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

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EXECUTIVE SUMMARY

In 2007, 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 663 yearling Chinook salmon and 665 juvenile steelhead released 7 km upstream from Lower Monumental Dam. Reference groups were comprised of 637 yearling Chinook salmon and 646 juvenile steelhead released into the tailrace of Lower Monumental Dam. Releases occurred during both daytime and nighttime operations for 25 d from 1 to 25 May. Project operations during the evaluation included bulk spill 24 h per day. River flow, percent spill, and tailwater elevation during releases averaged 79 kcfs, 27%, and 439 ft msl, respectively.

For yearling Chinook salmon, median forebay delay was 2.5 h overall. During passage, the largest proportion (38%) of yearling Chinook first approached Lower Monumental Dam near the middle of the dam in the vicinity of Spillbay 8. Passage route distribution was 74, 17, 7, and 2% through the spillway, juvenile bypass system (JBS), turbines, and undetermined routes, respectively. Within the spillway, the largest proportion (46%) of yearling Chinook passed through Spillbay 8. For fish with a known passage route, fish guidance efficiency (FGE) was 71% and fish passage efficiency (FPE) was 93%. Median tailrace egress was 7 min overall, and spill efficiency was 2.76 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 0.930 (95% CI, 0.898-0.964). Relative survival was 0.959 (95% CI, 0.937-0.982) for yearling Chinook passing through the spillway, 0.941 (95% CI, 0.883-0.998) for fish passing through the JBS, and 0.909 (95% CI, 0.808-1.010) for fish passing through turbines. Survival for fish passing through Spillbay 8 was 0.976 (95% CI, 0.948–1.005).

For juvenile steelhead, median forebay delay was 17.8 h. The greatest proportion of steelhead (38%) first approached Lower Monumental Dam near the middle of the dam in the vicinity of Spillbay 8. Passage distribution was 62, 32, 4, and 2% through the spillway, JBS, turbines, and undetermined routes, respectively.

Within the spillway, the largest proportion of steelhead (35%) passed through Spillbay 8. For fish with a known passage route, FGE was 90% and FPE was 96%. Median tailrace egress was 8 minutes overall, and spill efficiency was 2.45 to 1.

Relative dam survival was 0.888 (95% CI, 0.854–0.923) for juvenile steelhead. Relative survival was 0.939 (95% CI, 0.905-0.975) for juvenile steelhead passing through the spillway and 0.986 (95% CI, 0.955-1.018) for those passing through the JBS. Survival for juvenile steelhead passing through Spillbay 8 was 0.923 (95% CI, 0.879-0.968).

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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 hydropower system 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 and is expected to be operational in 2008. 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).

In 2007 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.

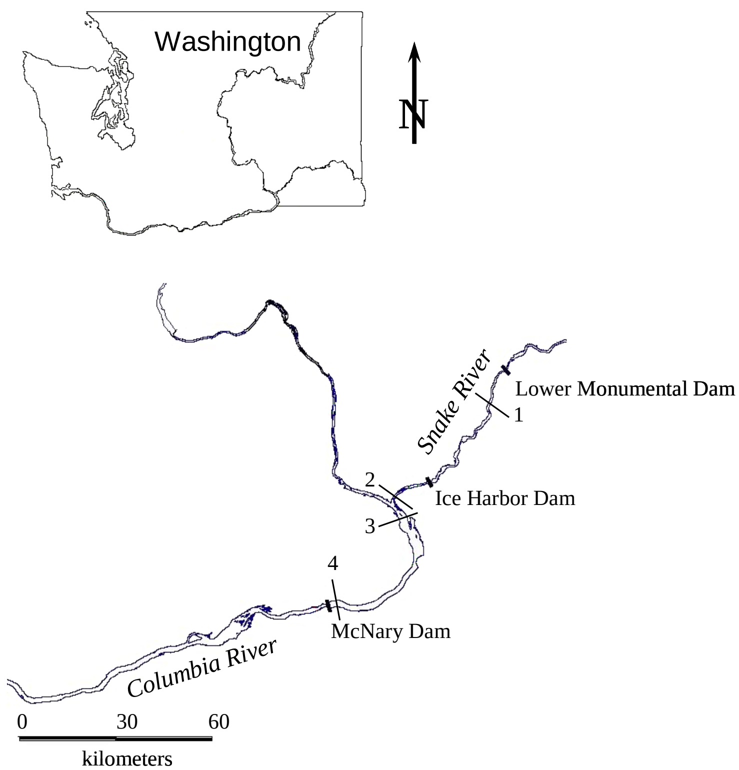

Figure 1. Detail of the study area showing locations of radio-telemetry transects used for estimating survival at Lower Monumental Dam in 2007. Transects included: 1 = primary survival array 16 km downstream from Lower Monumental Dam; 2 = mouth of the Snake River; 3 = Burbank/Finely Railroad Bridge and 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 29 April to 23 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 12 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 aerated 9-L buckets until they recovered from the anesthesia (2 fish per bucket). Buckets were then closed and placed into a large holding tank (1.5-m wide, 2.5-m long, 0.5-m deep) that accommodated up to 28 buckets and into which flow-through water was applied during tagging and holding. Fish were held a minimum of 24 h with flow-through water for recovery and determination of post-tagging mortality.

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 buckets placed within holding tanks to release locations (7 km upstream from Lower Monumental Dam or into the tailrace). Immediately prior to transport to release locations, transmitters of all tagged fish were checked for operation and to verify that codes were recorded correctly in the database. To provide mixing of treatment and reference groups, treatment groups

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

were released all at one time twice daily (daytime and nighttime periods), and reference release groups were released over a 6-h period twice daily (daytime and nighttime periods).

Treatment groups were transferred water-to-water from the recovery buckets to a release tank mounted on an 8.5 × 2.4-m barge, transported 7 km upstream from Lower Monumental Dam, and released mid-channel. Reference groups were transferred in their recovery buckets to a holding tank on the rear of a truck and then driven to their release location 1,250 m downstream from Lower Monumental Dam. Upon arrival at the release site, reference fish were maintained via flow-through river water until release. Fish were released one or two at a time, with the entire group released over a 6-h period during both the daytime and nighttime release periods. Reference fish were released using a flume that extended a minimum of 7.6 m from the north shoreline out into the river. The reference group release location was based on tailrace conditions observed in a 1:55 scale model of Lower Monumental Dam at the USACE Research and Development Center, Vicksburg, MS. Specific operating conditions were not requested for release days, and project operations at Lower Monumental Dam included voluntary 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 were those corresponding 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 2007 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, 2007.

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		

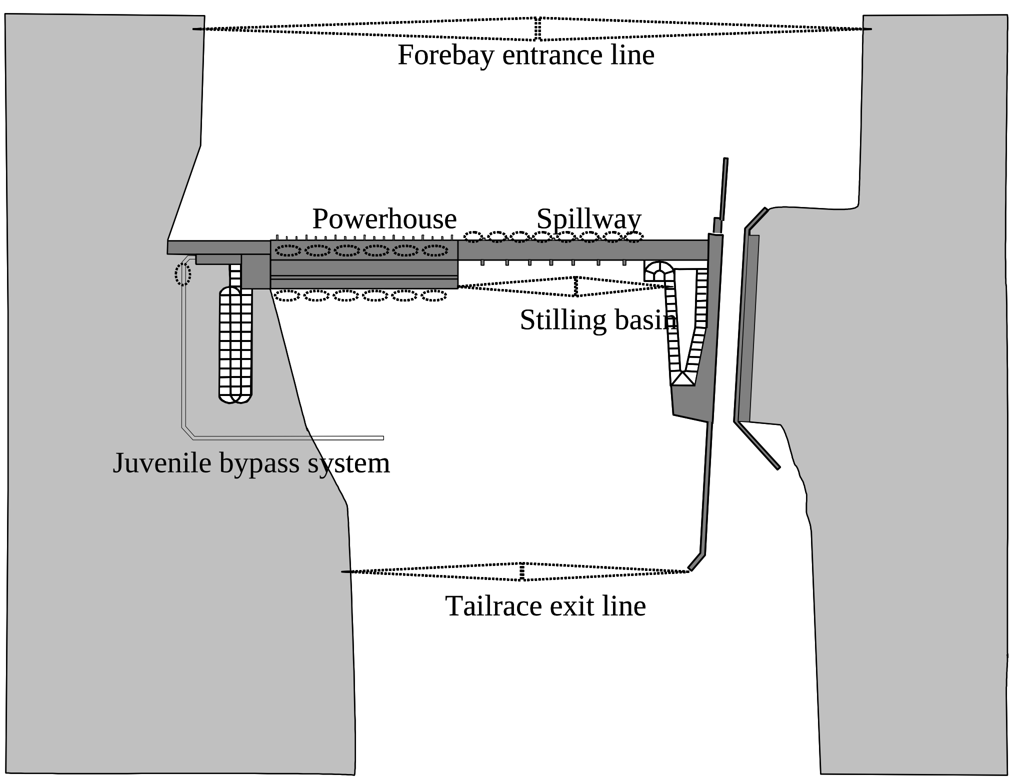

Figure 2. Lower Monumental Dam plan view showing approximate locations of detection zones for radiotelemetry receivers in 2007. Oval lines represent underwater antennas, and triangular lines represent aerial antennas.

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 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 time was characterized by constructing means and 95% confidence intervals (i.e. the mean ± $t_{(0.05,\, n\text{-}1)}$ standard errors, where t was the t-value, given n - 1 degrees of freedom and $\alpha = 0.05$, and was approximately 2.0) for the 10^{th}, 50^{th}, and 90^{th} percentiles of the residence time distributions. Replicates were fish grouped by dam passage day. These intervals were also constructed by route of passage (i.e., bypass, turbine, and spillway) where reasonable. For groups with insufficient sample size for replicates, intervals for all or some percentiles were not constructed (e.g., turbine and some bypass). 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 means and 95% confidence intervals (i.e. means +- $t_{(0.05,\, n\text{-}1)}$ standard errors, where t was the t-value, given n-1 degrees of freedom and $\alpha = 0.05$, and was approximately 2.0) for the 10th, 50th and 90th percentiles of the egress time distributions. Replicates were fish grouped by passage day. These intervals were also constructed by route of passage (i.e., bypass, turbine, and spillway) where reasonable. For groups with insufficient sample size for replicates, intervals for all or some percentiles were not constructed (e.g., turbine and some bypass).

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 single-release or CJS model (Cormack 1964; Jolly 1965; Seber 1965). Data were analyzed using *Survival with Proportional Hazards* (SURPH), a 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 1,250 m downstream from Lower Monumental Dam.

Concrete survival is an estimate of the treatment fish surviving through the combined passage routes of Lower Monumental Dam relative to survival of the tailrace reference fish. The effect zone extended from the exit of all passage routes to the tailrace control 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 array (16 km downstream from Lower Monumental Dam), detection 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 formed 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 the 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 have passed the dam through the location where they were last detected. We excluded from 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 by Caspian terns *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 2007 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 (S. Sebring, 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 25 d from 30 April to 24 May. The 2007 study period encompassed the smolt passage index at Lower Monumental Dam between the 3rd and 99th percentile for yearling Chinook salmon and between the 1st and 97th percentile for juvenile steelhead (Figure 3).

We released 663 radio-tagged yearling Chinook salmon 7 km upstream from Lower Monumental Dam and 637 yearling Chinook salmon into the tailrace. For yearling Chinook released above the dam, overall mean fork length was 145.0 mm (SD = 11.0) and overall mean weight was 25.3 g (SD = 6.7). For yearling Chinook released below the dam, overall mean fork length was 145.6 mm (SD = 12.2) and overall mean weight was 25.9 g (SD = 8.0; Tables 2 and 3).

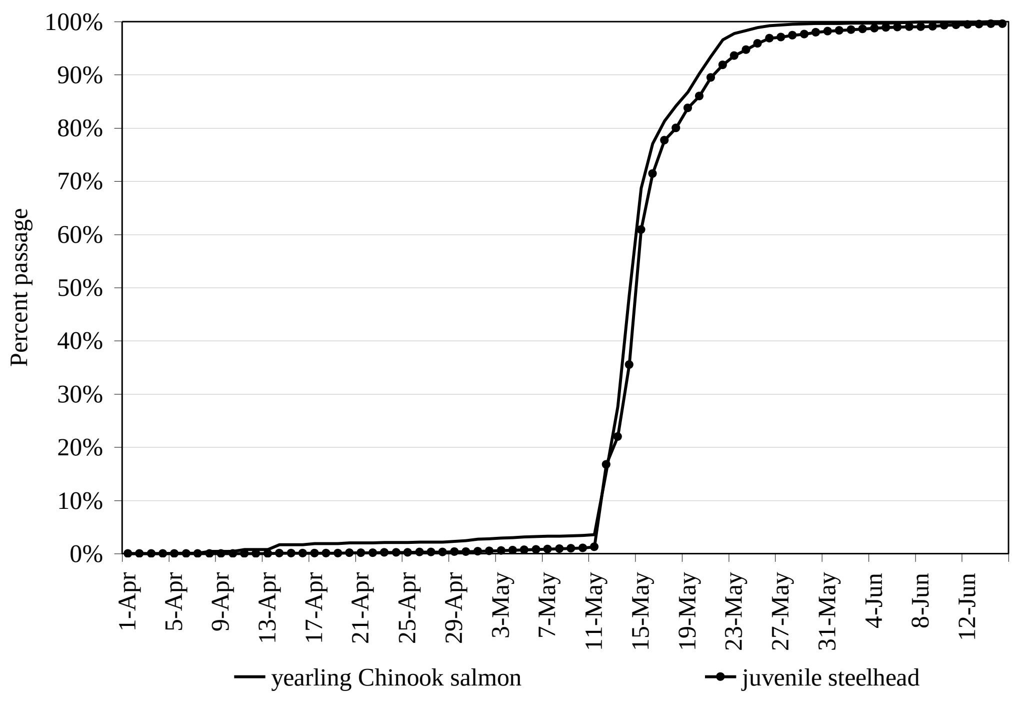

Figure 3. Cumulative passage distribution of hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam during 2007.

Table 2. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged, yearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2007.

	Fork length (mm)									
	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
30 Apr	33	121	178	144.5	13.5	---	---	---	---	---
1 May	27	125	183	146.9	11.7	24	125	169	141.3	11.3
2 May	27	126	159	141.1	10.2	17	116	161	139.2	13.3
3 May	28	123	165	141.6	12.4	23	123	181	145.5	12.6
4 May	28	127	166	142.3	9.4	31	128	168	144.3	12.9
5 May	25	125	186	146.1	13.3	28	127	173	146.1	12.2
6 May	36	131	182	150.0	12.4	34	127	176	146.6	10.9
7 May	28	126	179	146.8	14.4	28	123	168	144.6	10.3
8 May	27	122	160	145.9	10.3	26	129	191	148.2	13.0
9 May	26	121	157	145.2	8.7	27	123	199	148.8	14.4
10 May	24	127	164	142.1	10.3	28	114	189	140.7	16.5
11 May	28	132	188	151.6	14.5	25	128	210	157.0	21.5
12 May	28	124	181	143.4	14.0	26	117	182	141.0	13.4
13 May	26	135	190	145.0	10.7	27	127	180	142.0	11.2
14 May	27	134	161	145.9	7.2	26	132	158	144.5	6.7
15 May	27	129	159	142.9	7.9	28	127	194	145.3	14.7
16 May	26	130	162	146.4	9.4	28	128	164	144.2	8.0
17 May	28	124	173	143.9	9.7	26	126	168	147.6	9.9
18 May	27	126	160	144.5	8.1	28	129	164	147.1	7.7
19 May	27	126	158	144.3	6.7	27	131	159	145.6	8.4
20 May	27	126	198	146.0	13.7	27	122	172	144.9	10.5
21 May	28	126	164	144.9	8.9	26	128	160	145.9	9.3
22 May	28	129	170	145.8	9.0	27	133	169	149.5	9.1
23 May	27	126	158	142.6	7.6	27	129	173	144.6	10.5
24 May	---	---	---	---	---	23	125	175	149.4	10.2
Overall	663	121	198	145.0	11.0	637	114	210	145.6	12.2

Table 3. Sample size, range, mean, and standard deviation (SD) of weights (grams) for radio-tagged, yearling Chinook salmon released at Lower Monumental Dam to evaluate passage behavior and survival, 2007.

	Weight (g)									
	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
30 Apr	33	14	47	24.7	7.4	---	---	---	---	---
1 May	27	15	49	26.0	6.3	24	15	39	23.3	5.8
2 May	27	16	35	23.4	5.3	17	13	34	22.4	6.9
3 May	28	16	40	24.7	6.8	23	14	54	25.3	8.4
4 May	28	16	36	23.3	5.1	31	14	43	25.1	8.1
5 May	25	15	56	26.6	8.4	28	15	45	26.4	7.6
6 May	36	17	51	26.2	7.9	34	15	47	23.7	6.5
7 May	28	15	61	26.2	10.5	28	14	42	25.1	6.1
8 May	27	14	36	26.3	5.6	26	15	64	27.6	9.5
9 May	26	14	35	24.6	5.3	27	16	72	28.4	10.8
10 May	24	16	41	24.5	5.8	28	13	58	24.8	9.6
11 May	28	18	57	30.5	9.6	25	16	81	34.0	17.4
12 May	28	15	51	24.4	8.7	26	13	47	23.0	7.3
13 May	26	20	48	24.7	5.7	27	15	47	23.1	6.1
14 May	27	18	34	25.8	4.6	26	19	34	25.2	4.1
15 May	27	17	34	24.7	3.8	28	14	71	26.3	11.1
16 May	26	16	38	25.2	5.4	28	16	37	23.9	4.7
17 May	28	14	41	23.7	5.5	26	16	34	26.1	4.8
18 May	27	15	32	24.1	4.2	28	16	35	26.0	4.3
19 May	27	16	33	25.1	3.5	27	20	39	27.4	5.1
20 May	27	16	83	26.8	12.0	27	16	51	25.5	6.7
21 May	28	17	32	24.7	4.2	26	19	35	25.9	4.8
22 May	28	18	37	25.9	4.4	27	19	42	28.0	5.3
23 May	27	18	36	25.2	4.2	27	17	47	26.3	6.3
24 May	---	---	---	---	---	23	18	46	29.5	6.3
Overall	663	14	83	25.3	6.7	637	13	81	25.9	8.0

We released 665 radio-tagged juvenile steelhead 7 km upstream from Lower Monumental Dam and 646 steelhead into the tailrace. For juvenile steelhead released upstream from the dam, overall mean fork length was 217.9 mm (SD = 21.6) and overall mean weight was 83.4 g (SD = 25.4; Tables 4 and 5). For juvenile steelhead released below Lower Monumental Dam, overall mean fork length was 219.9 mm (SD = 21.1) and overall mean weight was 85.0 g (SD = 27.2; Tables 4 and 5).

Table 4. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged, juvenile steelhead released at Lower Monumental Dam to evaluate passage behavior and survival, 2007.

	Fork length (mm)									
	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
30 Apr	34	168	236	210.8	15.0	---	---	---	---	---
1 May	27	189	245	214.7	14.0	25	182	232	209.5	13.7
2 May	26	171	246	203.2	19.0	19	183	253	215.3	19.0
3 May	26	170	262	204.8	20.3	27	190	248	211.0	15.1
4 May	34	165	263	215.3	20.0	36	179	247	210.8	14.1
5 May	28	186	251	211.4	15.7	27	154	271	214.0	20.0
6 May	28	165	264	219.5	20.2	27	199	259	223.4	14.8
7 May	28	157	240	215.9	16.6	28	197	280	224.7	21.6
8 May	28	157	265	212.7	22.6	27	175	264	221.0	23.1
9 May	27	170	253	215.8	22.7	28	158	253	208.4	22.6
10 May	26	194	254	213.4	15.2	28	177	257	220.7	19.1
11 May	27	196	255	222.3	14.5	27	187	261	217.4	19.3
12 May	26	174	245	212.3	19.1	28	183	261	219.0	22.6
13 May	28	195	275	228.4	19.0	27	185	266	224.1	20.3
14 May	27	180	257	217.9	22.8	28	180	267	217.6	18.0
15 May	27	186	284	214.4	22.7	27	189	284	228.2	24.4
16 May	26	171	255	212.6	17.5	26	194	286	226.1	24.3
17 May	28	184	275	228.8	18.1	27	181	255	220.1	18.1
18 May	27	198	248	228.5	14.8	25	175	272	217.1	22.0
19 May	28	207	256	227.3	14.9	27	191	270	226.7	20.9
20 May	27	198	277	227.7	21.4	28	189	260	226.5	17.6
21 May	27	185	269	228.4	21.4	26	191	271	226.7	23.3
22 May	27	176	276	228.5	25.5	27	159	281	217.7	26.1
23 May	28	163	264	219.9	25.0	26	182	272	229.8	25.8
24 May	---	---	---	---	---	25	185	274	222.9	22.0
Overall	665	157	284	217.9	21.6	646	154	286	219.9	21.1

Table 5. Sample size, range, mean, and standard deviation (SD) of weights (grams) for radio-tagged, juvenile steelhead released at Lower Monumental Dam to evaluate passage behavior and survival, 2007.

	Weight (g)									
	Forebay treatment group					Tailrace reference group				
Tag date	n	Min.	Max.	Mean	SD	n	Min.	Max.	Mean	SD
30 Apr	34	53	121	79.4	16.8	---	---	---	---	---
1 May	27	52	122	80.6	16.1	25	53	108	76.0	14.3
2 May	26	36	117	67.3	21.2	19	52	135	82.7	24.1
3 May	26	35	150	71.0	25.1	27	54	140	76.3	21.0
4 May	34	36	154	80.6	23.8	36	44	120	72.6	16.4
5 May	28	54	140	77.1	20.4	27	25	180	81.5	27.0
6 May	28	30	148	85.4	27.4	27	61	151	89.4	22.6
7 May	28	33	120	82.4	19.7	28	57	180	90.6	30.0
8 May	28	26	174	81.1	29.5	27	42	147	91.2	28.4
9 May	27	42	138	84.0	25.8	28	30	144	73.9	25.1
10 May	26	57	141	78.2	19.4	28	42	141	88.5	23.6
11 May	27	51	132	86.3	18.5	27	47	144	82.2	25.0
12 May	26	37	121	76.6	23.7	28	44	137	80.2	26.4
13 May	28	51	154	96.6	27.9	27	45	176	90.2	29.2
14 May	27	40	141	80.9	28.3	28	43	161	79.8	23.4
15 May	27	48	190	80.0	31.7	27	52	196	101.5	38.7
16 May	26	35	139	74.2	22.3	26	53	206	92.2	43.3
17 May	28	47	159	94.8	26.3	27	43	125	83.2	20.5
18 May	27	53	119	88.4	19.8	25	36	151	80.7	26.1
19 May	28	70	138	93.7	22.1	27	64	155	96.4	27.5
20 May	27	54	155	93.6	28.5	28	47	137	84.4	20.1
21 May	27	49	148	93.3	26.6	26	48	153	90.5	29.4
22 May	27	37	158	93.7	31.3	27	32	176	80.9	30.7
23 May	28	32	132	83.9	27.2	26	43	155	95.3	32.8
24 May	---	---	---	---	---	25	50	152	86.2	25.8
Overall	665	26	190	83.4	25.3	646	25	206	85.0	27.2

Post-tagging mortality was 1.0% (11 fish) for yearling Chinook salmon and 0.5% (6 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 A17). Treatment fish were released between 0848 and 0938 and between 1300 and 1520 PDT. Reference fish were released between 0830 and 1528 and between 2001 and 0332 PDT. Thirty-eight yearling Chinook salmon and 40 juvenile steelhead were excluded from the analysis because they were not detected entering the forebay.

Project Operations

During our study period, project discharge averaged 79 kcfs per day, or approximately 74% of the previous 10-year average daily flow of 107 kcfs at Lower Monumental Dam (1996-2005; Figure 4). Project operations included voluntary 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 78.6 kcfs total discharge, 58.1 kcfs powerhouse discharge, 20.5 kcfs spillway discharge (27.2% of total project discharge), and tailwater elevation of 439.4 ft msl (Table 6 and Figure 7).

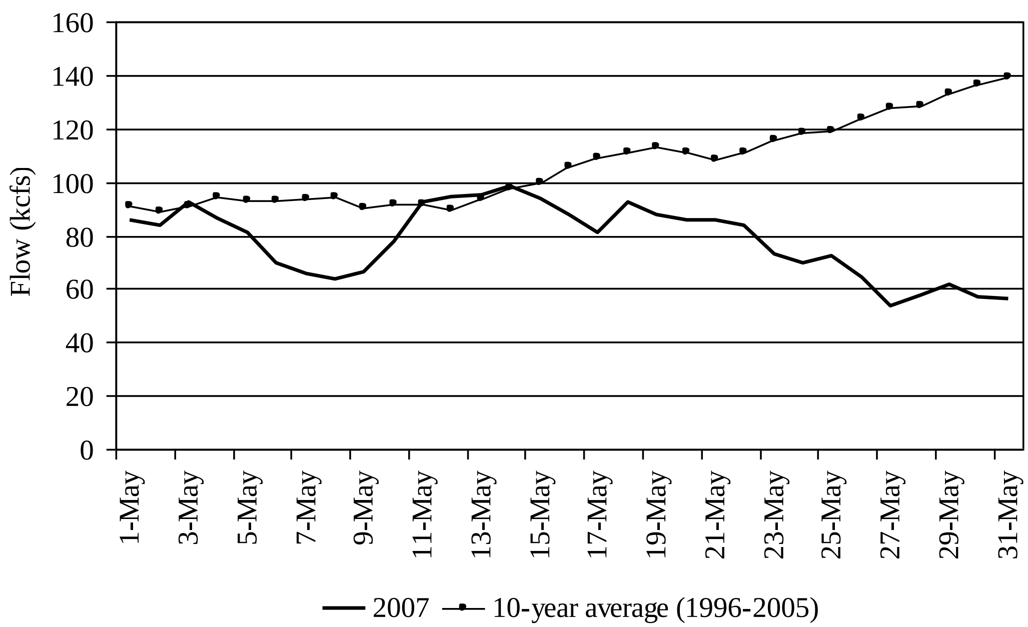

Figure 4. Daily and 10-year average (1996-2005) project discharge during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead for evaluating passage and survival at Lower Monumental Dam, 2007.

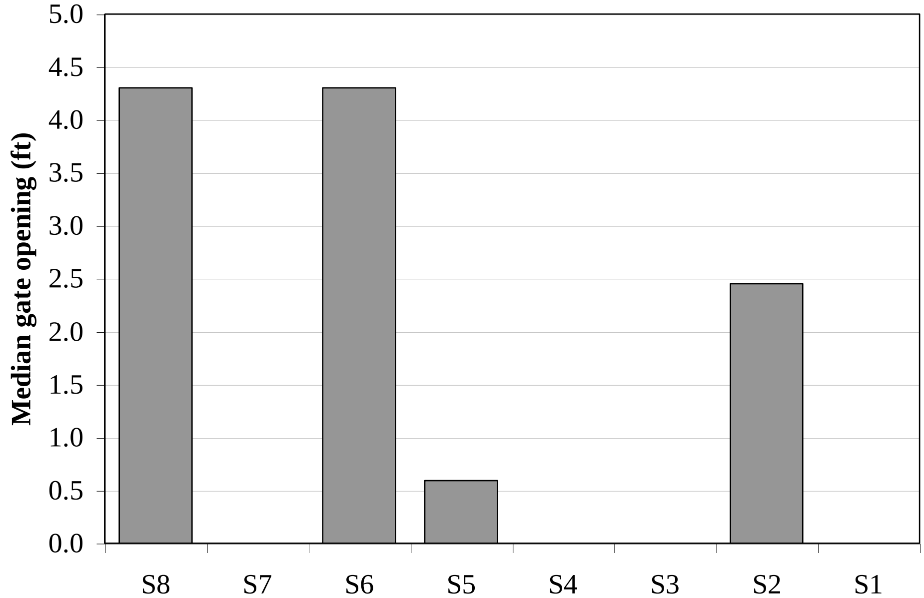

Figure 5. Median spillbay gate opening during passage of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2007.

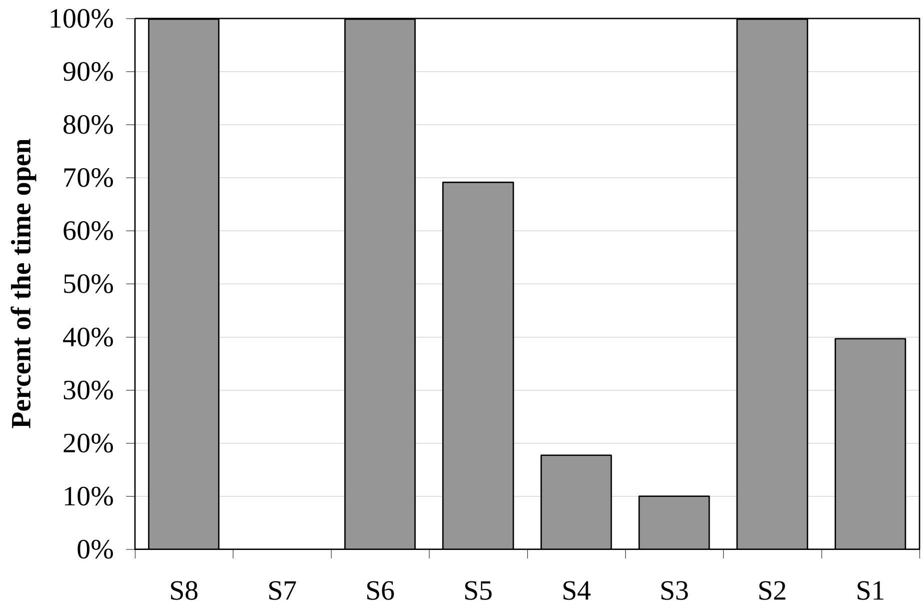

Figure 6. Percent of the time individual spillbays were open during passage of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2007.

Water temperature during tagging, the post-tagging holding period, and releases ranged from 11.0 to 14.2°C and averaged 12.7°C. Secchi disk measurements in the forebay of Lower Monumental Dam during releases averaged 1.1 m and ranged from 1.1 to 1.2 m (Table 6). Visible depth in the forebay of Lower Monumental Dam during 2007 was 157% of the previous 10-year average of 0.7 m (1996-2005; 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, 2007.

Release date	Total discharge (kcfs)	Powerhouse (kcfs)	Spill (kcfs)	Spill (%)	Water temperature (°C)	Tailwater (ft msl)	Secchi depth (m)
1 May	85.7	70.5	15.2	17.8	11.01	439.9	1.2
2 May	83.7	66.2	17.5	20.9	11.25	439.6	1.1
3 May	92.1	76.1	16.0	17.4	11.43	440.3	1.1
4 May	86.4	65.0	21.4	24.8	11.43	439.9	1.1
5 May	81.3	59.9	21.4	26.3	11.65	439.7	1.1
6 May	69.3	47.9	21.4	30.9	11.97	438.9	1.1
7 May	65.9	43.1	22.8	34.6	12.15	438.6	1.1
8 May	63.7	40.5	23.2	36.5	12.33	438.6	1.1
9 May	66.2	45.9	20.3	30.6	12.33	438.8	1.1
10 May	77.9	59.3	18.6	23.9	12.26	439.3	1.1
11 May	92.4	73.8	18.6	20.1	11.91	440.1	1.2
12 May	94.6	77.5	17.2	18.1	11.75	440.3	1.2
13 May	95.3	80.6	14.7	15.4	11.68	440.5	1.2
14 May	98.4	82.3	16.1	16.4	11.66	440.4	---
15 May	93.7	73.4	20.3	21.7	12.56	440.2	---
16 May	87.7	66.1	21.6	24.6	13.4	439.9	---
17 May	80.7	59.3	21.4	26.5	13.55	439.3	---
18 May	92.6	70.5	22.1	23.9	13.46	440.1	---
19 May	87.9	66.2	21.7	24.7	13.42	439.9	1.2
20 May	85.8	62.4	23.4	27.2	13.22	439.6	1.2
21 May	85.9	63.2	22.7	26.4	12.97	439.9	1.2
22 May	83.7	61.2	22.5	26.8	13.06	439.7	1.2
23 May	72.8	49.7	23.1	31.7	13.33	439.0	---
24 May	69.5	46.7	22.8	32.8	13.77	438.8	---
25 May	72.0	49.4	22.6	31.4	14.12	438.9	---
26 May	64.4	41.7	22.7	35.2	14.21	438.6	---
27 May	53.3	31.7	21.6	40.6	14.18	438.2	---
28 May	57.7	36.8	20.9	36.2	14.19	438.2	1.1
29 May	61.6	40.1	21.5	34.9	14.03	438.4	1.2
30 May	56.8	35.6	21.2	37.4	13.58	438.3	1.2
Average	78.6	58.1	20.5	27.2	12.7	439.4	1.1

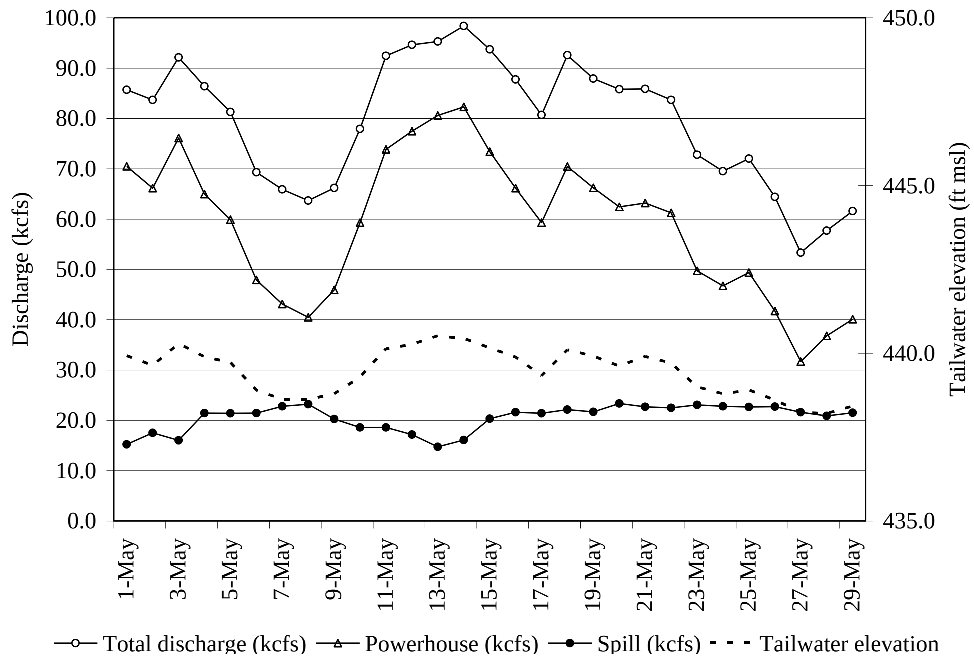

Figure 7. Average project discharge, powerhouse discharge, spillway discharge, and tailwater elevation by date during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2007.

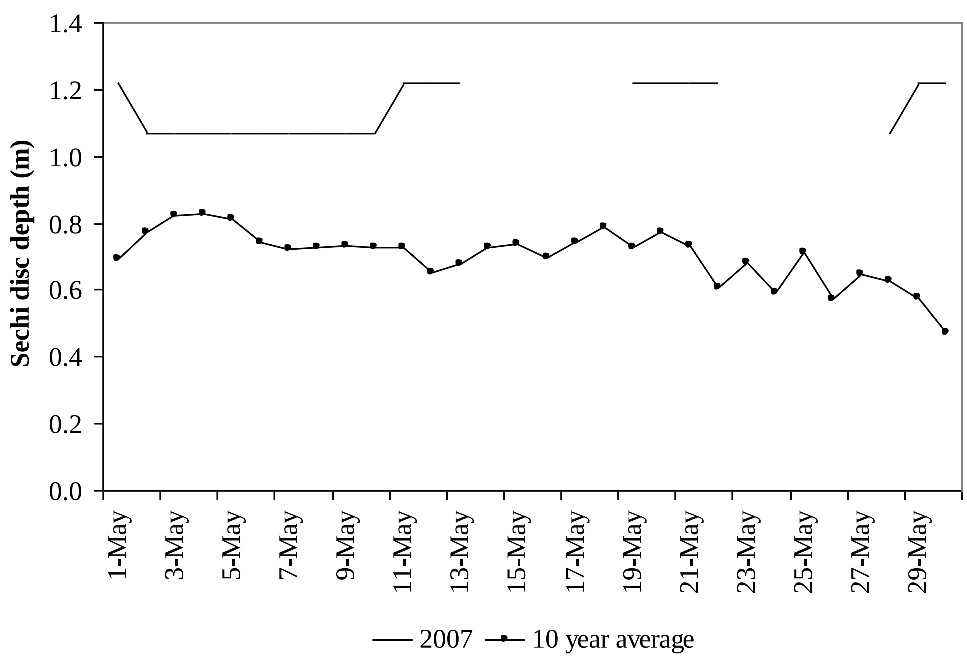

Figure 8. Daily and 10-year average (1996-2005) daily turbidity in the forebay of Lower Monumental Dam during releases of radio-tagged hatchery yearling Chinook salmon and juvenile steelhead for evaluating passage and survival at Lower Monumental Dam, 2007. Turbidity was measured by the visible depth of a Secchi disk below the surface.

Forebay Residence Time

Of the 663 radio-tagged yearling Chinook salmon released above Lower Monumental Dam, 625 (94%) 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 between 2300 and 0500 and between 1400 and 1600 (Figure 9). Median forebay residence time was 2.5 h (95% CI 2.1-2.9) and ranged from 0.4 to 125.4 h (Table 7). Median forebay residence time of yearling Chinook salmon that passed through the JBS (3.4 h; 95% CI 1.6-5.3) was similar to that of fish passing through the spillway (2.5 h; 95% CI 1.7-2.3) or turbines (1.3 h, no 95% CI calculated; P = 0.315).

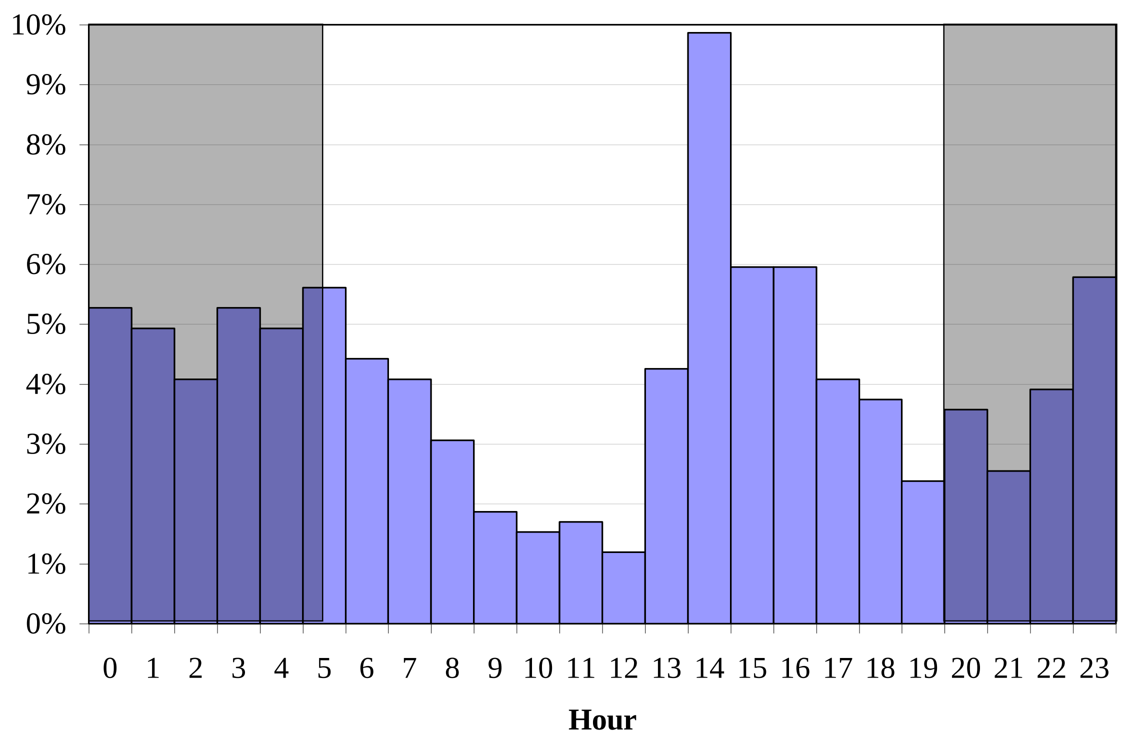

Figure 9. Hour of first detection for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam and detected in the forebay of Lower Monumental Dam. Shaded areas indicate night-time hours.

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, 2007.

	Forebay residence time (h)			
Passage percentile	JBS	Spillway	Turbine	Overall
N	98	443	42	583
10th	1.1	0.7	0.7	0.7
20th	1.3	1.0	0.8	1.0
30th	1.7	1.3	0.9	1.3
40th	2.4	1.7	1.0	1.7
50th	3.4	2.5	1.3	2.5
60th	4.5	3.9	1.6	3.9
70th	6.5	5.3	2.3	5.4
80th	10.0	8.8	5.8	8.7
90th	15.3	16.2	7.5	15.9
95th	24.0	23.0	8.9	23.0
Minimum	0.5	0.4	0.6	0.4
Mean	7.9	6.2	3.4	6.3
Median	3.4	2.5	1.3	2.5
Mode	4.5	0.5	0.9	0.7
Maximum	125.4	125.1	28.4	125.4

Of the 665 radio-tagged juvenile steelhead released above Lower Monumental Dam, 625 (94%) were detected on the forebay entrance line at the upstream end of the BRZ. The timing distribution of juvenile steelhead entering the forebay of Lower Monumental Dam is presented in Figure 10. Median forebay residence time was 17.8 h (95% CI 14.0-21.7) and ranged from 0.1 to 204.1 h (Table 8). Median forebay residence time of juvenile steelhead that passed through the JBS (18.7 h; 95% CI 13.9-23.6) was similar to that of fish that passed through the spillway (17.8 h ; 95% CI 10.8-24.7; P = 0.695). Only 20 juvenile steelhead passed through the turbines.

Median gatewell residence time was 0.4 h for yearling Chinook salmon and 1.6 h for juvenile steelhead (Table 9). For yearling Chinook salmon that passed via the JBS, median gatewell residence time accounted for 1% of forebay residence time. For juvenile steelhead that passed via the JBS, median gatewell residence time accounted for 9% of forebay residence time.

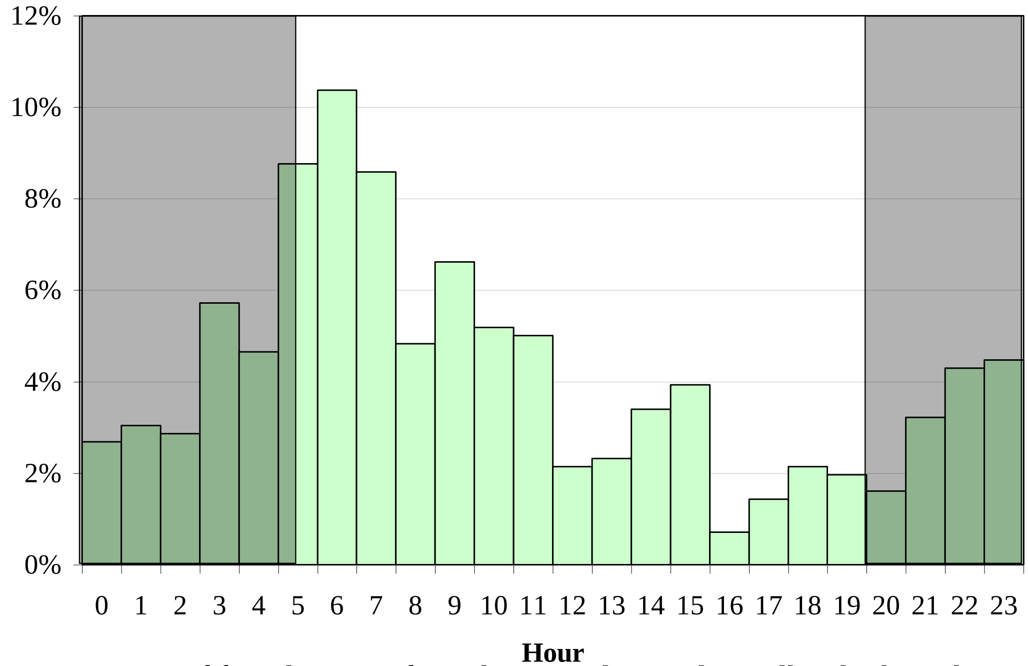

Figure 10. Hour of first detection for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam and detected in the forebay of Lower Monumental Dam. Shaded areas indicate night-time hours.

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, 2007.

	Forebay residence time (h)			
Passage percentile	JBS	Spillway	Turbine	Overall
n	183	360	19	562
10th	2.1	1.5	1.0	1.7
20th	4.0	3.3	1.5	3.3
30th	9.8	5.8	5.5	6.4
40th	15.3	11.6	11.0	13.0
50th	18.7	17.8	15.5	17.8
60th	23.8	23.2	18.3	23.3
70th	33.4	32.6	21.0	32.5
80th	43.6	45.6	31.9	43.8
90th	64.1	74.0	39.0	69.2
95th	90.1	107.6	40.8	98.9
Minimum	0.9	0.1	0.9	0.1
Mean	27.7	29.0	17.5	28.2
Median	18.7	17.8	15.5	17.8
Mode	2.6	1.1	N/A	1.7
Maximum	156.4	204.1	56.3	204.1

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, 2007.

	Gatewell residence time (h)	
Passage percentile	Yearling Chinook salmon	Juvenile steelhead
n	98	181
10th	0.1	0.2
20th	0.1	0.4
30th	0.2	0.6
40th	0.3	0.9
50th	0.4	1.6
60th	0.7	3.2
70th	1.1	6.3
80th	2.6	9.9
90th	5.4	16.9
95th	10.9	32.1
Minimum	0.0	0.0
Mean	3.7	7.4
Median	0.4	1.6
Mode	0.1	0.2
Maximum	124.0	117.9

Approach and Passage-Route Distribution

A total of 625 yearling Chinook salmon entered the forebay of Lower Monumental Dam, and 97% of these fish (608) subsequently passed the dam. Seventy-six percent of the yearling Chinook salmon first approached the spillway portion of the dam, with the majority of these (38%) approaching at Spillbay 8 (Figure 11). Passage-route distribution was 74, 17, and 7%, through the spillway, JBS, and turbines, respectively. The remaining 2% passed through undetermined routes. The greatest proportion of yearling Chinook passed through Spillbay 8 (46%; Figure 12).

A total of 625 juvenile steelhead entered the forebay of Lower Monumental Dam, 93% of these fish (581) subsequently passed the dam. Eighty percent of juvenile steelhead first approached the spillway portion of the dam, with the majority of these (38%) approaching at Spillbay 8 (Figure 13). Passage-route distribution was 62, 32, and 4% through the spillway, JBS, and turbines, respectively. The remaining 2% passed via undetermined routes. The largest proportion of juvenile steelhead passed through Spillbay 8 (35%; Figure 14).

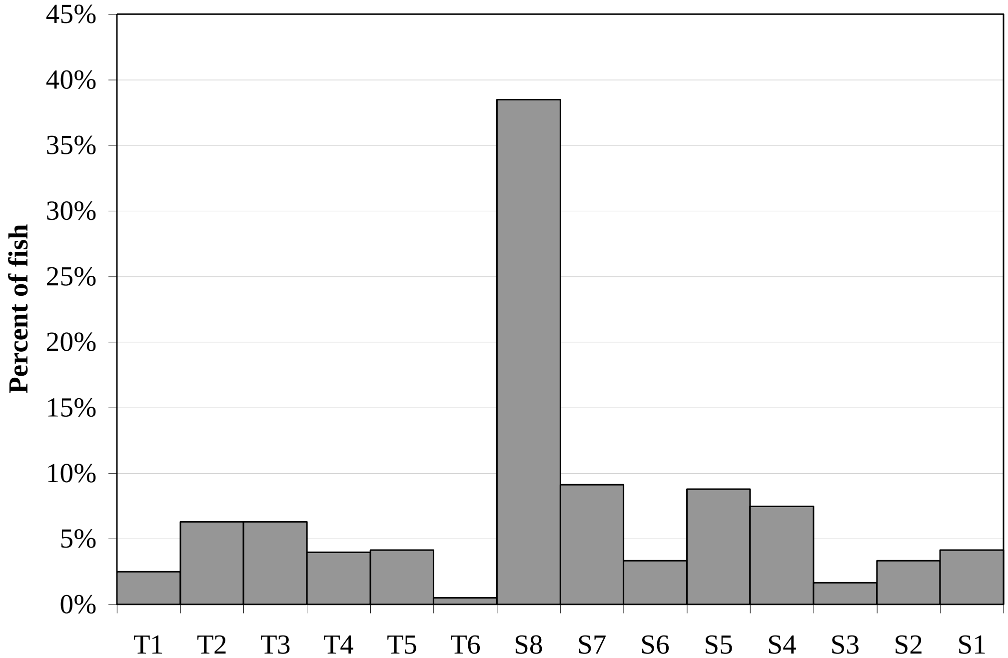

Figure 11. Horizontal approach distribution for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam based on first detection at individual turbine intakes (T) or spillbays (S), 2007.

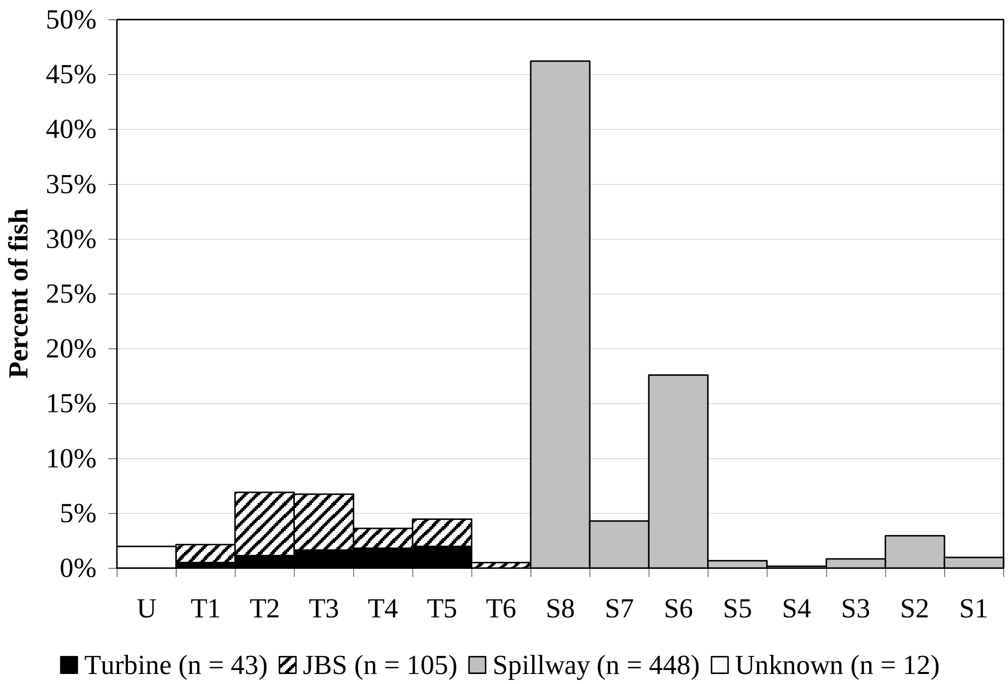

Figure 12. Passage route distribution for radio-tagged yearling Chinook salmon released upstream from Lower Monumental Dam, 2007. Passage locations are U = unidentified route, T = individual turbine intakes, and S = individual spillbays.

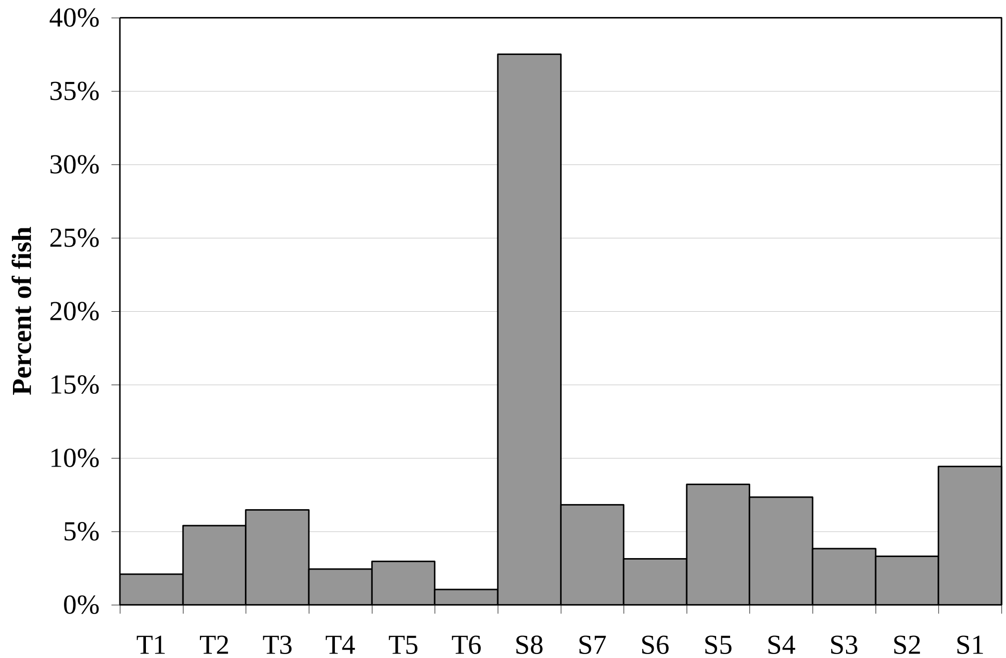

Figure 13. Horizontal approach distribution for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam based on first detections at either individual turbine intakes (T) or spillbays (S), 2007.

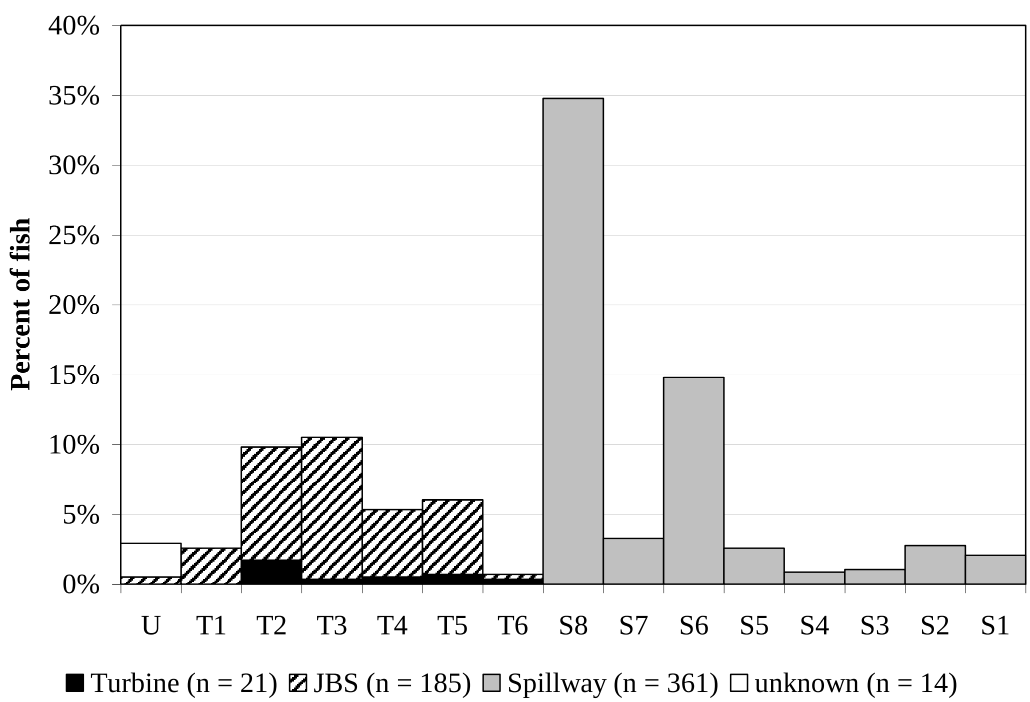

Figure 14. Passage distribution for radio-tagged juvenile steelhead released upstream from Lower Monumental Dam, 2007. Passage locations are U = unidentified route, T = individual turbine intakes, and S = individual spillbays.

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	0.709	0.670-0.749	0.898	0.873-0.923
FPE	0.928	0.914-0.942	0.963	0.952-0.974
Spill Efficiency	0.752	0.728-0.776	0.673	0.608-0.665
Spill effectiveness (mean spill of 26%)	2.76 to 1	2.676-2.851	2.45 to 1	2.338-2.559

Tailrace Egress

Overall median tailrace egress time was 7.2 min (95% CI, 6.5-7.9) for yearling Chinook salmon and ranged from 2 to 11,011 min (Table 10). Median tailrace egress time was longer for yearling Chinook that passed through the powerhouse (JBS; 12.8 min; 95% CI, 0.5-25.0: turbines; 11.9 min, no 95% CI calculated) than for those that passed through the spillway (5.7 min; 95% CI, 5.1-6.2; $P = 0.003$). 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 8.2 min (95% CI, 6.9-9.6) and ranged from 1 to 8,181 min (Table 11). Median tailrace egress time was significantly longer for juvenile steelhead that passed through the powerhouse (JBS 12.0 min, 95% CI 8.8-15.1; turbines 11.8 min, no 95% CI calculated) than for those that passed through the spillway (5.9 min, 95% CI, 5.1-6.6; $P < 0.001$). The longer egress times for JBS passage were likely related to the proximity of the powerhouse and strong clockwise eddy in the tailrace.

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, 2007.

	Yearling Chinook tailrace egress time (min)			
Passage percentile	JBS	Spillway	Turbine	Overall
n	102	443	41	586
10th	7.0	3.7	7.3	3.9
20th	7.9	4.3	8.3	4.5
30th	9.1	4.7	9.0	5.1
40th	10.3	5.1	9.6	5.9
50th	12.8	5.7	11.9	7.2
60th	15.5	7.0	12.4	9.0
70th	23.9	8.9	16.1	11.2
80th	38.7	12.1	19.6	16.4
90th	138.9	34.8	55.0	49.9
95th	831.0	223.9	624.7	347.8
minimum	5.0	2.0	6.0	2.0
mean	304.5	232.9	561.2	251.1
median	12.8	5.7	11.9	7.2
mode	7.9	4.9	N/A	4.9
maximum	10,142	11,011	10,763	11,011

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, 2007.

	Juvenile steelhead tailrace egress time (min)			
Passage percentile	JBS	Spillway	Turbine	Overall
n	184	337	21	542
10th	6.9	3.9	7.6	4.2
20th	7.9	4.3	9.2	4.9
30th	9.0	4.8	10.9	5.7
40th	10.0	5.2	12.3	6.9
50th	12.0	5.9	13.3	8.2
60th	15.1	7.1	14.7	10.1
70th	18.6	8.9	23.1	13.8
80th	27.6	14.4	41.4	20.5
90th	189.3	36.0	135.0	54.9
95th	618.3	146.8	348.0	330.6
minimum	5.4	1.1	11.8	1.1
mean	112.6	88.6	11.8	106.4
median	12.0	5.9	11.8	8.2
mode	9.6	4.3	N/A	6.3
maximum	4,029	8,181	11.8	8,181

Survival Estimates

Detection Probability

Detection histories used for survival estimates are presented in Appendix Tables A1-A11. Detection probabilities at the primary survival array, 16 km downstream from Lower Monumental Dam, are presented for each species in Appendix Table A12. 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 0.930 (geomean; SE = 0.016; 95% CI, 0.898-0.964; Table 12). Relative concrete survival (all passage routes combined to approximately 1 km downstream from the dam) for yearling Chinook salmon was estimated at 0.952 (geomean; SE = 0.011; 95% CI, 0.930-0.975).

For juvenile steelhead, relative dam survival was estimated at 0.888 (geomean; SE = 0.017; 95% CI, 0.854-0.923; Table 13). Relative concrete survival was estimated at 0.955 for juvenile steelhead (geomean; SE = 0.013; 95% CI, 0.927-0.983).

Route-Specific Survival

For radio-tagged yearling Chinook salmon, relative survival (treatment/reference) was estimated at 0.959 (SE = 0.011; 95% CI, 0.937-0.982) for fish passing via the spillway, 0.941 (SE = 0.029; 95% CI, 0.883-0.998) for those passing via the JBS, and 0.909 (SE = 0.051; 95% CI, 0.808-1.010) for those passing via turbines (Table 12). For yearling Chinook salmon passing through Spillbay 8, relative survival was estimated at 0.976 (SE = 0.014; 95% CI, 0.948-1.005).

For radio-tagged juvenile steelhead passing Lower Monumental Dam, relative survival was estimated at 0.939 (SE = 0.017; 95% CI, 0.905-0.975) for fish passing via the spillway and 0.986 (SE = 0.016; 95% CI, 0.955-1.018) for fish passing via the JBS (Table 13). For juvenile steelhead passing through Spillbay 8, survival was estimated at 0.923 (SE = 0.022; 95% CI, 0.879-0.986).

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), 2007. Standard errors are in parenthesis.

	Yearling Chinook salmon				
	Treatment		Reference		Relative survival
	n	Survival	n	Survival	
Project survival					
Dam survival	616	0.902 (0.015)	637	0.973 (0.007)	0.930 (0.016)
Concrete survival	596	0.927 (0.011)	637	0.973 (0.007)	0.952 (0.011)
Route-specific survival					
Spillway survival	448	0.934 (0.011)	637	0.973 (0.007)	0.959 (0.011)
JBS survival	105	0.914 (0.027)	637	0.973 (0.007)	0.941 (0.029)
Turbine survival	43	0.884 (0.049)	637	0.973 (0.007)	0.909 (0.051)
Spillbay 8	281	0.951 (0.015)	637	0.973 (0.007)	0.976 (0.014)

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), 2007. Standard errors are in parenthesis.

	Juvenile steelhead				
	Treatment		Reference		
	n	Survival	n	Survival	Relative survival
Project survival					
Dam survival	621	0.868 (0.016)	646	0.976 (0.006)	0.888 (0.017)
Concrete survival	566	0.933 (0.013)	646	0.976 (0.006)	0.955 (0.013)
Route-specific survival					
Spillway survival	361	0.919 (0.015)	646	0.976 (0.006)	0.939 (0.017)
JBS survival	185	0.964 (0.014)	646	0.976 (0.006)	0.986 (0.016)
Spillbay 8	202	0.902 (0.021)	646	0.976 (0.006)	0.923 (0.022)

Avian Predation

A total of 39 tags from yearling Chinook salmon released at Lower Monumental Dam during 2007 were recovered from avian colonies on Crescent or Foundation Island in the McNary Dam Reservoir, Columbia River (Table 14). The majority of these fish (47-55%) 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 array (16 km downstream from Lower Monumental Dam) prior to being recovered from Crescent Island.

A total of 104 tags from juvenile steelhead released at Lower Monumental Dam during 2007 were recovered from avian colonies on Crescent or Foundation Island (Table 15). The majority of these fish (58-61%) were last detected between Ice Harbor Dam and the mouth of the Snake River. Only two tags from a juvenile steelhead were last detected above our primary survival array (16 km downstream from Lower Monumental Dam) prior to being recovered from Crescent Island.

Table 14. Number and proportion 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, 2007. Recoveries are grouped by location of the last telemetry detection.

	Number and proportion (%) of yearling Chinook tags recovered on avian colonies	
Last location of telemetry detection	Treatment	Reference
Upstream of Lower monumental Dam forebay	0 (0.0)	N/A
Lower Monumental Dam forebay	0 (0.0)	N/A
Ice Harbor Dam pool	1 (0.1)	5 (0.8)
Ice Harbor forebay	1 (0.1)	1 (0.2)
Ice Harbor Dam to Snake River mouth	8 (1.2)	12 (1.8)
McNary Dam pool	7 (1.0)	4 (0.6)
McNary Dam forebay	0 (0.0)	0 (0.0)
Total	17 (2.5)	22 (3.3)

Table 15. Number and proportion 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, 2007. Recoveries are grouped by location of the last telemetry detection.

	Number and proportion (%) of juvenile steelhead tags recovered on avian colonies	
Last location of telemetry detection	Treatment fish	Reference fish
Upstream of Lower monumental Dam forebay	2 (0.3)	N/A
Lower Monumental Dam forebay	0 (0.0)	N/A
Ice Harbor Dam pool	14 (2.1)	12 (1.8)
Ice Harbor forebay	6 (0.9)	8 (1.2)
Ice Harbor Dam to Snake River mouth	12 (1.8)	15 (2.3)
McNary Dam pool	21 (3.1)	12 (1.8)
McNary Dam forebay	1 (0.1)	1 (0.2)
Total	56 (8.4)	48 (7.4)

DISCUSSION

This report is the second consecutive year of evaluating behavior and survival for volitionally passing radio-tagged juvenile steelhead and yearling Chinook salmon at Lower Monumental Dam. These two years had considerably different flow conditions during spring, with high flows in 2006 and low flows in 2007. Snake River flows in spring 2007 at Lower Monumental Dam averaged 79 kcfs, or 74% of the 10-year average (107 kcfs from 1996 through 2005). In contrast, Snake River flows in spring 2006 at the dam averaged 139 kcfs, or 130% of the same 10-year average (Hockersmith et al. 2008). Although flow conditions were vastly different between years, Lower Monumental Dam project operations were relatively similar between years, with 26% of the river spilled in 2006 and 27% in 2007. In addition to flow differences between years, water clarity also differed in the forebay of Lower Monumental Dam and averaged 0.4 m and 1.1 m in 2006 and 2007, respectively.

During both years the majority of our radio-tagged fish (yearling Chinook salmon and juvenile steelhead combined) approached and passed the dam in the thalweg of the river near Spillbay 8. Johnson et al. (1998), using hydroacoustics, observed similar horizontal distribution patterns, where smolts approached Lower Monumental Dam at the midpoint of the thalweg. We observed higher proportion of each species passing via the spillway during the low flow conditions in 2007 compared to the higher flow conditions in 2006 (yearling Chinook salmon 74% vs. 58%; juvenile steelhead 62% vs. 48%) even though the proportion of river spilled was almost identical between years (27% vs. 26%).

Median forebay residence time was the same for yearling Chinook salmon between low flow conditions in 2007 and the higher flow conditions in 2006 (2.5 hours). However, median forebay residence time for juvenile steelhead was more than three times longer under the low flow conditions in 2007 than under the high flow conditions in 2006 (17.8 vs. 5.5 hours).

We did not observe differences in median tailrace egress time among species or flow conditions between the two study years . In 2007 and 2006, respective tailrace egress time was 6 and 7 minutes for yearling Chinook and 6 and 8 minutes for juvenile steelhead.

Spill effectiveness was higher for both species during the low flows in 2007 than during the higher flows in 2006 (yearling Chinook salmon 2.9 vs. 2.3; juvenile steelhead 2.4 vs.1.9).

Relative dam and concrete survival for yearling Chinook salmon were slightly higher in 2007 compared to 2006 (dam survival 0.930 vs. 0.924; concrete survival 0.952 vs. 0.943). Relative spillway survival for yearling Chinook salmon was slightly higher (0.959 vs. 0.925) in 2007 compared to 2006. However, relative bypass survival for yearling Chinook salmon was slightly lower in 2007 compared to 2006 (0.941 vs. 0.987).

Relative dam, concrete, and spillway survival for juvenile steelhead were significantly lower in 2007 compared to 2006 (two sample *t*-test) (dam survival 0.888 vs. 0.980 ($P<0.001$); concrete survival 0.955 vs.1.000 ($P=0.007$); spillway survival 0.939 vs. 0.999 ($P=0.007$)).

Forebay delay and survival for yearling Chinook salmon did not appear related to river flow conditions at Lower Monumental Dam, since we observed similar results between high and low flow conditions. However for juvenile steelhead, forebay delay was longer and survival was lower during the low-flow conditions in 2007 compared to the higher flows in 2006.

Smith (1974) and Beeman and Maule (2006) reported differences in migrational depth among species of juvenile anadromous salmonids. Yearling Chinook salmon migrated in deeper water during the day and more shallow water at night, while juvenile steelhead migrated in shallow water during the day and deeper water at night. Thus, the lower survival for juvenile steelhead in 2007 may have been due to a combination of shallow migrational depth during the day, longer forebay delay, and greater water clarity in 2007, all resulting in increased vulnerability to predation.

Hockersmith et al. (2005) reported lower survival at Lower Monumental Dam associated with longer forebay residence times, and during periods of no spill compared to periods of spill. Vigg and Burley (1991) observed a correlation between survival and exposure time to predators for juvenile salmonids. Collis et al. (2001) and Ryan et al. (2003) reported significantly higher vulnerability to avian predation for juvenile steelhead compared to yearling Chinook salmon. Currently, there is no active monitoring of avian predation activities at Lower Monumental Dam; however, we observed more avian predation activity in both the forebay and tailrace during 2007 than in 2006. The lower flows and below-average water turbidity in 2007 may have influenced the predator/prey dynamics for our radio-tagged steelhead by increasing exposure times and opportunity due to increased water clarity (Gregory and Levings 1998) resulting in lower survival.

To increase the proportion of fish passing through the spillway, USACE engineers and biologists developed the RSW, which provides surface-oriented spillway passage. RSWs were installed at Lower Granite Dam in 2001 and at 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). The RSW that will be operational at Lower Monumental Dam in 2008 is expected to provide improvements in passage behavior and survival similar to those observed at Lower Granite and Ice Harbor Dams. 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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REFERENCES

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Transactions of the American Fisheries Society 27:128-136.

Axel, G. A., E. E. Hockersmith, D. A. Ogden, B. J. Burke, K. Frick, and B. P. Sandford. 2007. Passage behavior and survival for radio-tagged yearling Chinook salmon and steelhead at Ice Harbor Dam, 2005. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Beeman, J. W., C. Grant, and P. V. Haner. 2004. Comparison of three underwater antennas for use in radiotelemetry. North American Journal of Fisheries Management 24:275-281.

Beeman, J. W., and A. G. Maule. 2006. Migration depths of juvenile Chinook salmon and steelhead relative to total dissolved gas supersaturation in a Columbia River reservoir. Transactions of the American Fisheries Society 135:584-594.

Collis, K., D. D. Roby, D. P. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001. Colonial waterbird predations on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Cormack, R. M. 1964. Estimates of survival from sightings of marked animals. Biometrika 51:429-438.

Gregory, R. S. and C. D. Levings. 1998. Turbidity reduces predation of migrating juvenile pacific salmon. Transactions of the American Fisheries Society 127:275-285.

Hockersmith, E. E., G. A. Axel, M. B. Eppard, D. A. Ogden, and B. P. Sandford. 2005. Passage behavior and survival for hatchery yearling Chinook salmon at Lower Monumental Dam, 2004. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hockersmith, E. E., G. A. Axel, D. A. Ogden, B. J. Burke, K. E. Frick, B. P. Sandford, and R. F. Absolon. 2008. Passage behavior and survival for radio-tagged yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2006. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Holmes, H. B. 1952. Loss of salmon fingerlings in passing Bonneville Dam as determined by marking experiments. Unpublished manuscript, U.S. Bureau of Commercial Fisheries Report to U.S. Army Corps of Engineers, Northwestern Division, Portland, Oregon.

Johnson, G. E., N. S. Adams, R. L. Johnson, D. W. Rondorf, D. D. Dauble, and T. Y. Barila. 2000. Evaluation of the prototype surface bypass for salmonid smolts in spring 1996 and 1997 at Lower Granite Dam on the Snake River, Washington. Trans. Am. Fish. Soc. 129:381-397.

Johnson, G. E., R. A. Moursund, and J. R. Skalski. 1998. Fixed location hydroacoustic evaluation of spill effectiveness at Lower Monumental Dam in 1997. Report of Pacific Northwest National Laboratories to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometika 52:225-247.

Knight, A. E., G. Marancik, and J. B. Layzer. 1977. Monitoring movements of juvenile anadromous fish by radiotelemetry. Progressive Fish-Culturist 39:148-150.

Marsh, D. M., G. M. Matthews, S. Achord, T. E. Ruehle, and B. P. Sandford. 1999. Diversion of salmonid smolts tagged with passive integrated transponders from an untagged population passing through a juvenile collection system. North American Journal of Fisheries Management 19:1142-1146.

Muir, W. D., S. G. Smith, J. G. Williams, and B. P. Sandford. 2001. Survival of juvenile salmonids passing through bypass systems, turbines, and spillways with and without flow deflectors at Snake River Dams. North American Journal of Fisheries Management 21:135-146.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Netboy, A. N. 1980. Columbia River salmon and steelhead trout: their fight for survival. University of Washington Press, Seattle.

NMFS (National Marine Fisheries Service). 1991. Endangered and threatened species: endangered status for Snake River sockeye salmon. Final Rule. Federal Register 56:224 (20 November 1991):58619-58624.

NMFS (National Marine Fisheries Service). 1992. Endangered and threatened species: threatened status for Snake River spring/summer Chinook salmon, threatened status for Snake River fall Chinook salmon. Final Rule. Federal Register 57:78 (22 April 1992):14563-14663.

NMFS (National Marine Fisheries Service). 1995. Reinitiation of consultation on 1994-1998 operation of the federal Columbia River power system and juvenile transportation program in 1995 and future years. Endangered Species Act, Section 7 consultation, Biological opinion. (Available from NMFS Northwest Regional Office, Hydropower Program, 525 NE Oregon Street, Suite 500, Portland, OR 97232.)

NMFS (National Marine Fisheries Service). 1998. Endangered and threatened species: threatened status for two ESUs for steelhead in Washington, Oregon, and California. Final Rule. Federal Register 63:53 (19 March 1998):13347-13371.

NMFS (National Marine Fisheries Service). 1999. Endangered and threatened species: threatened status for three Chinook salmon ESUs in Washington and Oregon, and endangered status of one Chinook salmon ESU in Washington. Final Rule. Federal Register 64:56(24 March 1999):14307-14328.

NMFS (National Marine Fisheries Service). 2000. Reinitiation of consultation on operation of the Federal Columbia River power system, including the juvenile fish transportation program and 19 Bureau of Reclamation projects in the Columbia Basin. Endangered Species Act - Section 7 Consultation, Biological Opinion. www.nwr.noaa.gov/1hydrop/hydroweb/docs/Final/2000Biop.html (April 2005).

Ogden, D. A., E. E. Hockersmith, G. A. Axel, B. J. Burke, K. Frick, and B. P. Sandford. 2007. Passage behavior and survival for radio-tagged subyearling Chinook salmon at Ice Harbor Dam, 2005. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Northwestern Division, Walla Walla, Washington. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Peven, C., A. Giorgi, J. Skalski, M. Langeslay, A. Grassell, S. G. Smith, T. Counihan, R. Perry, S. Bickford. 2005. Guidelines and recommended protocols for conducting, analyzing, and reporting juvenile salmonid survival studies in the Columbia River Basin. Available at www.pnamp.org//web/workgroups/FPM/meetings/2007_0524/Guid__Sug_Prot_final.pdf (June 2007).

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, J. M. Sprando, G. T. George, N. S. Adams, and D. W. Rondorf. 2003. Behavior of radio-tagged juvenile Chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, Washington, 2002. Annual report to the U. S. Army Corps of Engineers, Contract W68SBV00104592, Walla Walla, Washington.

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, A. D. Cochran, Theresa K. Nation, J. M. Sprando, J. L. Schei, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2004. Behavior and survival of radio-tagged juvenile Chinook salmon and steelhead relative to the performance of a removable spillway weir at Lower Granite Dam, Washington, 2003. Annual report the U.S. Army Corps of Engineers, Contract W68SBV00104592, Walla Walla, Washington.

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River Estuary, 1998-2000. . Transactions of the American Fisheries Society 132:275-288.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J. R., R. Townsend, J. Lady, A. E. Giorgi, J. R. Stevenson, and R. D. McDonald. 2002. Estimating route-specific passage and survival probabilities at a hydroelectric project from smolt radiotelemetry studies. Canadian Journal of Fisheries and Aquatic Sciences 59:1385-1393.

Smith, J. R. 1974. Distribution of seaward-migrating Chinook salmon and steelhead trout in the Snake River above Lower Monumental Dam. Marine Fisheries Review 36-8:42-45.

Smith, S. G., J. R. Skalski, W. Schlechte, A. Hoffmann, and V. Cassen. 1994. Statistical survival analysis of fish and wildlife tagging studies. SURPH.1 Manual. (Available from University of Washington, School of Aquatic & Fisheries Science, 1325 Fourth Avenue, Suite 1820, Seattle, WA 98101-2509.)

Snedecor, G. W., and W. G. Cochran. 1980. Statistical Methods. 7th Ed. Iowa St. Univ. Press, Ames, IA. 507 pp.

Vigg, S., and C. C. Burley. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 48:2491-2498.

Whitney, R. R., L. Calvin, M. Erho, and C. Coutant. 1997. Downstream passage for salmon at hydroelectric projects in the Columbia River Basin: development, installation, and evaluation. U.S. Department of Energy, Northwest Power Planning Council, Portland, Oregon. Report 97-15. 101 p.

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 and juvenile steelhead 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 616 radio-tagged yearling Chinook salmon released above Lower Monumental Dam and detected on the forebay entrance array, 557 (90.4% of those released) were detected either at or below our primary survival array 16 km downstream from Lower Monumental Dam. Of the 637 radio-tagged yearling Chinook salmon released into the tailrace of Lower Monumental Dam, 618 (97.0% of those released) were detected either at or below our primary survival array 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 621 radio-tagged steelhead released above Lower Monumental Dam and detected on the forebay entrance array, 538 (86.6% of those released) were detected either at or below our primary survival array 16 km downstream from Lower Monumental Dam. Of the 646 radio-tagged steelhead released into the tailrace of Lower Monumental Dam, 631 (97.7% of those released) were detected either at or below our primary survival array 16 km downstream from Lower Monumental Dam. Capture histories for survival analysis of juvenile steelhead are presented in Appendix Tables A7-A11.

The detection probability for fish used in survival analysis was greater than 0.980 overall (Appendix Table A12). 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 2007. 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 (616)	0	0	59
	1	0	55
	0	1	0
	1	1	502
Reference group (637)	0	0	19
	1	0	60
	0	1	11
	1	1	547

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 2007. 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 (596)	0	0	43
	1	0	56
	0	1	0
	1	1	497
Reference group (637)	0	0	19
	1	0	60
	0	1	11
	1	1	547

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 2007. 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 (448)	0	0	29
	1	0	34
	0	1	0
	1	1	385
Reference group (637)	0	0	19
	1	0	60
	0	1	11
	1	1	547

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 2007. 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 (105)	0	0	9
	1	0	18
	0	1	0
	1	1	78
Reference group (637)	0	0	19
	1	0	60
	0	1	11
	1	1	547

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 2007. 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 (43)	0	0	5
	1	0	4
	0	1	0
	1	1	34
Reference group (637)	0	0	19
	1	0	60
	0	1	11
	1	1	547

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 2007. 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 (281)	0	0	14
	1	0	21
	0	1	0
	1	1	246
Reference group (637)	0	0	19
	1	0	60
	0	1	11
	1	1	547

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 2007. 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 (621)	0	0	83
	1	0	94
	0	1	3
	1	1	441
Reference group (646)	0	0	15
	1	0	58
	0	1	1
	1	1	572

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 2007. 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 (566)	0	0	40
	1	0	90
	0	1	3
	1	1	433
Reference group (646)	0	0	15
	1	0	58
	0	1	1
	1	1	572

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 2007. 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 (361)	0	0	31
	1	0	51
	0	1	2
	1	1	277
Reference group (646)	0	0	15
	1	0	58
	0	1	1
	1	1	572

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 2007. 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 (185)	0	0	7
	1	0	36
	0	1	1
	1	1	141
Reference group (646)	0	0	15
	1	0	58
	0	1	1
	1	1	572

Appendix Table A11. Detection histories of radio-tagged juvenile steelhead released above (treatment) and below (reference) Lower Monumental Dam to evaluate Spillbay 8 passage survival in 2007. The primary survival array was 16 km downstream from the dam 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 (202)	0	0	15
	1	0	27
	0	1	1
	1	1	159
Reference group (646)	0	0	15
	1	0	58
	0	1	1
	1	1	572

Appendix Table A12. 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, 2007.

Release group	Detection at primary array and below	Detection below primary array	Detection probability
Yearling Chinook salmon			
Treatment	507	508	0.998
Reference	547	558	0.980
Totals	1,054	1,056	0.989
Juvenile steelhead			
Treatment	445	448	0.993
Reference	572	573	0.998
Totals	1,017	1,021	0.996

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 array (16 km downstream from the dam) were examined to determine if groups were evenly mixed and travel together through downstream reaches (Appendix Tables A13 and A14). Mixing was compared for specific percentiles (10th, 50th, 90th) of the passage distribution with t tests for differences in passage distributions (Tables A15 and A16). 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 array showed statistically significant differences for both species between treatment and reference groups used to calculate relative survival estimates (Appendix Tables A15 and A16). However the biological significance is small (-1.5 and -4.0 hours for yearling Chinook salmon and steelhead, respectively) and is partly explained by the differential passage at Lower Monumental Dam of treatment (continuous) and control (systematically for six hours in daylight and darkness). We concluded the overall survival estimates were not biased regarding mixing through the common reach.

Appendix Table A13. Differences in passage timing at the primary survival array (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 2007. Standard errors are in parenthesis.

		Percentile		
Date	n	10th	50th	90th
2 May	40	-8.1	-5.9	2.4
3 May	44	0.9	4.8	6.7
4 May	39	-4.2	1.2	-2.5
5 May	47	3.1	-1.5	0.4
6 May	48	0.8	-4.8	-3.9
7 May	57	3.4	-1.6	-5.9
8 May	61	1.9	-3.2	-3.3
9 May	55	4.4	-1.3	-3.4
10 May	51	5.3	-3.0	-0.5
11 May	50	1.6	1.1	-0.9
12 May	47	-1.6	-4.7	1.2
13 May	49	4.4	3.2	0.3
14 May	51	0.2	0.1	-0.3
15 May	48	0.5	1.8	2.7
16 May	49	1.6	0.1	2.6
17 May	42	-1.1	-6.3	-1.1
18 May	53	4.8	-1.4	-0.1
19 May	44	7.5	1.0	1.0
20 May	51	1.0	3.9	9.4
21 May	56	2.0	1.1	4.6
22 May	47	1.0	-0.6	-2.1
23 May	47	-0.2	-8.2	1.5
24 May	35	-0.2	-5.9	0.9
25 May	47	-0.3	-5.1	-3.4
Mean		1.2 (0.7)	-1.5 (0.7)	0.3 (0.7)

Appendix Table A14. Differences in passage timing at the primary survival array (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 2007. Standard errors are in parenthesis.

		Percentile		
Date	n	10th	50th	90th
2 May	32	-6.2	-13.1	-3.7
3 May	41	1.1	0.1	-0.8
4 May	36	-7.1	-1.0	-1.4
5 May	59	1.0	1.2	2.3
6 May	64	0.3	-6.2	-0.3
7 May	43	1.3	-0.3	-5.5
8 May	54	-0.4	-2.8	-1.7
9 May	43	2.6	-3.3	0.9
10 May	57	-0.6	-5.7	-0.6
11 May	55	1.0	-2.5	-0.5
12 May	62	-0.9	-8.2	-1.7
13 May	45	2.8	8.6	0.0
14 May	51	-1.0	-8.4	1.2
15 May	47	-0.5	0.3	2.1
16 May	48	-0.8	-10.8	-7.4
17 May	37	-0.7	-10.1	-9.5
18 May	54	2.8	-1.6	-0.8
19 May	35	1.5	-7.2	-14.1
20 May	49	3.9	-6.2	0.1
21 May	48	6.4	-3.4	-1.5
22 May	50	-1.5	-6.4	0.3
23 May	40	0.0	-4.9	-7.8
24 May	47	1.4	-0.4	0.7
25 May	46	1.3	-3.5	2.8
Mean		0.3 (0.6)	-4.0 (1.0)	-2.0 (0.8)

Appendix Table A15. Mean difference and tests of homogeneity of passage timing at the primary survival array (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 2007. Significant differences in passage timing among tests was determined for $\alpha = 0.05$.

Passage percentile	Mean difference in timing (hours)	*t*	df	*P*
10^{th}	1.2	1.83	23	0.080
50^{th}	-1.5	-2.07	23	0.050
90^{th}	0.3	0.37	23	0.718

Appendix Table A16. Mean difference and tests of homogeneity of passage timing at the primary survival array (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 2007. Significant differences in passage timing among tests was determined for $\alpha = 0.05$.

Passage percentile	Mean difference in timing (hours)	*t*	df	*P*
10^{th}	0.3	0.56	23	0.583
50^{th}	-4.0	-4.20	23	<0.001
90^{th}	-2.0	-2.33	23	0.029

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 12 g or larger were used. Tagging comprised the period between the 3rd and 99th passage percentile for yearling Chinook salmon and between the 1st and 97th passage percentile for juvenile steelhead at Lower Monumental Dam in 2007 (Figure 3). Overall mean fork lengths for yearling Chinook salmon were 145.0 mm (SD = 11.0) and 145.5 mm (SD = 12.2) for fish released into the forebay and tailrace of Lower Monumental Dam, respectively (Table 2). Overall mean fork lengths for juvenile steelhead were 218.1 mm (SD = 20.5) and 219.8 mm (SD = 21.1) 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 2007, 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 5, 7, 4, and 2 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 A17). 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 A17. 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	5	7	11	4	2	6
Proportion of total released (%)	0.8	1.1	1.0	0.6	0.0	0.5
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 2,662 tags allocated for the evaluation of Lower Monumental Dam spillway survival 33 (1.2%) could not be activated and were therefore not used. A total of 2,629 tags were implanted in either hatchery yearling Chinook salmon of juvenile steelhead of which 2 (0.1%) were not working 24 h after tagging. Of the live fish released with functional tags, a total of 8 fish (0.3% of those released) (4 yearling Chinook salmon and 4 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 76 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. Four tags (5.3%) failed prior to the preprogrammed shut down after 10 d (Appendix Table A18). Of these, no tags failed in less than 6 d. Ninety-percent of the fish had travel times to the primary array in less than 4 d and the maximum travel time from release to our primary survival array was 9.2 d (Appendix Table A19). Although we documented transmitter failures during our study, the short travel times to our survival array and the relatively low failure rate were such that they would not have significantly changed our findings.

Appendix Table A18. Transmitter battery life testing.

Tags (n)	Tags (%)	Battery life (d)
0	0.0	1
0	0.0	2
0	0.0	3
0	0.0	4
0	0.0	5
1	1.3	6
1	1.3	7
0	0.0	8
2	2.6	9
72	94.7	10

Appendix Table A19. 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, 2007.

	Travel time (d) to primary survival array by release location and species			
	Yearling Chinook salmon		Juvenile steelhead	
Percentile	Forebay	Tailrace	Forebay	Tailrace
10	0.5	0.1	0.8	0.1
20	0.6	0.1	1.0	0.1
30	0.7	0.1	1.2	0.1
40	0.8	0.1	1.5	0.1
50	0.8	0.1	1.7	0.1
60	0.9	0.1	2.0	0.1
70	1.0	0.1	2.3	0.1
80	1.1	0.2	2.9	0.2
90	1.3	0.2	3.8	0.3
Max	7.4	0.6	9.2	3.5
Time > 6 d	1 (0.2%)	0 (0.0%)	10 (0.2%)	0 (0.0%)
n	564	607	539	630

APPENDIX B

Grouping of Treatment and Reference Release Groups for Estimating Survival

Appendix Table B1. Daily dam survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
1-2 May	36	0.767 (0.077)	16	1.010 (0.012)	0.759 (0.077)
3 May	25	0.840 (0.073)	25	0.920 (0.054)	0.913 (0.096)
4 May	23	0.913 (0.059)	16	1.000 (0.000)	0.913 (0.059)
5 May	20	0.900 (0.067)	31	1.005 (0.005)	0.896 (0.067)
6 May	24	0.917 (0.056)	27	0.963 (0.036)	0.952 (0.069)
7 May	26	0.923 (0.052)	32	1.000 (0.000)	0.923 (0.052)
8 May	35	0.914 (0.047)	30	0.967 (0.033)	0.946 (0.059)
9 May	28	0.964 (0.035)	29	0.931 (0.047)	1.036 (0.065)
10 May	27	0.963 (0.036)	26	0.962 (0.038)	1.002 (0.054)
11 May	23	1.000 (0.000)	27	1.000 (0.000)	1.000 (0.000)
12 May	26	0.885 (0.063)	25	0.960 (0.039)	0.921 (0.075)
13 May	30	0.867 (0.062)	26	0.885 (0.063)	0.980 (0.099)
14 May	29	0.862 (0.064)	28	0.929 (0.049)	0.928 (0.084)
15 May	26	0.923 (0.052)	24	1.000 (0.000)	0.923 (0.052)
16 May	24	0.917 (0.056)	28	0.964 (0.035)	0.951 (0.068)
17 May	17	0.941 (0.057)	28	0.978 (0.038)	0.962 (0.069)
18 May	31	0.903 (0.053)	26	0.962 (0.038)	0.939 (0.066)
19 May	24	0.792 (0.083)	28	1.005 (0.005)	0.788 (0.083)
20 May	27	0.963 (0.036)	28	0.978 (0.038)	0.985 (0.053)
21 May	29	0.966 (0.034)	28	1.000 (0.000)	0.966 (0.034)
22 May	21	1.000 (0.000)	26	1.000 (0.000)	1.000 (0.000)
23 May	21	0.952 (0.047)	27	1.000 (0.000)	0.952 (0.047)
24 May	19	0.684 (0.107)	25	0.929 (0.056)	0.737 (0.123)
25-27May	25	0.957 (0.043)	31	1.000 (0.000)	0.957 (0.043)
Overall	616	0.902 (0.015)	637	0.973 (0.007)	0.930 (0.016)

Appendix Table B2. Daily concrete survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
1-2 May	32	0.875 (0.059)	16	1.010 (0.012)	0.867 (0.059)
3 May	25	0.840 (0.073)	25	0.920 (0.054)	0.913 (0.096)
4 May	25	0.920 (0.054)	16	1.000 (0.000)	0.920 (0.054)
5 May	19	0.947 (0.051)	31	1.005 (0.005)	0.943 (0.051)
6 May	24	0.917 (0.056)	27	0.963 (0.036)	0.952 (0.069)
7 May	25	0.960 (0.039)	32	1.000 (0.000)	0.960 (0.039)
8 May	33	0.939 (0.042)	30	0.967 (0.033)	0.972 (0.054)
9 May	29	0.966 (0.034)	29	0.931 (0.047)	1.037 (0.064)
10 May	25	0.960 (0.039)	26	0.962 (0.038)	0.998 (0.056)
11 May	23	1.000 (0.000)	27	1.000 (0.000)	1.000 (0.000)
12 May	25	0.880 (0.065)	25	0.960 (0.039)	0.917 (0.077)
13 May	27	0.926 (0.050)	26	0.885 (0.063	1.047 (0.094)
14 May	29	0.862 (0.064)	28	0.929 (0.049)	0.928 (0.084)
15 May	25	0.920 (0.054)	24	1.000 (0.000)	0.920 (0.054)
16 May	23	0.957 (0.043)	28	0.964 (0.035)	0.992 (0.057)
17 May	18	0.944 (0.054)	28	0.978 (0.038)	0.966 (0.066)
18 May	30	0.933 (0.046)	26	0.962 (0.038)	0.971 (0.061)
19 May	21	0.905 (0.064)	28	1.005 (0.005)	0.901 (0.064)
20 May	26	1.000 (0.000)	28	0.978 (0.038)	1.023 (0.039)
21 May	28	0.964 (0.035)	28	1.000 (0.000)	0.964 (0.035)
22 May	21	1.000 (0.000)	26	1.000 (0.000)	1.000 (0.000)
23 May	21	0.952 (0.047)	27	1.000 (0.000)	0.952 (0.047)
24 May	17	0.765 (0.103)	25	0.929 (0.056)	0.823 (0.121)
25-27 May	25	0.920 (0.054)	31	1.000 (0.000)	0.920 (0.054)
Overall	596	0.927 (0.011)	637	0.973 (0.007)	0.952 (0.011)

Appendix Table B3. Daily spillway survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2 May	19	0.842 (0.084)	16	1.010 (0.012)	0.834 (0.083)
3 May	17	0.882 (0.078)	25	0.920 (0.054)	0.959 (0.102)
4 May	19	0.895 (0.070)	16	1.000 (0.000)	0.895 (0.070)
5 May	15	0.933 (0.064)	31	1.005 (0.005)	0.929 (0.064)
6 May	16	0.938 (0.061)	27	0.963 (0.036)	0.974 (0.073)
7 May	24	0.958 (0.041)	32	1.000 (0.000)	0.958 (0.041)
8 May	31	0.936 (0.044)	30	0.967 (0.033)	0.968 (0.056)
9 May	29	0.966 (0.034)	29	0.931 (0.047)	1.037 (0.064)
10 May	18	1.000 (0.000)	26	0.962 (0.038)	1.040 (0.041)
11 May	17	1.000 (0.000)	27	1.000 (0.000)	1.000 (0.000)
12 May	15	0.933 (0.064)	25	0.960 (0.039)	0.972 (0.078)
13 May	13	0.923 (0.074)	26	0.885 (0.063	1.044 (0.112)
14 May	19	0.842 (0.0837)	28	0.929 (0.049)	0.907 (0.102)
15 May	15	0.933 (0.064)	24	1.000 (0.000)	0.933 (0.064)
16 May	16	0.938 (0.061)	28	0.964 (0.035)	0.972 (0.072)
17 May	15	0.933 (0.064)	28	0.978 (0.038)	0.954 (0.075)
18 May	27	0.926 (0.051)	26	0.962 (0.038)	0.963 (0.065)
19 May	15	1.000 (0.000)	28	1.005 (0.005)	0.996 (0.005)
20 May	19	1.000 (0.000)	28	0.978 (0.038)	1.023 (0.039)
21 May	22	0.955 (0.044)	28	1.000 (0.000)	0.955 (0.044)
22 May	17	1.000 (0.000)	26	1.000 (0.000)	1.000 (0.000)
23 May	16	0.938 (0.061)	27	1.000 (0.000)	0.938 (0.061)
24 May	15	0.800 (0.103)	25	0.929 (0.056)	0.861 (0.123)
25-27 May	19	0.947 (0.051)	31	1.000 (0.000)	0.947 (0.051)
Overall	448	0.934 (0.011)	637	0.973 (0.007)	0.959 (0.011)

Appendix Table B4. Daily juvenile bypass system (JBS) survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n		n	Survival	Relative survival
Overall	105	0.914 (0.027)	637	0.973 (0.007)	0.941 (0.029)

Appendix Table B5. Daily turbine passage survival estimates and replicate group sizes for yearling Chinook salmon passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n		n	Survival	Relative survival
Overall	43	0.884 (0.049)	637	0.973 (0.007)	0.909 (0.051)

Appendix Table B6. Daily estimates of survival through Spillbay 8 for yearling Chinook salmon passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n		n	Survival	Relative survival
2 May	12	0.833 (0.108)	16	1.010 (0.012)	0.825 (0.107)
3 May	10	1.000 (0.000)	25	0.920 (0.054)	1.087 (0.064)
4 May	17	0.941 (0.057)	16	1.000 (0.000)	0.941 (0.057)
5 May	11	1.000 (0.000)	31	1.005 (0.005)	0.995 (0.005)
6 May	7	1.000 (0.000)	27	0.963 (0.036)	1.038 (0.039)
7 May	16	1.000 (0.000)	32	1.000 (0.000)	1.000 (0.000)
8 May	14	1.000 (0.000)	30	0.967 (0.033)	1.034 (0.036)
9 May	18	0.944 (0.054)	29	0.931 (0.047)	1.014 (0.077)
10 May	14	1.000 (0.000)	26	0.962 (0.038)	1.040 (0.041)
11 May	11	1.000 (0.000)	27	1.000 (0.000)	1.000 (0.000)
12 May	12	0.917 (0.080)	25	0.960 (0.039)	0.955 (0.092)
13 May	6	0.833 (0.152)	26	0.885 (0.063)	0.942 (0.184)
14 May	13	0.846 (0.100)	28	0.929 (0.049)	0.911 (0.118)
15 May	9	1.000 (0.000)	24	1.000 (0.000)	1.000 (0.000)
16 May	8	1.000 (0.000)	28	0.964 (0.035)	1.037 (0.038)
17 May	10	0.900 (0.095)	28	0.978 (0.038)	0.920 (0.103)
18 May	15	0.933 (0.064)	26	0.962 (0.038)	0.971 (0.077)
19 May	9	1.000 (0.000)	28	1.005 (0.005)	0.996 (0.005)
20 May	14	1.000 (0.000)	28	0.978 (0.038)	1.023 (0.039)
21 May	16	0.938 (0.061)	28	1.000 (0.000)	0.938 (0.061)
22 May	8	1.000 (0.000)	26	1.000 (0.000)	1.000 (0.000)
23 May	10	1.000 (0.000)	27	1.000 (0.000)	1.000 (0.000)
24 May	12	0.750 (0.125)	25	0.929 (0.056)	0.807 (0.143)
25-27 May	9	1.000 (0.000)	31	1.000 (0.000)	1.000 (0.000)
Overall	281	0.951 (0.015)	637	0.973 (0.007)	0.976 (0.014)

Appendix Table B7. Grouping, samples sizes, and estimated dam survival for juvenile steelhead passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
2 May	17	0.882 (0.078)	19	0.895 (0.070)	0.986 (0.117)
3 May	15	1.000 (0.000)	25	1.000 (0.000)	1.000 (0.000)
4 May	16	0.938 (0.061)	21	1.000 (0.000)	0.938 (0.061)
5 May	32	0.921 (0.054)	32	1.000 (0.000)	0.921 (0.054)
6 May	35	0.971 (0.028)	31	0.968 (0.032)	1.004 (0.044)
7 May	18	0.889 (0.074)	27	1.000 (0.000)	0.889 (0.074)
8 May	27	1.000 (0.000)	28	0.964 (0.035)	1.037 (0.038)
9 May	21	0.810 (0.086)	27	0.963 (0.036)	0.841 (0.094)
10 May	31	0.936 (0.044)	28	1.000 (0.000)	0.936 (0.044)
11 May	30	0.900 (0.055)	28	1.000 (0.000)	0.900 (0.055)
12 May	39	0.897 (0.049)	27	0.963 (0.036)	0.932 (0.061)
13 May	19	0.947 (0.051)	28	0.964 (0.035)	0.982 (0.064)
14 May	31	0.807 (0.071)	27	0.963 (0.036)	0.837 (0.080)
15 May	23	0.826 (0.079)	28	1.000 (0.000)	0.826 (0.079)
16 May	26	0.846 (0.071)	28	0.967 (0.035)	0.875 (0.080)
17 May	14	0.786 (0.110)	25	1.000 (0.000)	0.786 (0.110)
18 May	31	0.839 (0.066)	28	1.000 (0.000)	0.839 (0.066)
19 May	14	0.714 (0.121)	24	1.000 (0.000)	0.714 (0.121)
20 May	30	0.800 (0.073)	27	0.926 (0.05)	0.864 (0.092)
21 May	25	0.889 (0.067)	28	0.964 (0.035)	0.922 (0.077)
22 May	28	0.857 (0.066)	26	1.000 (0.000)	0.857 (0.066)
23 May	20	0.750 (0.097)	26	0.962 (0.038)	0.780 (0.105)
24 May	30	0.733 (0.081)	27	0.926 (0.050)	0.792 (0.097)
25-31 May	47	0.878 (0.079)	31	1.000 (0.000)	0.878 (0.079)
Overall	621	0.868 (0.016)	646	0.976 (0.006)	0.888 (0.017)

Appendix Table B8. Grouping, samples sizes, and estimated concrete survival for juvenile steelhead passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
1-2 May	18	0.944 (0.054)	19	0.895 (0.070)	1.056 (0.103)
3 May	16	1.000 (0.000)	25	1.000 (0.000)	1.000 (0.000)
4 May	15	1.000 (0.000)	21	1.000 (0.000)	1.000 (0.000)
5 May	29	0.982 (0.037)	32	1.000 (0.000)	0.982 (0.037)
6 May	33	1.000 (0.000)	31	0.968 (0.032)	1.033 (0.034)
7 May	15	1.000 (0.000)	27	1.000 (0.000)	1.000 (0.000)
8 May	26	1.000 (0.000)	28	0.964 (0.035)	1.037 (0.038)
9 May	17	0.941 (0.057)	27	0.963 (0.036)	0.977 (0.070)
10 May	29	0.931 (0.047)	28	1.000 (0.000)	0.931 (0.047)
11 May	28	0.964 (0.035)	28	1.000 (0.000)	0.964 (0.035)
12 May	37	0.946 (0.037)	27	0.963 (0.036)	0.982 (0.054)
13 May	19	0.947 (0.051)	28	0.964 (0.035)	0.982 (0.064)
14 May	26	0.923 (0.052)	27	0.963 (0.036)	0.959 (0.065)
15 May	22	0.864 (0.073)	28	1.000 (0.000)	0.864 (0.073)
16 May	22	0.955 (0.044)	28	0.967 (0.035)	0.987 (0.058)
17 May	14	0.857 (0.094)	25	1.000 (0.000)	0.857 (0.094)
18 May	26	0.962 (0.038)	28	1.000 (0.000)	0.962 (0.038)
19 May	11	0.909 (0.087)	24	1.000 (0.000)	0.909 (0.087)
20 May	26	0.885 (0.063)	27	0.926 (0.050)	0.955 (0.085)
21 May	22	1.011 (0.012)	28	0.964 (0.035)	1.048 (0.040)
22 May	25	0.920 (0.054)	26	1.000 (0.000)	0.920 (0.054)
23 May	16	0.813 (0.098)	26	0.962 (0.038)	0.845 (0.107)
24 May	27	0.815 (0.075)	27	0.926 (0.050)	0.880 (0.094)
25-27 May	47	0.830 (0.055)	31	1.000 (0.000)	0.830 (0.055)
Overall	566	0.933 (0.013)	646	0.976 (0.006)	0.955 (0.013)

Appendix Table B9. Grouping, samples sizes, and estimated spillway survival for juvenile steelhead passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
1-2 May	6	1.000 (0.000)	19	0.895 (0.070)	1.118 (0.088)
3 May	10	1.000 (0.000)	25	1.000 (0.000)	1.000 (0.000)
4 May	6	1.000 (0.000)	21	1.000 (0.000)	1.000 (0.000)
5 May	22	0.963 (0.046)	32	1.000 (0.000)	0.963 (0.046)
6 May	22	1.000 (0.000)	31	0.968 (0.032)	1.033 (0.034)
7 May	11	1.000 (0.000)	27	1.000 (0.000)	1.000 (0.000)
8 May	21	1.000 (0.000)	28	0.964 (0.035)	1.037 (0.038)
9 May	13	0.923 (0.074)	27	0.963 (0.036)	0.959 (0.085)
10 May	17	0.882 (0.078)	28	1.000 (0.000)	0.882 (0.078)
11 May	11	0.909 (0.087)	28	1.000 (0.000)	0.909 (0.087)
12 May	17	0.882 (0.078)	27	0.963 (0.036)	0.916 (0.088)
13 May	5	0.800 (0.179)	28	0.964 (0.035)	0.830 (0.188)
14 May	13	1.000 (0.000)	27	0.963 (0.036)	1.038 (0.039)
15 May	12	0.833 (0.108)	28	1.000 (0.000)	0.833 (0.108)
16 May	18	0.944 (0.054)	28	0.967 (0.035)	0.976 (0.066)
17 May	7	0.857 (0.132)	25	1.000 (0.000)	0.857 (0.132)
18 May	19	0.947 (0.051)	28	1.000 (0.000)	0.947 (0.051)
19 May	6	0.833 (0.152)	24	1.000 (0.000)	0.833 (0.152)
20 May	17	0.882 (0.078)	27	0.926 (0.050)	0.953 (0.099)
21 May	16	1.010 (0.012)	28	0.964 (0.035)	1.047 (0.040)
22 May	18	0.944 (0.054)	26	1.000 (0.000)	0.944 (0.054)
23 May	14	0.857 (0.094)	26	0.962 (0.038)	0.891 (0.103)
24 May	23	0.783 (0.086)	27	0.926 (0.050)	0.845 (0.104)
25-31 May	37	0.811 (0.064)	31	1.000 (0.000)	0.811 (0.064)
Overall	361	0.919 (0.015)	646	0.976 (0.006)	0.939 (0.017)

Appendix Table B10. Grouping, samples sizes, and estimated juvenile bypass system survival for juvenile steelhead passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
Overall	185	0.964 (0.014)	646	0.976 (0.006)	0.986 (0.016)

Appendix Table B11. Grouping, samples sizes, and estimated Spillbay 8 survival for juvenile steelhead passing Lower Monumental Dam, 2007. Standard errors are in parenthesis.

	Treatment		Reference		
Date	n	Survival	n	Survival	Relative survival
Overall	202	0.902 (0.021)	646	0.976 (0.006)	0.923 (0.022)

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.

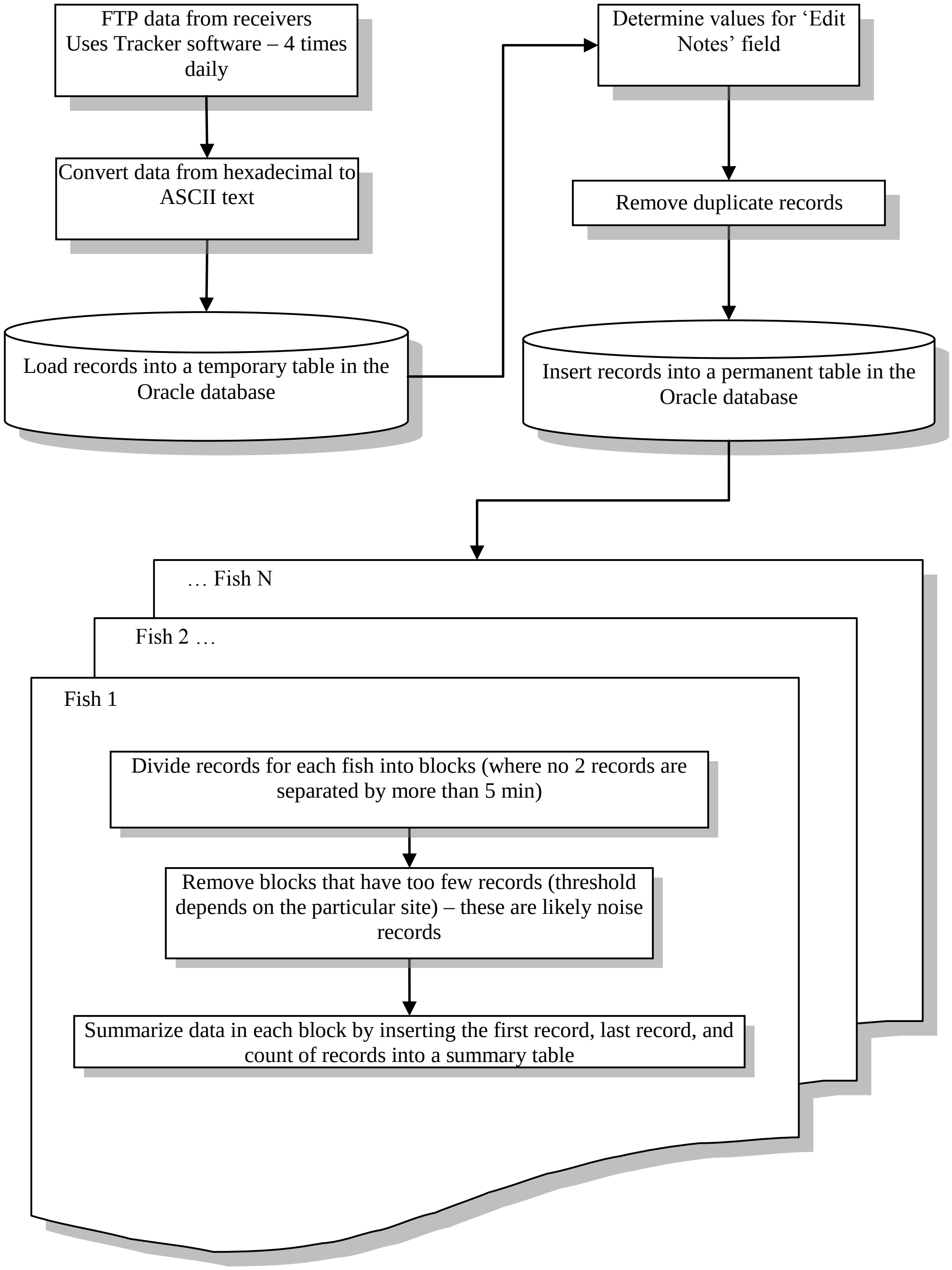
Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time). Note: these records are produced by radio frequency noise.

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, 2007.