorded on channel = 5, code = 575, which indicate a beacon being used to ensure proper functioning of the receivers. This combination does not indicate the presence of a tagged fish.

Invalid Record Date: denotes an observation whose date/time is invalid (occurring before we started the database, i.e., prior to 1 January 2004, or some time in the future). Due to improvements in the data loading process, such records are unlikely to arise.

Invalid Site: denotes an observation attributed to an invalid (non existent) site. These are typically caused by typographical errors in naming hex files at the receiver end. They should not be present in the database, since they should be filtered out during the data loading process.

Invalid Antenna: Denotes an observation attributed to an invalid (non existent) antenna. These are most likely due to electronic noise within the receiver.

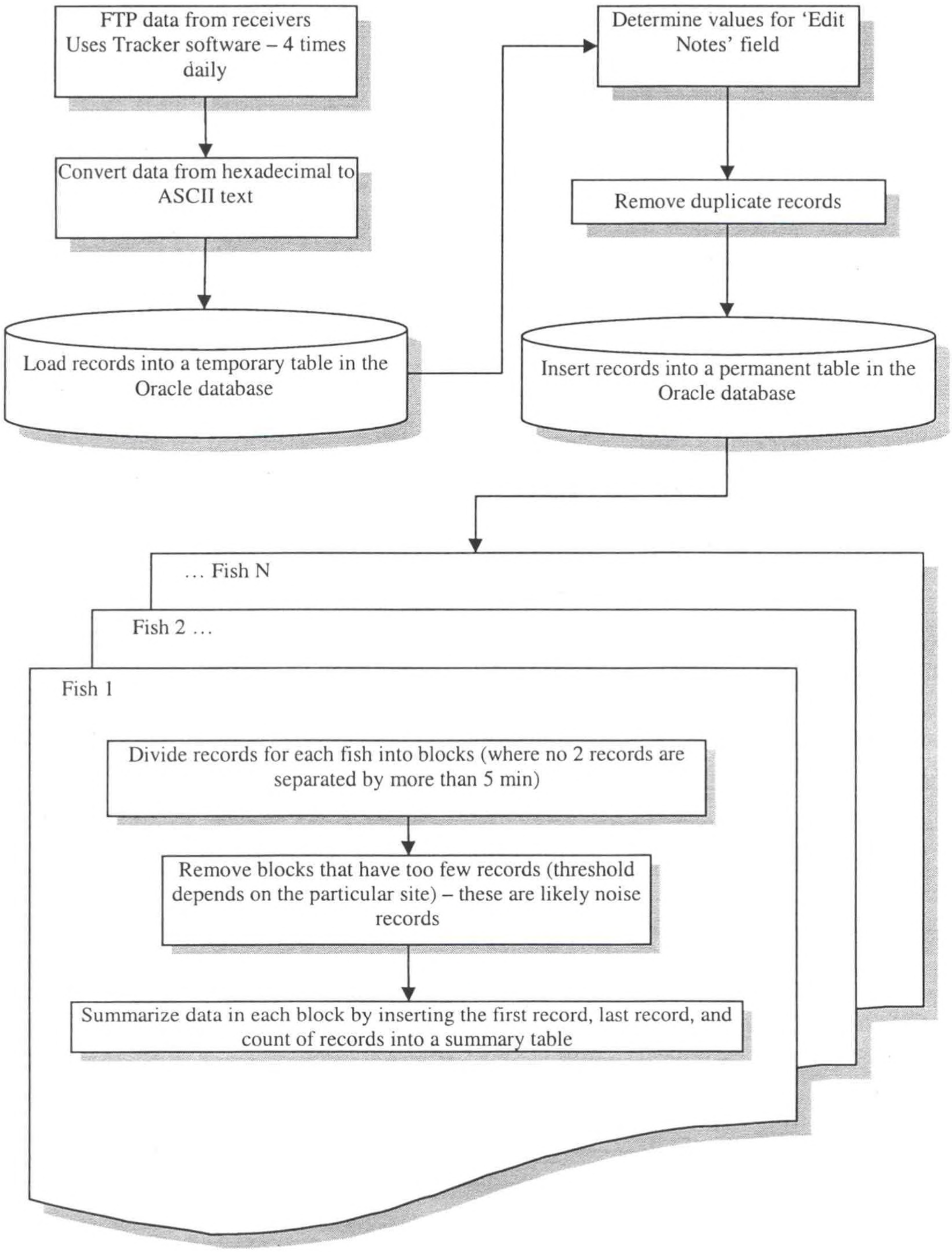
Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time). Note: these records are produced by radio frequency noise.

Gt end time: Assigned to records occurring after the end time on a tag (tags run for 10 d once activated). Note: these records are produced by radio frequency noise.

In addition, duplicate records (records for which the channel, code, site, antenna, date and time are the same as those of another record) are considered invalid. Finally, the records are copied from the preliminary tables into the appropriate storage table based on study year. The database can accommodate multiple years with differing sites and antenna configurations. Once a record's study year has been determined, its study year, site, and antenna are used to match it to a record in the sites table.

Generation of the Summary Tables

The summary table summarizes the first detection, last detection, and count of detections for blocks of records within a site for a single fish where no two consecutive records are separated by more than a specified number of minutes (currently using 5 min).



Appendix Figure C. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival at Lower Monumental Dam for yearling Chinook salmon, 2006.