Spillbay Survival for Radio-tagged Yearling Chinook Salmon at Lower Monumental Dam, 2005

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

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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

to

Walla Walla District
Northwestern Division
U.S. Army Corps of Engineers
201 North 3rd
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EXECUTIVE SUMMARY

In 2005, we estimated relative spillway passage survival for radio-tagged, river-run, hatchery yearling Chinook salmon released into spillbays 7 and 8 at Lower Monumental Dam on the Snake River. Fish were collected from the smolt-monitoring sample at either Lower Monumental or Little Goose Dams and were surgically tagged with a radio transmitter and PIT tagged. The treatment group comprised 901 and 889 fish released into spillbays 7 and 8, respectively. The reference group comprised 1,279 fish released into the tailrace of Lower Monumental Dam. Fish were released over 23 d, from 3 to 27 May, and during daytime hours between 1030 and 1330 PDT. This collection period encompassed the 41st through 97th percentiles of yearling Chinook based on the cumulative smolt passage index at Lower Monumental Dam.

Relative spillway 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 spillbay survival was similar for releases into bays 7 (0.926; 95% CI 0.894-0.959) and 8 (0.952; 95% CI 0.917-0.988; $t = 0.76$; $P = 0.46$). Median tailrace egress time for fish released into spillbay 7 was significantly longer (10.3 min) than for fish released into spillbay 8 (5.8 min; $F = 38.02$, $P < 0.001$).

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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 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 (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.

Juvenile anadromous salmonids in Columbia River Basin generally migrate in the upper 3 to 6 m of the water column. 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) have developed a removable spillway weir (RSW) to provide a 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 considered for installation at Lower Monumental Dam in 2007. The specific location for an RSW at Lower Monumental Dam has not been determined; however, either spillbay 7 or 8 are preferred because fish have been observed to approach the dam in this area (Hockersmith et al. 2005; Johnson et al. 1998). Estimated survival rates for juvenile salmon passing through spillbay 7 have ranged from 90 to 98% (Hockersmith et al. 2004, 2005; Muir et al. 1995a). Survival for fish passing through spillbay 8 has not been evaluated since 1994 (Muir et al. 1995a), prior to the installation of a flow deflector at this spillbay in 2003.

The proposed study design was to examine smolt passage and survival at Lower Monumental Dam during voluntary bulk spill, which included spillbays 7 and 8. However, due to projected low flows in the Snake River in 2005, voluntary spill at Lower Monumental Dam was not expected to occur. Therefore, a new study design, which minimized the amount of voluntary spill, was developed. The study redesign was developed in regional forums hosted by the USACE, including the Studies Review Regional Work Group, Systems Configuration Team, and Implementation Team.

The new study design would examine smolt passage and survival for radio-tagged fish released directly into spillbays 7 and 8. Results of this study will be used to inform management decisions for development 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.

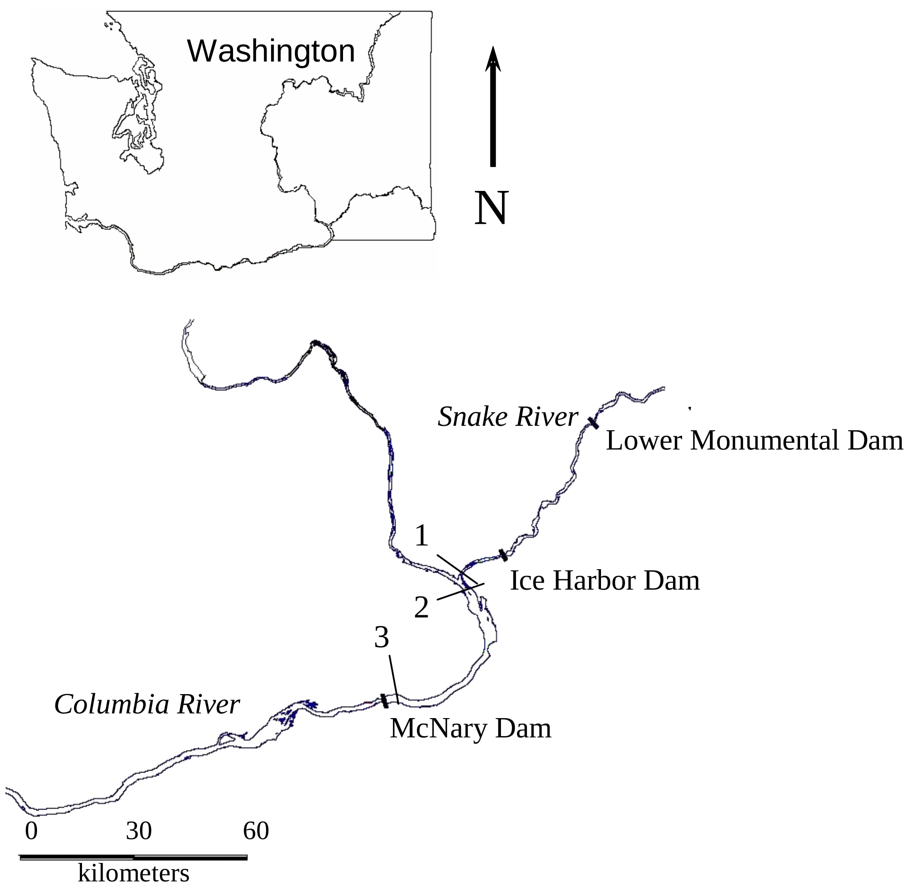

Figure 1. Detail of the study area showing locations of radiotelemetry transects used for estimating yearling Chinook salmon survival at Lower Monumental Dam in 2005. Transects included: 1 = mouth of the Snake River; 2 = Burbank/Finely Railroad Bridge and 3 = forebay of McNary Dam. The forebay, tailrace, 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 12 mm in length by 6 mm in diameter and weighed 0.99 g in air. Each tag had a 30-cm long external antenna.

River-run, hatchery yearling Chinook salmon were collected from smolt collection facilities at either Lower Monumental or Little Goose Dam from 2 to 26 May. We used only hatchery-origin yearling Chinook salmon that were not previously PIT tagged, that had no visual signs of disease or injury, and that weighed 15 g or more. Fish were anesthetized with tricaine methanesulfonate (MS-222) and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were randomly selected from the daily smolt-monitoring sample and transferred through a water-filled, 10.2-cm hose to a 935-L holding tank. Following collection and sorting, fish were maintained via flow-through river water and held a minimum of 18 h prior to radio tagging.

Fish were surgically tagged with a radio transmitter using techniques described by Adams et al. (1998). A PIT tag was also inserted with the radio transmitter so that test fish could be separated by code in the fish collection system and returned to the river (Marsh et al. 1999). Surgical tagging was conducted simultaneously at four tagging stations. During a 4-h shift, approximately 156 fish were tagged.

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

Release procedures followed those used in 2003 at Lower Monumental Dam during a study to evaluate spillway survival (Hockersmith et al. 2004). After a post-tagging recovery period, fish were transported in their recovery containers from the holding area to release areas (Lower Monumental Dam spillway or tailrace). Immediately prior to transport to release locations the transmitters of all tagged fish were

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

checked to verify that the transmitters were operating and that the codes were recorded correctly in the database. Treatment groups were transferred water-to-water from holding tanks to a release tank and released via fixed hoses just upstream from the Tainter gate in spillbays 7 and 8 (Figure 2).

Release hoses were positioned in the center of spillbays 7 and 8, 10 m upstream from the Tainter gates, and extended to a depth of 4 m below the water surface in the forebay. The hoses were attached to a 712-L release tank, and during each release, one-half of a tank of water was used to provide flush water.

Voluntary spill was provided from 3 through 27 May, beginning at 1000 PDT each day and continuing until one-half hour after the last fish was released. Releases began one-half hour after the initiation of voluntary spill in order to wait for tailrace conditions to stabilize.

Treatment fish were released in groups of four approximately every 5 min, alternating between spillbays 7 and 8. Reference groups were transferred water-to-water from holding tanks to a release tank mounted on an 8.5 by 2.4-m barge, transported to the

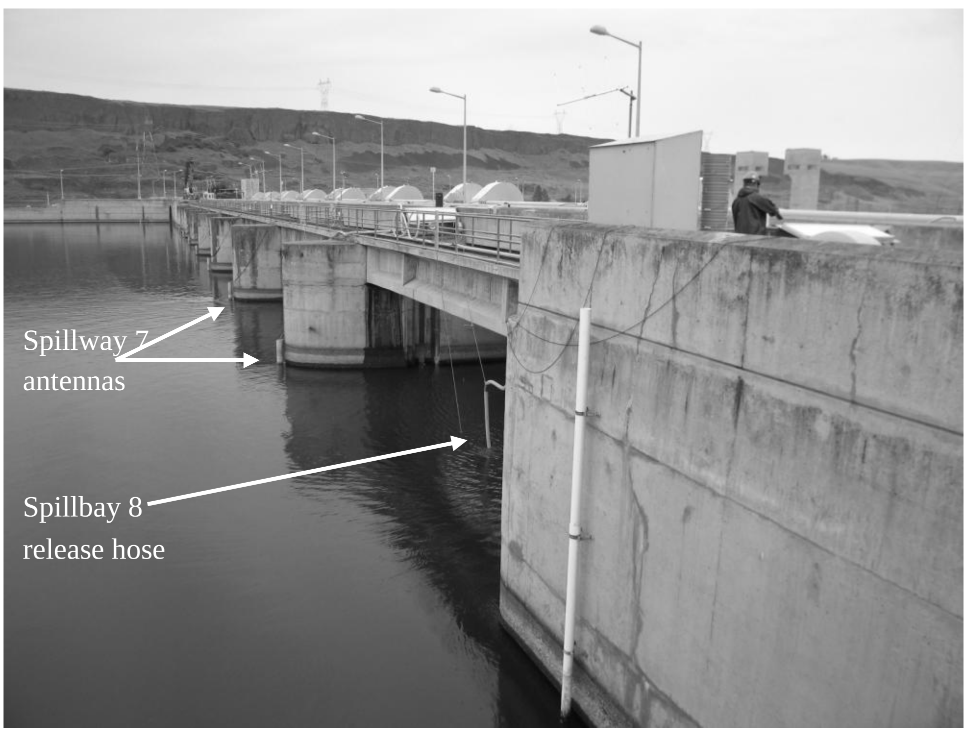

Figure 2. Forebay of Lower Monumental Dam spillway showing locations of spillbay 7 telemetry antennas and spillbay 8 release hose.

tailrace, and released mid-channel water-to-water approximately 1 km downstream from the dam. The reference-group release location was determined from operations testing on a 1:55 scale model of Lower Monumental Dam at the U.S. Army Engineer Research and Development Center in Vicksburg, MS.

To ensure temporal mixing of treatment and reference groups, treatment groups were released approximately 5 min prior to reference groups to allow time for them to pass through the spillbay and stilling basin. This time interval was chosen based on evaluations of tailrace-egress in 2003 and 2004 at Lower Monumental Dam (Hockersmith et al. 2004, 2005). Each day approximately 40, 40, and 56 radio tagged yearling Chinook salmon were released into spillbay 7, spillbay 8, and the tailrace of Lower Monumental Dam, respectively.

Voluntary spill of water through spillbays 1, 7, and 8 (Figure 3) began daily at approximately 1000 PDT and continued for at least one-half hour after the last release from 3 through 27 May. The spill pattern consisted of spillbays 7 and 8 open approximately 4.5 stops and spillbay 1 was open approximately 1 stop. Outside of the test period, only involuntary spill occurred.

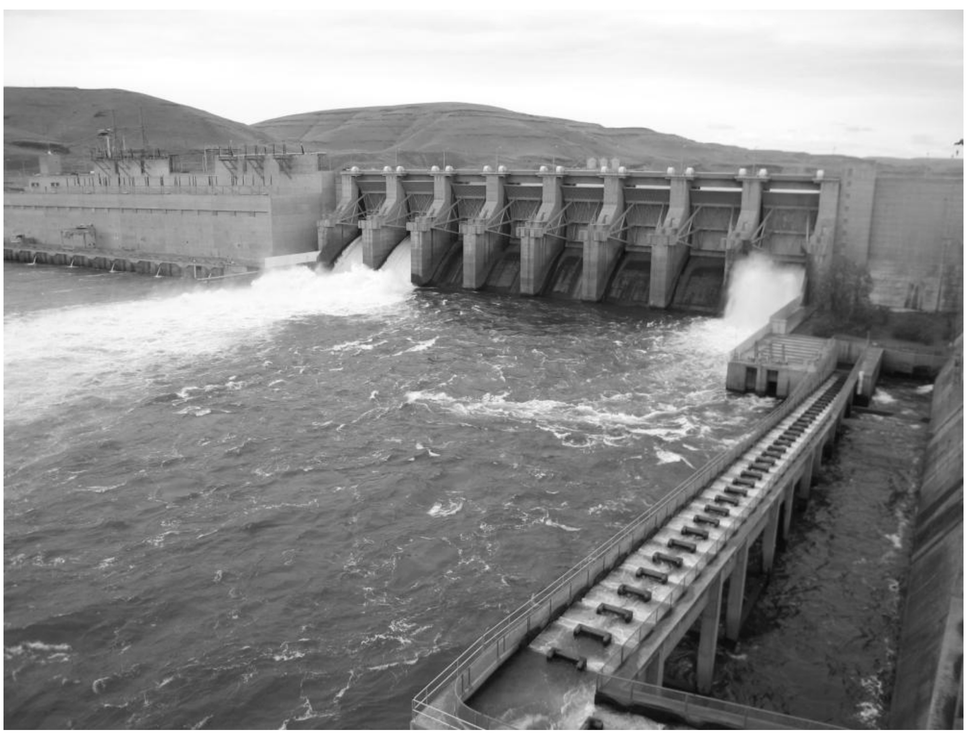

Figure 3. Bulk spill pattern used for evaluating spillbay survival for hatchery yearling Chinook salmon at Lower Monumental Dam, 2005.

The antennas used to monitor individual spillbays were approximately 10 m upstream from the release location (Figure 2). Therefore it was possible for fish released into a spillbay to pass through that bay without being detected on the associated passage array. Fish that passed the dam via a different location than where they were released would migrate upstream past the individual spillbay antennas and then back downstream past a passage route array. Fish without passage route detections were assumed to have passed the dam where they were released if they were a subsequent detected in the tailrace within 10 min of the release time. We excluded from the analysis fish that had not been detected on a passage route or whose subsequent detection in the tailrace was greater than 10 min after their release. We also excluded fish that did not have any tailrace detection, fish that passed in a location other than where it was released, and fish that did not pass the dam. 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 survival arrays (Appendix A, assumption A6).

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 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 passage timing, tailrace exit timing, and downstream detections and timing for individual radio-tagged fish.

Although treatment fish were released immediately upstream from spillbays 7 and 8 it was possible for fish to pass the dam at other locations. Route of passage through the dam was based on the location of last detection on a passage-route antenna. If a fish had no detection on a passage-route antenna, it was assumed to have passed where it was released, provided that the time between release and first detection in the tailrace was less than 10 min. Fish were assumed to have passed the dam only if they were detected on the stilling-basin, draft-tube exit, or tailrace-exit telemetry antennas. Locations of the fixed telemetry receiver sites at Lower Monumental Dam in 2005 are summarized in Table 1 and Figure 4.

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

Location	Number of receivers	Type of monitoring	Antenna type
Turbine units 1-6	6	Passage route and timing	Stripped coax
Draft tubes, turbine units 1-6	6	Project passage	Underwater dipole
Spillbays 1-8	8	Passage route and timing	Underwater dipole
Stilling basin, north and south shore	2	Project passage	2-element Yagi
Juvenile bypass system	1	Bypass system passage	Tuned loop
Tailrace exit, north and south shore	2	Project passage & tailrace egress	3-element Yagi
Total receivers	25		

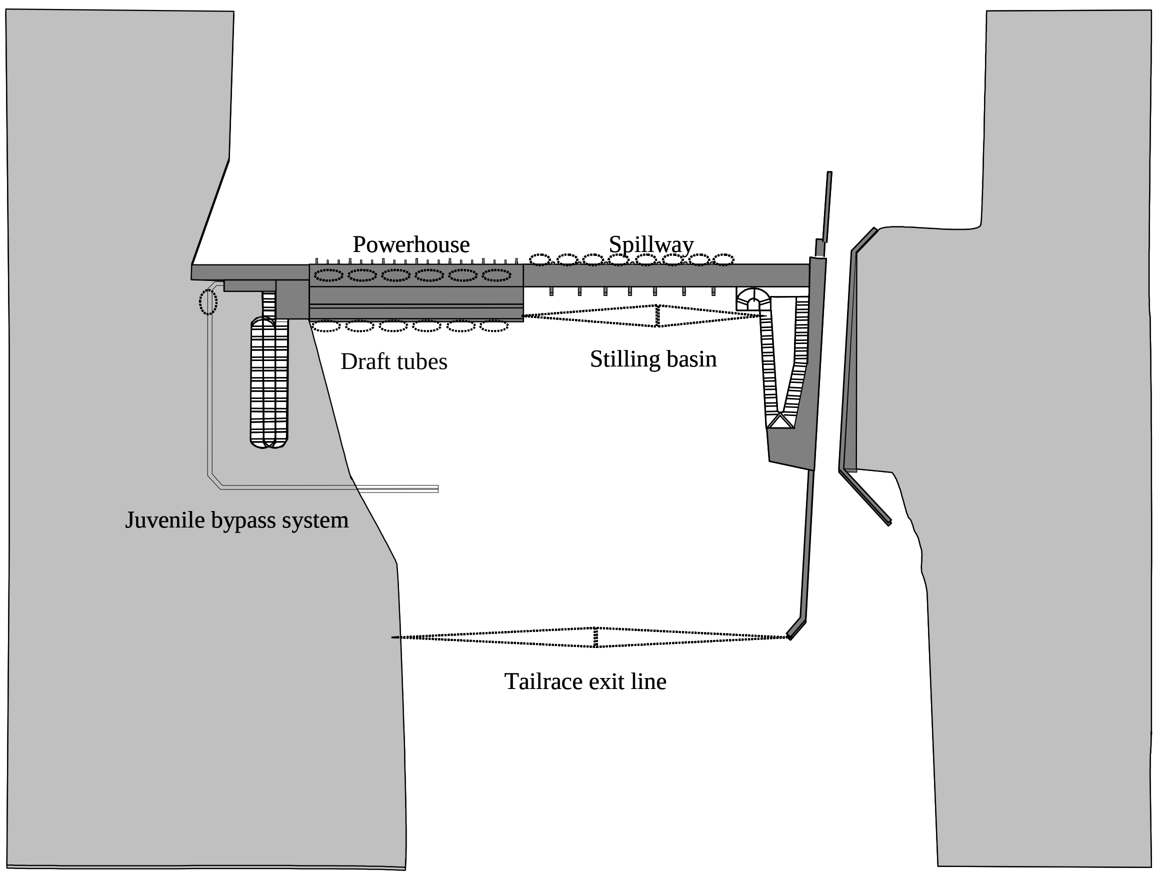

Figure 4. Plan view of Lower Monumental Dam showing approximate locations of radiotelemetry detection zones in 2005. Oval lines represent underwater antennas, and triangular lines represent aerial antennas.

Tailrace detections were needed to validate passage because it was possible for fish to be detected on a passage-route antenna while still in the forebay. Spillway passage was assigned to fish with a detection in the tailrace of the dam after last being detected in the forebay on 1 of the 8 antenna arrays deployed along each of the pier noses on the sides of individual spillbays. Similarly, powerhouse passage was assigned to fish last detected in a turbine intake prior to detection in the tailrace of the dam.

Fish assigned to powerhouse passage were further partitioned into either turbine or juvenile bypass system (JBS) passage based on the presence or absence of a JBS detection (either PIT or radiotelemetry). Fish that were assigned to powerhouse passage but that had no detection in the JBS were assigned to turbine passage. Analysis of the passage distribution included only fish that were released into the forebay of Lower Monumental Dam, detected in a passage route, and subsequently detected in the tailrace on either the stilling-basin, draft tube exit, or tailrace-exit telemetry receivers.

Tailrace Egress

Analysis of tailrace egress included only fish released into spillbay 7 or spillbay 8 and detected on the tailrace exit array. Due to the locations of the spillbay antennas and the release hose, fish released into a spillbay could pass through the bay without being detected. Therefore, tailrace egress time was defined as the time between release and last detection on the tailrace exit array. Tailrace egress data were partitioned by passage location and release date. Median tailrace egress times per release group for fish released into spillbays 7 and 8 were compared using one-way analysis of variance (ANOVA), where release location was a treatment factor and release day was a random (blocking) factor.

Survival Estimates

Estimates of survival were based on detection histories using the CJS single-release model (Cormack 1964; Jolly 1965; Seber 1965) as implemented in SURPH (Smith 1994). Survival estimates were based on detections of individual fish at Snake River telemetry transects at Ice Harbor Dam and at the river mouth and at Columbia River transects near Burbank, WA, and in the forebay of McNary Dam (Figure 1).

Capture histories of treatment and reference groups were partitioned into two periods for survival estimation: detection at Ice Harbor Dam and detection downstream from Ice Harbor Dam. Treatment groups for estimates of survival were comprised of fish released into a passage route (spillbay 7 or 8) and subsequently detected in the tailrace of the dam (either on the stilling-basin, draft-tube, or tailrace-exit telemetry receivers) on a specific day. Treatment and reference fish for estimates of survival were grouped by release date for 23 releases. Relative survival estimates were the ratios of survival estimates between groups of treatment (numerator) and reference (denominator) fish.

Confidence intervals for relative survival (spillbay relative to tailrace) were constructed using weighted geometric means, where weights were the inverse of estimated relative variance (Zabel et al. 2001). Since weighted geometric means were used, the ratios of proportions were assumed to be 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. The confidence intervals were of the form:

$$\left(e^{\log(\bar{x}_w) - t_{.05,22} \times SE_w},\ e^{\log(\bar{x}_w) + t_{.05,22} \times SE_w} \right)$$

where $|\bar{x}_w|$ was the weighted geomean; t was the t-value, given $\alpha = 0.05$ and 22 degrees of freedom; and SE_w was the weighted standard error of the geomean. We evaluated the null hypothesis that spillbay 7 and spillbay 8 had equal survival using a one-sample t-test where:

$$t = \frac{\bar{x}_w}{SE_w}$$

A P-value was determined by comparing t to a t-distribution with 22 degrees of freedom.

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 Granite Dam). This assumption is reasonable if the release groups have similar passage distributions at downstream detection sites, in this case, particularly at Ice Harbor Dam. To evaluate this assumption, we used chi-square contingency tables of expected detection rates at Ice Harbor Dam detections by release location. P-values for these tests were calculated using exact methods in StatXact (Mehta and Patel 1992). Model assumptions and methods used to evaluate them are detailed in Appendices A and B.

Treatment fish were assumed to pass the dam through the location where they were last detected. Fish not detected in a passage route were assumed to have passed where released, provided the difference between the time of release and first detection in the tailrace was less than 10 min. We excluded from the analysis any fish that had not been detected on a passage route or whose subsequent detection in the tailrace was greater than 10 min after release. We also excluded fish that were not detected in the tailrace, fish that passed in locations other than where released, and fish that did not pass the dam.

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

Avian Predation

Predation from the Caspian Tern *Sterna caspia* colony on Crescent Island, located 12.9 km downstream from the Snake River mouth (Figure 1), was evaluated by physical recovery of radio transmitters, which were visible on the island, and by PIT tag detection. Radio and PIT tags were recovered on the tern colony at Crescent Island during fall 2005 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 at Crescent Island were provided by NMFS (B. Ryan, NOAA Fisheries, personal communication) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication). There is an ongoing monitoring effort to detect PIT tags from active Caspian Tern colonies in the region conducted by NOAA Fisheries and by the Columbia Bird Research group.

RESULTS

Fish Collection, Tagging, and Release

Yearling Chinook salmon were radio tagged and PIT tagged at Lower Monumental Dam over 23 d from 3 to 27 May. Fish were collect from 2 to 26 May which encompassed the 41st through the 97th passage percentile from the 2005 Chinook salmon smolt index at Lower Monumental Dam (Figure 5). We tagged 970, 969, and 1,324 fish with radio tags for releases into spillbays 7, 8, and into the tailrace of Lower Monumental Dam, respectively (Table 2). Post-tagging mortality was 31, 20, and 29 fish for spillbay 7, spillbay 8, and tailrace release groups, respectively. 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 survival arrays (Appendix A, assumption A6). One hundred fourteen fish were excluded from the analysis because of tag failure, duplicate tag-code issues, or passage issues. Passage issues included fish that passed other than where released or fish whose passage could not be confirmed.

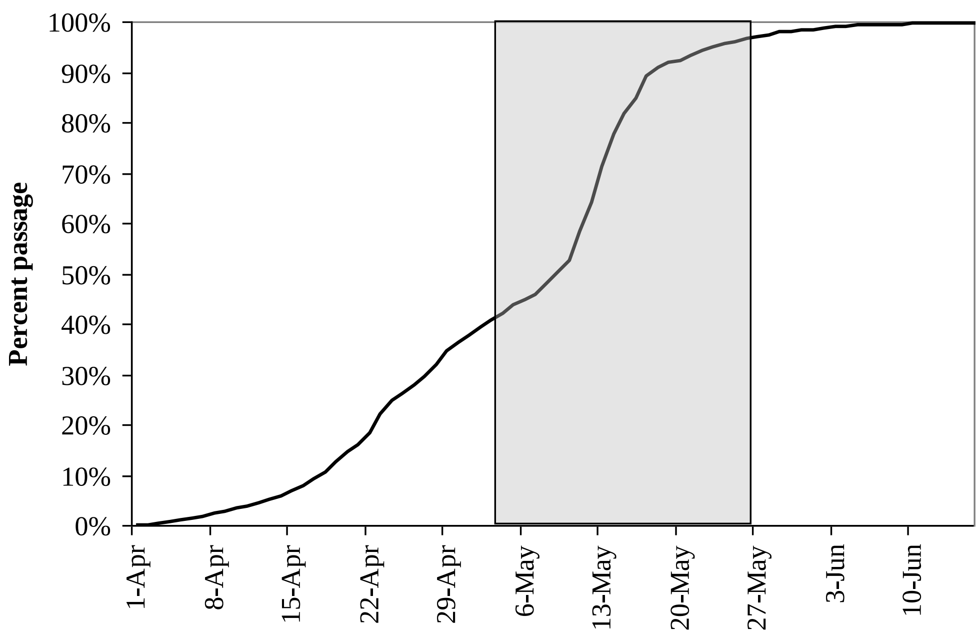

Figure 5. Cumulative passage distribution of hatchery yearling Chinook salmon at Lower Monumental Dam during 2005. Gray box indicates the period of fish collection and release for spillbay survival evaluations. .

Overall fork length ranged from 118 to 253 mm and is summarized by release date and release location in Table 3. We did not identify significant differences in fork length between release locations for fish released on the same day (ANOVA spillbay 7, spillbay 8, tailrace; $F = 0.05$; df = 2; $P < 0.950$). Fish were released between 1030 and 1330 PDT.

Table 2. Number of yearling Chinook salmon tagged, tagging mortality, and numbers of fish used in and excluded from analyses of passage behavior and survival for fish passing through spillbays 7 and 8 at Lower Monumental Dam, 2005.

	Treatment releases		Reference releases
	Spillbay 7	Spillbay 8	Tailrace
Tagged	970	969	1,324
post-tagging mortality	31	20	29
Excluded			
duplicate tag code	4	5	1
tag failure	9	10	15
passage other than release location	3	3	na
no passage-route detection	2	0	na
no passage-route or tailrace detection	14	39	na
timing of passage more than 10 min	6	3	na
Included			
Passage-route and tailrace detection	459	445	na
No passage-route detection, but tailrace detection within 10 min after release	442	444	na
Total used for analyses	901	889	1,279

Table 3. Sample size, mean fork length, standard deviation (SD), and range of fork lengths for radio-tagged, yearling Chinook salmon released at Lower Monumental Dam for evaluation of spillbay survival, 2005.

	Spillbay 7				Spillbay 8				Tailrace			
Release date	N	Mean length (mm)	SD	Range (mm)	N	Mean length (mm)	SD	Range (mm)	N	Mean length (mm)	SD	Range (mm)
3-May	41	151.3	20.0	126-201	44	154.8	17.5	129-213	52	150.8	19.3	123-213
4-May	43	151.0	15.8	126-198	40	144.1	13.6	126-175	63	142.1	16.5	125-233
5-May	39	145.4	12.3	124-173	45	149.4	19.4	129-253	63	143.1	11.7	125-179
6-May	42	144.5	15.1	123-187	43	142.6	11.7	125-170	61	141.2	9.9	126-175
7-May	45	143.6	11.0	124-168	42	141.4	9.6	126-174	60	141.1	11.7	121-183
8-May	41	141.2	8.4	124-158	38	143.4	8.1	125-159	63	145.5	8.7	129-172
9-May	44	143.3	8.5	125-165	40	143.0	8.9	129-172	59	143.7	8.1	118-164
10-May	42	142.0	6.8	129-155	37	144.1	8.0	127-163	61	148.4	8.5	128-169
11-May	39	142.2	9.9	123-178	37	143.6	7.2	129-163	58	141.7	9.9	128-172
12-May	40	142.6	7.4	128-157	43	142.0	7.3	131-162	62	143.4	6.9	133-164
13-May	44	143.6	6.5	128-161	39	145.5	9.4	134-184	62	143.2	8.5	126-163
14-May	41	142.8	6.5	127-157	40	143.5	7.2	129-158	57	143.3	7.2	130-168
15-May	42	143.0	7.2	129-157	44	140.8	6.5	127-163	60	143.8	7.0	128-166
16-May	20	140.7	6.1	130-153	22	146.5	7.7	135-165	17	141.5	5.4	133-152
17-May	32	146.8	9.0	133-171	32	146.4	9.2	133-166	45	145.6	7.7	128-158
18-May	38	143.6	7.3	128-160	39	142.6	8.2	124-158	48	143.0	8.5	126-161
19-May	41	146.4	7.7	135-165	41	146.9	8.4	134-169	55	146.9	7.6	134-171
20-May	35	148.8	8.7	135-171	40	147.1	8.9	129-163	57	148.7	8.2	131-162
21-May	41	152.2	7.2	137-172	39	150.5	10.8	133-178	61	150.3	6.9	136-165
22-May	33	133.5	9.0	118-154	33	138.4	8.1	118-155	52	138.5	8.5	120-156
24-May	29	141.5	10.8	122-158	28	138.0	8.7	121-158	62	145.2	10.0	122-166
26-May	53	140.9	9.4	124-168	51	135.9	9.5	118-156	63	138.4	10.5	124-166
27-May	36	140.3	10.6	120-161	32	141.2	11.3	121-162	38	139.2	10.4	120-165
Overall	901	144.1	10.9	118-201	889	144.0	11.2	118-253	1,279	144.0	10.5	118-233

Project Operations

During our evaluation of spillbay passage survival at Lower Monumental Dam the average daily project discharge was 97.7 kcfs or 90% of the 10-year average of 106 kcfs (Figure 6 and Table 4). Project operations at Lower Monumental Dam included voluntary bulk spill during releases. Spill began one-half hour before the start of releases and ended one-half hour after the last fish was released. Only involuntary spill occurred outside of times when fish were being released.

During releases Lower Monumental Dam project operations averaged 97.7 kcfs total project discharge, 78.3 kcfs powerhouse discharge, 19.4 kcfs total spill volume (19.9% of total project discharge), 8.2 kcfs individual spillbay discharge (for bays 7 and 8), and tailwater elevation of 441.1 ft msl (Table 4). Water temperature during tagging, the post-tagging holding period, and releases ranged from 11.4 to 12.6°C and averaged 12.0°C. During our releases, spillbays 7 and 8 spilled equal amounts of water simultaneously. We observed a hydraulic interaction where flow from spillbay 7 travels laterally into spillbay 8 in the vicinity of the flow deflector when spillbay 7 and 8 are operated at the same time (Figure 7).

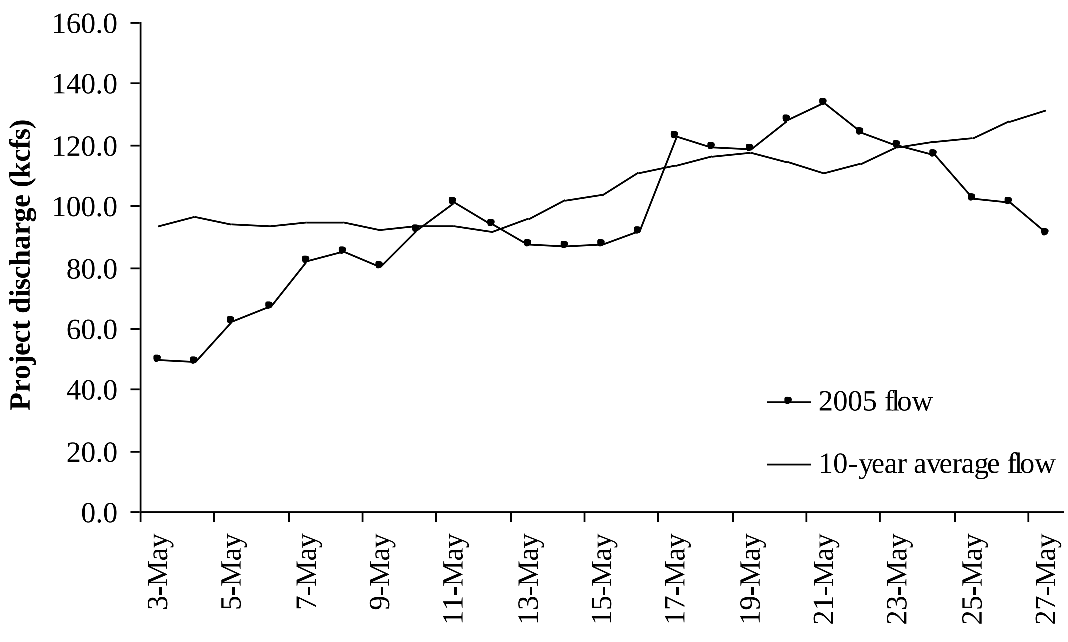

Figure 6. Daily and 10-year average (1995-2004) project discharge during releases of radio-tagged, hatchery yearling Chinook salmon for evaluating spillbay survival at Lower Monumental Dam, 2005.

Table 4. Average and range of project conditions during releases of radio-tagged hatchery yearling Chinook salmon at Lower Monumental Dam, 2005. Treatment fish were not released on 23 or 24 May.

Release	Project discharge (kcfs)			Spillway discharge (kcfs)			Powerhouse discharge (kcfs)		
date	average	min	max	average	min	max	average	min	max
3-May	63.7	63.5	63.8	18.2	18.2	18.2	45.5	45.3	45.7
4-May	71.4	71.3	71.6	18.2	18.2	18.2	53.3	53.1	53.4
5-May	84.1	79.7	85.0	18.2	18.2	18.2	65.9	61.6	66.9
6-May	76.8	74.4	94.6	17.1	17.1	17.1	59.8	57.3	77.5
7-May	104.2	103.9	104.4	17.6	17.6	17.6	86.6	86.3	86.8
8-May	86.9	86.7	87.2	17.6	17.6	17.6	69.3	69.1	69.6
9-May	90.5	90.2	91.0	18.2	18.2	18.2	72.3	72.0	72.8
10-May	84.6	84.4	84.7	18.3	18.3	18.3	66.3	66.1	66.5
11-May	115.5	115.2	115.8	18.2	18.2	18.2	97.4	97.0	97.6
12-May	104.6	100.6	114.5	18.4	18.4	18.4	86.2	82.3	96.2
13-May	94.0	85.3	99.2	12.2	12.2	12.2	81.9	73.1	87.1
14-May	82.4	81.7	84.0	16.9	16.9	16.9	65.4	64.8	67.1
15-May	91.6	84.2	108.4	20.3	20.3	20.3	71.2	63.9	88.1
16-May	93.9	93.7	94.1	18.2	18.2	18.2	75.7	75.5	75.9
17-May	113.7	113.4	114.2	18.9	18.9	18.9	94.8	94.5	95.2
18-May	111.1	110.1	111.9	16.9	16.9	16.9	94.2	93.2	95.0
19-May	113.0	112.7	113.2	18.3	18.3	18.3	94.7	94.4	94.9
20-May	117.5	117.2	117.7	21.7	21.7	21.7	95.8	95.4	95.9
21-May	136.8	136.5	137.3	40.9	40.9	40.9	95.9	95.6	96.4
22-May	120.4	119.6	121.1	39.3	39.3	39.3	81.2	80.4	81.9
24-May	111.2	110.7	111.4	16.9	16.9	16.9	94.3	93.8	94.5
26-May	111.6	111.2	112.0	18.2	18.2	18.2	93.4	93.0	93.9
27-May	113.1	112.9	113.2	17.8	17.8	17.8	95.2	95.1	95.4
Overall	97.7	63.5	137.3	19.4	12.2	40.9	78.3	45.3	97.6

Table 4. Continued.

Release date	Tailwater elevation (ft msl) average	min	max	Spillbay 7 discharge (kcfs) average	min	max	Spillbay 8 discharge (kcfs) average	min	max
3-May	439.6	439.5	439.7	8.5	8.5	8.5	8.5	8.5	8.5
4-May	439.6	439.4	439.8	8.5	8.5	8.5	8.5	8.5	8.5
5-May	440.6	440.3	440.8	8.5	8.5	8.5	8.5	8.5	8.5
6-May	440.1	439.8	440.9	7.9	7.9	7.9	8.1	8.1	8.1
7-May	441.5	441.4	441.5	8.3	8.3	8.3	8.3	8.3	8.3
8-May	440.4	440.3	440.5	8.3	8.3	8.3	8.3	8.3	8.3
9-May	440.6	440.5	440.7	8.5	8.5	8.5	8.5	8.5	8.5
10-May	440.3	440.2	440.4	8.6	8.6	8.6	8.5	8.5	8.5
11-May	441.7	441.6	441.8	8.5	8.5	8.5	8.5	8.5	8.5
12-May	441.2	440.8	441.9	8.6	8.6	8.6	8.6	8.6	8.6
13-May	441.2	440.7	441.6	5.5	5.5	5.5	5.5	5.5	5.5
14-May	440.1	440.0	440.2	7.9	7.9	7.9	7.9	7.9	7.9
15-May	440.6	440.1	441.4	9.6	9.6	9.6	9.6	9.6	9.6
16-May	440.8	440.7	440.9	8.5	8.5	8.5	8.5	8.5	8.5
17-May	441.5	441.4	441.7	8.5	8.5	8.5	8.5	8.5	8.5
18-May	441.7	441.7	441.8	7.9	7.9	7.9	7.9	7.9	7.9
19-May	441.8	441.7	442.1	8.3	8.3	8.3	8.3	8.3	8.3
20-May	442.1	442.1	442.2	8.3	8.3	8.3	8.3	8.3	8.3
21-May	443.3	443.2	443.4	8.4	8.4	8.4	8.4	8.4	8.4
22-May	442.4	442.3	442.4	7.9	7.9	7.9	7.9	7.9	7.9
24-May	441.7	441.6	441.8	7.9	7.9	7.9	7.9	7.9	7.9
26-May	441.7	441.6	442.1	8.5	8.5	8.5	8.5	8.5	8.5
27-May	442.0	441.9	442.0	8.3	8.3	8.3	8.3	8.3	8.3
Overall	441.1	439.4	443.4	8.2	5.5	9.6	8.2	5.5	9.6

Figure 7. Characteristics of the flow on the ogee and flow deflectors in spillbay 7 (left) and spillbay 8 (right) at Lower Monumental Dam. Spillbays 7 and 8 were each open at the same time (4.5 stops) and discharging 8.2 kcfs.

Passage Behavior

A total of 1,790 fish were used in the analysis of survival and passage as treatment fish (Table 2). Of these 904 (51%) were confirmed as passing where they were released based on last detection on spillbay antennas. The remaining 886 treatment fish were not detected on a passage-route antenna but were assumed to have passed where released because they were detected in the tailrace less than 10 min after release. The elapsed time between release and subsequent detection in the tailrace is summarized by release location in Table 5.

Table 5. Elapsed time in minutes between release and detection in the tailrace for radio-tagged hatchery yearling Chinook salmon released into spillbays 7 and 8 at Lower Monumental Dam, 2005.

	Passage time (min)			
	Confirmed passed where released		Assumed passed where released	
Percentile	Spillbay 7	Spillbay 8	Spillbay 7	Spillbay 8
min	0.1	0.1	0.1	0.1
10	0.3	0.3	0.1	0.1
20	0.5	0.6	0.1	0.1
30	0.8	0.9	0.1	0.1
40	1.2	1.3	0.1	0.1
50	1.9	2.2	0.1	0.2
60	2.5	3.1	0.2	0.3
70	3.7	4.4	0.3	0.4
80	6.4	7.6	0.5	0.7
90	14.0	14.4	1.0	1.0
max	62.0	142.1	8.7	7.9
Number of fish	459	445	442	444

Tailrace Egress

A total of 62 fish released into spillbay 7 and 37 fish released into spillbay 8 were used for the analysis of passage survival but were excluded from the analysis of tailrace egress because they were not detected on the tailrace exit array at Lower Monumental Dam. Median tailrace egress for fish released into spillbay 7 was 10.3 min and ranged from 1.1 to 12,758 min (Table 6). Median tailrace egress for fish released into spillbay 8 was 5.8 min and ranged from 1.0 to 11,768.5 min (Table 6). Median daily tailrace egress times for fish released into spillbay 7 were significantly longer than for fish released into spillbay 8 (ANOVA F = 38.02; df = 22; P <0.001).

Table 6. Tailrace egress (elapsed time in minutes from release to last detection on the tailrace exit array) for radio-tagged hatchery yearling Chinook salmon released into spillbays 7 and 8 at Lower Monumental Dam, 2005.

	Tailrace egress time (min)	
Percentile	Spillbay 7	Spillbay 8
min	1.1	1.0
10	3.7	3.0
20	4.6	3.7
30	5.8	4.2
40	7.6	4.9
50	10.3	5.8
60	14.6	7.2
70	22.2	9.6
80	44.8	14.5
90	155.9	40.9
max	12,758.1	11,768.5
Number of fish	839	852

Survival Estimates

Sample sizes and estimated survival from the CJS single-release model by release location and release date are presented in Table 7. The weighted geomean estimate of spillway survival for radio-tagged yearling Chinook salmon released into spillbay 7 relative to those released in the tailrace was 0.926 (SE = 0.017; 95% CI 0.894-0.959; Table 8). The weighted geomean estimate of spillway survival for radio-tagged yearling Chinook salmon released into spillbay 8 relative to those released in the tailrace was 0.952 (SE = 0.018; 95% CI 0.917-0.988; Table 8). Relative spillbay survival for fish released into spillbays 7 and 8 at Lower Monumental Dam was not significantly different (0.926 vs. 0.952; $t = 0.757$, df = 22; $P = 0.457$). The sample sizes used and data obtained from our evaluation were sufficient to detect a survival difference of 4% (or larger) with an 80% power 95% of the time ($\alpha = 0.05$).

Table 7. Sample sizes and estimates of survival (CJS single-release model) for radio-tagged hatchery yearling Chinook released into spillbay 7, spillbay 8, and the tailrace of Lower Monumental Dam, 2005. Standard errors in parenthesis.

	Spillbay 7		Spillbay 8		Tailrace	
Release Date	N	Survival	N	Survival	N	Survival
3-May	41	0.561 (0.078)	44	0.841 (0.055)	52	0.846 (0.050)
4-May	43	0.814 (0.059)	40	0.750 (0.069)	63	0.794 (0.051)
5-May	39	0.897 (0.049)	45	0.822 (0.057)	63	0.905 (0.037)
6-May	42	0.786 (0.063)	43	0.907 (0.044)	61	0.918 (0.035)
7-May	45	0.800 (0.060)	42	0.810 (0.061)	60	0.934 (0.032)
8-May	41	0.732 (0.069)	38	0.842 (0.059)	63	0.889 (0.040)
9-May	44	0.800 (0.061)	40	0.900 (0.047)	59	0.932 (0.033)
10-May	42	0.857 (0.054)	37	0.811 (0.064)	61	0.951 (0.028)
11-May	39	0.872 (0.054)	37	0.865 (0.056)	58	0.862 (0.045)
12-May	40	0.875 (0.052)	43	0.744 (0.067)	62	0.855 (0.045)
13-May	44	0.864 (0.052)	39	0.821 (0.062)	62	0.936 (0.032)
14-May	41	0.707 (0.071)	40	0.750 (0.069)	57	0.965 (0.024)
15-May	42	0.857 (0.054)	44	0.796 (0.061)	60	0.933 (0.032)
16-May	20	0.850 (0.080)	22	0.864 (0.073)	17	1.000 (0.000)
17-May	32	0.878 (0.059)	32	0.844 (0.064)	45	0.889 (0.047)
18-May	38	0.737 (0.071)	39	0.872 (0.054)	48	0.896 (0.044)
19-May	41	0.829 (0.059)	41	0.781 (0.065)	55	0.855 (0.048)
20-May	35	0.771 (0.071)	40	0.700 (0.073)	57	0.965 (0.024)
21-May	41	0.927 (0.041)	39	0.897 (0.049)	61	0.984 (0.016)
22-May	33	0.849 (0.062)	33	0.758 (0.075)	52	0.925 (0.037)
24-May	29	0.967 (0.034)	28	1.000 (0.000)	62	0.936 (0.031)
26-May	53	0.868 (0.047)	51	0.922 (0.038)	63	0.968 (0.022)
27-May	36	0.917 (0.046)	32	0.969 (0.031)	38	0.947 (0.036)
Overall	901	0.826 (0.018)	889	0.838 (0.016)	1,279	0.920 (0.010)

Table 8. Estimated survival for radio-tagged hatchery yearling Chinook salmon released into spillbays 7 and 8 (treatment) at Lower Monumental Dam relative to fish released into the tailrace (reference), 2005. Standard errors in parenthesis.

	Relative survival	
Release date	Spillbay 7	Spillbay 8
3-May	0.663 (0.100)	0.994 (0.088)
4-May	1.026 (0.100)	0.945 (0.106)
5-May	0.992 (0.067)	0.909 (0.073)
6-May	0.856 (0.076)	0.988 (0.061)
7-May	0.856 (0.070)	0.867 (0.071)
8-May	0.823 (0.086)	0.947 (0.079)
9-May	0.853 (0.072)	0.965 (0.061)
10-May	0.901 (0.063)	0.853 (0.072)
11-May	1.011 (0.082)	1.003 (0.084)
12-May	1.023 (0.081)	0.870 (0.090)
13-May	0.923 (0.063)	0.877 (0.072)
14-May	0.733 (0.076)	0.777 (0.074)
15-May	0.918 (0.066)	0.852 (0.071)
16-May	0.850 (0.080)	0.864 (0.073)
17-May	0.987 (0.084)	0.949 (0.088)
18-May	0.823 (0.089)	0.973 (0.077)
19-May	0.971 (0.0874)	0.913 (0.091)
20-May	0.799 (0.076)	0.725 (0.077)
21-May	0.942 (0.044)	0.912 (0.052)
22-May	0.917 (0.077)	0.819 (0.087)
24-May	1.033 (0.050)	1.069 (0.036)
26-May	0.896 (0.052)	0.952 (0.044)
27-May	0.968 (0.061)	1.023 (0.051)
Wt. Geomean	0.926 (0.017)	0.952 (0.018)

Avian Predation

A total of 41 tags from fish released at Lower Monumental Dam during 2005 were recovered from the Caspian tern colony on Crescent Island in the McNary Dam pool of the Columbia River (Table 9). The majority of these fish were last detected in the McNary Dam pool (below our primary survival line at Ice Harbor Dam) prior to being recovered from Crescent Island.

Table 9. Numbers and proportion of radio tags by location of last telemetry detection from the 41 tags of hatchery yearling Chinook salmon recovered on the Caspian tern colony on Crescent Island. Fish were released for evaluations of spillway survival at Lower Monumental Dam, 2005.

	Radio tags recovered					
	Spillbay 7		Spillbay 8		Tailrace	
Last telemetry detection	n	(%)	n	(%)	n	(%)
Lower Monumental Dam tailrace	2	0.2	1	0.1	3	0.2
Ice Harbor Dam forebay	0	0.0	0	0.0	0	0.0
Ice Harbor Dam tailrace	0	0.0	0	0.0	0	0.0
McNary Pool	6	0.7	7	0.8	20	1.6
McNary Dam forebay	1	0.1	0	0.0	1	0.1
Total	9	1.0	8	0.9	24	1.9

DISCUSSION

In general, among the various passage routes (spillway, bypass, or turbine) at lower Snake River dams, spillway passage is considered to provide the highest survival for juvenile salmonids (Muir et al. 2001). Higher survival for spillway passage is attributed to reductions in passage time with less exposure to predators in the forebay and tailrace (Beamesderfer et al. 1990; Vigg et al. 1991). Potential positive effects of spill likely go beyond those directly measured as dam survival. Smith et al. (2002) found a strong inverse relationship between travel time and spill exposure in the Snake River for yearling Chinook salmon.

Positive effects of spill on a season-wide basis have also been demonstrated (Zabel et al. 2002). Analysis based on early data (1973-1979) suggested that increases in spill had a direct impact on increasing survival (Sims and Ossiander 1981). Zabel et al (2002) reported lower survival through the hydropower system in 1993 and 1994, when spill occurred only in excess of powerhouse capacity, than after spill was prescribed at all dams in the 1995 Biological Opinion (NMFS 1995).

To increase the proportion of fish passing through the spillway, engineers and biologists within the USACE have developed a removable spillway weir (RSW) to provide surface-oriented spillway passage. RSWs were installed at Lower Granite Dam in 2001 and Ice Harbor Dam in 2005. At both projects, the RSWs reduced migrational delays, improved fish passage efficiency (FPE) and provided increased passage survival (Plumb et al. 2003, 2004; Axel et al. *In prep*.; Ogden et al *In prep*). An RSW is being developed for installation at Lower Monumental Dam in 2007. The goal of this study was to determine the best location for an RSW (spillbay 7 or spillbay 8) at Lower Monumental Dam based on survival and tailrace egress.

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

Few spillway survival studies have identified relationships between survival and project operations because the range of project operations available to evaluate are often limited by river flow, lack of a power supply, regulations governing dam operations, or timing of the juvenile migration. Previous evaluations of spillway survival at Lower Monumental Dam have also seen considerable variation across species, runs, and years; this variation may have been species- or run-specific, or it may be related to differences in project operations.

Long and Ossiander (1974) reported spillway passage survival of 97 to 110% for coho salmon released into spillbays with flow deflectors. Estimated survival of steelhead was 98% for releases into a spillbay with a flow deflector and 76% for releases into a spillbay without a flow deflector (Long et al. 1972). For subyearling Chinook salmon released into a spillbay with a flow deflector, survival estimates were 83 to 84% (Long et al 1972). For yearling Chinook salmon, Muir et al. (1995a) estimated survival at 93% for releases into a spillbay with a flow deflector (spillbay 7) and 98% for releases into a spillbay without a flow deflector (spillbay 8) at Lower Monumental Dam.

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

In 2004, Hockersmith et al. (2005) estimated spillway survival for hatchery yearling Chinook salmon volitionally passing Lower Monumental Dam to be 96%. In 2005, our estimates of survival for hatchery yearling Chinook salmon released directly into spillbays 7 and 8 at Lower Monumental Dam (92 and 95%) were within the range of previously reported estimates.

Our estimate of median tailrace egress in 2005 for spillbay 7 (10 min) was longer and for spillbay 8 (6 min) was shorter than the median spillway egress of 9 min reported by Hockersmith et al. (2005). This may have been due to differences in the way tailrace egress was estimated, in the spill patterns, or annual variability between years. In 2004, the estimate of median tailrace egress was calculated for all fish passing through the spillway, whereas in 2005, median tailrace egress was calculated for individual spillbays. The spill pattern in 2004 consisted primarily spillbays 7, 3, and 1 whereas in 2005 the spill pattern consisted of spillbays 8, 7, and 1.

Snake River flows in the spring of 2005 were expected to be very low; therefore project operations upstream from Lower Monumental Dam were adjusted to minimize spill and maximize the collection and transportation of smolts. With little or no spill, an estimated 91% of non-tagged yearling Chinook salmon arriving at Lower Granite Dam were subsequently transported from Lower Granite, Little Goose, or Lower Monumental Dams (Steve Smith, NOAA Fisheries, personal communication). The high percentage of fish transported in 2005 reduced the overall abundance of Snake River juvenile salmonids arriving at and passing Lower Monumental Dam compared to previous years. This may have influenced predator/prey dynamics for our radio-tagged fish and had a large impact on their survival. Zabel et al (2002) reported that the combination of decreased spill and operations associated with full transportation at Snake River dams during a low flow year (2001) resulted in substantially decreased in-river survival for yearling Chinook salmon.

The slightly lower survival and significantly longer tailrace egress for fish released into spillbay 7 vs. spillbay 8 may have been due to physical differences in the flow deflectors of these bays. The deflector in spillbay 7 has an abrupt transition from the spill chute to the deflector, whereas the transition in spillbay 8 is a smooth radius; the deflector in spillbay 7 is 2 ft higher in elevation (434 ft msl) than the deflector in spillbay 8 (432 ft msl). In addition, the deflector in spillbay 7 does not extend as far into the tailrace as that in spillbay 8, falling 2.17 ft short of the downstream extension distance of spillbay 8. One or more of these factors of the spillbay 7 flow deflector--its lower submergence, sharper transition, and shorter downstream extension distance--present conditions that increase the probability of fish contacting the deflector in spillbay 7 as compared to that in spillbay 8.

The findings of our study, as well as those from the balloon-tag study of Normandeau Associates and Skalski (2006) and the sensor-fish study of Carlson et al. (2006), support spillbay 8 as a better location for an RSW at Lower Monumental Dam than spillbay 7. During our releases, spillbays 7 and 8 spilled equal amounts of water simultaneously. When these spillbays are operated at the same time, a hydraulic interaction occurs wherein flow from spillbay 7 travels laterally into spillbay 8 in the vicinity of the flow deflector. The impact of this lateral flow on fish passing through either spillbay 7 or 8 is unknown; however, it may create hydraulic shears which may reduce survival. The development of future project operations for the RSW at Lower Monumental Dam should include consideration of this hydraulic interaction and aim to minimize its occurrence.

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APPENDIX A

Evaluation of Study Assumptions

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

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

Of the 901 radio-tagged yearling Chinook salmon released into spillbay 7 at Lower Monumental Dam, 741 (82.2% of those released) were detected either at or below Ice Harbor Dam. Of the 889 radio-tagged yearling Chinook salmon released into spillbay 8 at Lower Monumental Dam, 741 (83.4% of those released) were detected either at or below Ice Harbor Dam. Of the 1,279 radio-tagged yearling Chinook salmon released into the tailrace of Lower Monumental Dam, 1,170 (91.5% of those released) were detected either at or below Ice Harbor Dam. The detection probability for fish used in survival analysis at Ice Harbor Dam was 1.000 overall (Appendix Table A1).

Thus radiotelemetry detection probability at Ice Harbor Dam was 100%, with no fish detected downstream that were not detected at Ice Harbor Dam. 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. Detections at Ice Harbor Dam and below, and the resulting detection probabilities at Ice Harbor Dam. These probabilities satisfied assumptions of the CJS model used in evaluating survival of hatchery yearling Chinook salmon passing through spillbays 7 and 8 at Lower Monumental Dam, 2005.

Release group	Release location	Detection at Ice Harbor Dam	Detection at or below Ice Harbor Dam	Detection probability
Treatment	Spillbay 7	741	741	1.000
Treatment	Spillbay 8	741	741	1.000
Reference	Tailrace	1,170	1,170	1.000
Totals		2,652	2,652	1.000

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 Ice Harbor Dam by using contingency tables (chi-square goodness-of-fit) to test for differences in arrival distributions. The release 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 (95%) were detected in less than 3 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 in arrival distributions at Ice Harbor Dam were not significantly different between treatment and reference groups in 17 of the 23 paired releases used for each relative survival estimate (Appendix Tables A2). There were more significant differences in these tests than would be expected if all groups were generally mixed (for $\alpha = 0.05$ level, we would expect 1 out of 20 tests not to be mixed). However, the differences between arrival times at Ice Harbor Dam were generally less than 1 d. Since our survival estimates were pooled over the treatment period, and the bulk of distributions generally occurred over a 2- to 3-d period, it is reasonable to conclude that the survival estimates were not significantly biased by this violation of the assumption regarding mixing through the common reach. Arrival distributions for releases that were not mixed are plotted in Appendix Figures B1 through B6.

Appendix Table A2. Test of homogeneity of arrival timing at Ice Harbor Dam for treatment (spillbay 7 and spillbay 8) and reference groups (tailrace) of radio-tagged hatchery yearling Chinook salmon used for estimating spillbay survival at Lower Monumental Dam in 2005. The release date of treatment fish at Lower Monumental Dam was paired with the release date of reference fish. Ice Harbor detections 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 ($\alpha = 0.05$).

Release date	χ^2	Degrees of freedom	*P*
3-May	6.98	10	0.828
4-May	10.41	8	0.211
5-May	12.96	6	0.031
6-May	4.65	6	0.651
7-May	13.03	10	0.149
8-May	12.86	10	0.186
9-May	15.66	6	0.006
10-May	3.71	6	0.892
11-May	1.81	6	0.986
12-May	2.95	4	0.681
13-May	14.24	4	0.004
14-May	18.99	4	0.001
15-May	9.01	4	0.031
16-May	5.02	4	0.269
17-May	5.30	6	0.541
18-May	4.89	8	0.852
19-May	4.45	6	0.649
20-May	10.23	6	0.080
21-May	9.44	8	0.262
22-May	10.37	8	0.194
24-May	3.37	4	0.524
26-May	16.82	8	0.019
27-May	12.13	8	0.115

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

River-run, hatchery yearling Chinook salmon were collected at the Lower Monumental Dam smolt collection facility from 3 to 27 May. Only hatchery-origin yearling Chinook salmon not previously PIT tagged, without any visual signs of disease or injuries, and 15 g or larger were used. Tagging comprised the period between the 41st and 97th percentile of the 2005 Chinook salmon smolt index at Lower Monumental Dam (Fig. 5). Overall mean fork lengths was 144.1 mm (SD = 10.9), 144.0 (SD = 11.20), and 144.0 mm (SD = 10.5) for fish released into spillbay 7, spillbay 8, and the tailrace of Lower Monumental Dam, respectively (Table 3).

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

Assumption A4 was not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids 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.

We released 31, 19, and 29 dead radio-tagged hatchery yearling Chinook salmon into spillbay 7, spillbay 8, and the tailrace of Lower Monumental Dam to test Assumption A5 (Appendix Table A3). The distance between release at Lower Monumental Dam and the first downstream telemetry array used to estimate survival (Ice Harbor Dam) was 51 km. Similar to the findings of Axel et al. (2003), no dead radio-tagged fish were detected at a downstream telemetry transect used for estimating survival.

Appendix Table A3. Numbers of dead fish released and subsequent detections at and below Ice Harbor Dam. 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			
	Spillbay 7	Spillbay 8	Tailrace	Overall
Number released	31	19	29	79
Proportion of total released (%)	3.3	2.1	2.2	2.5
Number detected at Ice Harbor Dam	0	0	0	0
Number detected below Ice Harbor Dam	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 3,371 tags allocated for the evaluation of Lower Monumental Dam spillway survival 107 (3.2%) could not be activated and were therefore not used. A total of 3,264 tags were implanted in hatchery yearling Chinook salmon of which 34 (1.0%) were not working 24 h after tagging. Of the live fish released with functional tags, a total of 5 fish (3 released into spillbay 7 and 2 released into spillbay 8) 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 not functioning properly were excluded from the study.

In addition, a total of 86 radio transmitters throughout the study were tested for tag life by allowing them to run in river water and checking them daily to determine if they functioned for the predetermined period of time. Seven tags (8%) failed prior to the preprogrammed shut-down after 10 d (Appendix Table A4). Of these only 1 (1.2%) failed in less than 5 d. Median travel time from release to Ice Harbor Dam was 1.6 d overall with less than 1% of the fish taking 5 d or more to reach Ice Harbor Dam (Appendix Table A5). Although we documented transmitter failures during our study, the short travel times to our survival line and the relatively low failure rate were such that they would not have significantly changed our findings.

Appendix Table A4. Number of days tags lasted in tag life testing.

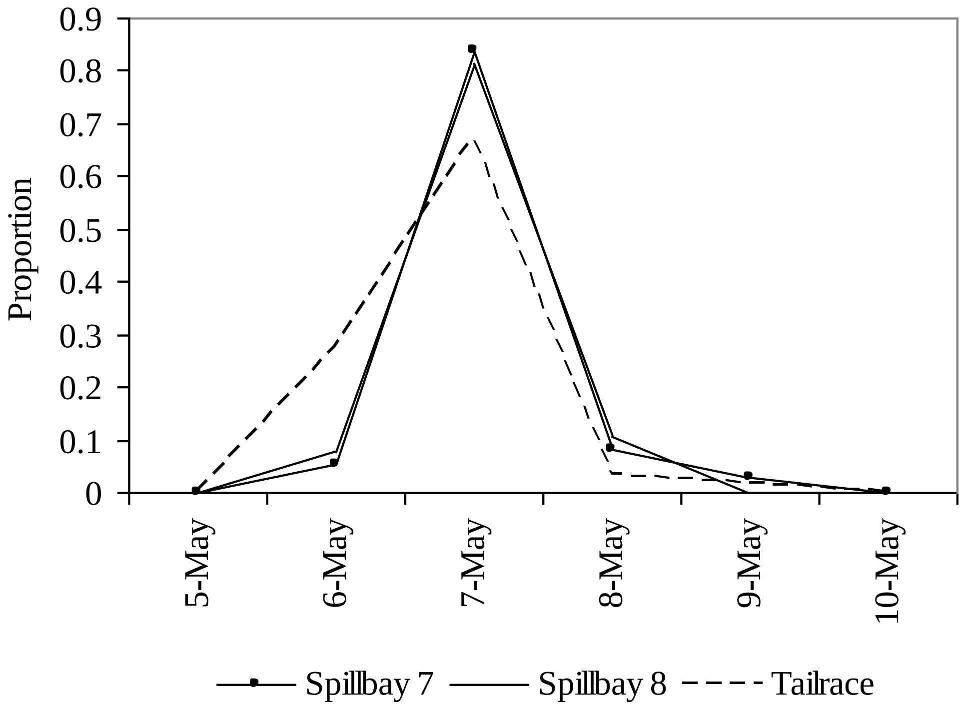
Tags (N)	Tags (%)	Tag life (d)
0	0	1
1	1	2
0	0	3
0	0	4
4	5	5
0	0	6
2	2	7
0	0	8
0	0	9
79	92	10

Appendix Table A5. Travel time from release to detection at Ice Harbor Dam for radio-tagged, hatchery yearling Chinook salmon released into spillbay 7, spillbay 8, and the tailrace of Lower Monumental Dam, 2005.

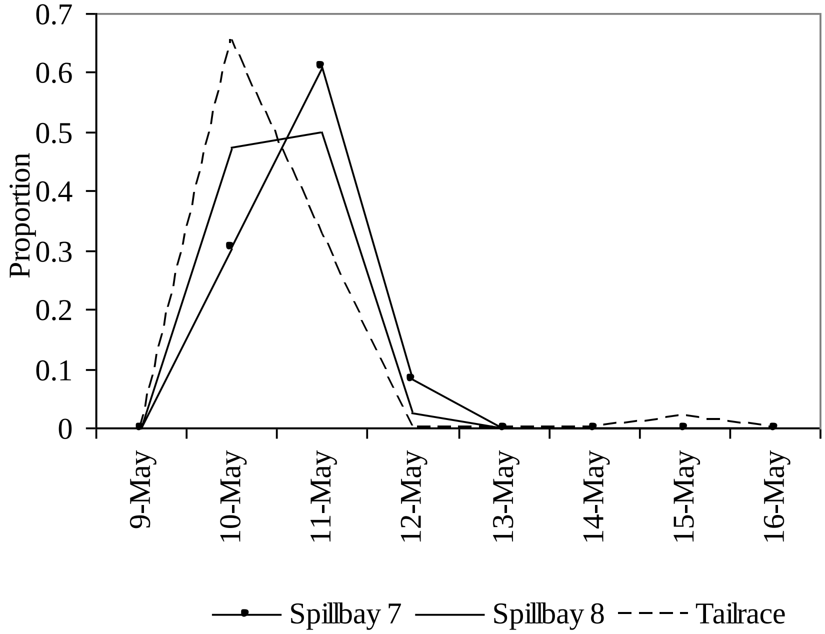
	Travel time (d) to Ice Harbor Dam by release location			
Percentile	Spillbay 7	Spillbay 8	Tailrace	Overall
Min	0.8	0.7	0.7	0.7
10	1.1	1.1	1.0	1.0
20	1.3	1.2	1.1	1.2
30	1.4	1.3	1.2	1.3
40	1.6	1.4	1.3	1.4
50	1.7	1.6	1.5	1.6
60	1.8	1.8	1.6	1.7
70	2.0	2.0	1.8	1.9
80	2.2	2.1	2.0	2.1
90	2.7	2.6	2.4	2.5
Max	8.46	7.19	1.46	8.46
Travel time > 5 d	1 (0.1%)	4 (0.5%)	11 (0.9%)	16 (0.6%)
N	755	770	1,283	2,808

APPENDIX B

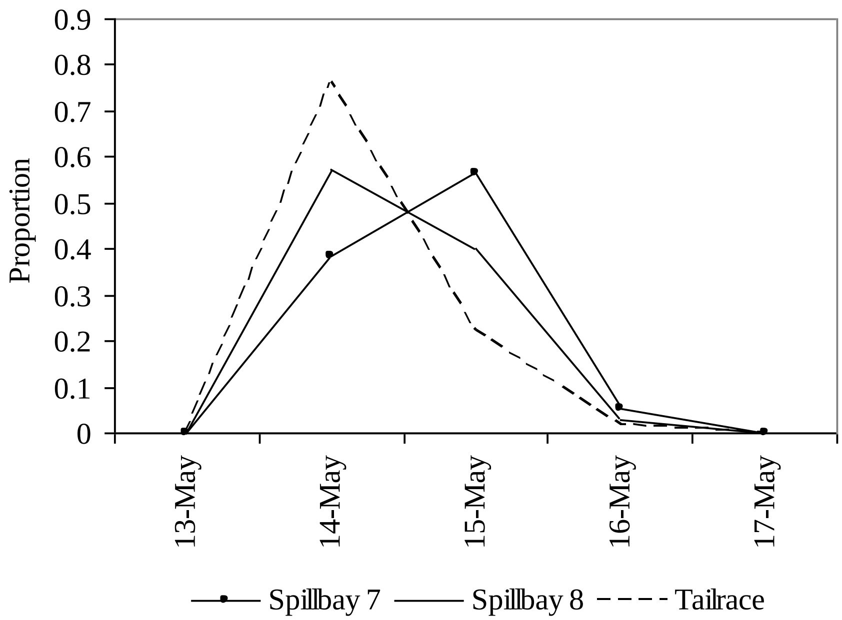
Ice Harbor Dam Arrival Distributions for Treatment and Reference Release Groups with Significantly Different Travel Timing



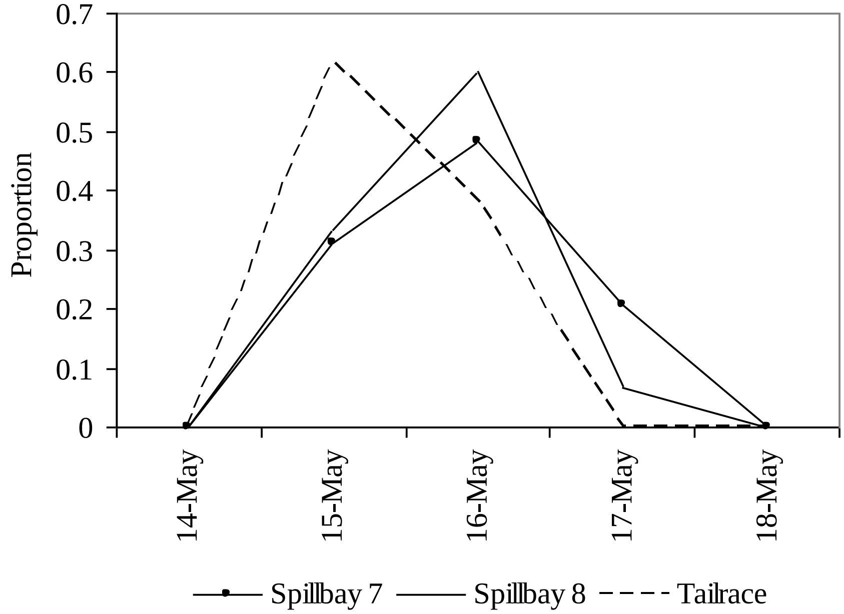
Appendix Figure B1. Arrival distribution at Ice Harbor Dam for treatment fish released into spillbay 7 and spillbay 8 and reference fish released into the tailrace of Lower Monumental Dam on 5 May 2005.



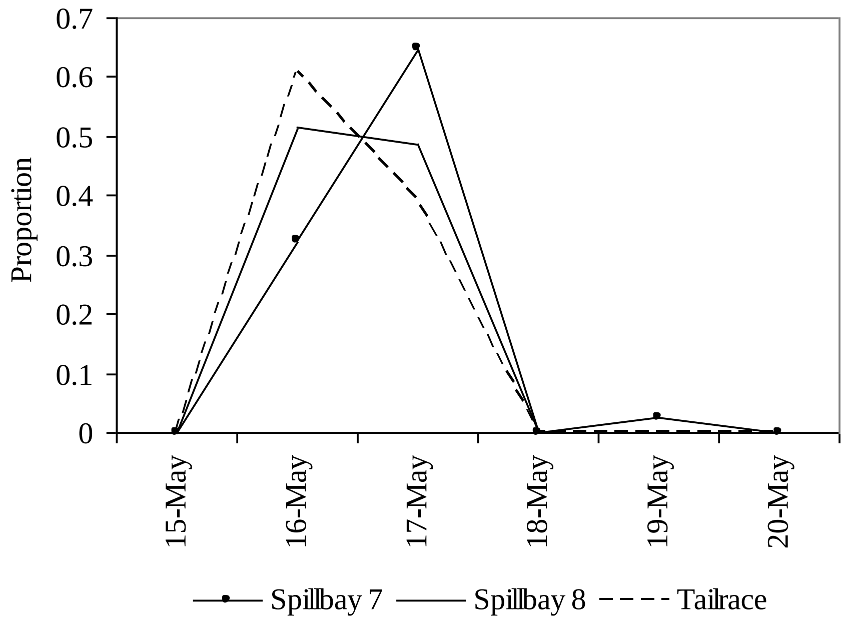
Appendix Figure B2. Arrival distribution at Ice Harbor Dam for treatment fish released into spillbay 7 and spillbay 8 and reference fish released into the tailrace of Lower Monumental Dam on 9 May 2005.



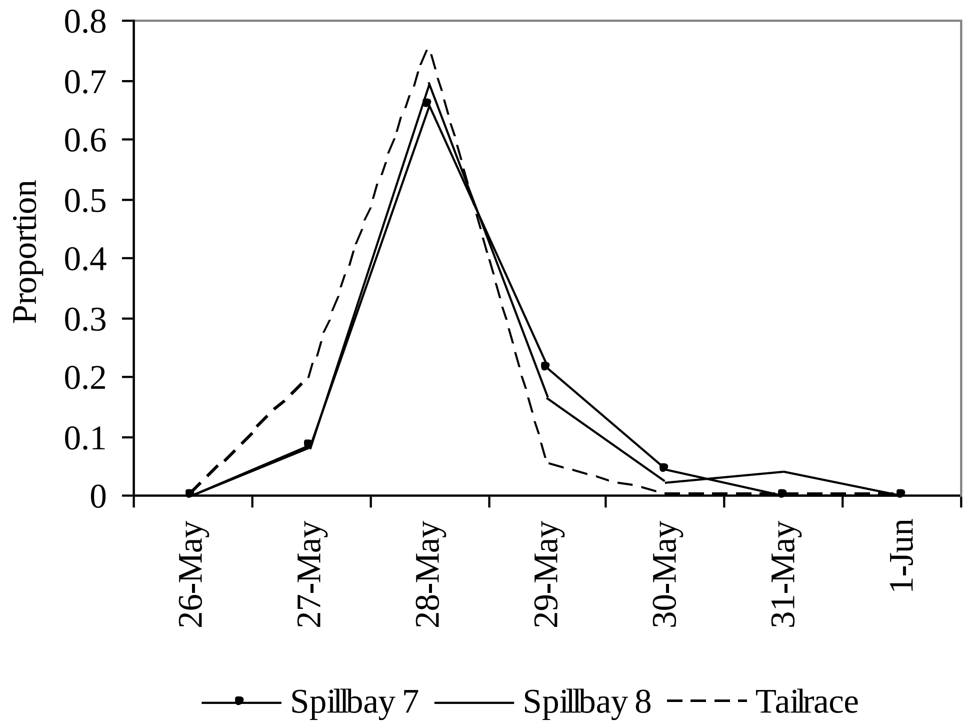
Appendix Figure B3. Arrival distribution at Ice Harbor Dam for treatment fish released into spillbay 7 and spillbay 8 and reference fish released into the tailrace of Lower Monumental Dam on 13 May 2005.



Appendix Figure B4. Arrival distribution at Ice Harbor Dam for treatment fish released into spillbay 7 and spillbay 8 and reference fish released into the tailrace of Lower Monumental Dam on 14 May 2005.



Appendix Figure B5. Arrival distribution at Ice Harbor Dam for treatment fish released into spillbay 7 and spillbay 8 and reference fish released into the tailrace of Lower Monumental Dam on 15 May 2005.



Appendix Figure B6. Arrival distribution at Ice Harbor Dam for treatment fish released into spillbay 7 and spillbay 8 and reference fish released into the tailrace of Lower Monumental Dam on 26 May 2005.

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 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 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.

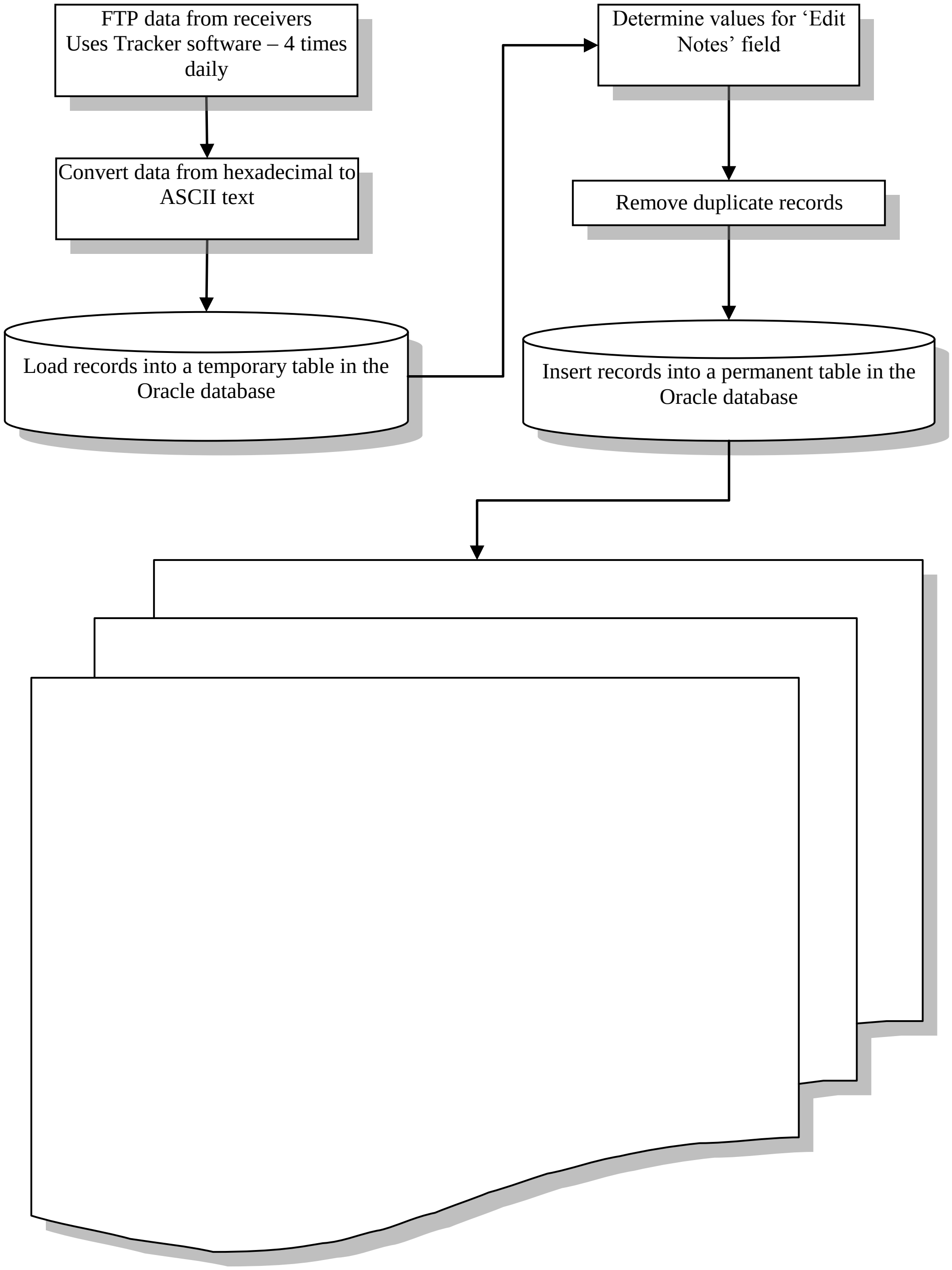
Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time).

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