Passage Behavior and Survival for Radio-Tagged Subyearling Chinook Salmon at Lower Monumental Dam, 2005

Randall F. Absolon, Eric E. Hockersmith, Gordon A. Axel, Darren Ogden,
Brian J. Burke, Kinsey E. Frick, and Benjamin P. Sandford

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Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

to

Walla Walla District
North Pacific Division
U.S. Army Corps of Engineers
201 North 3rd
Walla Walla, Washington 99362-1876
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EXECUTIVE SUMMARY

In June 2005, an Oregon District Court ordered spill to be used at McNary Dam and the four lower Snake River dams in an effort to improve survival of juvenile Pacific salmon (*Oncorhynchus* spp.). As a result, the U.S. Army Corps of Engineers initiated a study to evaluate passage behavior and estimate survival during the subyearling Chinook salmon juvenile migration period, which coincided with the period of mandated spill.

River-run subyearling Chinook salmon were collected and surgically radio and PIT tagged at Lower Monumental Dam. The study was conducted from 6 through 16 July, which included the 86th through 95th percentiles of the cumulative subyearling Chinook salmon passage index at Lower Monumental Dam. We released 1,103 and 1,092 radio-tagged fish into the forebay and tailrace of Lower Monumental Dam, respectively. Releases were made during both daytime and nighttime throughout the study period.

Of the 1,103 fish released into the forebay, we included only 602 in the evaluation of relative survival. This was due to the large number of fish that were not detected by any of the telemetry arrays after release. The fate of these fish remains unknown, but may include being consumed by predators, not moving downstream to the detection arrays, or not moving downstream until after the life of the radio tag had expired. Similar results were noted in 2004 for radio-tagged subyearling Chinook salmon released after about 4 July during a study of passage behavior and survival at Ice Harbor Dam.

Relative spillway passage survival was estimated at 0.905 (0.760-1.077 95% CI). Estimated relative dam survival was 0.722 (0.668-0.780 95% CI). Spillway passage was estimated at 88%, juvenile bypass passage at 8%, and turbine and unknown passage routes at 2% each. Spill efficiency was estimated at 0.874 (0.831-0.916 95% CI), fish guidance efficiency at 0.832 (0.709-0.954 95% CI), and overall fish passage efficiency at 0.955 (0.921-0.990 95% CI). Spill effectiveness was estimated at 1.53 (1.44-1.58 95% CI). Median forebay residence time was 3 h, and median tailrace egress time was 2 min.

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INTRODUCTION

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

The spillway has long been considered the safest passage route for migrating juvenile salmonids at Columbia and Snake River dams. Holmes (1952) reported survival estimates of 96 (weighted average) to 97% (pooled) for fish passing the Bonneville Dam spillway during the 1940s. A review of 13 estimates of spillway mortality published through 1995 concluded that the most likely mortality rate for fish passing standard spillways ranges from 0 to 2% (Whitney et al. 1997).

Similarly, recent survival studies on juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that survival was highest through spillways, followed by bypass systems, and then turbines (Iwamoto et al. 1994; Muir et al. 1995a,b, 1996, 1998, 2001; Smith et al. 1998). Pursuant to the National Marine Fisheries Service (NMFS) 2000 Biological Opinion (NMFS 2000), project operations at Lower Monumental Dam have relied on a combination of voluntary spill and collection of fish for transportation to improve hydrosystem passage survival for migrating juvenile salmonids.

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

On 10 June 2005, an Oregon District Court (Judge James Redden) ordered spill at McNary Dam and the four lower Snake River dams. The region agreed to evaluate passage behavior and survival of subyearling Chinook salmon passing Lower Monumental Dam during the period of mandated spill. Therefore, the present study was initiated by the Walla Walla District USACE. No specific operations were requested for this study; thus, passage metrics were evaluated under extant flow conditions.

A bulk spill pattern with most flow passing through spillbays 7 and 8 was used. The amount of water spilled was limited by maximum allowable levels of dissolved gas resulting from spill, generally found to be 25-40 kcfs. This was based on a total dissolved gas limit of 120% in the tailrace of Lower Monumental Dam or 115% in the forebay of Ice Harbor Dam.

This study was conducted with the same telemetry equipment and personnel that were used during the spring evaluation of yearling Chinook salmon at Lower Monumental Dam (Hockersmith et al. 2006; Axel et al. 2007).

METHODS

Study Area

The primary study area included a 15-km reach of the Snake River from 5 km upstream from Lower Monumental Dam at river kilometer (rkm) 589 to Windust Park approximately 10 km downstream (Figure 1). Additional data were obtained from telemetry receivers located at Ice Harbor Dam (rkm 537).

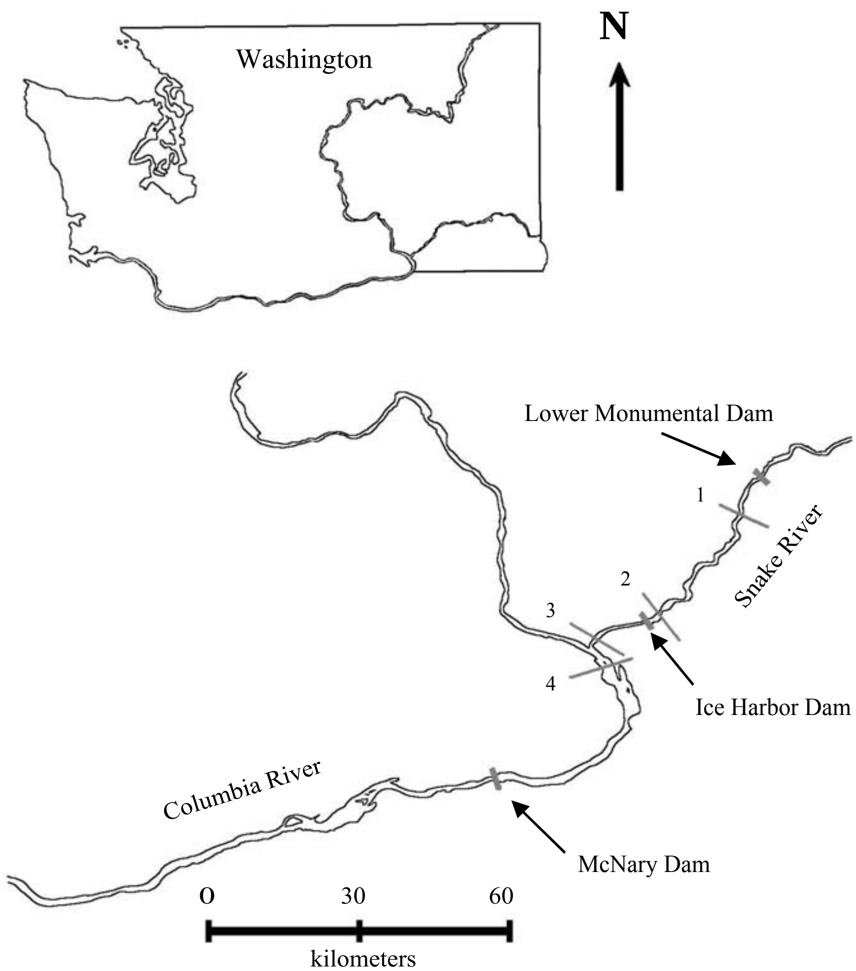

Figure 1. Study area showing location of radiotelemetry transects used for estimating subyearling Chinook salmon survival at Lower Monumental Dam (rkm 589) in 2005. Transects locations are 1 = Windust Park (rkm 579), 2 = forebay of Ice Harbor Dam (rkm 538), 3 = Sacajawea State Park (rkm 532), and 4 = Burbank railroad bridge (rkm 520). The forebay, tailrace, and all routes of passage at Lower Monumental and Ice Harbor Dams (rkm 537) were also monitored.

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were collected at the Lower Monumental Dam smolt collection facility. We chose only fish that did not have gross injuries or deformities, were of sufficient size for tagging (minimum 105 mm FL). Only fish not previously tagged with a passive integrated transponder (PIT) tag were used. Fish were collected from the smolt monitoring sample after it was processed until the target number of fish were obtained each day. Tagging occurred each day of the study, but the number of fish tagged was not weighted to the passage index.

Fish were anesthetized with tricaine methanesulfonate (MS-222) and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were transferred through a water-filled 10.2-cm hose to a 935-L tank. Following collection and sorting, fish were maintained via flow-through river water and held for 24 h prior to radio-transmitter implantation.

Radio tags were purchased from Advanced Telemetry Systems Inc[1] and had a predetermined tag life of 10 d. They were pulse-coded for unique identification of individual fish. Each tag measured 16 mm in length. The pottings of the tags were ground down lengthwise to reduce weight. One end of each tag measured 6 mm in diameter, while the other end measured 4.2 mm, bringing the volume of the tag to 400 mm^3 and the weight to 0.96 g in air and 0.4 g in water.

Fish were surgically implanted with a radio transmitter using techniques described by Adams et al. (1998). A PIT tag was also inserted with the radio transmitter before the incision was closed. Surgical tagging was conducted simultaneously at three tagging stations. Immediately following tagging, fish were placed into a 19-L container (2 fish per container) with aeration and flow-through river water at ambient temperature until they had recovered from the anesthesia. Containers were then covered and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers. Fish holding containers were perforated with 1.3-cm holes in the top 30.5 cm of the container to allow an exchange of water during holding. All holding tanks were supplied with flow-through river water during tagging and holding and were aerated with oxygen during transport to release locations. After tagging, fish were held a minimum of 24 h with flow-through river water temperature for recovery and determination of post-tagging mortality.

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

After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas (the forebay and tailrace). Release groups were transferred from holding tanks to a release tank mounted on an 8.5 × 2.4-m barge, transported to the release location, and released water-to-water at mid-channel. Two fish were released every 15 min in order to distribute the releases over a period of 6-7 h.

Median start and end times of daytime releases were 0938 and 1625 PDT, respectively. Median start and end times of nighttime releases were 2100 and 0345 PDT, respectively. We released 10 groups of approximately 112 fish per group during both day- and nighttime releases. A total of 1,103 radio-tagged fish were released 5 km upstream from Lower Monumental Dam, and a total of 1,092 radio-tagged fish were released 1 km downstream of the dam (Figure 2). These were the same release locations used in a similar evaluation during spring 2004 (Hockersmith et al. 2005).

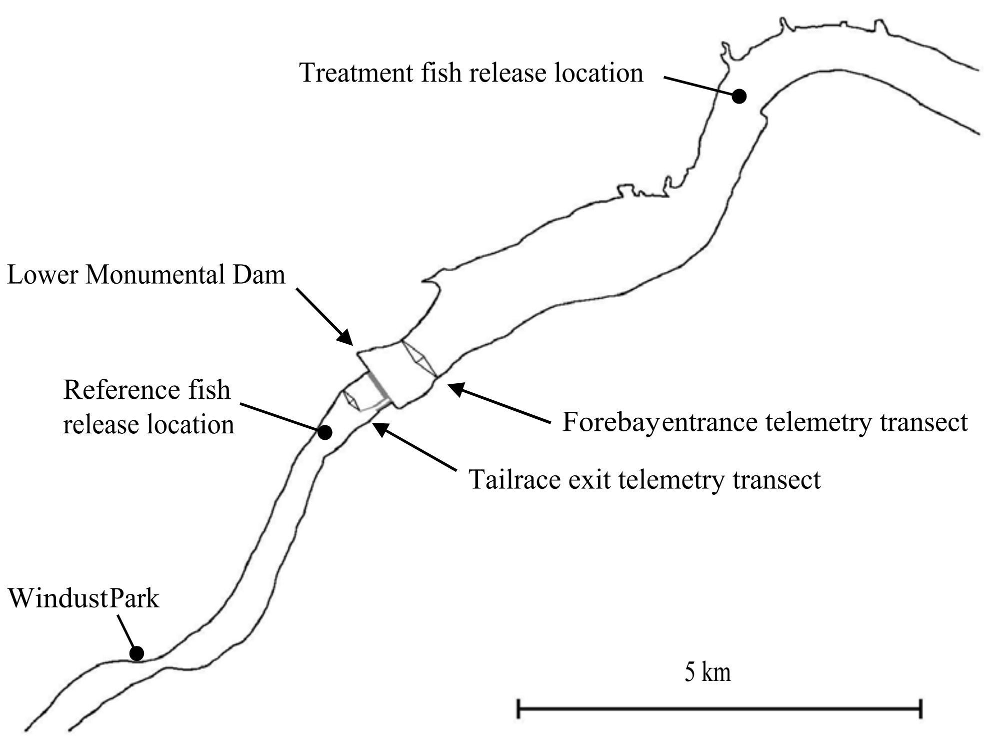

Figure 2. The Lower Snake River and Lower Monumental Dam showing release locations for treatment and reference groups of radio-tagged subyearling Chinook salmon, 2005. Also shown are radiotelemetry transects used to detect fish entering the immediate forebay, 2005.

Monitoring and Data Analysis

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

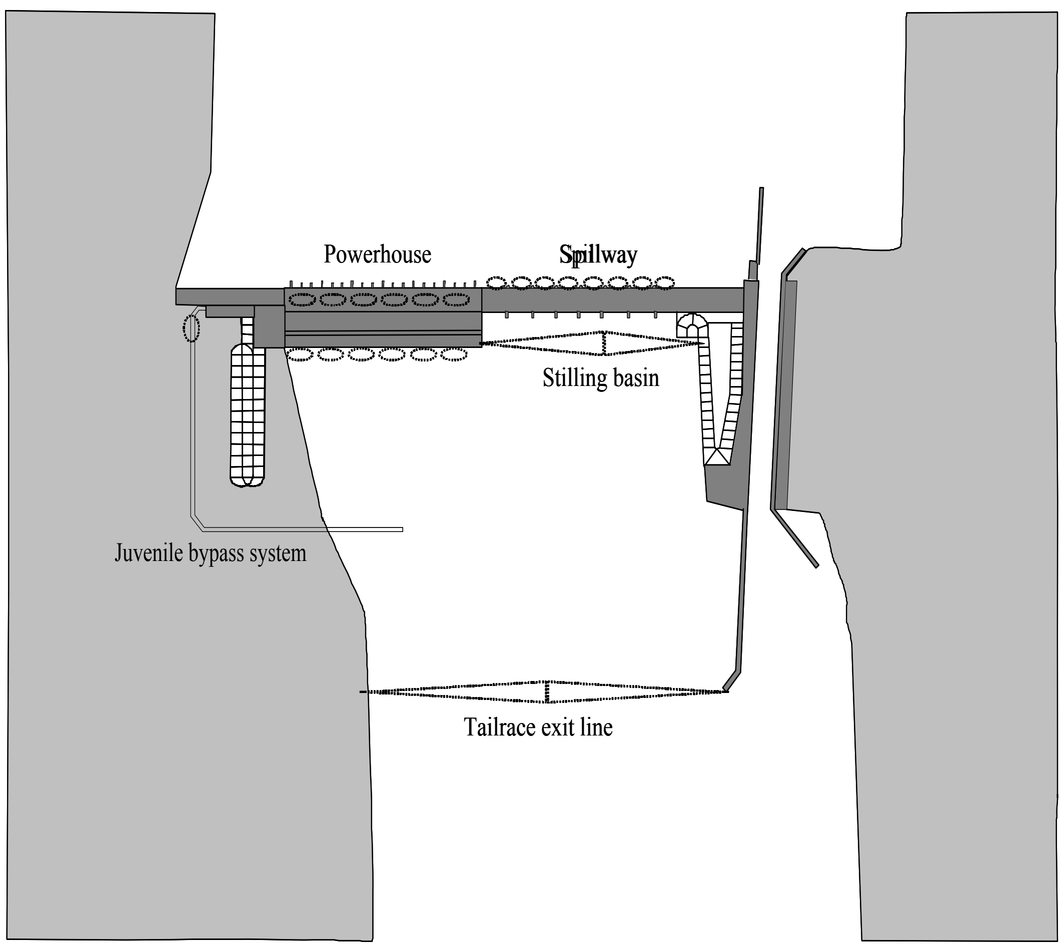

Figure 3. Plan view of Lower Monumental Dam showing approximate radiotelemetry detection zones in 2005 (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas).

Table 1. Fixed-site telemetry receivers for evaluating passage behavior and survival of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2005.

Site description	Type of monitoring	Antenna type
Forebay		
north shore	Entrance line and residence time	3-element Yagi
mid channel	Entrance line and residence time	3-element Yagi
south shore	Entrance line and residence time	3-element Yagi
Turbine Units 1-6	Approach and passage	Striped coax
Spillbays 1-8	Approach and passage	Underwater dipole
Draft tube units 1-6	Project passage	Striped coax
Stilling basin		
north shore	Project passage	Tuned loop
south shore	Project passage	Tuned loop
Juvenile bypass system	Bypass passage	Tuned loop
Tailrace exit		
north shore	Project passage and tailrace egress	3-element Yagi
south shore	Project passage and tailrace egress	3-element Yagi
Windust Park		
north shore	Project passage and survival	3-element Yagi
south shore	Project passage and survival	3-element Yagi

Telemetry data were retrieved through an automated process that downloaded network telemetry receivers up to four times daily. After downloading, individual data files were compressed by recording the first time a radio-tagged fish was detected and counting the number of subsequent detections at the same location where the time difference between detections was less than or equal to 1 min. When the time difference became greater than 1 min, the last detection time was recorded, and a new line of data was created. All compressed data were combined and loaded to a database where automated queries and algorithms were used to remove erroneous data (Appendix C). On the cleaned data set, detailed detection histories were created for each radio-tagged fish. These detection histories were used to calculate arrival time in the forebay, forebay approach pattern, passage route and timing, tailrace exit timing, and timing of downstream detections for individual radio-tagged fish.

Forebay arrival time was based on the first time a fish was detected on the forebay entry line at the upstream end of the boat restricted zone (BRZ) at Lower Monumental Dam. Forebay residence time was determined for fish that had been released upstream from Lower Monumental Dam, detected in the forebay, detected in a passage route, and detected in the immediate tailrace on either the stilling-basin or tailrace-exit telemetry receivers (Figure 3). Forebay residence time for individual fish was measured as the time between first detection on the forebay entrance line and last detection on a passage route.

Approach patterns were established based on the first detection on one of the receivers located at each spillway and turbine unit.

Route of passage through the dam was based on the last time a fish was detected on a passage-route receiver prior to detection in the tailrace. Passage routes were assigned only to fish detected below the dam, meaning at least one valid detection in the stilling basin, tailrace exit transect, or at Windust Park (Figures 2 and 3). Spillway passage was assigned to fish last detected in the forebay on one of the antenna arrays deployed in each spillway. Similarly, turbine passage was assigned to fish last detected in a turbine intake prior to detection in the draft tube and tailrace. Passage through the juvenile bypass system (JBS) was assigned to fish detected in the bypass pipe prior to detection in the tailrace.

Survival Estimates

A paired-release study design was used to estimate relative survival for groups of radio-tagged fish released at one of two sites: upstream (treatment) and downstream (reference) from Lower Monumental Dam (Figure 2). Treatment groups were formed by grouping daily detections of radio-tagged fish as they entered the forebay of Lower Monumental Dam; reference groups were composed of fish released directly into the tailrace (Figure 2).

The CJS (Cormack-Jolly-Seber) single-release model was used to estimate probabilities of detection and survival from release to Windust Park for both treatment and reference groups (Cormack 1964; Jolly 1965; Seber 1965). This model provides unbiased estimates of survival if specific assumptions are met (Zabel et al. 2002; Smith et al. 2003), in particular, that detection and survival probabilities downstream from detection sites were not conditional on radiotelemetry detection at upstream sites.

Relative spillway survival was then expressed as the ratio of survival estimates for treatment fish to those for reference fish. Average relative survival was calculated using weighted geometric means, with weights being the inverses of the respective sample variances (Muir et al. 2003). A primary assumption of the paired-release model is that treatment and reference groups have similar survival probabilities in the reach that is common to both groups (Burnham et al. 1987); that is, groups are mixed temporally upon detection at the primary detection array. Evaluation of this and other assumptions required for our study design are reported in Appendix A.

Passage Behavior and Timing

Forebay residence time was defined as elapsed time from detection on the forebay entrance transect to detection on a passage-route receiver; tailrace egress was defined as the time from detection on a passage route to first detection on the tailrace exit transect.

Passage Route Distribution

To determine the route of passage used by individual fish at Lower Monumental Dam, we monitored the spillway, fish guidance screens, draft tubes, and JBS. The spillway was monitored by four underwater dipole antennas in each spillway: two antennas were installed along each of the pier noses at depths of 20 and 40 ft. Previous range testing demonstrated that this configuration monitored the entire spillway. To detect fish passage in the turbine units, draft tubes, and JBS, we used armored coaxial cable, stripped at the end. Antennas in turbine units were attached on both ends of the downstream side of the fish screen support frame located within each slot of the turbine intake.

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

Fish Passage Metrics

Fish-passage metrics of spill efficiency (SPE), spill effectiveness, fish guidance efficiency (FGE), and fish passage efficiency (FPE) were also evaluated at Lower Monumental Dam using radiotelemetry detections from the same locations used for passage route evaluation. Spill efficiency was estimated as the number of fish passing the dam via the spillway divided by the total number of fish passing the dam. Spill effectiveness was estimated as the proportion of fish passing the dam via the spillway divided by the proportion of water spilled. Fish guidance efficiency was estimated as the number of fish passing the dam through the JBS divided by the total number of fish passing the dam through the powerhouse (turbine and JBS). Fish passage efficiency was estimated as the number of fish passing the dam through non-turbine routes divided by the total number of fish passing the dam.

RESULTS

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were collected and tagged at Lower Monumental Dam for 10 d from 5 to 14 July. No effort was made to adjust the number of fish tagged each day to the passage index. Tagging began after the 86th percentile of the juvenile subyearling Chinook salmon index had passed Lower Monumental Dam, and tagging was completed when the 95th percentile had passed (Figure 4). Fish condition information and data on the size and timing of the juvenile migration is reported in the 2005 Lower Monumental Dam Smolt Monitoring annual report (Lind et al. 2006). Overall mean fork length was 116 mm (range 106-156 mm) for treatment fish and 116 mm (range 105-148 mm) for reference fish (Table 2). Mean length of the run at large sampled at the Lower Monumental smolt collection facility was 110 mm (data provided by Monty Price WDFW, Table 3). Due to logistical concerns, data on the weight of fish at tagging was not collected. During the study period, handling and tagging mortality for subyearling Chinook salmon held for a minimum of 24 h after tagging was 1.8%.

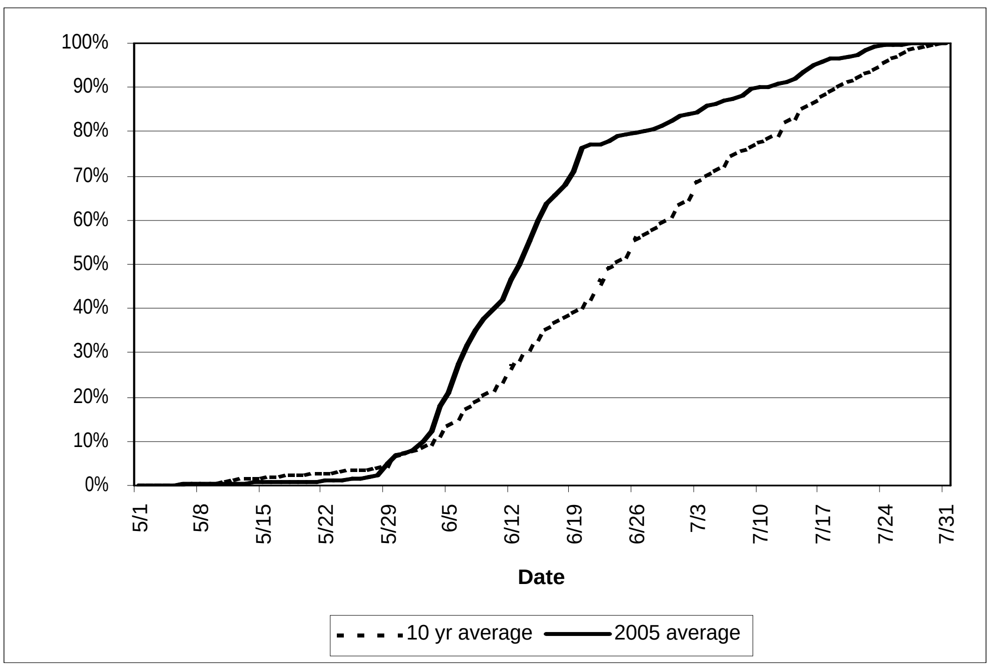

Figure 4. Cumulative passage distribution for 2005 compared to the historical average (1996-2005) for subyearling Chinook salmon passing Lower Monumental Dam.

Table 2. Mean length of radio-tagged subyearling Chinook salmon (sample size, mean, range, and standard deviation) releases at Lower Monumental Dam to evaluate passage behavior and relative dam and spillway survival, 2005.

	Subyearling Chinook salmon length (mm)							
	Forebay				Tailrace			
Release date	n	Mean	Range	SD	n	Mean	Range	SD
	Daytime releases							
6 July	56	118	108-133	5.3	55	118	108-136	6.8
7 July	56	117	108-136	6.8	54	117	108-142	7.0
8 July	55	115	107-136	5.5	56	115	107-148	6.3
9 July	56	115	106-126	5.2	56	114	107-130	5.2
10 July	56	116	107-137	6.1	54	116	108-126	4.6
11 July	56	115	107-129	5.6	54	115	107-126	4.3
12 July	55	116	107-134	6.2	53	116	108-132	5.4
13 July	55	116	107-131	4.6	50	115	108-125	4.1
14 July	56	117	109-136	6.0	55	117	107-139	6.1
15 July	56	119	108-144	6.4	55	118	108-138	6.4
Subtotal	557	116	106-144	5.8	542	116	107-148	5.6
	Nighttime releases							
6 July	56	116	110-127	4.0	53	118	109-133	6.2
7 July	56	116	108-132	5.5	55	115	107-135	6.4
8 July	54	112	106-124	3.7	56	113	105-140	5.8
9 July	53	115	106-142	6.3	56	113	106-129	4.3
10 July	55	116	106-150	7.8	56	115	106-138	6.2
11 July	55	115	107-127	4.9	56	116	107-128	4.7
12 July	55	115	108-124	3.9	54	116	107-130	4.6
13 July	55	117	110-156	7.3	55	116	108-134	5.4
14 July	54	120	110-139	6.2	55	118	108-125	3.8
15 July	56	118	108-131	6.2	56	118	110-127	4.6
Subtotal	549	116	106-156	5.6	552	116	105-140	5.2
Total	1,106	116	106-156	5.7	1,094	116	105-148	5.5

Table 3. Sample size (n), mean, and range of length (mm) by tagging date for smolt monitoring facility sampled, river-run, subyearling Chinook salmon at Lower Monumental Dam, 2005.

Collection date	Release date	n	Mean (mm)	Range (mm)
4 July	6 July	100	105	80-135
5 July	7 July	100	107	80-125
6 July	8 July	100	109	95-130
7 July	9 July	100	105	90-130
8 July	10 July	100	110	80-125
9 July	11 July	100	111	90-135
10 July	12 July	100	111	60-140
11 July	13 July	100	111	80-130
12 July	14 July	100	112	90-130
13 July	15 July	100	114	95-130
		1,000	110	60-140

Project Operations

No special project operations were requested for this study. From 20 June through 31 August, spill occurred at Lower Monumental Dam in accordance with the ruling issued on 10 June 2005 by Oregon District Court Judge James Redden. During the 6 through 16 July study period, spill averaged 21,000 ft^3/s, which equates to 59% of the total discharge during that period (Table 4). The spill pattern used in 2005 is shown in Appendix B.

Table 4. Average daily conditions during releases and passage of radio-tagged hatchery subyearling Chinook salmon at Lower Monumental Dam, 2005.

Date	Spill (kcfs)	Powerhouse (kcfs)	Total discharge (kcfs)	Total discharge range (kcfs)	Tailwater elevation (ft msl)	Water temperature (°C)
6 July	22.8	19.9			438.5	19.1
7 July	23.9	20.3	44.2	35.2-55.4	438.5	19.7
8 July	23.4	17.4	40.8	35.0-60.0	438.5	19.6
9 July	22.8	17.9	40.7	34.5-51.7	438.2	19.6
10 July	16.0	12.5	28.4	24.0-35.6	438.1	19.6
11 July	22.4	15.1	37.4	28.2-45.7	438.3	19.7
12 July	21.5	16.4	37.9	27.9-43.8	438.4	19.7
13 July	20.4	14.5	34.9	30.7-43.2	438.4	19.8
14 July	22.8	16.0	38.8	33.9-45.3	438.3	20.3
15 July	20.1	12.7	32.7	28.0-38.4	438.3	20.2
16 July	21.8	16.1	37.9	26.5-50.8	438.2	20.0
17 July	16.9	14.2	31.1	22.8-45.5	438.4	20.6
18 July	17.7	16.4	34.1	21.9-60.2	438.3	20.9
Averages	20.9	16.1	37.0	21.9-60.2	438.3	19.9

Migration Behavior and Passage Distribution

Forebay Behavior and Timing

Of the 1,103 radio-tagged treatment fish released above Lower Monumental Dam, 602 were detected entering the forebay. Of these fish, 90% were detected approaching the spillway and 10% were first detected approaching the powerhouse.

Forebay residence times were calculated for 430 fish, each with detections on both the forebay entrance transect and a known passage route. Of these fish, 387 (90.0%) passed through the spillway, 35 (8.1%) passed through the JBS, and 8 (1.9%) passed through turbine units (Table 5). Forebay residence time data is also presented by treatment group in Table 6, without consideration to passage route.

Table 5. Forebay residence time for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2005.

	Forebay residence time (h)		
Percentile	Bypass (n = 35)	Spillway (n = 387)	Turbine (n = 8)
Minimum	0.8	0.3	1.8
10th		0.8	
20th	1.8	1.2	
30th		1.6	
40th		2.1	
50th (median)	5.7	2.8	2.8
60th		3.7	
70th		6.0	
80th	15.7	9.1	
90th		17.3	
95th		28.2	
100th	62.6	159.1	39.9

Table 6. Forebay residence times for all passage routes combined, by treatment group, for radio-tagged, river-run subyearling Chinook salmon at Lower Monumental Dam, 2005. Represented are the 10th 50th (median) and 90th percentile passage times and the number of fish in each group. Times are presented in hh:mm:ss format.

Group	n	10th	50th	90th
1	59	0:36:27	1:48:32	8:49:13
2	49	0:44:52	2:23:34	12:16:41
3	46	0:49:30	2:19:57	18:16:42
4	34	0:48:16	3:43:15	12:45:10
5	58	0:49:08	3:57:51	22:09:04
6	53	0:45:33	3:13:43	4:00:58
7	58	0:40:38	3:05:16	19:00:00
8	71	0:41:39	5:55:32	7:04:46
9	42	1:03:42	3:18:40	2:00:23
10	44	0:58:53	4:16:38	11:02:44
11	32	0:42:48	7:48:17	13:18:25
total/mean	546	0:47:24	3:48:18	11:53:06
SE		0:02:24	0:31:20	1:53:20
95% lower CI		0:42:03	2:38:30	7:40:34
95% upper CI		0:52:46	4:58:06	16:05:38

Passage Distribution and Metrics

Of the 1,103 radio-tagged treatment fish released, 602 (55%) were detected at or below Lower Monumental Dam, while 501 were not detected after release. Of the 442 (40%) fish that passed the dam, 390 (88%) passed the dam through the spillway, 36 (8%) through the JBS, 8 (2%) through the turbines, and 8 (2%) passed the dam through an undetermined route (Figure 5). The remaining 160 (15%) fish entered the forebay but were not recorded as having passed the dam.

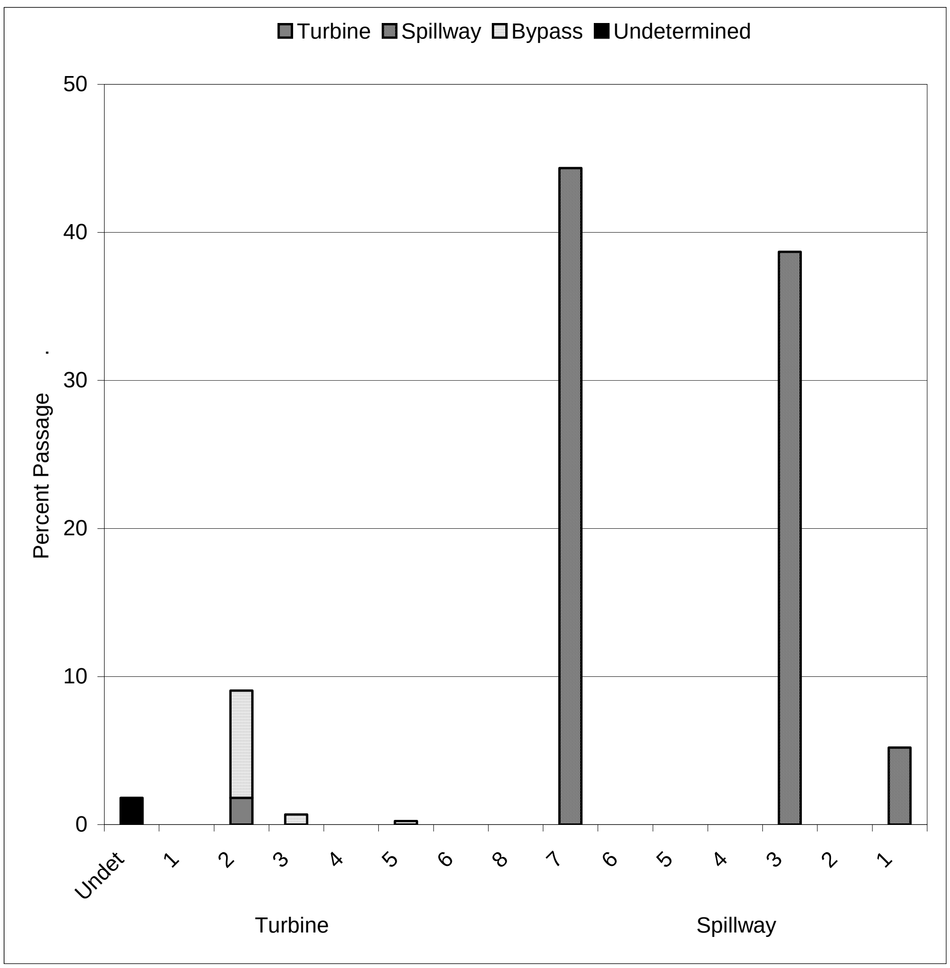

Figure 5. Passage distribution of radio-tagged subyearling Chinook salmon at Lower Monumental Dam, 2005. Undet = undetermined passage route.

Fish passage efficiency (FPE) at Ice Harbor Dam was 0.955 (0.921-0.990 95% CI). Spill efficiency (SPE) was 0.874 (0.831-0.916 95% CI). Spill effectiveness was 1.53:1 (1.44-1.61 95% CI; Table 7). Figure 6 presents the percentage of time during the study period that each spill bay was open, and the percentage of fish that passed through each spillbay.

Table 7. Fish passage metrics by release group for river-run subyearling Chinook salmon at Lower Monumental Dam, 2005. SPE = spill passage efficiency, FPE = fish passage efficiency, FGE = fish guidance efficiency, and n = number of fish per group.

Group	n	SPE	FPE	Spill efficiency	n	FGE
1	50	0.920	0.980	1.70	3	1.000
2	42	0.857	0.976	1.50	6	0.833
3	39	0.897	1.000	1.60	4	1.000
4	28	0.857	0.964	1.53	4	0.750
5	51	0.824	0.922	1.38	7	0.714
6	46	0.957	1.000	1.68	2	1.000
7	53	0.925	0.981	1.58	4	0.750
8	55	0.945	1.000	1.61	3	1.000
9	32	0.813	0.906	1.33	3	1.000
10	37	0.865	0.946	1.50	5	0.600
11	24	0.750	0.833	1.38	4	0.500
Total/mean	457	0.874	0.955	1.53	45	0.832
SE		0.019	0.015	0.04		0.055
95% CI lower		0.831	0.921	1.44		0.709
95% CI upper		0.916	0.990	1.61		0.954

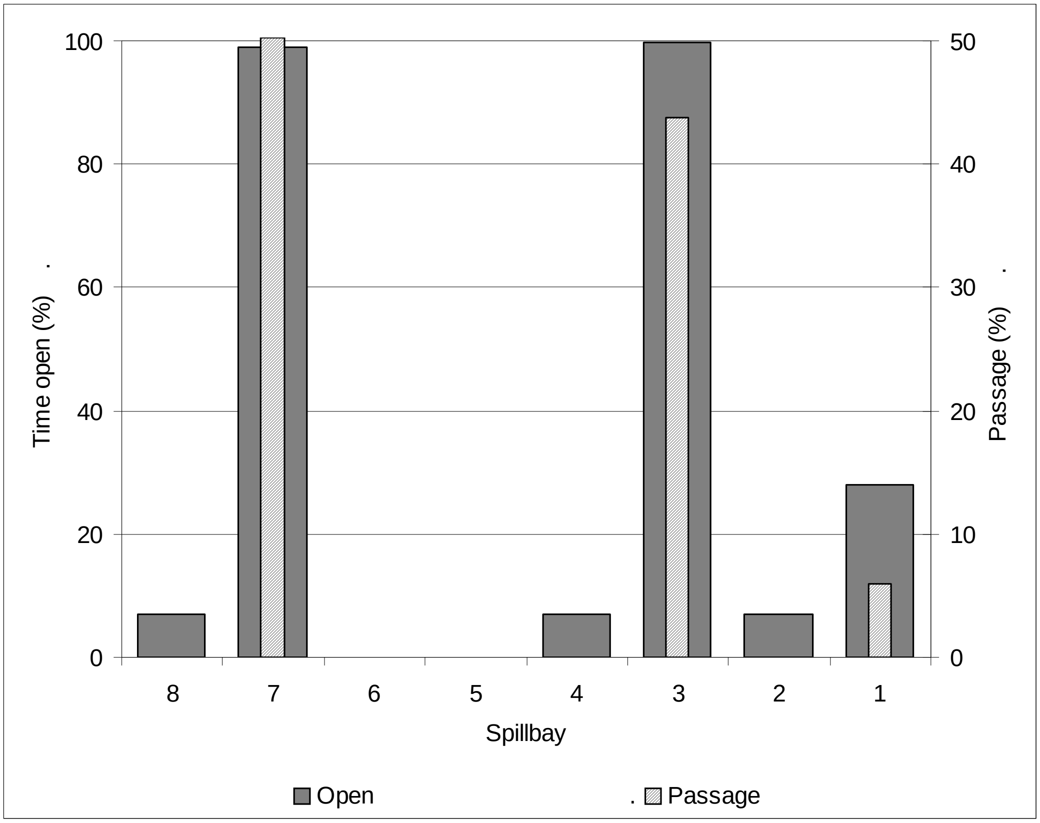

Figure 6. Percent time individual spillbays were open and passage distribution for radio-tagged river-run subyearling Chinook salmon at Lower Monumental Dam, 2005.

Tailrace Behavior and Timing

Tailrace egress time was calculated for 345 radio-tagged, river-run subyearling Chinook salmon. Median tailrace egress time was 1.9 min for fish that passed through the spillway (n = 311), 6.5 min for those that passed through the JBS (n = 28), and 4.7 min for fish that passed through turbine units (n = 6; Table 8). The longer egress time for fish that passed through the JBS was expected and was due to fish passing through the fish and debri separator after detection in the JBS, which would have added to their egress time. Tailrace egress data for tagged fish that passed through the spillway is shown by release group, and also by spillbay in Table 9.

Table 8. Tailrace egress times in minutes for radio-tagged, river-run subyearling Chinook salmon passing through the bypass and spillway at Lower Monumental Dam, 2005.

	Tailrace egress (min)	
Percentile	Bypass (n = 28)	Spillway (n = 311)
Minimum	1.2	0.1
10th	2.0	0.7
20th	2.7	1.0
30th	3.3	1.2
40th	4.2	1.5
50th (median)	6.5	1.9
60th	10.0	2.4
70th	14.9	3.1
80th	54.2	4.0
90th	77.0	6.1
95th	98.1	12.6
100th	307.9	418.8

Table 9. Tailrace egress timing for radio-tagged river-run subyearling Chinook salmon by release group and spillbay passage route. Represented are the 10th, 50th (median), and 90th percentile passage times and the number (n) of fish in each group. Times are presented as h:mm:ss.

Group	n	10th	50th (median)	90th
1	32	0:00:41	0:01:19	0:04:42
2	30	0:00:34	0:01:19	0:04:46
3	29	0:00:35	0:01:48	0:04:22
4	17	0:00:48	0:01:42	0:05:22
5	31	0:00:30	0:02:16	0:15:29
6	31	0:00:41	0:01:33	0:05:03
7	37	0:00:52	0:02:17	0:11:47
8	41	0:00:50	0:02:08	0:06:05
9	18	0:00:58	0:02:35	0:09:12
10	29	0:00:59	0:02:16	0:05:09
11	16	0:00:30	0:01:38	0:10:16
Total/mean	311	0:00:43	0:01:54	0:07:28
SE		0:00:03	0:00:08	0:01:07
95% CI lower		0:00:36	0:01:36	0:05:00
95% CI upper		0:00:50	0:02:11	0:09:57
	Spillbay			
1	15	0:01:01	0:01:45	0:03:36
3	136	0:00:39	0:02:07	0:06:09
7	160	0:00:44	0:01:44	0:06:28

Detection Probability and Estimated Survival

Detection probabilities at Windust Park for treatment and reference groups were 0.601 (0.561-0.641 95% CI) and 0.889 (0.870-0.908 95% CI), respectively. The difference between the treatment and reference groups was due to the large number of treatment fish which were never detected at either the forebay entry line or the dam. Estimated overall relative dam survival at Lower Monumental Dam using the weighted geomean was 0.772 (0.668-0.780 95% CI). Detection histories of fish used in survival analysis are shown in Table 10.

Overall estimated route-specific survival through the spillway using the weighted geomean was 0.905 (0.760-1.077 95% CI). Insufficient numbers of fish passed through the turbines or JBS (powerhouse) to estimate survival with precision through either of these routes.

Avian Predation

When the Crescent Island Caspian Tern colony had left the island for the season, we initiated a recovery effort for the radio tags that were deposited on the island. Radio and PIT tags were recovered on the tern colony at Crescent Island during August 2005. Radio tags were collected by physically walking the island looking for visible tags. Radio-tag serial numbers were used to identify individual tagged fish. PIT tags were "recovered" by a thorough search with a detection system as described by Ryan et al. 2001. PIT-tag detections and physical recovery of radio transmitters at Crescent Island were provided by NMFS and Real Time Research, Inc. (B. Ryan, NMFS, personal communication). There were 32 mortalities recorded with the tern colony representing approximately 1.5% of the fish we released into the Snake River. This should be considered a minimum estimate because of the probability that not all of the radio tags were recovered from the island. Tern predation accounted for 1.2% of the fish we released into the forebay of Lower Monumental Dam as treatment fish and 1.7% of the fish that were released into the tailrace of Lower Monumental Dam as reference fish.

Table 10. Detection history of treatment groups of subyearling Chinook salmon used in survival estimates at Lower Monumental Dam, 2005.

		Detection history					
Group	Passage route	Not detected	Windust	Ice Harbor	Both	Route total	Group total
1	bypass	1	2			3	49
	spillway	7	30		9	46	
	turbine						
2	bypass	1	2		2	5	42
	spillway	3	23	1	9	36	
	turbine		1			1	
3	bypass	1	3			4	39
	spillway	5	21	2	7	35	
	turbine						
4	bypass		3			3	30
	spillway	5	17	1	3	26	
	turbine				1	1	
5	bypass	1	2	1	1	5	49
	spillway	9	22	2	9	42	
	turbine		2			2	
6	bypass	2				2	46
	spillway	11	27	1	5	44	
	turbine						
7	bypass	1	1		1	3	53
	spillway	8	37	2	2	49	
	turbine		1			1	
8	bypass	1	1	1		3	55
	spillway	19	28	2	3	52	
	turbine						
9	bypass	1	2			3	29
	spillway	5	16	2	3	26	
	turbine						
10	bypass	3				3	38
	spillway	1	25		7	33	
	turbine	1	1			2	
11	bypass	2				2	22
	spillway	7	8	2	1	18	
	turbine		2			2	
Totals		95	277	17	63	452	452

DISCUSSION

As reported above, we began testing after 85th percentile of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and finished when 95th percentile had passed. Typically, we would have preferred to tag during the period when the 30-70th percentile was passing the project, based on the 9-year average observed at Lower Monumental Dam. However, because of the timing of the court ordered spill, it was necessary to conduct the study later in the juvenile migration season.

We spread out releases of radio-tagged fish over time in order to have equal numbers of fish passing Lower Monumental Dam throughout each 24-hour period. Our tagged fish entered the forebay throughout this period (Figure 7). Daylight hours were designated as 0300-1900, which is 67% of a day, and we recorded 64% of the fish entering the forebay during these hours. The sample sizes were not large enough to provide meaningful results of survival or passage metrics between day and night releases, or trends in the data during the study period.

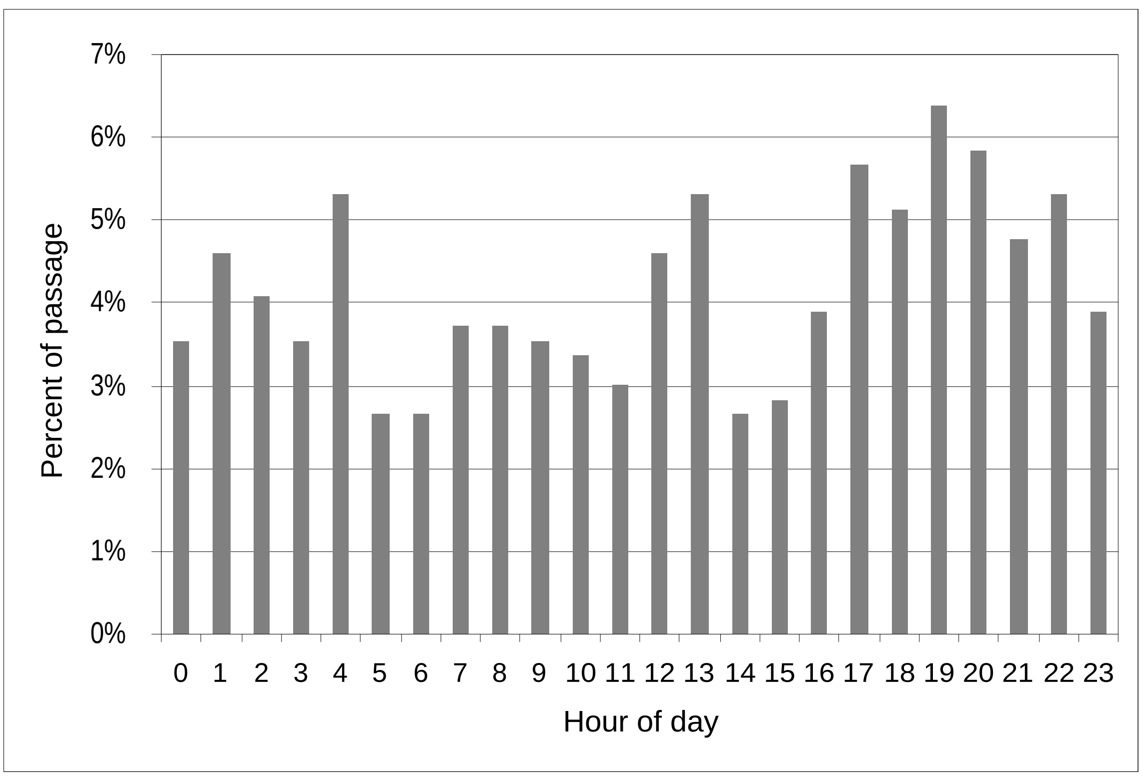

Figure 7. Percentage by hour of radio-tagged subyearling Chinook salmon entering the forebay of Lower Monumental Dam, 2005.

The hour of dam passage was also spread across the 24 h period, except for a decrease in passage between 1500-1900 PST (Figure 8). This corresponds in part to the relatively lower number of approaches to the dam seen from 1400-1500 (Figure 7). Percentages of fish passing the dam each hour did not vary as much as percentages entering the forebay approach, as shown in Figure 7. About 61% of fish passed the dam during daylight hours, a proportion similar to that of fish that approached the dam during daylight hours.

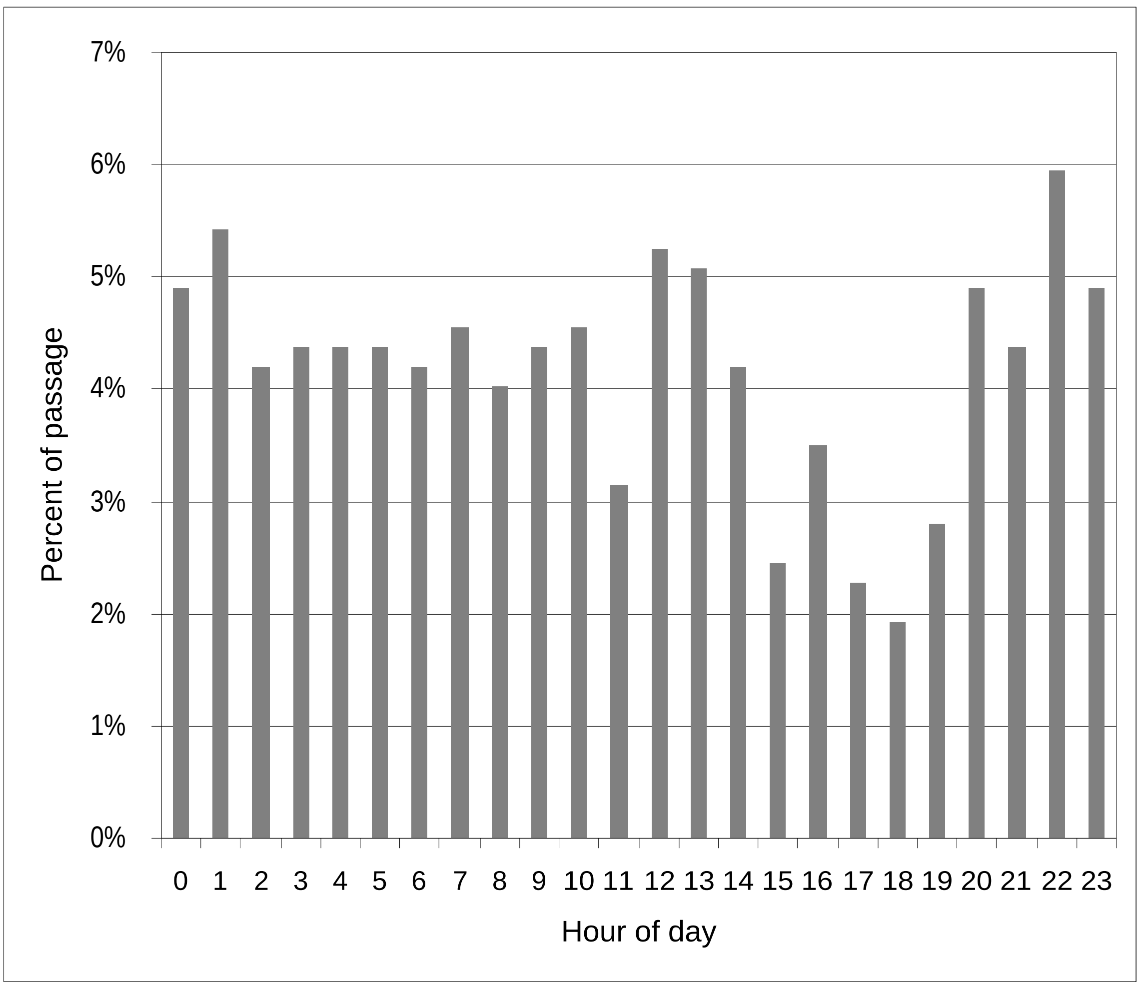

Figure 8. Percentage by hour of radio-tagged subyearling Chinook salmon passing Lower Monumental Dam, 2005.

We noted a substantial proportion of the treatment fish released upstream from Lower Monumental Dam were not detected at the forebay entrance array after release. This was also observed in 2004 during the Ice Harbor Dam evaluation with subyearling Chinook salmon released after about 4 July (Ogden et al. 2005). Several factors may have contributed to this occurrence, including water temperature and predation. Fish may also have adopted a "reservoir-type" life history strategy, wherein they overwinter in reservoirs and complete their migration the following spring, at age 1 (Connor et al. 2005).

Temperatures above 20°C have been shown to increase predation (Vigg and Burley 1991), disrupt physiological processes (Mesa et al. 2002), reduce levels of smoltification, and decrease growth (Marine and Cech 2004) of young subyearling Chinook salmon. Though temperatures in the Lower Monumental Dam forebay did rise above 20°C during the study period, this did not occur until 0100 on 14 July, which was toward the end of our releases of study fish. A delay in migration, which caused the radio tag to shut off before migration occurred, could also be an explanation. Predation or a change to a reservoir-type life history are other potential causes for the large number of treatment fish which were not detected after release. None of these fish were subsequently interrogated by PIT-tag detectors the following spring, which would have indicated they delayed migration until the following year.

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APPENDIX A: Evaluation of Study Assumptions

We used the CJS model (Cormack 1964; Jolly 1965; Seber 1965) to estimate survival of radio-tagged juvenile Chinook salmon released above and below Lower Monumental Dam. Ratios of treatment to reference survival estimates were calculated to determine relative survival. Evaluation of critical model and biological assumptions of the study are detailed below.

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

Of the 1,103 radio-tagged subyearling Chinook salmon released above Lower Monumental Dam, 602 were detected at either the forebay entry line upstream from the dam or at the dam. Of these 602 fish, 362 (60.1% of those released) were detected either at or below Windust Park. Of the 1,091 radio-tagged subyearling Chinook salmon released into the tailrace of Lower Monumental Dam, 970 (88.9% of those released) were detected either at or below Windust Park. Thus, the detection probability for fish used in survival analysis at Windust Park was 0.787 overall. This detection probability was lower than expected, and it had the effect of widening confidence intervals about the survival estimates; however, it was not so low as to indicate a violation of the model assumption.

Radiotelemetry detection probability at Windust Park was almost 100%, with only 15 fish (1.1%) detected downstream that were not detected the park. With detection probabilities at or near 100% for all fish, there was no disparity between detection probabilities of treatment and reference groups (Appendix Table A1).

Appendix Table A1. Detections at and below Windust Park and detection probabilities at Windust Park for evaluating survival of hatchery subyearling Chinook salmon passing Lower Monumental Dam, 2005.

Release group	Detection at Windust Park	Detection at or below Windust Park	Detection Probability
Treatment	357	362	0.601
Reference	960	970	0.889
Totals	1,317	1,332	0.787

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

To test that treatment and reference fish mixed evenly and traveled together downstream, we evaluated mixing of release groups at Windust Park by using contingency tables (chi-square goodness-of-fit) to test for differences in arrival distributions (Burnham et al. 1987). The passage date of treatment fish at Lower Monumental Dam was paired with the release date of reference fish. Windust Park observations were grouped by date, since nearly all fish were detected in less than 1 d. *P*-values were calculated using the Monte Carlo approximation of the exact method described in the StatXact software user manual (Mehta and Patel 1992; $\alpha<0.05$).

Tests of homogeneity of arrival distributions at Windust Park were similar for treatment and reference groups in 9 of the 10 paired releases for each relative survival estimate (Appendix Tables A2). Therefore, we concluded that treatment and corresponding reference groups were evenly mixed and traveled together through downstream reaches for 9 of 10 groups. In the group with significant differences between treatment and reference arrival timing, most reference fish arrived at Windust Park during the same day, while some treatment fish (7 of 34) arrived the following day (but all arrived before 0400). Because this difference was unlikely to have been biologically meaningful, we believe assumption A2 was not violated for this group.

Appendix Table A2. Test of homogeneity of arrival timing at Ice Harbor Dam for treatment and reference groups of radio-tagged hatchery subyearling Chinook salmon used for estimating dam survival at Lower Monumental Dam. The passage date of treatment fish at Lower Monumental Dam was paired with the release date of reference fish. Ice Harbor observations were grouped by date, since nearly all fish were detected in less than 3 d. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Passage/release date	χ^2	Degrees of freedom	*P*
7 July	10.84	7	0.100
8 July	5.84	3	0.155
9 July	9.03	5	0.100
10 July	10.93	4	0.070
11 July	6.00	3	0.091
12 July	0.33	2	1.000
13 July	2.71	2	0.271
14 July	2.45	2	0.354
15 July	3.03	3	0.539
16 July	4.79	1	0.010

Since all but the last group was mixed on arrival at Windust Park, and our survival estimates were pooled over the treatment period, and the bulk of distributions generally occurred over a 2-3 day period, it is reasonable to conclude that the survival estimates were not significantly biased by violation of the assumption regarding mixing through the common reach.

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

River-run hatchery subyearling Chinook salmon were collected at the Lower Monumental Dam smolt monitoring collection facility from 4 to 14 July. We tagged only hatchery-origin subyearling Chinook salmon that were not previously PIT tagged, had no visual signs of disease or injury, and were at least 105 mm in length. The tagging period encompassed the passage period between the 86th and 95th passage percentile based on the 10-year average subyearling Chinook salmon passage index at Lower Monumental Dam. Overall mean length of study fish was 115 mm for fish released both above and below Lower Monumental Dam (Table 2). Overall mean for lengths of river-run subyearling Chinook salmon collected at the Smolt Monitoring Facility during the study period was 110 mm.

The study was conducted during the later part of the juvenile migration and the mean length of study fish was greater than that of river-run fish overall. Either (or both) of these conditions may have violated assumption A3, and this should be kept in mind when considering the results. However, for the relative survival estimates, fish sizes and release dates were not different between treatment and reference groups.

A4. The tag and/or tagging method does not significantly affect the subsequent behavior for 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. (1988) and Hockersmith et al. (2003). From their conclusions, we assumed that behavior and survival were not significantly affected over the length of our study area.

A5. Fish that die as a result of passing through a passage route are not subsequently detected at a downstream array that is used to estimate survival for that passage route.

Assumption A5 was not vigorously tested for validation in this study. The distance between release at Lower Monumental Dam and the first downstream detection array used to estimate survival Windust Park was 10 km. Axel et al. (2003) found that dead radio-tagged fish released into the bypass systems at Ice Harbor and McNary Dams were not subsequently detected at telemetry transects more than 3.2 km downstream. In addition, we released 25 tagged fish that had died during holding at the reference release location, and none of them were detected at the Windust Park array.

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

Radio tags for this evaluation were the same as those purchased for passage survival evaluations of subyearling Chinook salmon at Ice Harbor Dam in June (Ogden et al. 2007). For both studies, 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. Tags not functioning properly were not used in either study. At Ice Harbor Dam in June, several tags were removed on each tagging day (total of 63 tags) and allowed to run in river water. These tags were checked daily to evaluate tag function. None of the tags tested for tag life failed prior to the preprogrammed shut down after 10 d. We did not repeat these tests in July, but because the same tags, procedures, personnel, and fish species were used in both studies, and the studies were temporally proximate, it is highly unlikely that tag performance differed between the June and July evaluations.

A7. Treatment fish that pass through a specific route are appropriately assigned to that route.

The route of passage for individual fish was determined from telemetry receivers and antenna arrays which monitored individual turbine intakes, individual spillbays, and the JBS. Passage routes were assigned to individual fish based on the last detection within a passage route and subsequent detection in the immediate tailrace. Tailrace detections were used to validate passage because it was possible for fish to be detected on a passage array while still in the forebay.

APPENDIX B: Spill Pattern

Appendix Table B1. Lower Monumental Dam High Gate Spill Pattern, 2005

Spill bay								Total	
1	2	3	4	5	6	7	8	Stops	Spill (kcfs)
						5		5	7.9
						6		6	9.6
						7		7	11.3
		5				5		10	15.8
		5				6		11	17.5
		6				6		12	19.2
		6				7		13	20.9
		7				7		14	22.6
		5		5		5		15	23.7
		5		5.5		5.5		16	25.4
		5.5		5.5		6		17	27.1
		6		6		6		18	28.8
		6		6.5		6.5		19	30.5
		6		7		7		20	32.2
		7		7		7		21	33.9
1		7		7		7		22	35.0
2		7		7		7		23	36.7
2		7		7		7	1	24	37.8
2		7		7		7	2	25	39.5
2		6		6	4	6	2	26	40.6
2		7		6	4	6	2	27	42.3
2		7		7	4	6	2	28	44.0
2	5	4	4	4	4	4	2	29	44.5
2	5	4	4	4	4	5	2	30	46.2
2	5	5	4	4	4	5	2	31	47.9
2	5	5	4	4	5	5	2	32	49.6
2	5	5	5	4	5	5	2	33	51.3
2	5	5	5	5	5	5	2	34	53.0
2	6	5	5	5	5	5	2	35	54.7
2	6	5	5	5	5	6	2	36	56.4
2	6	6	5	5	5	6	2	37	58.1
2	6	6	5	5	6	6	2	38	59.8
2	6	6	6	5	6	6	2	39	61.5
2	6	6	6	6	6	6	2	40	63.2
2	7	6	6	6	6	6	2	41	64.9
2	7	6	6	6	6	7	2	42	66.6
2	7	7	6	6	6	7	2	43	68.3
2	7	7	6	6	7	7	2	44	70.0
2	7	7	7	6	7	7	2	45	71.7
2	7	7	7	7	7	7	2	46	73.4
2	8	7	7	7	7	7	2	47	75.2
2	8	7	7	7	7	8	2	48	77.0
2	8	8	7	7	7	8	2	49	78.8
2	8	8	7	7	8	8	2	50	80.6

APPENDIX C: Telemetry Data Processing and Reduction Flowchart

Data Collection and Storage

Data from radiotelemetry studies are stored in the Juvenile Salmon Radio Telemetry project, an interactive database maintained by staff of the Fish Ecology Division at the NOAA Fisheries Northwest Fisheries Science Center. This project tracks migration routes and passage of juvenile salmon and steelhead past dams within the Columbia and Snake Rivers using a network of radio receivers to record signals emitted from radio transmitters ("tags") implanted into the fish. Special emphasis is placed on routes of passage and on survival for individual routes at hydroelectric dams on the lower Columbia and Snake Rivers. The database includes observations of tagged fish and the locations and configurations of radio receivers and antennas.

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

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

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

The processed in this database fall into three main categories or stages in the flow of data from input to output: loading, validation, and summarization. These are explained below and summarized in Appendix Figure C1.

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

Data Validation

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

Null: denotes a valid observation of a tag

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

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

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

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

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

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

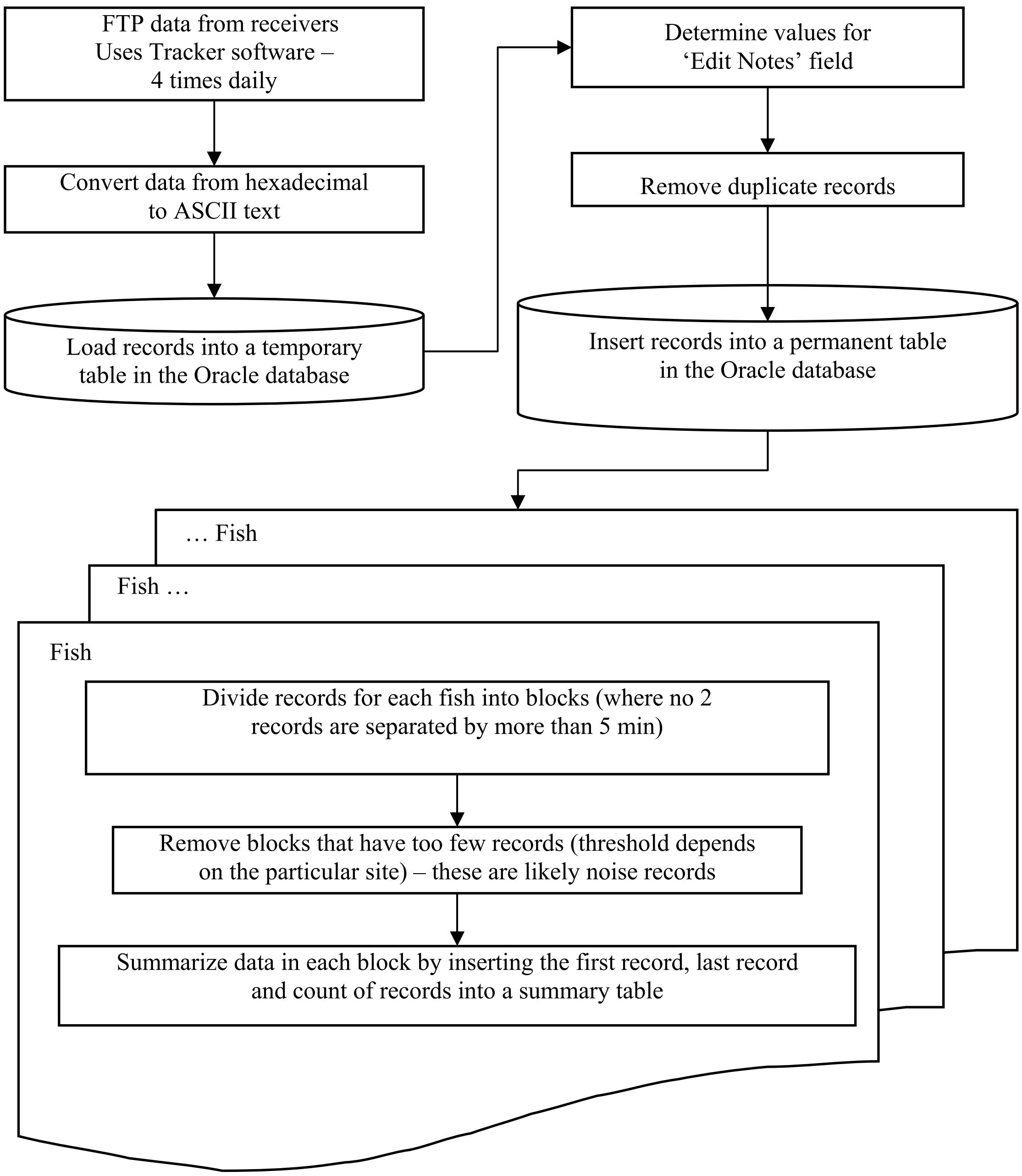
Lt start time: assigned to records occurring prior to the time at tag was activated (its start time).

Gt end time: assigned to records occurring after the end time on a tag (tags run for 10 d once activated).

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

Generation of Summary Tables

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



Appendix Figure C1. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival at Lower Monumental Dam for subyearling Chinook salmon, 2005.

Appendix D: Summary of Survival Study at Lower Monumental Dam, 2005

Year	2005		
Study site	Lower Monumental Dam		
Objectives	Evaluation of:	forebay residence time fish passage efficiency fish guidance efficiency project survival	passage distribution passage effectiveness route-specific survival tailrace egress timing
Fish	Species-race:	river-run subyearling Chinook salmon	
	Source:	Lower Monumental Dam smolt monitoring facility	
	Size:	Length	
		median:	116 mm
		range:	106-156 mm
		Weight:	not recorded
Tag	Type:	Advanced Telemetry Systems	
	Weight (gm):	0.96 in air	
	Implant procedure:	surgical	

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

Survival estimate

Type	Value	SE	Mean replicate size (range)	No. of replicates	Analytical model
dam	0.722	0.025	52 (32-74)	11	CJS
spillway	0.905	0.071	52 (32-74)	11	CJS

Passage metrics

Type	Value	SE	Mean replicate size (range)	No. of replicates
FPE	0.955	0.015	42 (24-55)	11
SPE	0.874	0.019	42 (24-55)	11
Spill eficiency	1.53	0.04	42 (24-55)	11
FGE	0.832	0.055	4 (2-7)	11

Environmental operating conditions

Daily operations	Mean	range
Spill (%)	57	52-61
Total river flow	37	28.4-44.2
Water temperature (°C)	19.9	19.1-20.9