Passage Behavior and Survival for Hatchery Yearling Chinook Salmon at Ice Harbor Dam, 2004

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EXECUTIVE SUMMARY

The voluntary spill program at Ice Harbor Dam has been very effective at guiding fish to the spillway. However, recent studies to evaluate spillway passage survival have resulted in lower-than-expected survival estimates. Based on results from research in 2003, it was hypothesized that increasing the volume of water spilled through individual bays would increase spillway passage survival. To achieve this condition without additional volumes of water, fewer bays would be opened during periods of spill. This "bulk" spill operation would comply with spill volumes mandated by the 2000 National Marine Fisheries Service biological opinion; that is, daytime spill of 45,000 ft^3/s and nighttime spill up to 100% of total river flow, or to the total dissolved gas limit.

To evaluate fish passage at Ice Harbor Dam under bulk spill, hatchery yearling Chinook salmon were collected and radio tagged at Lower Monumental Dam in 2004. From 30 April through 27 May, 3,936 radio-tagged fish were released above Ice Harbor Dam; of these, 2,882 entered the forebay and were grouped as replicate release "groups" by arrival date and time. Detections from these groups were used for evaluation of passage behavior and for estimates of spillway- and dam-passage survival. A 4-d block study design was used, where the spillway was operated under a bulk spill pattern for 2 d followed by 2 d of standard or “flat” spill (daytime spill of 45,000 ft^3/s through all 10 bays as prescribed by BiOp). To estimate relative spillway passage survival, an additional 1,511 radio-tagged fish were released into the tailrace of Ice Harbor Dam. Detection arrays were installed at multiple locations between Ice Harbor Dam on the lower Snake River and Irrigon, Oregon on the lower Columbia River.

Both spill operations were effective at guiding fish to the spillway: spill efficiency was estimated at 98% during bulk spill and 88% during flat spill operations. Forebay passage was also rapid during both operations, with median forebay residence times of 1.4 h during the bulk spill operation and 2.4 h during flat spill. Similarly, tailrace passage was rapid, with median tailrace egress times of 23 and 22 min for bulk and flat spill operations, respectively.

Spillway passage survival was estimated at 0.974 (95% CI, 0.94-1.01%) for radio-tagged fish passing during bulk spill operations compared to 95% (95% CI, 93-97%) for the flat spill operation. Estimates of dam survival were 93 (95% CI, 86-100%) and 90% (95% CI, 85-95%) for all radio-tagged fish passing during bulk and flat spill operations, respectively.

CONTENTS

INTRODUCTION

Spillway passage has long been considered the safest route for migrating juvenile salmonids *Oncorhynchus* spp. at Snake and Columbia River hydroelectric projects. A review of 13 spillway passage mortality estimates published through 1995 concluded that the most likely range in mortality for standard spillbays is 0-2% (Whitney et al. 1997). The 1991 listing of Snake River sockeye salmon *O. nerka* as endangered under the Endangered Species Act (ESA), and further listings of other Columbia Basin salmon stocks, led to consultation between regional action agencies and the National Marine Fisheries Service (NMFS) resulting in a series of Biological Opinions.

Since 1994, spill has been utilized increasingly to expedite the migration of juvenile salmonids past hydroelectric dams and to reduce the proportion of smolts passing through turbines, where survival is lower (Iwamoto et al. 1994; Muir et al. 2001). Pursuant to the 2000 Biological Opinion (NMFS 2000), project operations at Ice Harbor Dam have relied on increased volumes of spill to maximize spillway passage by migrating juvenile salmonids. The current spill program calls for daytime (0600-1800 PDT) spill volumes of 45,000 ft^3/s and nighttime volumes up to 100% of total river flow or to state and federal limits for total dissolved gas (as prescribed by NMFS 2000 BiOp).

Under these operations, Eppard et al. (2000) estimated Ice Harbor fish passage efficiency (FPE) at 97%, with 81% passage through the spillway for hatchery yearling Chinook salmon during the 1999 spring migration. In 2000, Eppard et al. (2002, 2005a) estimated spillway passage survival at 0.978 for hatchery yearling Chinook salmon and 0.885 for hatchery subyearling Chinook; in 2002, they estimated spillway passage survival for these fish at 0.892 and 0.894, respectively.

Results from these studies indicated that spillway passage survival at Ice Harbor Dam is correlated with total river flow and tailwater elevation. It was hypothesized that the lower-than-expected survival estimates in spring 2002 and summer 2000 and 2002 may have resulted from hydraulic conditions in the stilling basin that occur when total river flows are low (<90,000 ft^3/s). Testing on the Ice Harbor Dam general model at the U.S. Army Corps of Engineers Engineering Research and Development Center showed that at most river flows spill volumes above 50% spill create a condition where water plunges into the stilling basin, whereas spill volumes at or near 50% create a skimming flow over the stilling basin. It was further hypothesized that this skimming flow would increase spillway passage survival for migrating juvenile salmon.

However, tests in 2003 found survival estimates were not significantly different between the "plunging" BiOp spill and the "skimming" 50% spill, with survival under the respective spill operations estimated at 0.952 and 0.937 (Eppard et al. 2005b). In a concurrent study at Ice Harbor Dam, Normandeau Associates (2004) reported that injury rates were higher for fish released during the lower, 50% spill volumes compared to those released during 100% spill (BiOp night operation). Based on these results, the U.S. Army Corps of Engineers altered the spill pattern at Ice Harbor Dam to spill the BiOp-mandated volumes of water through fewer bays.

This new pattern was termed "bulk" spill and was tested by NMFS during the juvenile fall Chinook salmon migration at Ice Harbor Dam. Absolon et al. (2005) reported relative spillway passage survival estimates of 0.964 for PIT-tagged fall Chinook salmon released during summer 2003 under bulk spill. These estimates were significantly higher than those obtained in 2000 (0.885, $t = 2.24$, $P = 0.036$) and 2002 (0.894, $t = 2.72$, $P = 0.012$) by Eppard et al. (2002, 2005a). We concluded that operating the Ice Harbor Dam spillway under a bulk spill pattern when total project discharge is low may increase survival of migrating juvenile salmonids passing through the spillway.

In 2004, we further evaluated bulk spill in a study comparing relative spillway and dam passage survival of radio-tagged hatchery yearling Chinook salmon passing Ice Harbor Dam during 4-day blocks of bulk vs. flat spill operation. Additionally, we evaluated the behavior and timing of these fish as they entered the forebay, approached and passed the powerhouse, and exited the tailrace of Ice Harbor Dam.

Terms describing fish passage behavior, passage performance metrics, project survival, and route-specific survival as used in this report are defined as follows:

Bulk spill: Spill pattern using fewer bays, a minimum gate opening of 6 stops, and spill volume equivalent to BiOp-recommended nighttime spill (total dissolved gas limit or 100% of total river flow).

Flat spill: Standard spill pattern using all bays, a maximum gate opening of 3 stops, and spill volumes equivalent to BiOp-recommended daytime spill (45,000 ft^3/s).

Spill Efficiency (SPE):	Number of fish passing the dam through the spillway divided by the total number of fish passing the dam.
Spill Effectiveness (SPF):	Proportion of fish passing the dam via the spillway divided by the proportion of water spilled.
Fish Passage Efficiency (FPE):	Number of fish passing the dam through non-turbine routes divided by total project passage.
Tailrace Egress:	Elapsed time from project passage to exit from the tailrace.
Forebay Residence Time:	Elapsed time from arrival in the forebay of the dam until passage through the spillway, bypass, or turbines.
Pool survival:	Survival from release of treatment fish in the tailrace of Lower Monumental Dam to the upstream limit of the boat restricted zone at Ice Harbor Dam.
Dam Survival:	Relative survival from the upstream limit of the boat restricted zone at Ice Harbor Dam to the release location of reference groups downstream from the dam.
Route Survival:	Relative survival between detection within a passage route at Ice Harbor Dam and the release location of reference groups downstream from the dam.

Results of this study will be used to help inform management decisions that will optimize survival for juvenile salmonids arriving at Ice Harbor Dam. This study addressed research needs outlined in SPE-W-00-1 of the U.S. Army Corps of Engineers, North Pacific Division, Anadromous Fish Evaluation Program.

METHODS

Study Area

The study area included the 134-km reach of the lower Snake and Columbia Rivers from Lower Monumental Dam to Irrigon, Oregon (Figure 1). Lower Monumental Dam is located 67 km above the confluence of the Snake and Columbia Rivers and 51 km above Ice Harbor Dam. Irrigon is located on the Columbia River, 455 km above its confluence with the Pacific Ocean.

Fish Collection, Tagging, and Release

River-run, hatchery yearling Chinook salmon were collected at the Lower Monumental Dam smolt collection facility from 28 April to 27 May. Only hatchery origin yearling Chinook salmon not previously PIT tagged were used. Fish were anesthetized with tricaine methanesulfate (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 holding tank with flow-through river water and held 24 h prior to radio tagging.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a programmatically defined life of 10 d, and were pulse-coded for unique identification of individual fish. Each radio tag measured 16 mm in length by 7 mm in diameter and weighed 1.4 g in air.

Radio transmitters were surgically implanted into fish using techniques described by Eppard et al. (2000). A PIT tag was also implanted in the body cavity of each fish during the surgical procedure. Immediately following tagging, fish were placed in a 19-L recovery container with aeration until recovery from the anesthesia. Recovery containers were closed 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 water during tagging and holding and aerated with

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

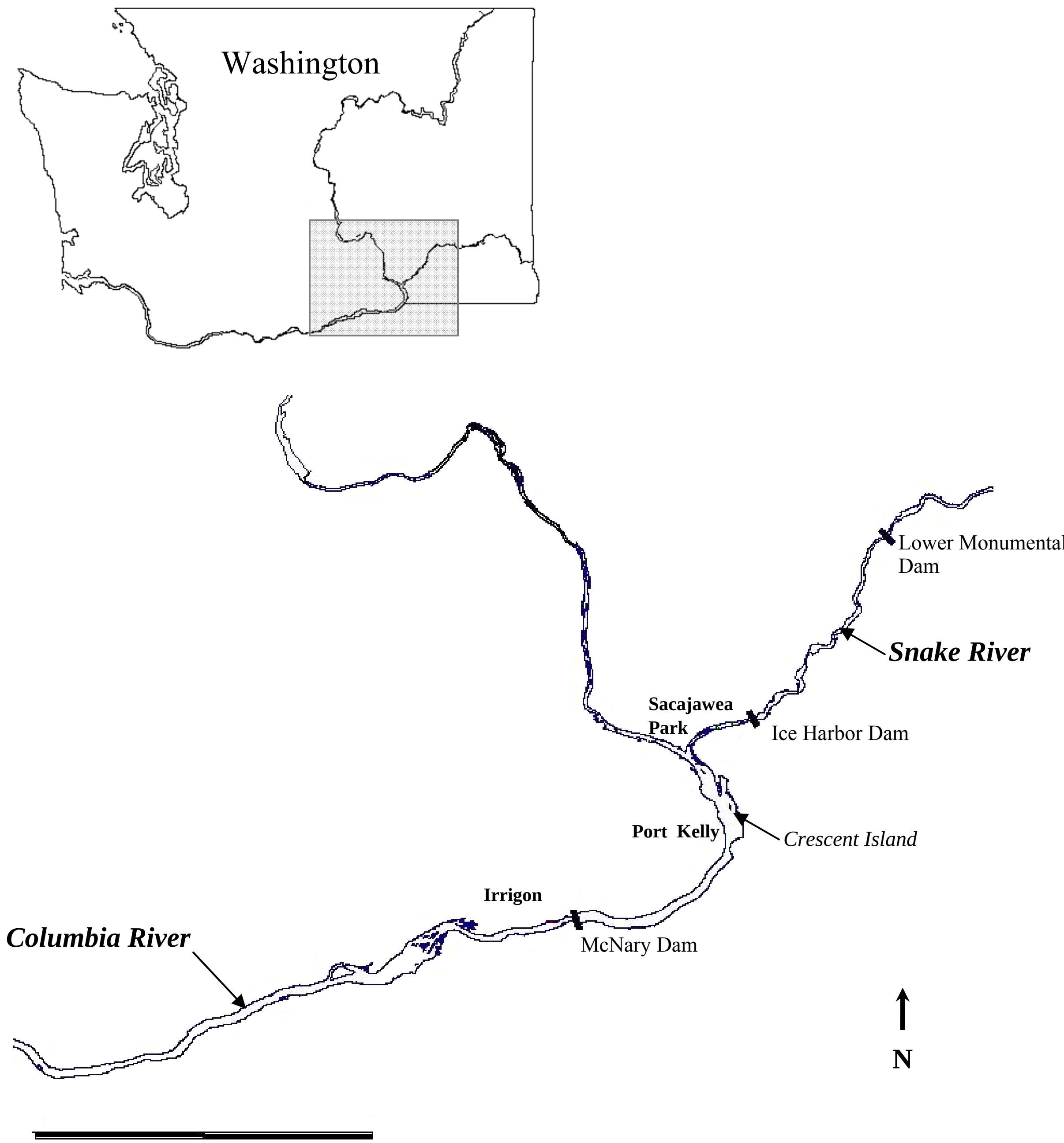

Figure 1. Study area showing location of radiotelemetry transects for estimating survival at Ice Harbor Dam, 2004.

oxygen during transportation to release locations. Holding density did not exceed two fish per recovery container. Treatment fish were held at Lower Monumental Dam for approximately 24 h prior to release for recovery and determination of post-tagging mortality. After tagging, reference fish were transported to Ice Harbor Dam, where they were held on flow-through water for approximately 48 h.

After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to the release areas. Treatment fish were released into the forebay or tailrace of Lower Monumental Dam as part of a concurrent project passage survival study. Reference groups were transferred in their recovery containers from the holding tanks to a 1,152-L tank mounted on an 8.5 × 2.4-m barge in the forebay of Ice Harbor Dam, transported to the tailrace, and released at the upstream end of Goose Island approximately 2 km downstream of the dam (Figure 2).

Monitoring

Radiotelemetry receivers and multiple-element aerial antennas were used to establish detection transects between the forebay of Ice Harbor Dam on the Snake River and Irrigon, Oregon on the Columbia River (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 Ice Harbor Dam, while underwater antennas were used to monitor passage routes (Figures 2 and 3). Monitored passage routes included the juvenile fish bypass system, individual spillbays, and all turbine unit gate slots (gatewells).

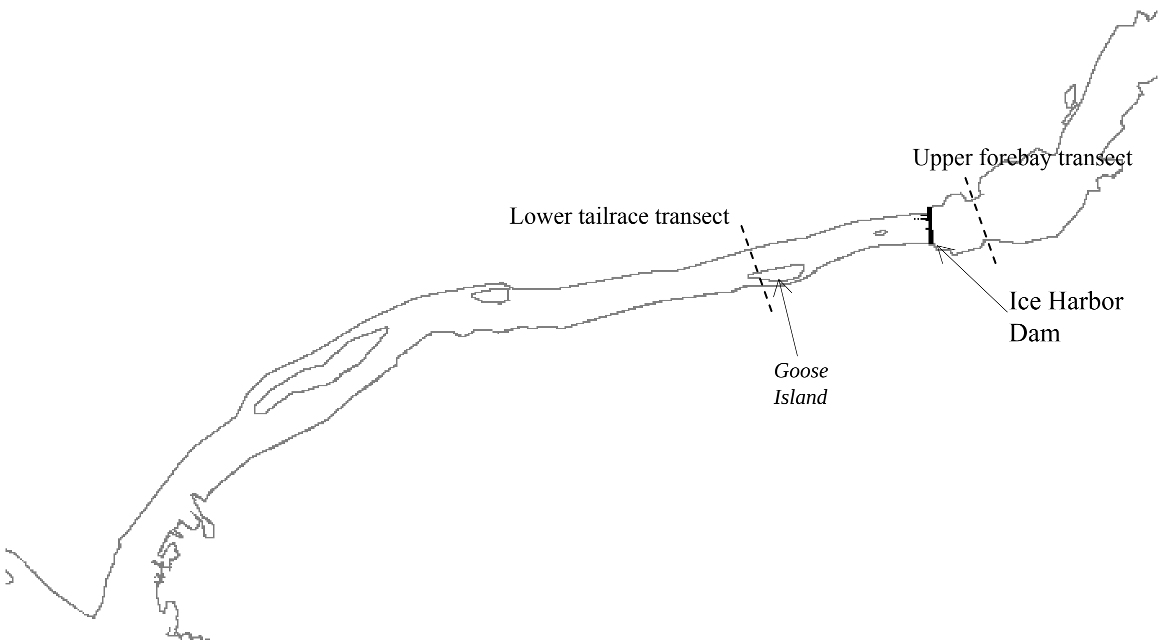

Figure 2. Ice Harbor Dam on the lower Snake River with the release locations for reference groups and radiotelemetry arrays used to detect radio-tagged yearling Chinook salmon entering the immediate forebay (rkm 538.5) and subsequently exiting the tailrace at Goose Island (rkm 534.2), 2004.

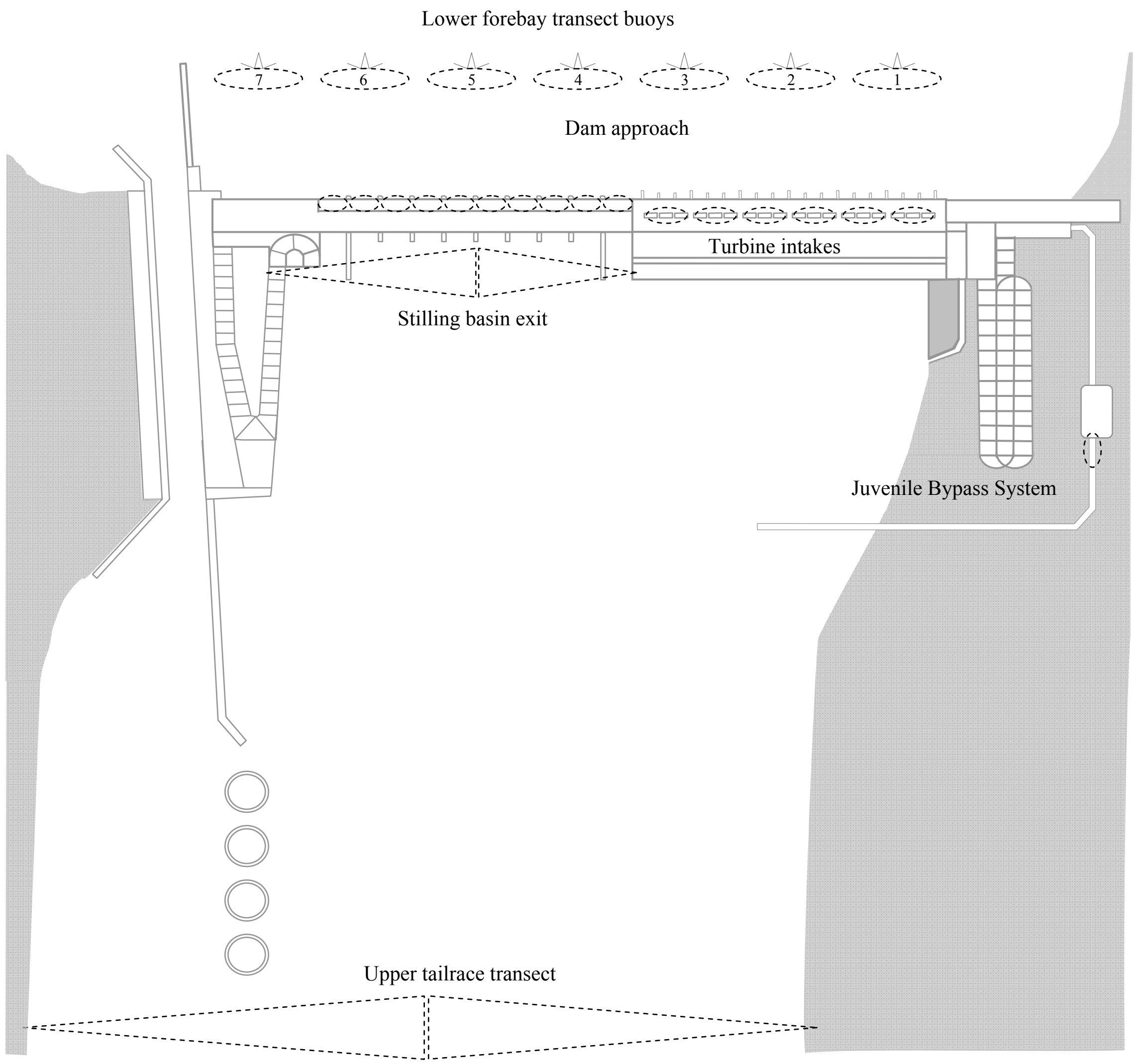

Figure 3. Plan view of Ice Harbor Dam showing approximate radiotelemetry detection zones in 2004 (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas).

Data Analysis

The majority of our telemetry data was retrieved through an automated process that downloaded networked telemetry receivers up to four times daily. Telemetry sites not initially accessible over the network were downloaded manually once a day until network access was established. After downloading, individual data files were compressed by recording the first time a radio-tagged fish was detected at an individual receiver location and counting the number of subsequent detections at that same location that occurred within 1 min or less. When the time difference between detections at a single location was greater than 1 min, the subsequent 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, thus creating a detailed detection history for each radio-tagged fish.

Using these individual detection histories, we determined arrival time in the forebay, immediate forebay approach patterns, passage distribution and timing, exit from the tailrace, and timing of downstream detection for each radio-tagged fish. Forebay arrival time was based on the first time a fish was detected in the forebay of the dam. Approach patterns were established based on the first detection on 1 of 5 telemetry buoys equally spaced across the forebay of the dam.

Route of passage through the dam was assigned based on the last time a fish was detected on a passage-route receiver prior to subsequent detection in the tailrace (i.e., detection in the stilling basin, immediate tailrace, or at Goose Island was required for assignment to a passage route; Figures 1 and 3). Spillway passage was assigned to fish detected in the forebay on one of the antenna arrays deployed in each spillbay. Similarly, turbine passage was assigned to fish last detected in a turbine intake prior to detection in the tailrace. Passage through the juvenile bypass system was assigned to fish detected within the collection channel and/or bypass outfall pipe immediately downstream of the collection facility.

A paired-release study design was used for estimating relative survival where groups of radio-tagged fish were "released" at one of two sites: upstream (treatment) or downstream (reference) from Ice Harbor Dam. Treatment groups were formed based on daily detections of radio-tagged fish (released at Lower Monumental Dam) as they entered the forebay of Ice Harbor Dam. Reference groups were released directly into the tailrace of Ice Harbor Dam at the upstream end of Goose Island (Figure 2).

The single-release model (Cormack 1964; Jolly 1965; Seber 1965) was used to estimate survival and probability of detection for both treatment and reference groups from "release" to the mouth of the Snake River at Sacajawea Park. This model provides unbiased estimates if basic assumptions are met (Zabel et al. 2002; Smith et al. 2003), including the primary assumption that detection and survival probabilities at a detection site are not affected by previous radiotelemetry detection upstream. Evaluations of model assumptions are detailed in Appendix A.

Relative spillway passage survival was expressed as the ratio of survival estimates of treatment fish to those of reference fish. Average relative survival was calculated using weighted geometric means, where weights were inversely proportional to their respective sample variances (Burnham et al. 1987, p. 259). Because the variance of a survival probability estimate based on the SR model is a function of the estimate itself, lower survival estimates tend to have smaller estimated variance. Therefore, the inverse estimated absolute variance was not used in weighting, since this could result in a weighted mean that is biased toward the lower estimates (Muir et al. 2001, 2003).

Another model assumption when using a paired-release study design is that treatment and reference groups have similar survival probabilities in the reach that is common to both groups; that is, groups are mixed temporally upon detection at the primary detection array. Evaluation of this assumption is detailed in Appendix A.

Forebay residence time calculated for radio-tagged fish was defined as elapsed time from entry in the forebay to passage at Ice Harbor Dam; tailrace egress time was defined as elapsed time from passage at the dam to exit from the tailrace based on the first detection at Goose Island. We compared forebay residence and tailrace egress times between treatments using paired *t*-tests on the 50th percentiles of the temporally-paired replicate groups. Significance was set at $\alpha = 0.05$.

RESULTS

Project Operations

Between 1 May and 6 June 2004, Ice Harbor Dam was operated in nine 4-day block intervals, with 2 d of bulk spill followed by 2 d of flat spill. During this time the project was operated for 432 and 423 h under the bulk and flat spill patterns, respectively. Total project discharge, regulated by the Bonneville Power Administration and the U.S. Army Corps of Engineers for changing regional power needs, varied greatly on many days during this time period (Figure 4 and Table 1).

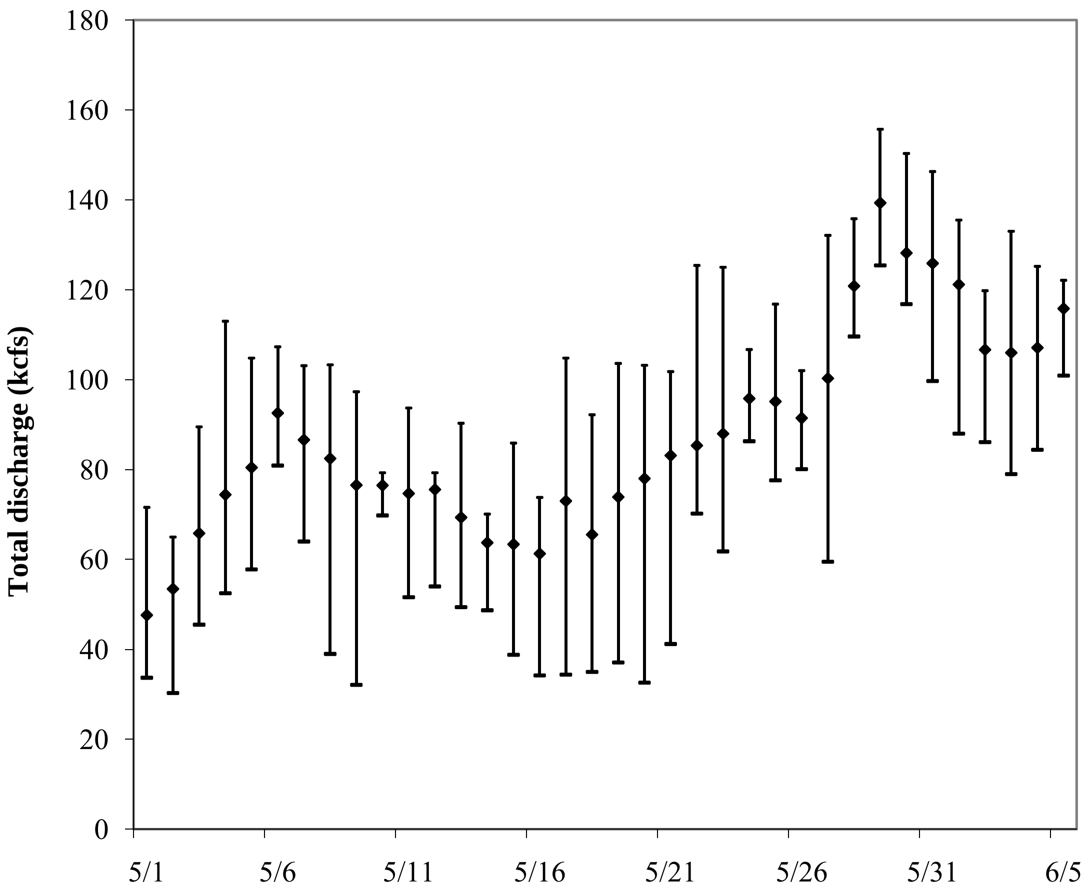

Figure 4. Average daily total project discharge at Ice Harbor Dam during the 2004 spillway passage survival study (whisker bars represent the range of operations for each day).

Table 1. Mean, range, and standard deviation (SD) of operations and/or conditions during bulk spill ("B") and fish passage plan or flat ("F") spill patterns at Ice Harbor Dam, 2004.

Test	Date Range		Total discharge ($ft^3/s \times 1000$)			Total spill ($ft^3/s \times 1000$)			Percent Spill (%)			Tailwater elevation (ft)		
block	Start	End	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
B01	5/01 05:40	5/03 04:30	50.5	30.3-71.6	11.2	42.1	21.1-60.0	11.0	82.7	63.5-100.0	8.4	341.0	339.7-343.3	0.8
B02	5/05 04:55	5/07 04:55	86.7	57.8-107.3	12.6	73.4	45.4-92.9	11.8	84.7	64.3-100.0	8.2	344.1	341.7-345.7	1.0
B03	5/09 04:50	5/11 04:50	77.9	32.1-97.3	12.3	70.3	30.0-81.7	10.5	90.3	76.6-100.0	6.7	343.1	340.0-344.9	1.1
B04	5/13 04:50	5/15 04:50	65.6	44.1-90.3	13.0	56.4	35.4-80.9	13.0	85.3	74.4-89.8	2.9	342.2	340.3-344.3	1.0
B05	5/17 04:25	5/19 04:45	69.6	35.0-104.8	19.6	62.6	35.0-92.6	16.5	90.7	79.7-100.0	5.5	342.4	338.9-345.6	1.6
B06	5/21 05:15	5/23 05:50	89.5	41.2-125.4	14.6	79.5	34.1-92.0	11.1	89.3	65.7-100.0	6.2	344.0	340.1-347.0	1.3
B07	5/25 05:00	5/27 04:50	89.2	65.5-105.7	10.1	82.1	58.3-92.7	8.6	92.2	56.4-100.0	5.1	344.2	341.9-347.0	0.8
B08	5/29 05:00	5/31 04:50	134.3	116.8-155.7	9.9	90.8	86.2-92.2	1.9	68.0	55.4-78.7	5.4	347.8	346.3-349.1	0.8
B09	6/02 05:00	6/04 04:30	107.5	79.0-133.0	13.9	82.0	69.8-84.1	3.3	77.4	62.4-100.0	9.0	345.6	343.3-347.6	1.2
F01	5/03 04:35	5/05 04:50	72.7	52.5-113.0	16.0	44.5	43.4-44.8	0.1	63.8	39.4-84.8	12.0	343.6	341.1-347.4	1.5
F02	5/07 05:00	5/09 04:45	82.5	39.0-103.3	19.9	43.8	29.8-58.7	3.7	56.5	43.4-100.0	14.8	344.4	340.4-346.5	1.8
F03	5/11 04:55	5/13 04:45	73.7	51.6-93.7	10.3	44.6	34.0-58.3	1.4	61.9	47.7-85.9	10.3	343.6	341.6-345.4	1.0
F04	5/15 04:55	5/17 04:20	61.0	34.2-85.9	15.3	43.1	31.0-45.3	3.9	74.5	51.8-100.0	16.3	342.2	339.5-344.7	1.5
F05	5/19 04:50	5/21 05:10	76.3	32.6-103.6	23.0	43.2	32.3-45.1	4.1	62.1	43.0-100.0	19.0	343.7	339.7-346.6	2.2
F06	5/23 05:55	5/25 04:55	93.8	61.8-116.8	13.8	45.0	41.8-53.7	0.4	49.2	38.6-72.7	8.4	345.2	342.2-347.2	1.3
F07	5/27 04:55	5/29 04:55	116.9	59.5-137.1	14.5	45.3	45.1-52.3	0.4	39.6	33.3-87.4	6.6	347.2	342.0-349.0	1.3
F08	5/31 04:55	6/02 04:55	119.1	86.1-135.8	13.5	44.8	44.3-68.5	1.0	38.1	32.8-58.7	4.9	347.5	345.0-349.0	1.0
F09	6/04 04:35	6/06 04:50	109.9	84.4-125.2	12.4	45.3	44.1-62.3	1.7	41.8	36.0-70.2	5.8	346.8	344.8-348.2	1.0

Fish Collection, Tagging, and Release

Yearling Chinook salmon were collected and tagged at Lower Monumental Dam on 25 d from 29 April to 25 May. Overall tagging mortality was 2.1%. Tagging began after 70th percentile of migrating yearling Chinook salmon had passed Lower Monumental Dam, and was completed when 98th percentile had passed (Figure 5). Temporal distribution for yearling Chinook salmon at Lower Monumental Dam in 2004 appeared to differ from the historical average distribution. This may have been due to a shift in transportation policy to protect migrating juvenile salmonids in a low flow year, wherein all juveniles collected are transported from collector dams rather than using voluntary spill to pass fish (NMFS 2000).

This shift occurred on 23 April at Lower Granite and Little Goose Dam, and nearly all fish arriving at Lower Monumental Dam after this date were previously PIT-tagged. At Lower Monumental Dam, spill continued until 14 May, after which a total transport policy was adopted. These shifts in transportation strategy, combined with a release of nearly 500,000 yearling fall Chinook salmon from Lyons Ferry Hatchery from 12 to 14 April, skewed the temporal distribution of yearling Chinook salmon passing Lower Monumental Dam toward the beginning of the migration season. Based on the cumulative average passage data for yearling Chinook salmon at Lower Monumental Dam (1993-2003), the study period had been expected to coincide with the 27th to 94th passage percentiles of the 2004 yearling Chinook salmon migration.

Treatment groups were formed from the 3,936 radio-tagged fish released above Ice Harbor Dam as part of a spillway survival study at Lower Monumental Dam (Hockersmith et al. 2005). Releases at Lower Monumental Dam occurred over approximately 14 h each day. Overall mean fork length was 149 mm (SD = 12.5 mm) for fish released during daytime and 150 mm (SD = 12.2 mm) for fish released during nighttime hours (Table 2). Overall mean weight was 27.8 g (SD = 8.3) for daytime releases and 27.7 g (SD = 8.6) for nighttime releases of treatment fish (Table 3.)

We released 1,517 radio-tagged fish as reference groups at the upstream end of Goose Island. To maximize mixing of reference releases with the volitional passage of treatment fish, reference groups were released during both the day and night over approximately 6 h on each day. Overall mean fork length was 148 mm (SD = 12.2) for reference fish released during daytime hours and 149 mm (SD = 11.8) for those released during nighttime hours (Table 4). Overall mean weight was 27.3 g (SD = 8.0) and 27.1 g (SD = 8.2) for reference fish released during daytime and nighttime hours, respectively (Table 5).

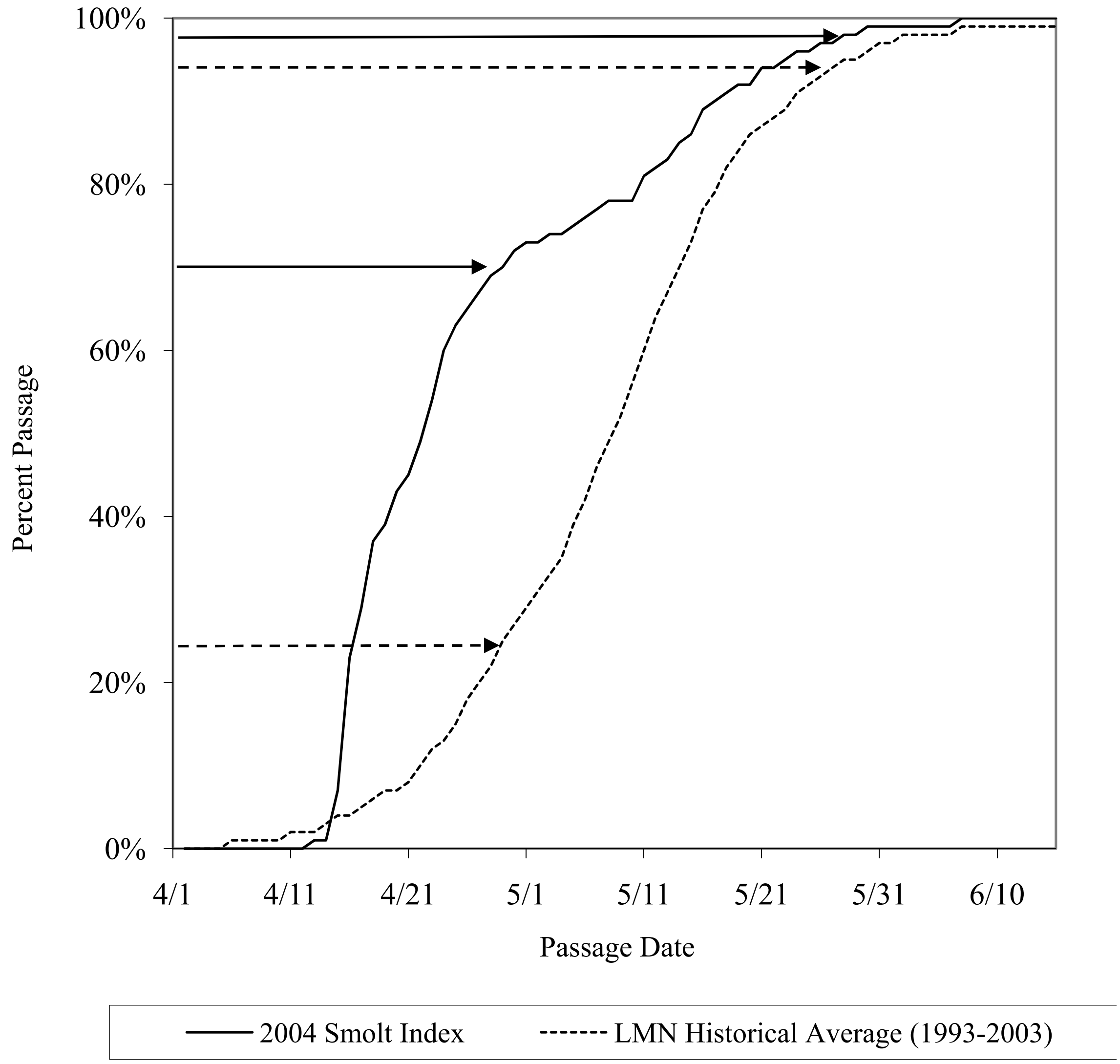

Figure 5. The 2004 cumulative temporal distribution compared to the historical average (1993-2003) for yearling Chinook salmon passing Lower Monumental Dam. Arrows indicate (solid arrows represent actual, dashed arrows represent expected) beginning and end of releases for evaluation of Ice Harbor Dam spillway survival, 2004. (NOTE: Due to artificial changes in smolt monitoring protocols in 2002, that year was excluded from the historical average.)

Table 2. Release date and time, sample size, and fork length (mean, range, and standard deviation) of radio-tagged, hatchery yearling Chinook salmon (with a known length at tagging) released at Lower Monumental Dam to evaluate dam and spillway passage survival at Ice Harbor Dam, 2004.

	Treatment fish fork length (mm)									
	Daytime release					Nighttime release				
Release date	Release time	n	Mean	Range	SD	Release time	n	Mean	Range	SD
30 Apr	11:05-15:00	66	139	122-163	8.4	19:15-23:00	65	146	129-179	10.2
01 May	09:35-13:45	83	156	124-189	18.7	18:45-22:16	83	162	127-209	18.6
02 May	10:07-13:41	81	153	128-194	16.1	18:30-21:39	79	152	132-187	13.5
03 May	09:10-11:00	52	155	124-197	16.7	18:23-20:45	58	149	126-190	15.5
05 May	09:10-13:10	66	153	128-199	15.1	19:30-03:01	81	156	131-189	14.0
07 May	09:40-14:30	83	146	126-189	13.7	18:19-00:57	82	149	126-205	16.7
08 May	09:40-16:15	85	143	122-174	10.5	18:10-23:47	84	149	127-187	13.0
09 May	09:24-14:45	66	149	129-184	12.2	18:17-23:45	74	154	131-214	15.2
10 May	09:22-15:45	84	151	131-189	11.3	18:05-00:50	83	149	133-199	11.1
11 May	09:25-16:00	85	147	128-183	11.5	19:05-02:06	83	149	131-195	12.4
12 May	09:42-16:05	83	144	127-178	9.6	18:05-00:40	84	146	128-181	10.9
13 May	09:08-15:45	84	146	133-178	10.1	18:03-00:25	84	150	132-204	14.5
14 May	09:10-15:15	84	150	133-195	11.7	18:07-00:10	84	148	130-194	9.9
15 May	09:14-15:00	73	148	130-189	13.4	18:01-23:40	73	145	131-179	9.8
16 May	09:28-15:15	72	141	127-177	9.0	18:05-23:05	69	148	133-196	10.7
18 May	09:40-15:10	83	150	129-203	12.1	18:00-23:55	83	150	128-192	14.1
18 May	09:40-14:20	83	147	133-193	9.2	18:00-23:45	83	149	130-172	8.8
19 May	09:18-15:45	82	147	132-176	8.7	19:13-00:45	84	149	136-178	8.4
20 May	09:24-15:45	83	145	132-179	8.1	18:01-23:15	82	147	133-190	9.1
21 May	09:30-16:00	90	147	132-170	8.6	18:01-00:25	89	147	135-178	9.3
22 May	09:15-15:55	84	148	135-171	6.8	18:02-22:45	84	148	132-172	7.8
23 May	09:05-15:25	84	155	141-178	7.9	18:01-00:40	83	150	134-178	8.7
24 May	09:22-15:45	83	161	136-207	11.8	18:03-22:36	87	151	135-175	8.7
25 May	09:15-15:30	77	158	139-204	11.1	18:05-00:46	76	152	137-178	8.3
26 May	09:33-16:15	77	150	130-182	10.0	18:03-22:57	84	152	138-181	8.4
Overall		1,973	149	122-207	12.5		2,001	150	126-214	12.2

Table 3. Release date and time, sample size, and weight (mean, range, and standard deviation) of radio-tagged, hatchery yearling Chinook salmon (with a known weight at tagging) released at Lower Monumental Dam to evaluate dam and spillway passage survival at Ice Harbor Dam, 2004.

Release date	Treatment fish weight (g)									
	Daytime release					Nighttime release				
	Release time	n	Mean	Range	SD	Release time	n	Mean	Range	SD
30 Apr	11:05-15:00	65	23.9	16.4-67.7	7.2	19:15-23:00	66	27.2	16.7-51.9	7.7
01 May	09:35-13:45	83	35.8	15.7-63.8	13.4	18:45-22:16	83	37.5	17.5-84.0	14.3
02 May	10:07-13:41	82	33.1	19.2-65.3	10.9	18:30-21:39	78	29.8	18.3-56.6	8.7
03 May	09:10-11:00	52	32.9	20.1-63.0	10.3	18:23-20:45	58	29.4	20.0-58.5	10.0
05 May	09:10-13:10	66	33.4	21.1-66.9	10.7	19:30-03:01	81	34.4	18.2-64.0	10.6
07 May	09:40-14:30	83	28.2	19.3-51.3	8.8	18:19-00:57	83	28.7	18.1-67.2	11.3
08 May	09:40-16:15	82	26.4	17.9-50.0	7.1	18:10-23:47	83	28.4	18.5-59.1	9.1
09 May	09:24-14:45	66	28.6	19.0-54.2	8.7	18:17-23:45	74	31.1	18.6-93.3	12.0
10 May	09:22-15:45	84	27.8	18.2-59.2	8.2	18:05-00:50	83	27.1	18.7-64.1	7.5
11 May	09:25-16:00	85	27.1	19.0-58.1	7.1	19:05-02:06	83	27.6	18.1-62.0	8.8
12 May	09:42-16:05	82	25.8	17.8-53.0	6.3	18:05-00:40	84	25.5	18.7-51.0	6.5
13 May	09:08-15:45	84	27.1	19.5-46.4	6.6	18:03-00:25	84	28.4	18.8-77.0	11.2
14 May	09:10-15:15	84	29.3	19.3-58.9	8.1	18:07-00:10	84	26.5	19.0-74.7	7.6
15 May	09:14-15:00	73	28.0	18.9-60.1	8.8	18:01-23:40	73	25.2	17.0-43.5	5.5
16 May	09:28-15:15	72	24.0	18.6-44.8	4.8	18:05-23:05	69	26.3	18.6-63.8	7.7
18 May	09:40-15:10	81	27.0	17.3-81.2	10.0	18:00-23:55	83	26.7	17.8-59.3	9.4
18 May	09:40-14:20	84	25.6	19.0-68.9	6.1	18:00-23:45	83	24.2	17.7-41.2	4.4
19 May	09:18-15:45	82	26.0	17.5-46.0	5.5	19:13-00:45	83	26.3	20.4-57.3	5.2
20 May	09:24-15:45	83	26.0	18.8-47.3	5.1	18:01-23:15	82	24.7	19.5-54.0	4.9
21 May	09:30-16:00	89	27.7	19.1-53.5	7.0	18:01-00:25	89	25.8	19.8-53.7	6.2
22 May	09:15-15:55	82	26.9	18.5-45.9	5.1	18:02-22:45	84	26.0	19.9-45.5	4.6
23 May	09:05-15:25	84	24.3	18.3-37.2	4.2	18:01-00:40	83	26.3	19.3-47.9	5.5
24 May	09:22-15:45	83	28.2	19.2-56.1	7.2	18:03-22:36	87	26.8	19.7-43.3	5.0
25 May	09:15-15:30	77	26.6	19.1-59.8	6.7	18:05-00:46	75	26.6	19.6-41.2	4.8
26 May	09:33-16:15	84	27.8	18.5-56.4	6.7	18:03-22:57	84	27.4	19.8-58.3	5.9
Overall		1,972	27.8	15.7-81.2	8.3		1,999	27.7	16.7-93.3	8.6

Table 4. Release date and time, sample size, and fork length (mean, range and standard deviation) of radio-tagged, hatchery yearling Chinook salmon (with a known length at tagging) released into the Ice Harbor Dam tailrace and used as reference groups to evaluate dam and spillway passage survival at Ice Harbor Dam, 2004.

	Reference fish fork length (mm)									
Release	Daytime release					Nighttime release				
date	Release times	n	Mean	Range	SD	Release times	n	Mean	Range	SD
01 May	16:15-17:30	25	151	126-186	16.9	01:10-02:10	27	153	133-186	16.1
02 May	16:20-17:31	33	158	127-187	17.3	00:01-01:01	31	154	128-195	19.5
03 May	13:10-14:20	33	150	131-182	13.8	22:39-23:49	31	158	129-180	16.3
04 May	09:20-11:50	33	149	132-176	12.6	18:42-19:32	24	148	134-182	12.7
07 May	10:00-12:30	32	150	132-178	13.5	19:00-21:30	31	152	135-178	13.2
08 May	10:00-12:30	33	149	130-184	14.6	17:50-20:20	31	143	130-168	9.3
09 May	09:50-12:15	31	150	113-190	17.1	17:50-20:20	31	146	131-189	12.2
10 May	09:30-11:20	24	141	130-154	6.1	18:10-20:00	23	151	134-187	14.1
11 May	09:30-12:00	31	151	137-177	11.5	18:20-20:40	32	149	135-178	11.5
12 May	09:30-12:00	32	143	130-164	6.9	18:00-20:20	31	150	134-174	9.6
13 May	09:40-12:10	33	142	124-177	11.9	17:30-19:50	31	146	127-175	12.5
14 May	09:20-11:50	33	150	135-186	13.5	17:30-19:50	32	151	137-188	12.1
15 May	09:30-12:00	33	143	129-166	8.1	18:30-20:53	31	147	133-199	12.0
16 May	09:30-11:40	28	148	135-187	13.0	17:40-19:40	27	146	135-170	8.8
17 May	10:20-12:20	27	144	132-166	8.4	18:40-20:40	26	144	136-174	7.4
18 May	08:45-11:15	33	147	133-168	7.0	17:40-20:10	32	152	137-204	14.0
19 May	09:25-11:55	33	147	132-180	10.7	17:45-20:15	32	149	135-178	9.7
20 May	09:30-12:00	32	141	129-156	6.6	17:40-19:00	32	148	135-179	10.9
21 May	09:45-12:15	33	143	126-162	7.2	17:40-20:10	32	147	138-159	6.1
22 May	09:30-12:20	39	143	128-159	7.6	17:40-20:40	39	148	129-159	7.4
23 May	09:20-12:00	33	147	132-168	8.9	17:45-20:15	31	149	136-170	8.9
24 May	09:25-11:55	33	158	135-190	11.7	18:05-20:25	32	149	135-175	9.8
25 May	09:30-12:20	36	156	135-178	8.6	17:10-20:10	36	148	133-171	8.8
26 May	09:35-11:55	29	158	147-186	8.0	17:40-20:00	31	151	137-171	9.5
27 May	09:20-11:40	30	148	134-168	7.5	17:40-20:10	32	149	135-174	8.1
Overall		792	148	113-190	12.2		768	149	127-204	11.8

Table 5. Release date and time, sample size, and weight (mean, range, and standard deviation) of radio-tagged, hatchery yearling Chinook salmon (with a known weight at tagging) released into the Ice Harbor Dam tailrace as reference groups to evaluate dam and spillway passage survival at Ice Harbor Dam, 2004.

	Reference fish weight (g)									
	Daytime release					Nighttime release				
Release date	Release times	n	Mean	Range	SD	Release times	n	Mean	Range	SD
01 May	16:15-17:30	25	32.0	16.7-58.4	12.3	01:10-02:10	27	31.1	17.8-55.9	11.3
02 May	16:20-17:31	33	37.8	17.4-65.3	13.0	00:01-01:01	30	32.6	15.2-74.6	14.7
03 May	13:10-14:20	33	30.8	19.7-52.1	9.1	22:39-23:49	30	36.3	20.0-53.3	10.9
04 May	09:20-11:50	33	29.5	18.9-51.5	9.1	18:42-19:32	24	28.2	20.3-50.5	8.3
07 May	10:00-12:30	32	29.2	18.3-51.0	8.0	19:00-21:30	31	30.1	18.5-48.4	8.4
08 May	10:00-12:30	33	29.1	19.8-53.3	9.5	17:50-20:20	31	24.4	18.0-44.5	6.6
09 May	09:50-12:15	32	30.0	18.8-59.1	11.1	17:50-20:20	31	26.4	19.2-65.1	9.6
10 May	09:30-11:20	23	23.1	18.3-34.6	3.5	18:10-20:00	23	29.1	19.1-56.2	10.5
11 May	09:30-12:00	31	27.7	18.3-41.7	7.5	18:20-20:40	32	26.5	18.9-51.3	8.0
12 May	09:30-12:00	32	25.2	18.6-42.5	5.4	18:00-20:20	31	28.1	19.9-49.3	7.4
13 May	09:40-12:10	33	26.5	18.2-45.8	7.2	17:30-19:50	31	26.1	18.5-50.0	8.0
14 May	09:20-11:50	33	29.7	19.2-51.5	9.6	17:30-19:50	32	28.0	20.2-60.2	8.2
15 May	09:30-12:00	33	24.8	19.1-41.5	5.3	18:30-20:53	30	26.4	19.1-65.5	8.8
16 May	09:30-11:40	28	28.2	19.1-62.4	9.5	17:40-19:40	27	25.1	19.2-40.3	5.0
17 May	10:20-12:20	27	26.6	19.3-39.7	5.4	18:40-20:40	26	23.6	19.2-44.8	5.0
18 May	08:45-11:15	33	25.7	18.6-43.7	5.2	17:40-20:10	32	26.6	17.6-71.4	10.5
19 May	09:25-11:55	33	23.1	17.5-42.2	5.9	17:45-20:15	32	24.8	19.2-40.2	4.8
20 May	09:30-12:00	32	23.4	18.7-34.3	3.6	17:40-19:00	32	26.6	20.0-55.8	8.7
21 May	09:45-12:15	33	25.6	17.5-37.2	5.0	17:40-20:10	32	24.2	18.0-31.7	3.6
22 May	09:30-12:20	39	24.2	18.0-34.3	4.7	17:40-20:40	39	25.7	19.6-35.7	4.0
23 May	09:20-12:00	32	25.7	18.5-37.5	5.1	17:45-20:15	31	25.2	20.0-39.4	4.2
24 May	09:25-11:55	33	26.8	19.0-47.8	6.8	18:05-20:25	32	26.5	19.3-44.1	5.9
25 May	09:30-12:20	35	25.3	19.9-37.4	3.8	17:10-20:10	36	25.9	19.9-41.8	5.3
26 May	09:35-11:55	29	25.9	19.2-40.3	4.2	17:40-20:00	31	26.2	18.8-38.7	4.8
27 May	09:20-11:40	32	26.2	20.4-36.0	4.4	17:40-20:10	32	25.7	20.1-44.0	4.8
Overall		792	27.3	16.7-65.3	8.0		765	27.1	15.2-74.6	8.2

Migration Behavior and Passage Distribution

Forebay Behavior and Timing

Of the 3,936 radio-tagged fish released at Lower Monumental Dam, 2,882 were detected in the forebay of Ice Harbor Dam; 2,843 (98.6%) of these were first detected on the upper forebay transect, 13 (0.5%) on the lower forebay transect (dam approach line), and 26 (0.9%) in front of the spillway. Based on the time of these first detections, 1,461 (50.7%) radio-tagged fish entered the forebay during bulk spill operations, 1,392 (48.3%) during flat spill operations, and 29 (1.0%) during a short period of no spill.

Of the 2,882 radio-tagged fish detected in the forebay 1,829 (63.5%) were detected on the lower forebay transect buoys. Of these 1,829, 898 (49.1%) were detected during bulk spill and 906 (49.5%) during flat spill; the remaining 25 (1.4%) were detected during no spill. For the 898 fish detected on the lower forebay transect during bulk spill operations, 79.3% were first detected on buoys located in front of the spillway vs. 20.7% on buoys in front of the powerhouse (Figure 6). For the 906 fish detected on the lower forebay transect during flat spill operations, 64.3% were first detected on buoys in front of the spillway vs. 35.7 % on buoys in front of the powerhouse.

Forebay residence times were calculated for 2,617 fish, each with detections on both the upper forebay transect and a passage-route receiver. Of these fish, 1,346 (51.4%) arrived during bulk spill, 1,246 (47.6%) during flat spill, and 25 (1.0%) during no spill. Of the 1,346 that entered the forebay during bulk spill operations, 1,275 (94.7%) passed during bulk spill with a median forebay residence time of 1.3 h. Of the remaining fish, 69 (5.1%) passed during flat spill with a median residence time of 4.3 h.

For the 1,246 fish that entered the forebay during flat spill operations and were detected on a passage route, 1,103 (88.5%) passed the dam during flat spill with a median forebay residence time of 2.2 h, and 137 (11.0%) passed during bulk spill with a median forebay residence time of 6.9 h. Median forebay residence time for the 25 fish entering the forebay under the short period of no spill was 2.9 h, and most of these fish passed the dam after the no-spill period had ended.

We further calculated forebay residence time by operational test block. Forebay residence time was consistently longer during flat spill operations than during bulk spill operations, with a negative temporal trend during both operations (Figure 7). The mean difference between median forebay residence times for bulk spill and flat spill operations was statistically significant at 0.9 h (t = 3.11, P = 0.021).

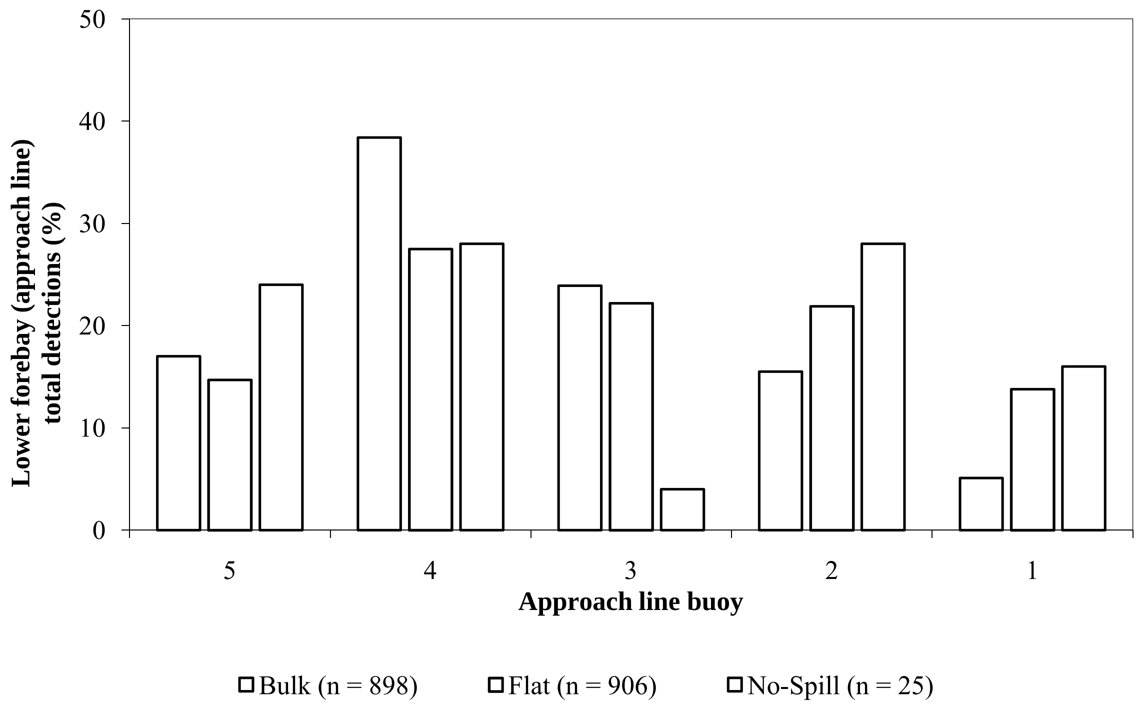

Figure 6. Approach patterns for the 1,829 radio-tagged, hatchery yearling Chinook salmon detected on the forebay approach line at Ice Harbor Dam, 2004. See Figure 3 for location of lower forebay transect (dam approach line) buoys.

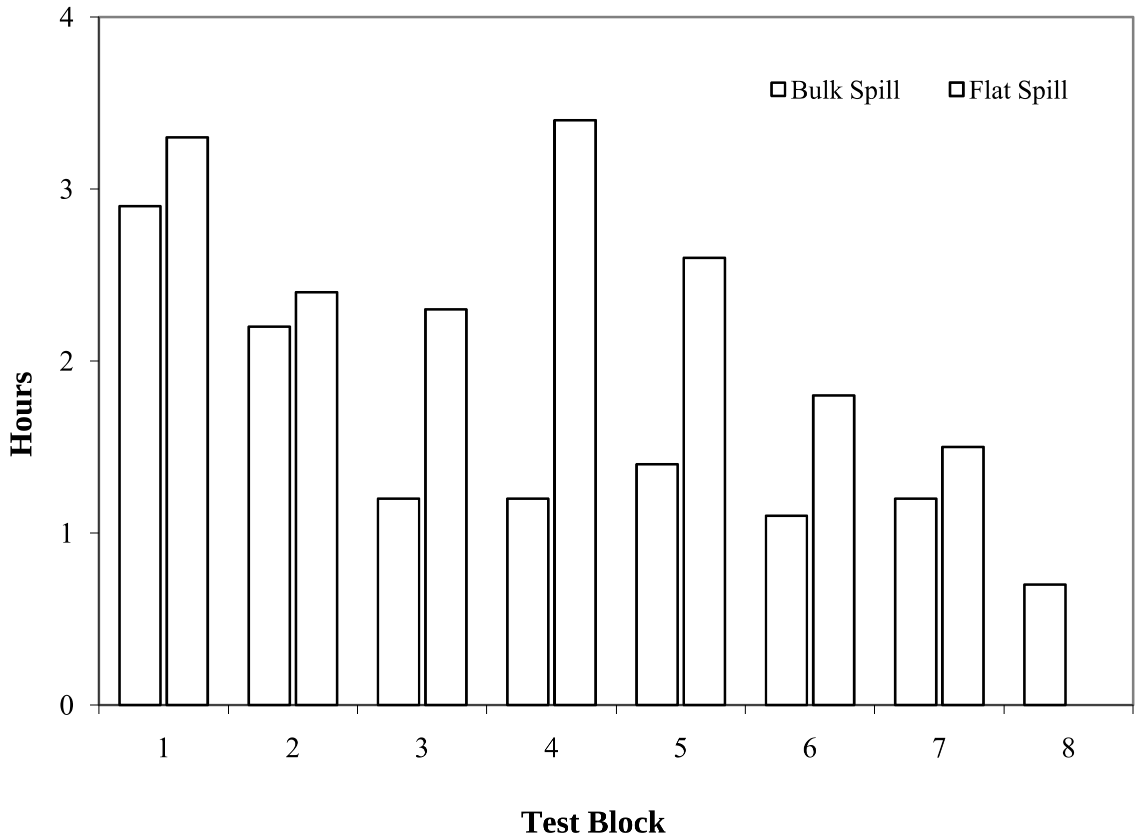

Figure 7. Median forebay residence times in hours by test block (see Table 1) for radio-tagged, hatchery yearling Chinook salmon at Ice Harbor Dam, 2004.

Passage Distribution and Metrics

Of the 3,936 radio-tagged fish released at Lower Monumental Dam, 2,882 were detected at or below Ice Harbor Dam. Of these fish, 2,507 (87.0%) passed through the spillway, 117 (4.1%) through the juvenile bypass system, and 28 (1.0%) through turbines. Of the remaining fish, 175 (6.0%) entered the forebay but were not recorded as passing the dam, and 55 (1.9%) passed the dam through an undetermined passage route.

We assigned a spill operation to each radio-tagged fish based on its last detection in the forebay: 1,560 were last detected in the forebay during bulk spill, while 1,313 were last detected during flat spill. Nine fish entered the powerhouse and subsequently the juvenile bypass system during a short period of no spill. Most radio-tagged fish passed via the spillway during both bulk and flat spill operations.

Of the 1,560 radio-tagged fish last detected in the forebay during bulk spill 1,438 (92.2%) passed via the spillway, 20 (1.3%) via the juvenile bypass system, and 3 (0.2%) through turbines. Of the remaining fish, 80 (5.1%) were never detected downstream from Ice Harbor Dam, and 19 (1.2%) passed the project through an undetermined route (Figure 8).

Of the 1,313 radio-tagged fish last detected in the forebay during flat spill, 1,069 (81.4%) passed the dam through the spillway, 91 (6.9%) through the juvenile bypass, and 24 (1.8%) through turbines at Ice Harbor Dam. Of the remaining fish, 93 (7.1%), last detected in the forebay during bulk spill operations were never detected downstream, and 36 (2.7%) passed the project through an undetermined route.

Spillway passage distribution favored the south half of the spillway (Spillbays 1-5) under both test operations, with 57.4 and 66.6% of radio-tagged fish passing through the spillway during bulk and flat spill operations, respectively. Distribution through individual spillbays is presented in Figure 9. A broken antenna in Spillbay 5, discovered when antennas were removed, likely resulted in inflation of passage numbers through Spillbay 6.

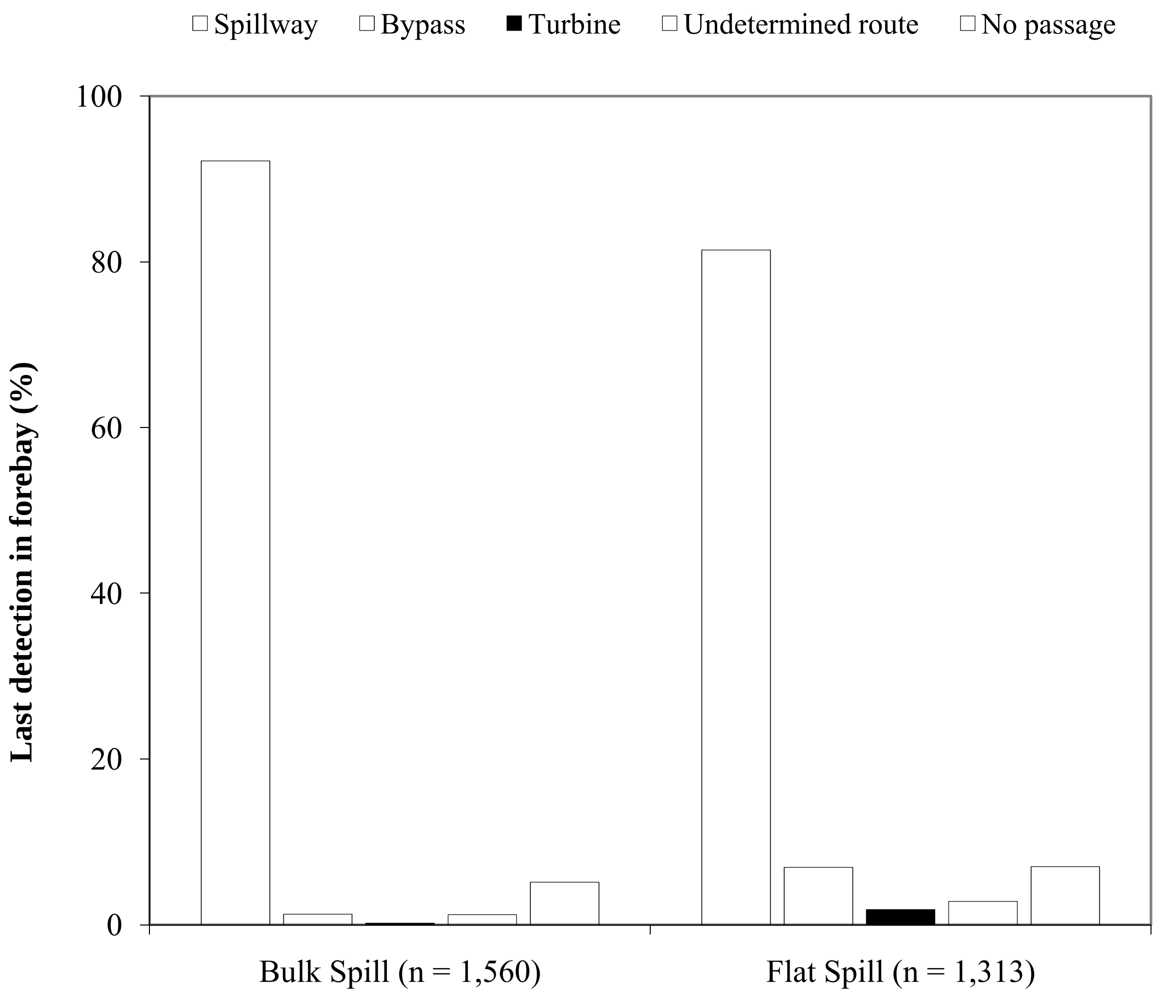

Figure 8. Distribution of radio-tagged, hatchery yearling Chinook salmon during bulk and flat spill operations at Ice Harbor Dam, 2004.

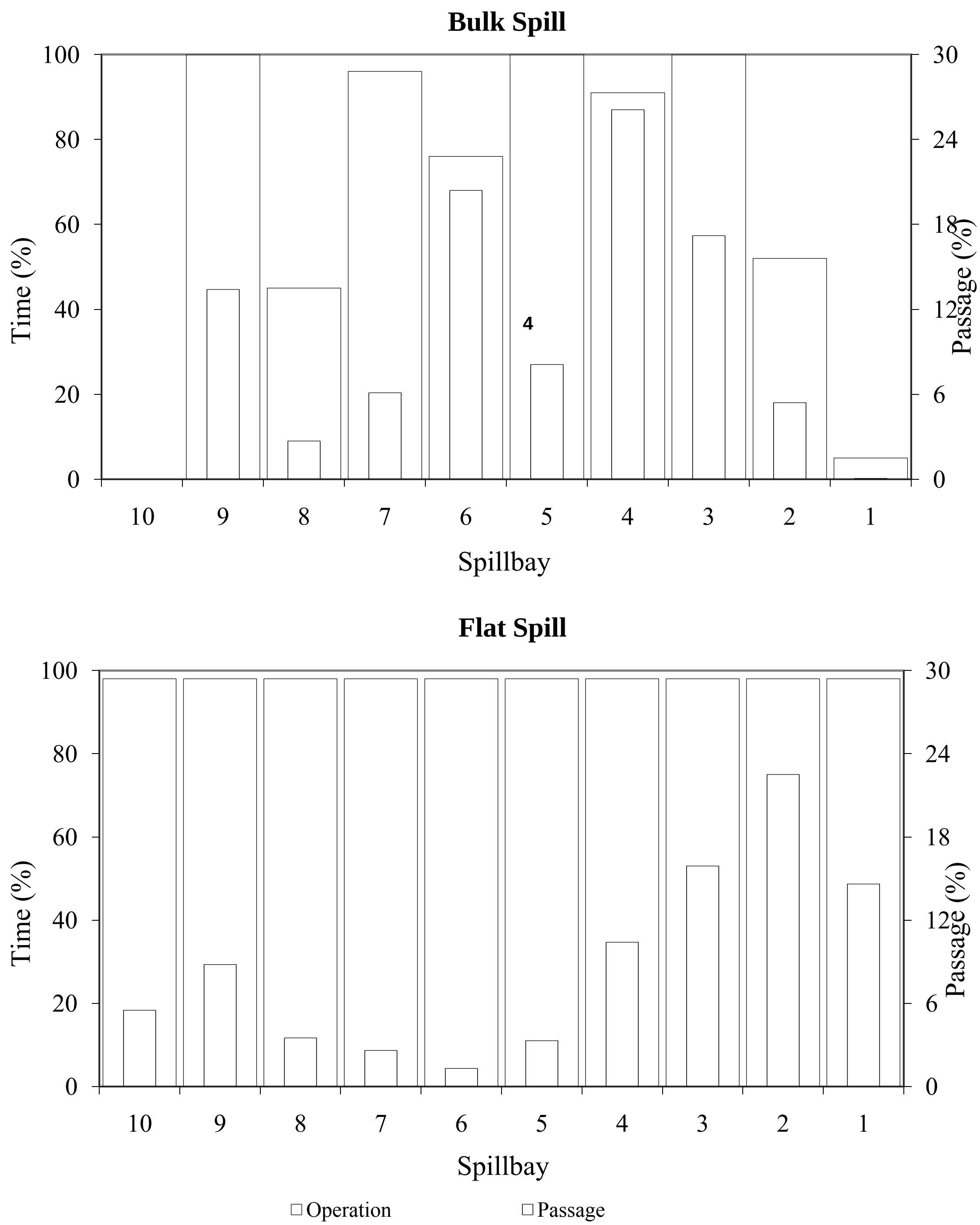

Figure 9. Percent time of individual spillbay operation with passage distribution for radio-tagged, hatchery yearling Chinook salmon passing through the spillway during testing at Ice Harbor Dam, 2004.

Spill passage efficiency (SPE), spill effectiveness (SPF), and fish passage efficiency (FPE) were calculated for radio-tagged fish passing Ice Harbor Dam during individual test blocks (Table 1). Grouping was based on the time of last detection in the forebay of the dam. Since some fish passed the dam undetected on a passage route telemetry receiver we calculated minimum and maximum estimates of SPE, SPF, and FPE.

To calculate minimum estimates, we counted all fish that had passed the dam through an undetermined route as having passed through turbines. To calculate maximum estimates, we assumed these same fish had passed through the spillway. Due to the small numbers of "undetermined passage route" fish (56 fish overall), differences between minimum and maximum estimates were small (Table 6). Overall SPE and FPE estimates were consistently higher for radio-tagged fish passing Ice Harbor Dam during bulk spill than for those passing during flat spill operations.

A total of 138 radio-tagged fish were detected passing Ice Harbor Dam through the powerhouse, with 23 (16.7%) detected during bulk spill and 115 (83.3%) during flat spill operations. During bulk spill, 20 fish (87.0%) were guided by standard length screens into the juvenile bypass system; during flat spill, 91 fish (79.1%) were guided into the bypass system.

Table 6. Minimum and maximum estimates of spill efficiency (SPE), spill effectiveness (SPF), and fish passage efficiency (FPE) by test block for radio-tagged, hatchery yearling Chinook salmon passing Ice Harbor Dam during bulk ("B") and flat ("F") spill operations, 2004.

Operations grouping	Minimum estimates			Maximum estimates		
	SPE	SPF	FPE	SPE	SPF	FPE
	Bulk spill					
B01	---	---	---	---	---	---
B02	96.2	1.1	99.5	96.7	1.1	100.0
B03	96.8	1.1	98.4	96.8	1.1	100.0
B04	98.7	1.2	98.7	98.7	1.2	100.0
B05	98.9	1.1	99.4	98.9	1.1	100.0
B06	97.8	1.1	98.2	97.8	1.1	98.9
B07	95.8	1.0	96.2	95.8	1.0	100.0
B08	100.0	1.5	100.0	100.0	1.5	100.0
Overall	**97.7**	**1.2**	**98.6**	**97.8**	**1.2**	**99.8**
	Flat spill					
F01	91.4	1.4	97.5	92.9	1.5	99.0
F02	85.5	1.5	93.5	89.9	1.6	97.8
F03	86.1	1.4	94.6	89.8	1.4	98.2
F04	95.0	1.3	98.1	96.3	1.3	99.4
F05	88.6	1.4	96.4	90.2	1.5	97.9
F06	85.0	1.7	93.2	89.3	1.8	97.6
F07	80.8	2.0	91.0	85.9	2.2	96.2
F08	---	---	---	---	---	---
Overall	**87.5**	**1.5**	**94.9**	**90.6**	**1.6**	**98.0**

Tailrace Behavior and Timing

Tailrace egress time was calculated for 2,143 radio-tagged, hatchery yearling Chinook salmon as elapsed time from passage at Ice Harbor Dam to first detection at Goose Island approximately 2 km downstream. Of these fish 1,180 passed via the spillway during bulk spill, and 963 passed the spillway during flat spill operations. Overall median residence times were similar between bulk and flat spill operations at 23 and 22 min, respectively. As with forebay residence times, we calculated and compared tailrace egress by test block (Figure 10).

Radio-tagged fish passing during flat spill operations exited the tailrace faster than fish passing during bulk spill operations. The mean difference between median tailrace egress times for fish passing during bulk and flat spill operations, although statistically significant (t =2.60, P =0.041), was small at 1.8 min. However, the mean difference between operations at the 90th percentile was greater at 34.0 min, and was also statistically significant (t =4.53, P =0.004).

Tailrace egress times were calculated for 130 radio-tagged fish that passed through the powerhouse at Ice Harbor Dam and were subsequently detected downstream at Goose Island. Of these, 109 fish passed through the juvenile bypass system and 21 fish passed through turbines. Median egress times were 56 and 50 min for fish passing through the juvenile bypass system and turbines, respectively. Of the 109 fish that passed through the juvenile bypass system, 11 entered the tailrace during bulk spill, 85 during flat spill, and 13 during a brief “no-spill” condition. Median tailrace egress times for these fish were 298, 41, and 163 min for fish exiting the juvenile bypass system during bulk spill, flat spill, and “no-spill” operations, respectively.

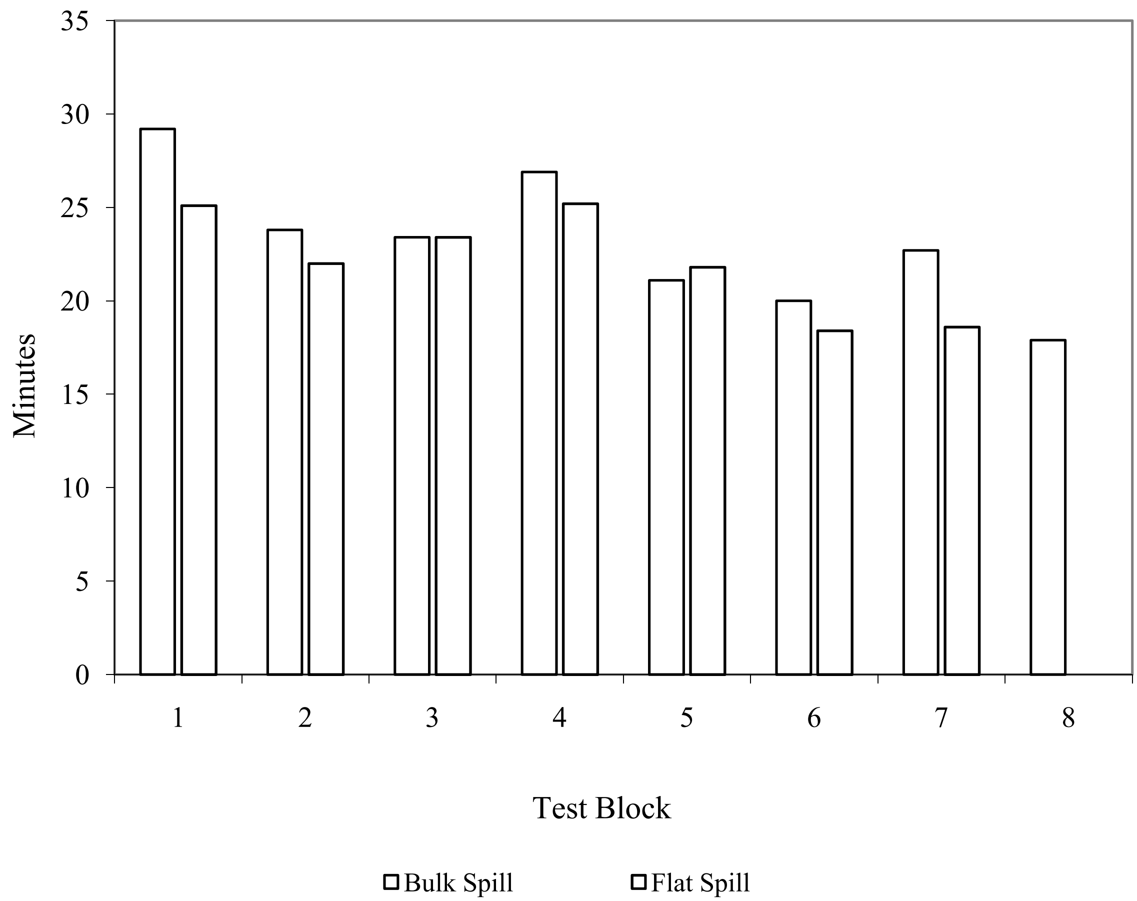

Figure 10. Median tailrace egress times in minutes by test block (see Table 1) for radio-tagged, hatchery yearling Chinook salmon at Ice Harbor Dam, 2004.

Detection and Survival

Of the 4,360 radio-tagged hatchery yearling Chinook salmon detected on the forebay entry line (2,843 treatment fish) or released in the tailrace (1,517 reference fish), 4,003 were used for estimation of dam and spillway passage survival at Ice Harbor Dam. Data collected by manual download from the Sacajawea Park sites prior to 4 May at 1600 PDT was lost. This loss of data required us to remove 357 fish from the survival analysis (154 treatment and 203 reference fish). This data represented fish passing Ice Harbor Dam during the first bulk-spill test block and most of the first flat-spill test block.

Of the 4,003 radio-tagged fish used for survival estimation 3,591 (89.7%) unique radio tags were detected at downstream transects on the Snake and Columbia Rivers. Of these, 3,581 (99.7%) were detected at Sacajawea Park. Detection probabilities at Sacajawea Park were similar for both treatment and reference groups at 0.997 (SE = 0.001) and 0.998 (SE = 0.002), respectively.

Survival estimates for groups of radio-tagged yearling Chinook salmon passing through the forebay and all available passage routes through Ice Harbor Dam relative to those released into the tailrace (dam survival) ranged from 0.841 (SE = 0.028) to 0.996 (SE = 0.036) during bulk spill and from 0.813 (SE = 0.029) to 0.938 (SE = 0.025) during flat spill operations (Table 7). Weighted geometric mean relative survival estimates for fish passing under bulk and flat spill conditions were 0.930 (95% CI, 0.864-0.997) and 0.895 (95% CI, 0.845-0.945), respectively. There was no significant difference between relative dam-passage survival estimates (t =1.14, P =0.285) for the two operations.

Survival estimates for groups of radio-tagged yearling Chinook salmon passing through the spillway of Ice Harbor Dam relative to those released into the tailrace ranged from 0.928 (SE = 0.025) to 1.008 (SE = 0.036) during bulk spill and from 0.935 (SE = 0.030) to 1.004 (SE = 0.039) during flat spill operations (Table 8). Weighted geometric mean relative survival estimates for fish passing under bulk and flat spill conditions were 0.974 (95% CI, 0.936-1.011) and 0.952 (95% CI, 0.930-0.974), respectively. There was no significant difference between relative spillway passage survival estimates (t = 1.34, P = 0.212) for the two operations.

Table 7. Estimates based on the single-release model with relative dam survival estimates (standard errors in parentheses) for radio-tagged, hatchery yearling Chinook salmon passing Ice Harbor Dam under bulk and flat spill operations, 2004. Overall relative survival estimates are presented as weighted geometric means. Test blocks without estimates represent blocks containing no fish or too few fish for valid estimates.

Test block	Dam passage survival estimates: Treatment n	Treatment Survival	Reference n	Reference Survival	Relative Survival
			Bulk spill		
B01	---	---	---	---	---
B02	199	0.910 (0.020)	---	---	---
B03	248	0.913 (0.018)	104	0.917 (0.028)	0.996 (0.036)
B04	238	0.925 (0.017)	126	0.968 (0.016)	0.956 (0.024)
B05	184	0.908 (0.021)	113	0.956 (0.019)	0.950 (0.029)
B06	286	0.871 (0.020)	140	0.957 (0.017)	0.910 (0.026)
B07	235	0.822 (0.025)	129	0.977 (0.013)	0.841 (0.028)
B08	74	0.811 (0.046)	---	---	---
B09	---	---	---	---	---
Overall	**1,191**	**0.880 (0.018)**	**612**	**0.955 (0.010)**	**0.930 (0.024)**
			Flat spill		
F01	79	0.899 (0.034)	23	---	---
F02	142	0.923 (0.022)	123	0.984 (0.011)	0.938 (0.025)
F03	175	0.851 (0.027)	93	0.935 (0.025)	0.910 (0.038)
F04	170	0.848 (0.028)	117	0.966 (0.017)	0.878 (0.033)
F05	205	0.844 (0.025)	123	0.951 (0.019)	0.887 (0.032)
F06	221	0.833 (0.025)	129	0.899 (0.027)	0.927 (0.039)
F07	182	0.813 (0.029)	64	1.000 (0.000)	0.813 (0.029)
F08	5	---	---	---	---
F09	---	---	---	---	---
Overall	**1,174**	**0.859 (0.015)**	**672**	**0.956 (0.015)**	**0.895 (0.020)**

Table 8. Estimates based on the single-release model with relative spillway passage survival estimates (standard errors in parentheses) for radio-tagged, hatchery yearling Chinook salmon passing Ice Harbor Dam under bulk and flat spill operations, 2004. Overall relative survival estimates are presented as weighted geometric means. Test blocks without estimates represent blocks containing no fish or too few fish for valid estimates.

	Spillway passage survival estimates				
Test	Treatment		Reference		Relative
block	n	Survival	n	Survival	Survival
	Bulk spill				
B01	---	---	---	---	---
B02	185	0.958 (0.015)	---	---	---
B03	233	0.924 (0.018)	104	0.917 (0.028)	1.008 (0.036)
B04	185	0.952 (0.016)	126	0.968 (0.016)	0.983 (0.023)
B05	155	0.955 (0.017)	113	0.956 (0.019)	0.999 (0.027)
B06	259	0.923 (0.017)	140	0.957 (0.017)	0.964 (0.025)
B07	194	0.907 (0.021)	129	0.977 (0.013)	0.928 (0.025)
B08	---	---	---	---	---
B09	---	---	---	---	---
Overall	**1,026**	**0.937 (0.009)**	**612**	**0.955 (0.010)**	**0.974 (0.014)**
	Flat spill				
F01	70	0.900 (0.036)	23	---	---
F02	118	0.941 (0.022)	123	0.984 (0.011)	0.956 (0.025)
F03	140	0.900 (0.025)	93	0.935 (0.025)	0.963 (0.037)
F04	153	0.903 (0.024)	117	0.966 (0.017)	0.935 (0.030)
F05	147	0.891 (0.026)	123	0.951 (0.019)	0.937 (0.033)
F06	175	0.903 (0.022)	129	0.899 (0.027)	1.004 (0.039)
F07	126	0.944 (0.020)	64	1.000 (0.000)	0.944 (0.020)
F08	2	---	---	---	---
F09	---	---	---	---	---
Overall	**931**	**0.912 (0.008)**	**672**	**0.956 (0.015)**	**0.952 (0.008)**

DISCUSSION

Operations at Ice Harbor Dam continue to be effective at passing migrating juvenile Chinook salmon quickly while efficiently guiding fish away from turbines. Under the two operations evaluated in this study, radio-tagged fish entered the forebay and passed the project quickly, and although median residence times were significantly different between bulk and flat spill operations, the difference of 0.9 h was not likely of biological significance.

Overall passage-route distribution was dominated by spillway passage, with 87% of radio-tagged fish detected in the forebay passing via this route. Overall spill efficiency and fish passage efficiency were higher for bulk spill operations, and spill effectiveness was higher during flat spill. However, fish passage efficiency, widely considered the most important of these metrics, was generally well above 90% for both spill operations. Additionally, the FPE results from this study closely match those of our 1999 and 2003 studies, wherein FPE was estimated at 97.1 and 97.5%, respectively (Eppard et al. 2000, 2005b).

Timing data for radio-tagged fish migrating through the tailrace under either bulk or flat spill operations indicated that, as for passage through the forebay, little to no delay occurred for the large majority of fish. Ninety percent of all radio-tagged fish passing through the spillway exited the tailrace in less than 1 h. Median egress times for radio-tagged fish passing through the turbines and the bypass system were twice as long as for fish passing through the spillway; however, they still were less than 1 h. Based on tailrace egress timing, predation on fish in the tailrace does not appear to be a major problem.

We found no statistical difference between relative survival estimates under flat vs. bulk spill operations, either for dam passage or spillway passage of radio-tagged fish. For both bulk and flat spill operations overall, mean spillway passage survival estimates (0.974 and 0.952, respectively) were higher than mean dam passage survival estimates (0.930 and 0.895, respectively).

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APPENDIX A: Tests of Model Assumptions

Methods

The single-release model (Cormack 1964; Jolly 1965; Seber 1965) was used to estimate survival from Ice Harbor Dam to Sacajawea Park, based on radiotelemetry detections at these locations. Additional telemetry detections at Port Kelley, and PIT-tag detections at and below McNary Dam were used to estimate total dam survival, reference fish survival, and spillway test fish survival. The SR model provides unbiased estimates if its critical assumptions are met, particularly assumption A1: that detection and survival probabilities are not influenced by previous detection upstream from the site of interest (Zabel et al. 2002; Smith et al. 2003).

We assessed the validity of assumption A1 using the methods of Burnham et al. (1987). We constructed χ^2 contingency tables of the total detections expected in each detection history category. Based on these tables, we tested goodness-of-fit of the actual detections to expected detections for each temporal group and for the groups overall. The assumption was considered violated if we found more significant differences between observed and expected detections than would be expected by chance ($\alpha = 0.05$). In these cases, we examined the tables to determine whether the nature of the violation could be explained by a consistent pattern. We excluded any contingency table wherein the expected value in a cell was less than 1.0, as the test statistic did not sufficiently approximate the asymptotic χ^2 distribution in these cases.

For our data (a grouped cohort or release at Ice Harbor Dam, detection at Sacajawea, Port Kelley, McNary Dam, and downstream from McNary Dam), five of Burnham et al.'s (1987) goodness-of-fit tests were applicable: Tests 2.C2, 2.C3, 3.SR3, 2.Sm3, and Test 3.SR4. Test 2.C2 was based on the contingency table:

Test 2.C2	First site detected below Sacajawea		
df = 2	Port Kelley	McNary	Below McNary
Not detected at Sacajawea	n_{11}	n_{12}	n_{13}
Detected at Sacajawea	n_{21}	n_{22}	n_{23}

If assumption A1 was met, the counts for fish detected at Sacajawea should be in constant proportion to those for fish not detected (i.e., n_{11}/n_{21} and n_{12}/n_{22}, and n_{13}/n_{23} should be equal).

Test 2.C3 was based on the contingency table:

Test 2.C3	First site detected below Port Kelley	
df = 1	McNary Dam	Below McNary Dam
Not detected at Port Kelley	N_{11}	n_{12}
Detected at Port Kelley	N_{21}	n_{22}

Again, if assumption A1 was met, then numbers of fish detected at and below McNary Dam and previously detected at Port Kelley should be in constant proportion to those of fish not detected at Port Kelly (i.e., n_{11}/n_{21} and n_{12}/n_{22} should be equal).

Test 3.SR3 was based on the contingency table:

Test 3.SR3	Detected again at McNary Dam or below?	
df = 1	YES	NO
Detected at Port Kelley Not detected at Sacajawea	n_{11}	n_{12}
Detected at Port Kelley Detected at Sacajawea	n_{21}	n_{22}

If assumption A1 was met, counts of fish detected at McNary Dam or below McNary Dam vs. those of fish not detected should be in constant proportion between fish with detection histories "detected at Sacajawea and Port Kelley" and "detected at Port Kelley but not at Sacajawea."

Test 3.Sm3 was based on the contingency table:

Test 3.Sm3	Site first detected below Port Kelley	
df = 1	McNary Dam	Below McNary Dam
Detected at Port Kelley; not detected at Sacajawea	n_{11}	n_{12}
Detected at Port Kelley; detected at Sacajawea	n_{21}	n_{22}

This test is similar to Test 3.SR3, except that counts are for site of first detection downstream from Port Kelley. Again, the proportions will be similar if the model assumption is met.

The final test, Test 3.SR4, was based on the contingency table:

Test 3.SR4	Detected below McNary Dam?	
df = 1	YES	NO
Detected at McNary Dam, not detected previously	n_{11}	n_{12}
Detected at McNary Dam, also detected previously	n_{21}	n_{22}

If the model assumption is met, the detection history prior to detection at McNary Dam did not affect detection below McNary Dam, and detection/non-detection ratios would be in constant proportion.

A second assumption of the SR model, assumption A2, stipulates that survival and detection probabilities downstream from the reference release site are equitable among regrouped-test cohorts and reference releases. We examined the data for violations of this assumption by testing whether passage distributions were homogeneous between groups, or whether groups were "mixed" at downstream sites. This test used a $2 \times c$ contingency table, with two columns for the 2 groups and c rows for the number of days when fish were detected.

Again, we calculated χ^2 tests for each temporal group, and if more significant differences between observed and expected data were found than would be expected by chance, we examined the table to determine the nature of the violation.

In addition to model assumptions, this study also relied upon several biological assumptions, which included:

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

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

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

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

Results

We found no statistical evidence that assumptions of the single-release model were violated in this study. To assess assumption A1, very few of the "Burnham tests" were calculable for any of the five groups of tests, since the detection rate at Sacajawea Park was very high (only ten tagged fish detected below Ice Harbor Dam were not detected there, and detection probability estimates were 99.7 and 99.8% for treatment and reference groups, respectively) and the resulting rows or columns in these tests that were for fish "not detected at Sacajawea" had very small cell counts. There were high detection proportions at other sites as well. Therefore, these data sets provided very little statistical power to test for differences in detection rates based on previous detection history. However, with such high detection rates, the tests are somewhat moot.

Treatment and corresponding reference groups were not evenly mixed at the Sacajawea Park detection array, potentially violating assumption A2. Chi-square homogeneity tests showed that 9 of the 12 test blocks had significantly different temporal distributions at the Sacajawea Park detection array (Appendix Table A1). However, visual assessment suggested differences in temporal arrival distributions for treatment and reference groups at Sacajawea Park were small.

Appendix Table A1. Mixing test results for Ice Harbor Dam study and reference cohorts to compare passage distributions at Sacajawea, 2004.

Test block	χ^2	Degrees of freedom	*P*-value
		Bulk condition	
B03	13.95	3	0.002
B04	2.28	4	0.812
B05	8.42	3	0.032
B06	13.15	3	0.003
B07	16.13	3	0.001
		Flat spill condition	
F01	28.42	2	<0.001
F02	17.81	2	<0.001
F03	7.96	4	0.056
F04	6.43	3	0.066
F05	44.76	2	<0.001
F06	19.97	3	<0.001
F07	33.44	2	<0.001

Releases occurred over 2 d, and nearly all fish from both groups were detected within a few hours after passage or release (Appendix Table A2). Treatment fish passed Ice Harbor Dam somewhat continuously, while reference groups were released over a few hours twice daily. Since Sacajawea Park is relatively close to Ice Harbor Dam, the reference groups did not necessarily disperse sufficiently before passing that location. Additionally, we calculated travel time from passage at Ice Harbor Dam for treatment fish and from release of reference fish to the first detection at Sacajawea Park. At the 90th percentile, travel time to Sacajawea Park differed by only 18 min between treatment and reference groups.

Since we did not use survival estimates to Port Kelley, McNary Dam, or below McNary Dam to assess the objectives of this study, we did not conduct mixing tests of the treatment groups at those locations.

Assumptions A3, could not be tested for validation in this study, as tagging began after the 70th percentile of the yearling Chinook salmon migration had passed (although the study had been scheduled to coincide with the 27th to 94th passage percentiles). However, the overall mean fork length and weight of tagged fish was reported, and was within normal limits.

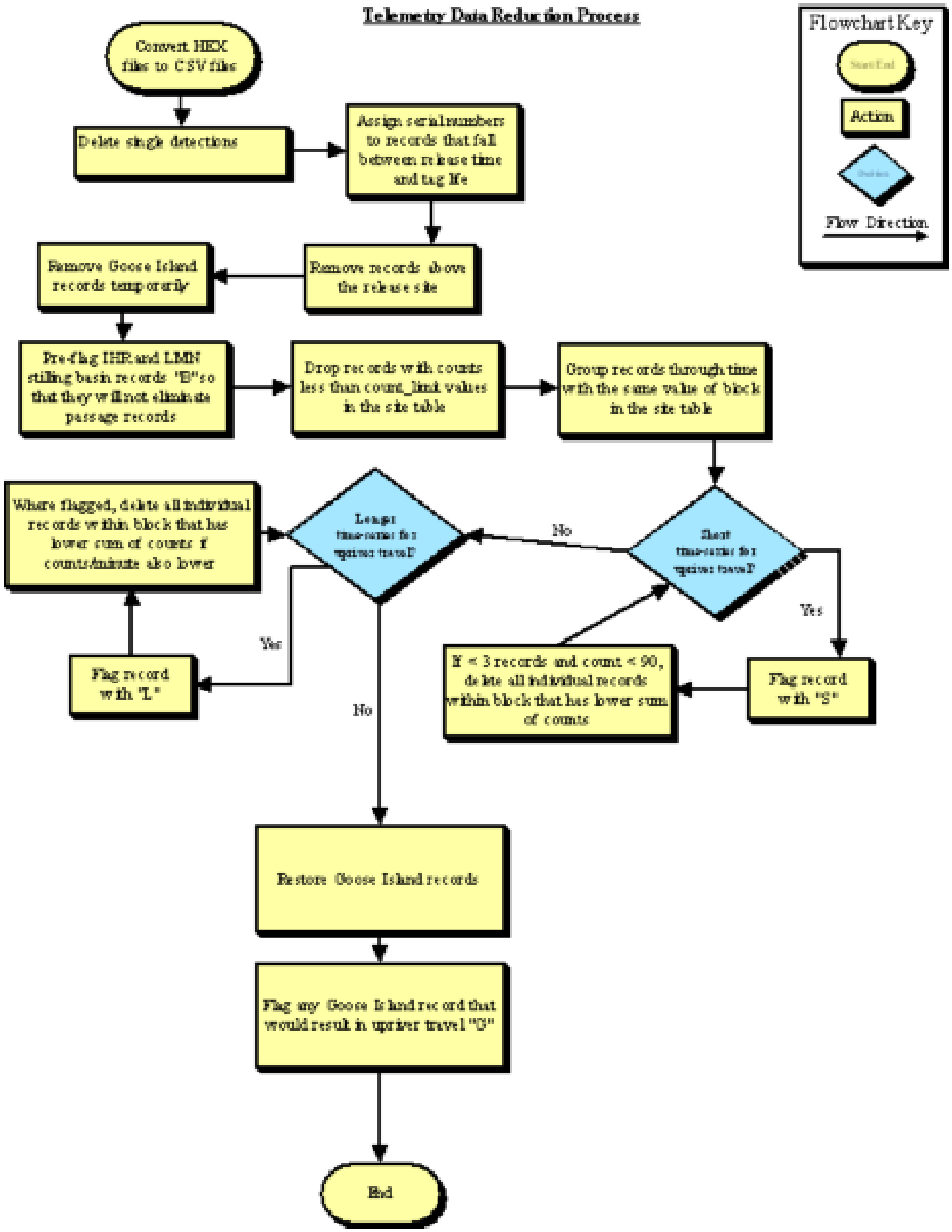
No testing was conducted to evaluate Assumption A4; however, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have been previously evaluated by Adams et al. (1998a,b) and Hockersmith et al. (2003). For Assumption A5, we released dead radio-tagged fish concurrently with live fish into the tailrace of the dam, and these fish were not detected on the Sacajawea Park detection array. Also, Axel et al. (2003) reported that dead radio-tagged fish released into the bypass systems at Ice Harbor Dam were not subsequently detected at telemetry transects more than 3.2 km downstream. The distance between our releases in the Ice Harbor Dam tailrace and the first downstream array used to estimate survival (Sacajawea Park) was much longer, at approximately 14 km.

For assumption A6, all transmitters were checked upon receipt from the manufacturer, prior to implantation in fish and prior to release, to ensure that the transmitter was functioning properly. Tags not functioning properly were not used in the study. In addition, 54 radio transmitters were tested for tag life prior to the study by allowing them to run while recording detections until each tag expired. None of the tags tested for tag life failed prior to the end of the programmed shut-down period of 11 d.

Appendix Table A2. Passage distribution at Sacajawea Park by test block for treatment (T) and reference (R) groups of radio-tagged hatchery yearling Chinook salmon released used for estimating relative dam and spillway survival at Ice Harbor Dam, 2004.

Detection	B03		B04		B05		B06		B07		F01		F02		F03		F04		F05		F06		F07	
date	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R
04 May											24	21												
05 May											46													
06 May											1													
07 May													46	51										
08 May													62	68										
09 May	80	51											23	2										
10 May	99	36																						
11 May	44	6													26	25								
12 May	1														92	52								
13 May			91	50											30	10								
14 May			97	60											1									
15 May			29	12													47	47						
16 May			1													1	70	57						
17 May					94	44											25	9						
18 May					58	43																		
19 May			1		16	21													22	54				
20 May					2	1											1		114	55				
21 May							98	54											39	8				
22 May							109	74																
23 May							41	6													53	55		
24 May																					87	53		
25 May							1		67	63											45	8		
26 May									91	58											1			
27 May									32	5													75	59
28 May									2														59	5
29 May																							14	

APPENDIX B:


Telemetry Data Reduction Process
Flowchart Key
Action
Flow Direction
Convert HEX files to CSV files
Delete single detections
Assign serial numbers to records that fall between release time and tag life
Remove records above the release site
Remove Goose Island records temporarily
Pre-flag IHR and LMN stilling basin records "B" so that they will not eliminate passage records
Drop records with counts less than count_limit values in the site table
Group records through time with the same value of block in the site table
Where flagged, delete all individual records within block that has lower sum of counts if counts/minute also lower
No
Yes
Flag record with "L"
No
If < 3 records and count < 90, delete all individual records within block that has lower sum of counts
Yes
Flag record with "S"
Restore Goose Island records
Flag any Goose Island record that would result in upriver travel "G"
End