Partitioning reach survival for steelhead between Lower Monumental and McNary Dams, 2004

Fish Ecology Division

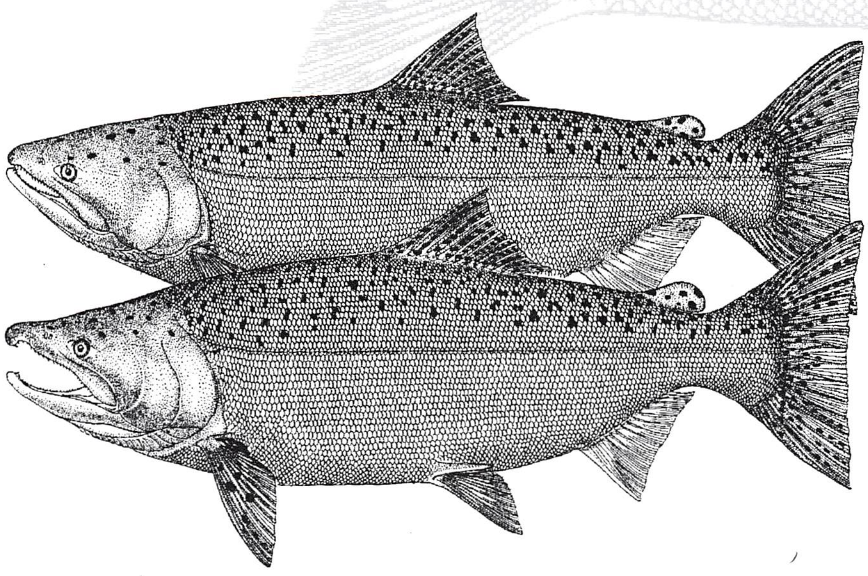
Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
Gordon A. Axel, Darren A. Ogden,
Eric E. Hockersmith, M. Brad Eppard,
and Benjamin P. Sandford,

September 2005



Partitioning Reach Survival for Steelhead between Lower Monumental and McNary Dams, 2004

Gordon A. Axel, Darren A. Ogden, Eric E. Hockersmith, M. Brad Eppard, and Benjamin P. Sandford

Report of research by

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
U.S. Army Corps of Engineers
201 North 3rd
Walla Walla, WA 99363-1876
Contract W68SBV92844866

May 2005

EXECUTIVE SUMMARY

In 2004, NOAA Fisheries Service determined reach survival estimates for juvenile steelhead *Oncorhynchus mykiss* between Lower Monumental Dam and McNary Dam in order to ascertain areas of loss more accurately. Fish were collected, PIT tagged, and surgically tagged with a radio transmitter at Lower Monumental Dam. We released 921 and 935 radio-tagged fish in the tailraces of Lower Monumental and Ice Harbor Dam on the lower Snake River, respectively. Releases occurred during day and night operations for 20 days from 7 to 27 May.

We estimated pool survival between the tailrace of Lower Monumental Dam and the forebay of Ice Harbor Dam and partitioned the Ice Harbor-McNary reach into three smaller reaches. Ice Harbor pool survival was 0.841 (95% CI, 0.817–0.865). Pooled survival estimates for the three smaller reaches were as follows: 0.944 (95% CI, 0.932-0.956) from the tailrace of Ice Harbor Dam to the mouth of the Snake River; 0.760 (95% CI, 0.736-0.784) from the mouth of the Snake River to Port Kelley; and 0.840 (95% CI, 0.814-0.866) from Port Kelley to the forebay of McNary Dam. At Ice Harbor Dam, relative dam survival was 0.870 (95% CI, 0.838–0.902).

Project operations at Ice Harbor Dam consisted of 2-day blocks alternating between bulk spill and flat spill. Spillway passage survival was 0.977 (95% CI, 0.948-1.007) under bulk spill operations and 0.977 (95% CI, 0.926-1.028) during flat spill. Insufficient numbers of tagged fish passed through the powerhouse to enable us to estimate survival through turbines or the juvenile bypass system.

Median forebay residence time for juvenile steelhead passing Ice Harbor Dam was nearly twice as long for radio-tagged fish approaching during flat spill operations (3.1 hours) as it was for those approaching during bulk spill (1.8 hours). Mean spill discharge was nearly twice as high during bulk spill as it was during flat spill. Overall passage distribution for radio-tagged Snake River juvenile steelhead through spillway, bypass, and turbine routes at Ice Harbor Dam was 88.1, 8.6, and 0.4%, respectively, with 2.9% of the fish having undetermined passage routes.

During bulk spill treatments, 99% (348) of the fish passed via the spillway with the other 1% (5) going through the bypass system. For the periods of flat spill, 82% (240) of the fish passed via the spillway, 17% (50) through the bypass system, and 1% (2) through the turbines. Fish passage efficiency (FPE) during bulk spill was 100 and 99% during flat spill. Fish guidance efficiency (FGE) was 100% during bulk spill and 96% during flat spill. Spill efficiency was 99% under bulk spill operations and 82% during flat spill. Mean spill effectiveness was 1.00:1 for bulk spill and 1.08:1 during flat spill.

CONTENTS

INTRODUCTION

The Columbia and Snake River Basins historically produced some of the largest runs of salmon *Oncorhynchus* spp. and steelhead *O. mykiss* in the world (Netboy 1980). More recently, however, some stocks have decreased to levels warranting listing under the U. S. Endangered Species Act of 1973 (NMFS 1991, 1992, 1998, 1999). Human activities contributing 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 hydroelectric projects and their reservoirs. Recent survival studies on juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that, among the different passage routes, 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).

Since the listing of Columbia River Basin salmonid stocks under the Endangered Species Act, juvenile salmonid passage behavior evaluations and project and/or route-specific survival estimates at Lower Monumental, Ice Harbor, and McNary Dams (Figure 1) have been conducted primarily with Chinook salmon. However, it is also essential that regional managers have passage information and survival estimates for juvenile steelhead in order to make decisions in the best interests of this species.

As part of a Bonneville Power Administration (BPA) funded study, the National Marine Fisheries Service (NMFS) has provided annual survival estimates from the Lower Monumental Dam tailrace to the McNary Dam tailrace (two reservoirs and two dams) for river-run PIT-tagged juvenile salmonids migrating through the Lower Snake and Columbia River hydropower system. Per-project survival for steelhead has been substantially lower in the Lower Monumental Dam to McNary Dam reach (two projects) than in the Lower Granite Dam to Little Goose Dam reach and the Little Goose Dam to Lower Monumental Dam reach (Zabel et al. 2002).

However, because Ice Harbor Dam does not have PIT-tag detection capability, this study has not been able to partition survival between Lower Monumental and McNary Dams (Muir et al. 2001). Since the behavior and life history of juvenile steelhead are different and in some ways more complex than Chinook salmon, we proposed a pilot study to determine travel times, passage behavior, radiotelemetry detection probabilities, and partition survival between Lower Monumental and McNary

Dams for juvenile steelhead. This information will assist in designing more comprehensive studies to evaluate behavior and survival in future years and will help inform management on strategies to optimize survival for juvenile steelhead between Lower Monumental and McNary Dams.

METHODS

Study Area

The study area included the 119-km reach of the Snake and Columbia Rivers from Lower Monumental Dam, located at river kilometer 589 on the lower Snake River, to McNary Dam on the lower Columbia River (Figure 1). McNary Dam, the fourth dam on the Columbia River, is located at river kilometer 470.

Fish Collection, Tagging, and Release

River-run steelhead were collected at the Lower Monumental Dam smolt collection facility from 05 to 25 May. We chose fish that did not have any gross injury or deformity, that were at least 140 mm in length, and 20 g in weight. Only those fish that were 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. Following collection and sorting, fish were maintained via flow-through river water and held for 24 hours prior to radio transmitter implantation.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a user defined tag life of 10 days, and were pulse-coded for unique identification of individual fish at 30 MHz. Each radio tag measured 16 mm in length by 6 mm in diameter and weighed 1.3 g in air.

Fish were surgically tagged with radio transmitters using techniques described by Adams et al. (1998). Each fish also received a PIT tag before the incision was closed in order to monitor radio-tag performance. Immediately following tagging, fish were placed into a 19-L recovery container (2 fish per container) with aeration until recovery from the anesthesia. Recovery containers were then 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

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

tagging and holding, and were aerated with oxygen during transportation to release locations. After tagging, fish were held a minimum of 24 hours with flow-through water for recovery and determination of post-tagging mortality.

After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas (Lower Monumental Dam and Ice Harbor Dam tailraces). Release groups were transferred from holding tanks to a release tank mounted on an 8.5 × 2.4-m barge, transported to the release location, and released mid-channel water-to-water, 2 fish every 15 minutes in order to spread out the fish over a period of 8 to 10 hours.

Daytime releases occurred between 0920 and 1400 hours PDT. Nighttime releases were made between 1710 and 2250 hours PDT. We released twenty groups of approximately 20-25 fish. A total of 921 radio-tagged fish were released into the tailrace of Lower Monumental Dam. A total of 935 radio-tagged fish were released into the tailrace of Ice Harbor Dam.

Survival Estimates

Estimates of pooled survival from the tailrace of Lower Monumental Dam to the forebay of Ice Harbor Dam were made based on detection histories using the single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965). Survival estimates for the model use recapture records (in this case, detections) of single release groups. These estimates consider the probability that a tagged fish may pass the downstream boundary of the area in question without being detected. Thus, in order to separate the probability of detection from that of survival, the model requires detections of at least some fish downstream from the area of interest.

For this purpose, we used data from detections at Goose Island, located 2 km below Ice Harbor Dam, for survival estimates through the pool. We also used the SR model to estimate reach survival between Ice Harbor and McNary Dam using telemetry transects located at Sacajawea State Park (mouth of the Snake River), Port Kelley, the forebay of McNary Dam, and at Irrigon, OR. Previous studies indicated that dead, radio-tagged fish released at Ice Harbor Dam and also in the bypass system at McNary Dam are not detected at the downstream survival transects (Axel et al. 2003); therefore, we could safely assume that fish detected at each transect did not die as a result of passage at Ice Harbor or McNary Dam.

For estimates of dam survival through Ice Harbor Dam, we created "release groups" based on day of detection at the telemetry transect on the upstream edge of the Ice Harbor Dam Boat Restricted Zone. These release groups were then paired with reference groups released in the tailrace of Ice Harbor Dam. The ratio of these pooled survival estimates provide the dam survival estimate. Relative spillway survival was estimated for fish that were last seen on a spillway receiver and subsequently seen on a stilling basin receiver, thus validating the spill passage assumption. The fish were regrouped by spill treatment and paired with reference fish released during that particular spill treatment group. For both dam and spill survival, subsequent downstream detections at Sacajawea State Park and below were used for survival estimation (Figure 1).

Since radio-tagged fish were also tagged with a PIT tag, detections at the juvenile collection/detection facilities (Prentice 1990a, b) at McNary, John Day, and Bonneville Dams and with the PIT-trawl towed-array in the Columbia River estuary were also used for survival estimates.

Key assumptions underlying the SR model must be met in order to obtain unbiased estimates of survival through specific reaches or areas. One such assumption is that radiotelemetry detection at a given site does not affect subsequent detection probabilities downstream from that site. Tests of model assumptions are presented in Appendix A. For a more detailed discussion of the SR model and its associated tests of assumption, see Iwamoto et al. (1994), Zabel et al. (2002), and Smith et al. (2003).

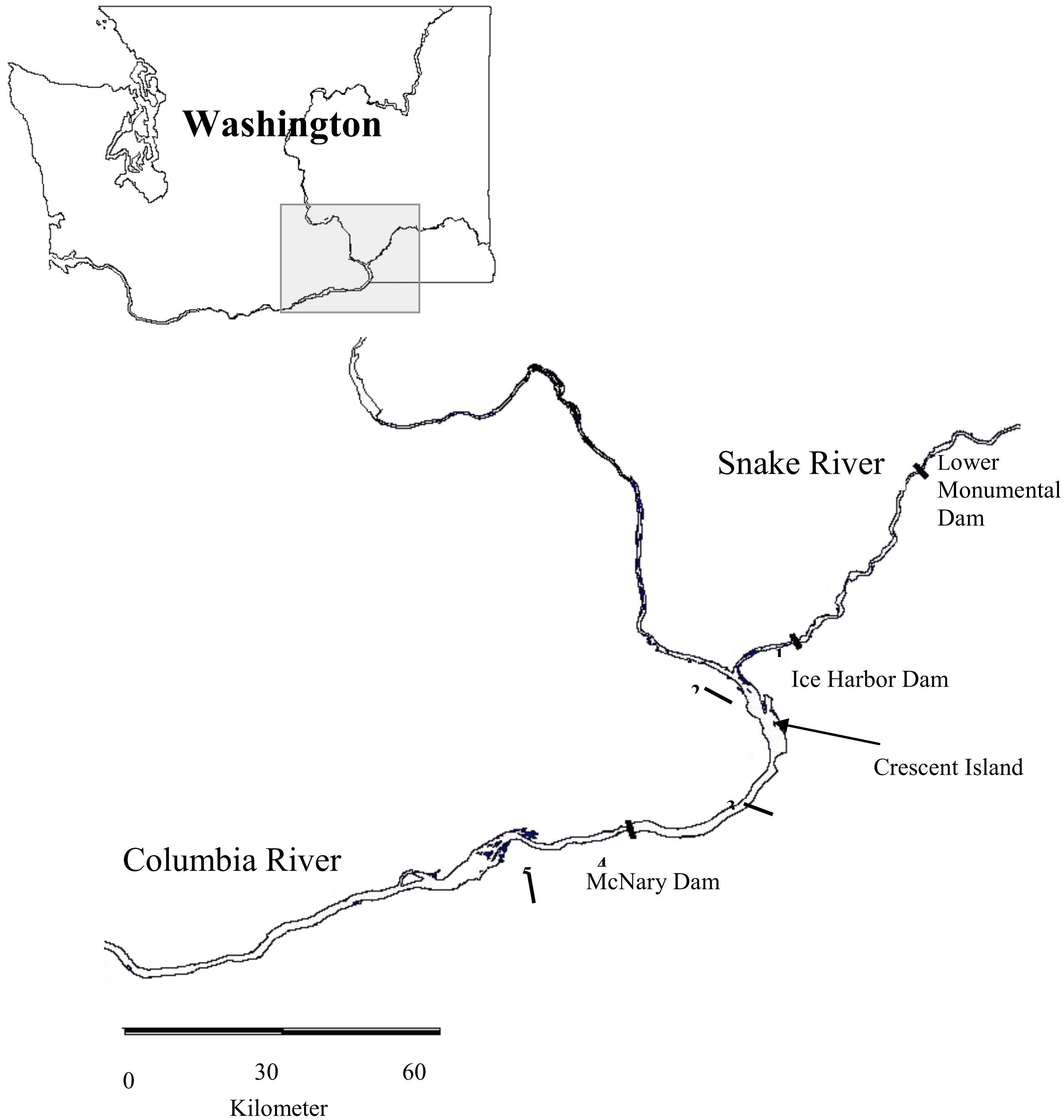


Figure 1. 2004 Study area showing location of radiotelemetry transects used for estimating partitioned reach survival for radio-tagged juvenile steelhead between Lower Monumental and McNary dams (Note: 1 = Ice Harbor Dam forebay; 2 = Sacajawea State Park; 3 = Port Kelley; 4 = McNary Dam forebay; and 5 = Irrigon, OR.)

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

Travel time was measured from the release site to the first detection at the entrance line of the next dam downstream. The first detection on the entrance line at Ice Harbor Dam was also used to determine arrival times at the project. Passage timing was determined by using the last detection in a passage route and only those that had subsequent detection in the stilling basin and immediate tailrace detection areas.

Forebay Residence Time

Forebay residence time at Ice Harbor Dam was measured from the first detection on the forebay entrance line to either the last detection during spillway passage or the first detection moving past a fish guidance screen into a turbine unit or gatewell. We compared forebay residence and tailrace egress times between treatments using paired t-tests on the 50th and 90th percentiles of the temporally-paired replicate groups.

Passage Route Distribution

To determine the route of passage individual fish used at Ice Harbor Dam, we monitored the spillway, standard traveling screens (STS's), and the bypass system. The spillway was monitored by four underwater dipole antennas in each spillbay. Two antennas were installed along each of the two pier noses of each spillbay at depths of 20 and 40 ft. Pre-season range testing showed that this configuration monitors the entire spillbay. We used armored co-axial cable, stripped at the end, to detect fish passage in the turbine unit and bypass system. These antennas were attached on both ends of the downstream side of the fish screen support frame located within each slot of the turbine intake.

We also placed an underwater antenna into the fish separator located upstream from the juvenile bypass system raceways. Fish that were detected on the fish guidance screen telemetry antennas but were not subsequently detected on the PIT-detection system or the telemetry monitor located in the separator were designated turbine passed fish.

Fish Passage Metrics

The standard fish-passage metrics of spill efficiency, spill effectiveness, fish passage efficiency (FPE), and fish guidance efficiency (FGE) were also evaluated at Ice Harbor Dam using radiotelemetry detections in the locations used for passage route evaluation (described above). However, the method of calculating these metrics using radiotelemetry differs from those used in previous evaluations (e.g., FGE was formerly calculated based on the percentage of fish caught in gatewells and fyke nets). Fish-passage metrics used for this evaluation were defined as follows:

Spill efficiency: Total number of fish passing the spillway divided by total number passing the dam

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

Fish passage efficiency: Number of fish passing the dam via non-turbine routes divided by total number passing the dam

Fish guidance efficiency: Number of fish guided into the bypass system divided by total number passing via the powerhouse (Bypass system + turbines)

Tailrace Egress

Tailrace egress was measured from the last known detection through the project (spillway, turbine, or bypass system) to the last known detection at the telemetry transect located approximately 1 km downstream from Ice Harbor Dam. Hypothesis testing to compare specific cohorts was conducted using the same methodology used for forebay residence time (above).

Avian Predation

Predation from the Caspian Tern colony on Crescent Island, located 12.9 km downstream from the Snake River mouth (Figure 1), was measured by physical recovery of tags deposited on the island and PIT-tag detection. Radio tags and PIT tags were recovered on the tern colony at Crescent Island during fall 2004 after the birds left the island. We physically recovered radio transmitters that were visible on the island and used radio-tag serial numbers to identify individual tagged fish. PIT-tag detections and physical recovery of radio transmitters at Crescent Island were provided by NMFS and Real Time Research, Inc. (B. Ryan, NMFS, personal communication; see also Ryan et al. 2001; A. Evans, Real Time Research, Inc., personal communication).

RESULTS

Fish Collection, Tagging, and Release

Unmarked juvenile steelhead were collected, radio tagged and PIT tagged at Lower Monumental Dam for 20 days from 07 May to 27 May. Tagging began after 40% of the juvenile steelhead had passed Lower Monumental Dam and was completed when 73% of these fish had passed (Figure 2). Overall mean fork length was 195 mm and mean weight was 60 g for tagged fish (Table 1). This compared closely with the unclipped run-at-large sampled at the smolt collection facility (193 mm and 63.4 g). Handling and tagging mortality for juvenile steelhead was 0.6%.

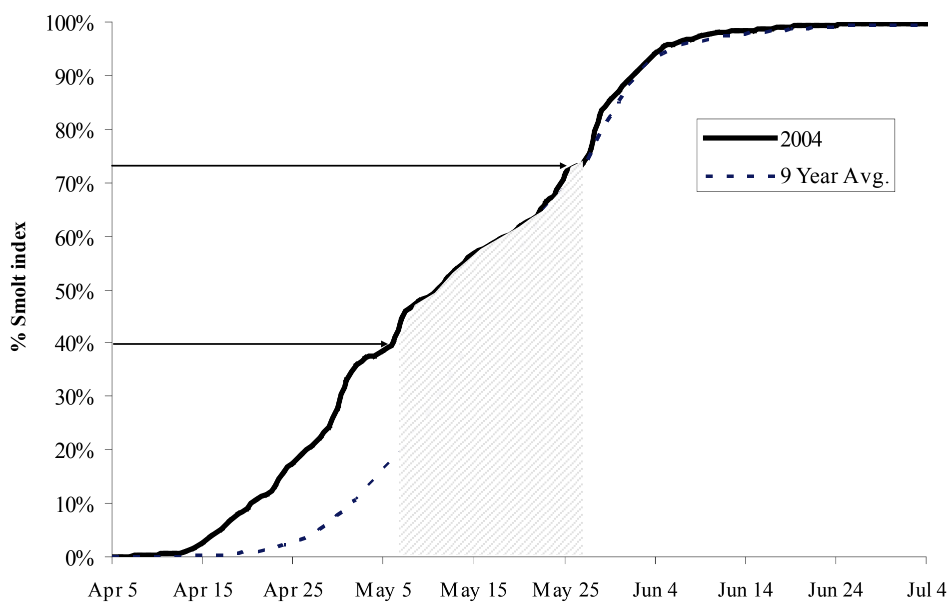


Figure 2. Percentage of juvenile steelhead smolt index estimated at Lower Monumental Dam during 2004. The shaded area depicts the portion of the run targeted for tagging. The 9-year average (1996-2004) is also shown.

Table 1. Mean fork length and weight for radio-tagged juvenile steelhead and the untagged run-at-large.

	Tagged		Run-at-large	
	Wt. (g)	Length (mm)	Wt. (g)	Length (mm)
Min	19.7	140.0	10.9	110.0
Max	180.4	277.0	280.8	365.0
Mean	60.0	195.0	63.4	193.0

Dam Operations

Based on results from the 2003 spillway survival evaluation, the 2004 voluntary spill program followed a 4-day block design with 2 days of spill discharge volume in a "flat" spill pattern described in the 2000 FCRPS Biological Opinion (NMFS 2000) through all 10 spillbays, 24 hours per day, followed by 2 days of spill discharge volume in a "bulk" spill pattern 24 hours per day. Bulk spill patterns typically utilize fewer spillbays and spillway gates for each bay are open at least 5 stops. Mean spill during bulk spill was 70.9 thousand cubic feet per second (kcfs) while flat spill was 44.7 kcfs. Mean spill for each treatment group is displayed in Figure 3. Mean daily total discharge during the study was 87.5 kcfs, ranging from 61.3 to 139.3 kcfs (Figure 4).

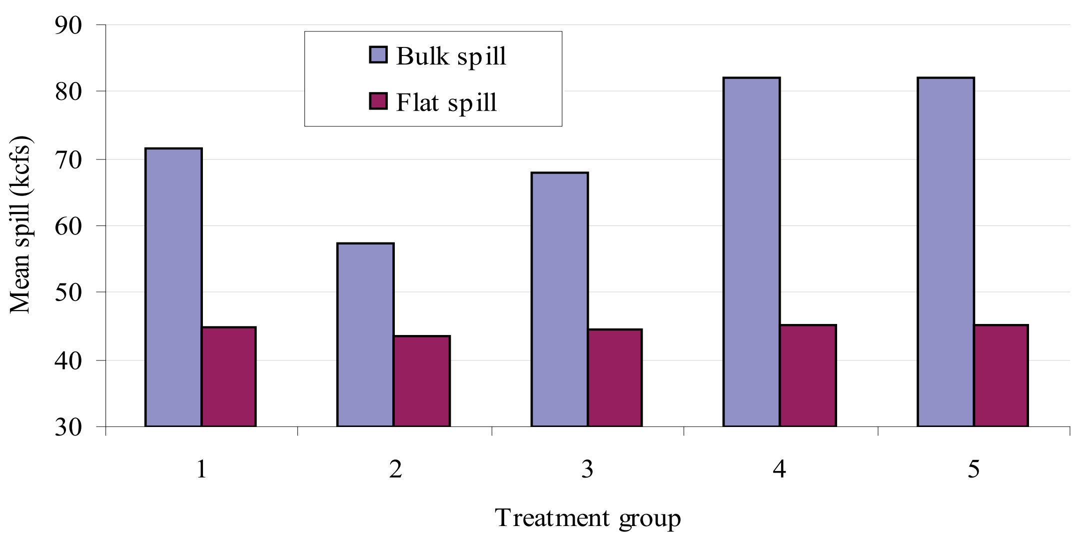


Figure 3. Mean spill (kcfs) for each treatment group for radio-tagged juvenile steelhead arriving at Ice Harbor Dam, 2004.

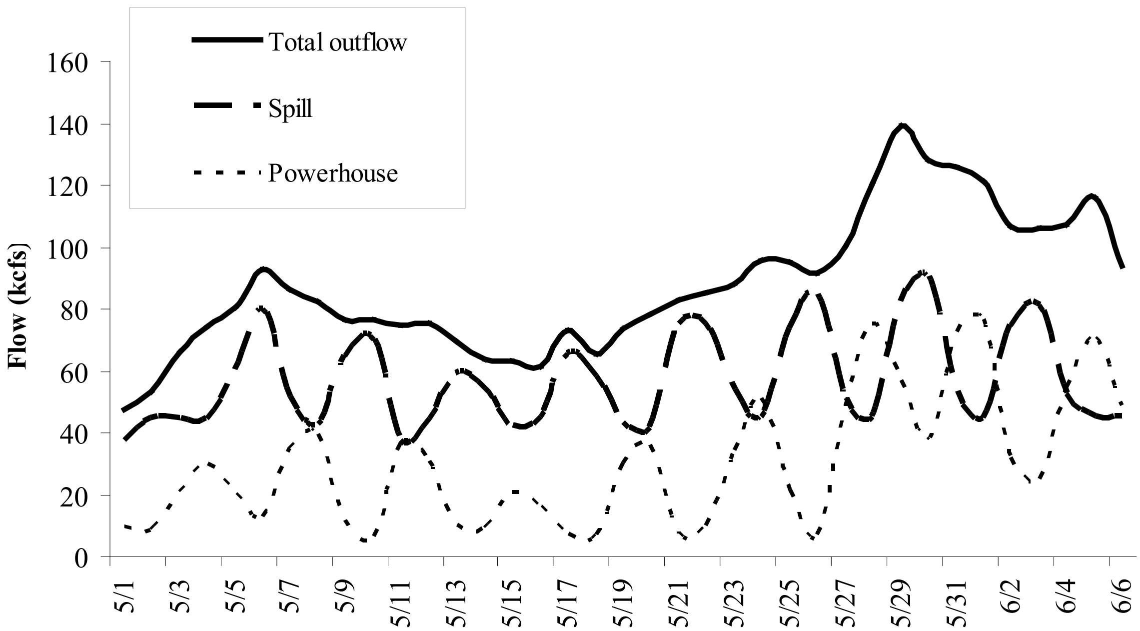


Figure 4. Mean daily project operations (kcfs) for radio-tagged juvenile steelhead arriving at Ice Harbor Dam, 2004.

Survival Estimates

Ice Harbor pool survival was estimated as 0.841 (95% CI, 0.817–0.865). Estimated survival through the partitioned reaches between Ice Harbor and McNary Dams were as follows: 0.944 (95% CI, 0.932-0.956) from the tailrace of Ice Harbor Dam to Sacajawea State Park, 0.760 (95% CI, 0.736-0.784) from Sacajawea to Port Kelley, and 0.840 (95% CI, 0.814-0.866) from Port Kelley to the forebay of McNary Dam.

Estimated dam survival at Ice Harbor Dam was 0.870 (95% CI, 0.838–0.902). Relative spillway survival for bulk spill operations was 0.977 (95% CI, 0.948-1.007) and 0.977 (95% CI, 0.926-1.028) for flat spill. As a result of varying forebay delay and the alternating project operations, regrouping of fish in order to analyze dam survival during the two spill treatments was virtually impossible. Insufficient numbers of fish passed through the powerhouse to enable us to estimate survival through the turbines or the juvenile bypass system.

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

We detected 775 radio-tagged Snake River juvenile steelhead released into the tailrace of Lower Monumental Dam that approached the forebay of Ice Harbor Dam. We detected 469 radio-tagged Snake River juvenile steelhead released into the tailrace of Ice Harbor Dam that approached the forebay of McNary Dam. Travel times and migration rates were calculated for each reach (Table 2 and 3).

Hours of arrival and passage at Ice Harbor Dam were fairly consistent throughout the study. The percentage of fish per hour entering the forebay of Ice Harbor Dam was slightly higher during daylight hours (3.7-7.6%) than during the night (1.8-3.7%) (Figure 5). We observed a slight decline in fish passage from 0300 to 0600 hours and an increase from 2000 to 0100 hours.

Table 2. Travel time and migration rate for radio-tagged juvenile steelhead released in the tailrace of Lower Monumental Dam and detected at the forebay entrance of Ice Harbor Dam, 2004.

			Lower Monumental Dam Travel time (days)				Migration rate (km/day)			
	Released	Detected	Min	Max	Mean	SD	Min	Max	Mean	SD
Day	472	384	0.6	9.4	1.6	0.6	0.2	3.5	1.4	0.4
Night	463	391	0.5	7.2	1.6	0.6	0.3	4.5	1.5	0.4
Total	935	775	0.5	9.4	1.6	0.6	0.2	4.5	1.4	0.4

Table 3. Travel time and migration rate for radio-tagged juvenile steelhead released in the tailrace of Ice Harbor Dam and detected at the forebay entrance of McNary Dam, 2004.

			Ice Harbor Dam Travel time (days)				Migration rate (km/day)			
	Released	Detected	Min	Max	Mean	SD	Min	Max	Mean	SD
Day	465	247	0.4	8.3	1.6	0.7	0.3	7.6	2.0	0.8
Night	456	222	0.4	8.2	1.5	0.6	0.3	7.3	2.1	0.6
Total	921	469	0.4	8.3	1.5	0.6	0.3	7.6	2.0	0.7

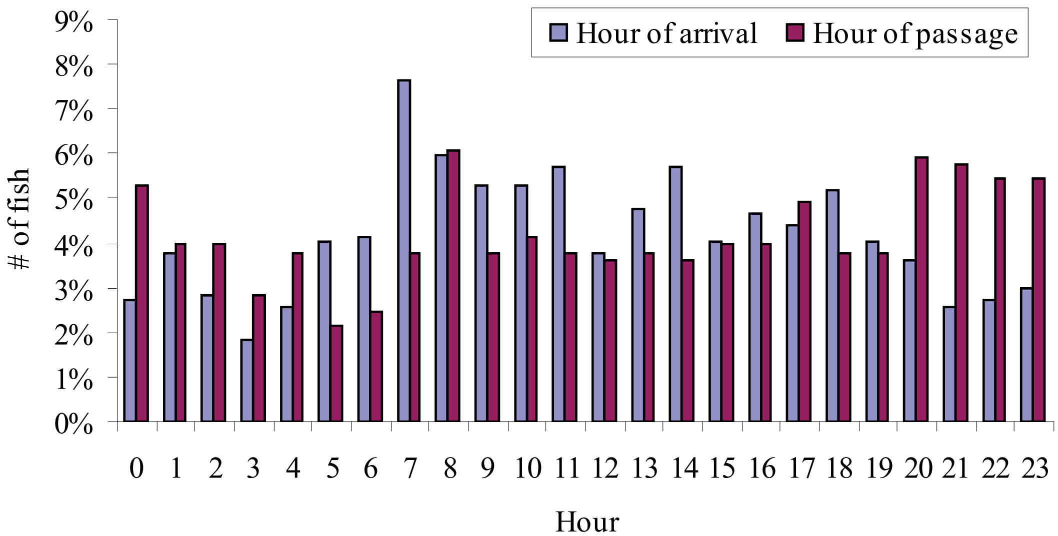


Figure 5. Hour of arrival and passage for radio-tagged juvenile steelhead at Ice Harbor Dam, 2004.

Forebay Residence Time

Median forebay residence time was longer for juvenile steelhead passing during flat spill operations (3.1 hours) versus those that passed during bulk spill (1.8 hours) (Figure 6); however, the difference was not statistically significant ($P = 0.065$) when we compared times between treatments using paired *t*-tests on the 50th percentiles of the temporally-paired replicate groups (Figure 7). The difference between the two treatments becomes highly significant as forebay residence times approach the 90th percentile with fish passing during bulk spill having the lower residence time (P=0.017) (Figure 8).

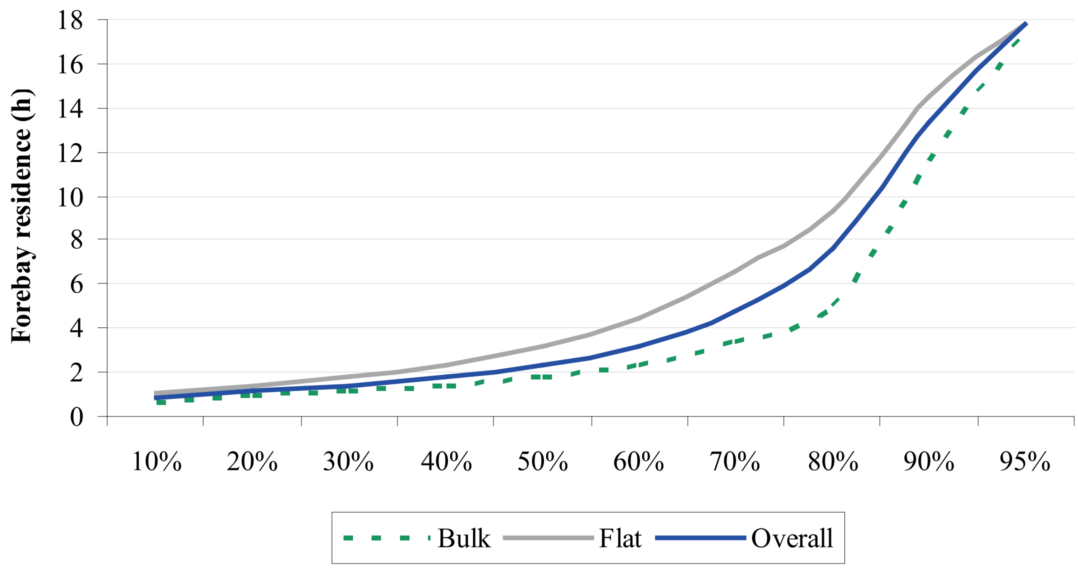


Figure 6. Forebay residence time versus the cumulative percent of radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2004.

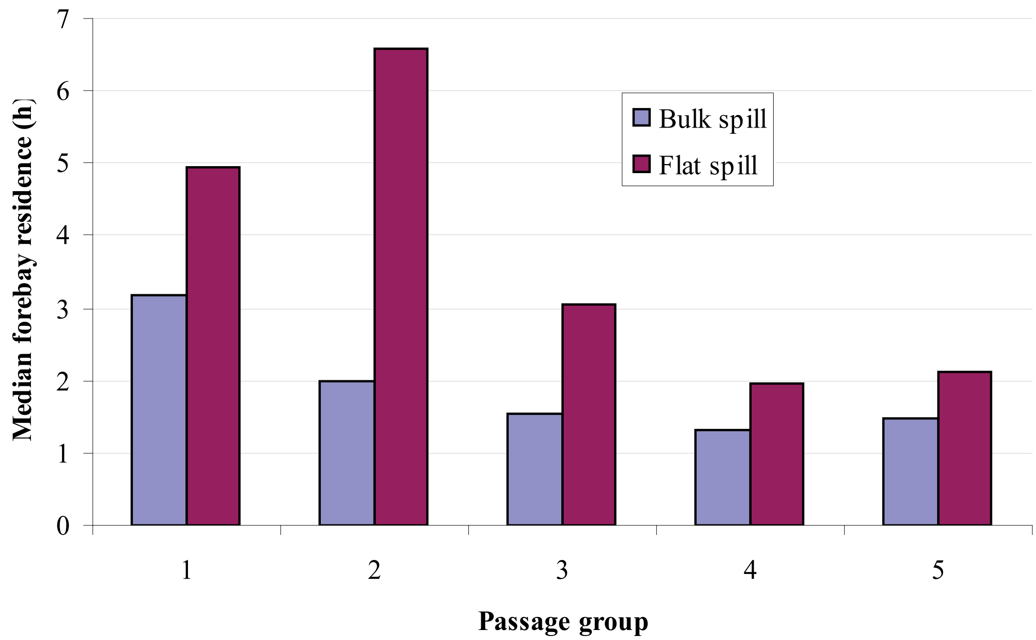


Figure 7. Paired 50th percentiles of forebay residence of radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2004.

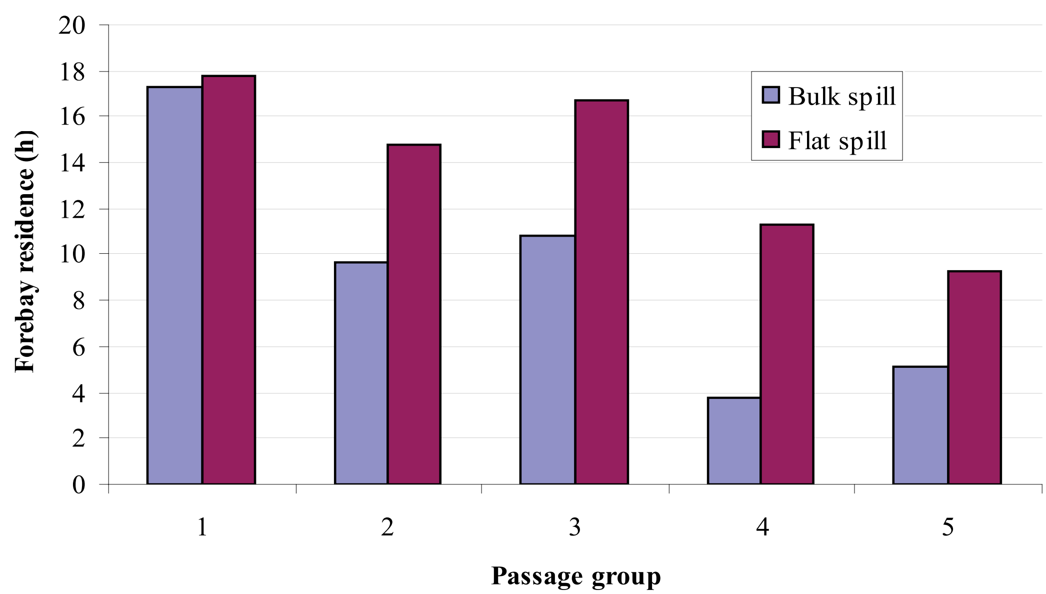


Figure 8. Paired 90th percentiles of forebay residence for radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2004.

Passage Route Distribution

Overall passage distribution for radio-tagged Snake River juvenile steelhead through spillway, bypass, and turbine routes was 88.1, 8.6, and 0.4%, respectively. Approximately 2.9% of the fish passed the project by an unknown route and while an additional 85 fish entered the forebay but did not pass the project. During bulk spill treatments 99% (348) of the fish passed via the spillway with the other 1% (5) going through the bypass system. For the periods of flat spill 82% (240) of the fish passed via the spillway, 17% (50) through the bypass system, and 1% (2) through the turbines. Horizontal spillway distribution during both spill treatments is shown in Figure 9.

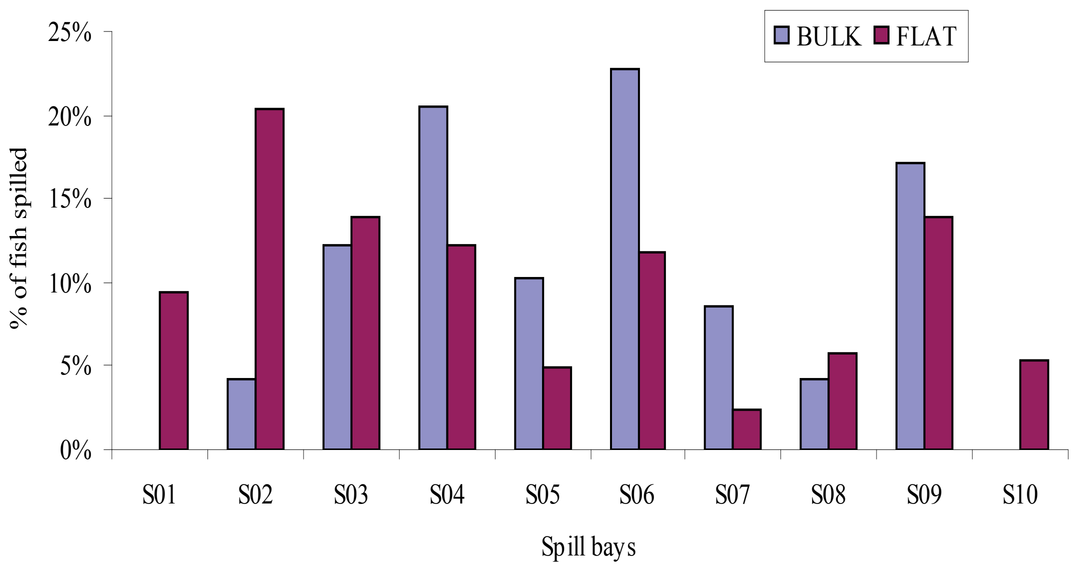


Figure 9. Horizontal spillway passage distribution of radio-tagged juvenile steelhead during both spill treatments at Ice Harbor Dam, 2004.

Fish Passage Metrics

Overall FPE at Ice Harbor Dam was 97%. Overall FGE was 95% (95% CI 90-96%) with a minimum estimate of 72% by factoring in the fish with unknown passage routes as possible turbine passed fish. Overall spill efficiency was 91% (Table 4).

FPE during bulk spill was 100% and 99% during flat spill (Table 5). Fish guidance efficiency (FGE) was 100% during bulk spill and 96% during flat spill. Spill efficiency was 99% under bulk spill operations and 82% during flat spill. Mean spill effectiveness was 1.00:1 for bulk spill and 1.08:1 during flat spill.

Table 4. Passage route distribution and spill efficiency by percent spill for radio-tagged juvenile steelhead at Ice Harbor Dam, 2004.

	Passage route				Spill efficiency
Spill (%)	Spill	Bypass	Turbine	Total	(%)
0.0-0.29	0	1	1	2	0.0
0.3-0.39	44	24	0	68	64.7
0.4-0.49	63	16	0	79	79.7
0.5-0.59	45	9	0	54	83.3
0.6-0.69	44	2	1	47	93.6
0.7-0.79	20	0	1	21	95.2
0.8-0.89	223	5	0	228	97.8
0.9-1.00	169	2	0	171	98.8
Overall	608	59	3	670	90.7
				SE	0.10
				lo CI	0.66
				hi CI	1.15

Table 5. Passage distribution and fish passage metrics for radio-tagged juvenile steelhead passing Ice Harbor Dam during bulk and flat spill treatments, 2004.

			Passage route				Fish passage metrics		
Date	Spill treatment	Mean spill (kcfs)	Spillway	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
May 9-11	Bulk 1	71.7	82	1		83	0.99	1.00	1.00
May 13-15	Bulk 2	57.3	71	1		72	0.99	1.00	1.00
May 17-19	Bulk 3	67.8	90			90	1.00	1.00	N/A
May 21-23	Bulk 4	82.0	60	1		61	0.98	1.00	1.00
May 25-27	Bulk 5	82.2	45	2		47	0.96	1.00	1.00
	Totals		348	5	0	353	0.99	1.00	1.00
May 11-13	Flat 1	44.9	45	10		55	0.82	1.00	1.00
May 15-17	Flat 2	43.6	55		2	57	0.96	0.96	0.00
May 19-21	Flat 3	44.5	31	4		35	0.89	1.00	1.00
May 23-25	Flat 4	45.0	60	9		69	0.87	1.00	1.00
May 27-29	Flat 5	45.3	49	27		76	0.64	1.00	1.00
	Totals		240	50	2	292	0.82	0.99	0.96

Tailrace Egress

Median tailrace egress was longer for juvenile steelhead passing during flat spill operations (4.4 min) versus those that passed during bulk spill (3.0 min; Figure 10). This difference was found to be highly significant ($P = 0.003$) when we compared times between treatments using paired *t*-tests on the 50th percentiles of the temporally-paired replicate groups (Figure 11). The difference between the two treatments becomes less statistically significant as forebay residence times approach the 90th percentile ($P = 0.294$).

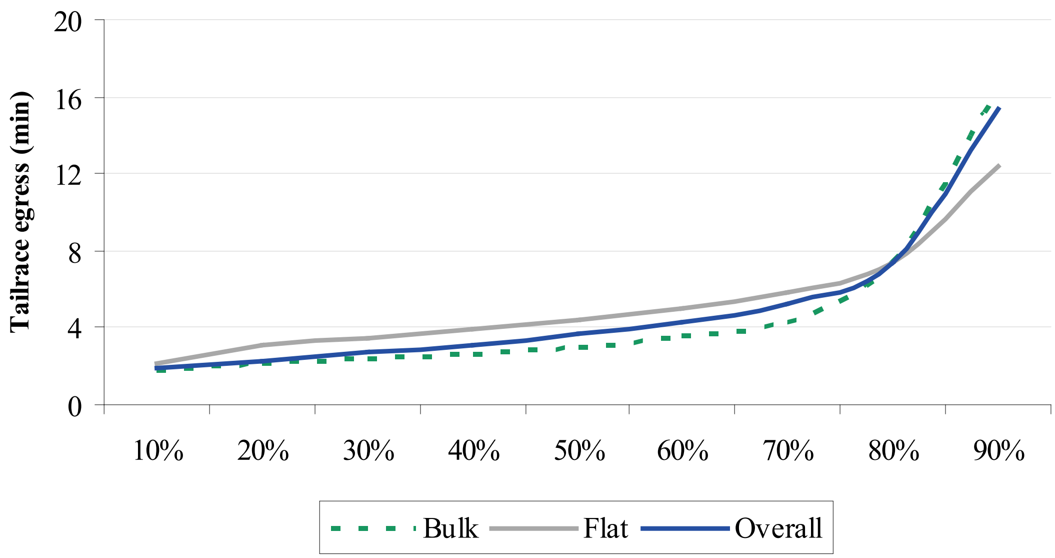


Figure 10. Tailrace egress of radio-tagged juvenile steelhead during two different spill treatments at Ice Harbor Dam, 2004.

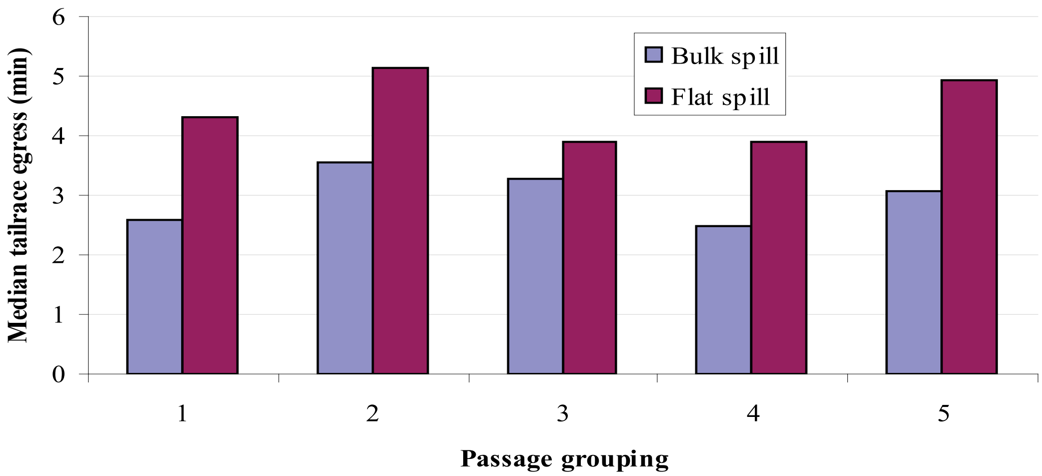


Figure 11. Paired 50th percentile of tailrace egress of radio-tagged juvenile steelhead at Ice Harbor Dam under two different spill treatments, 2004.

Avian Predation

After the Crescent Island Caspian Tern colony had left the island for the season, we initiated a recovery effort for radio tags that were deposited on the island. We recovered tags by means of physical recovery and PIT-tag detection. There is an ongoing monitoring effort to recover PIT tags from the active Caspian Tern colonies in the region conducted by NOAA Fisheries Service and by the Columbia Bird Research group. In total, 318 mortalities were recorded within the tern colony representing approximately 17% of the fish we released into the Snake River. Tern predation accounted for 20% of the fish we released into the tailrace of Lower Monumental Dam and 14% of the fish that were released into the tailrace of Ice Harbor Dam (Figure 12).

Queries on the PTAGIS database yielded a total of 23,316 juvenile steelhead which were detected by PIT tags at Lower Monumental Dam and returned back to the river rather than transported. Subsequent PIT-tag detection on Crescent Island showed that 4,190 of these fish were found on the tern colony representing 18% of the population. During a similar low flow year (2001), tern predation accounted for approximately 21% of the PIT-tagged juvenile steelhead returned to the river at Lower Monumental Dam (3,210 out of 15,242). Both years exhibited similar turbidity measurements where Caspian Terns could take advantage of increased water clarity (Figure 13).

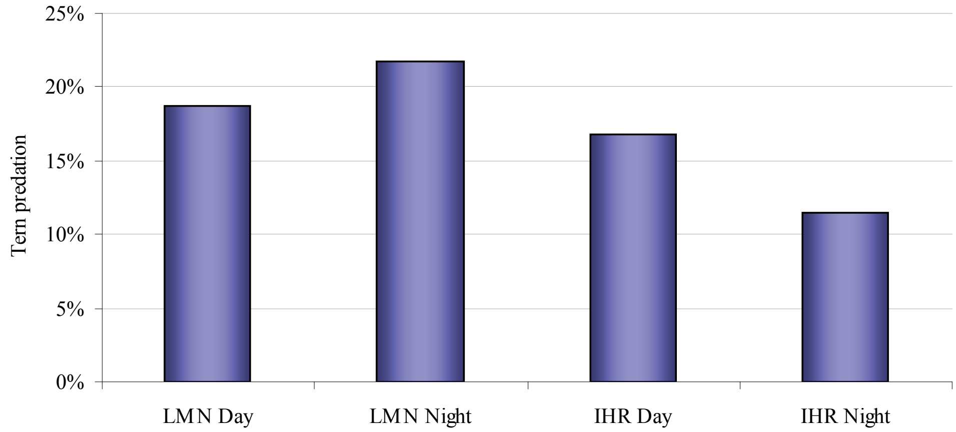


Figure 12. Percent of mortality attributed to tern predation of radio-tagged juvenile steelhead released into the tailraces of Lower Monumental and Ice Harbor Dams during both day and night, 2004.

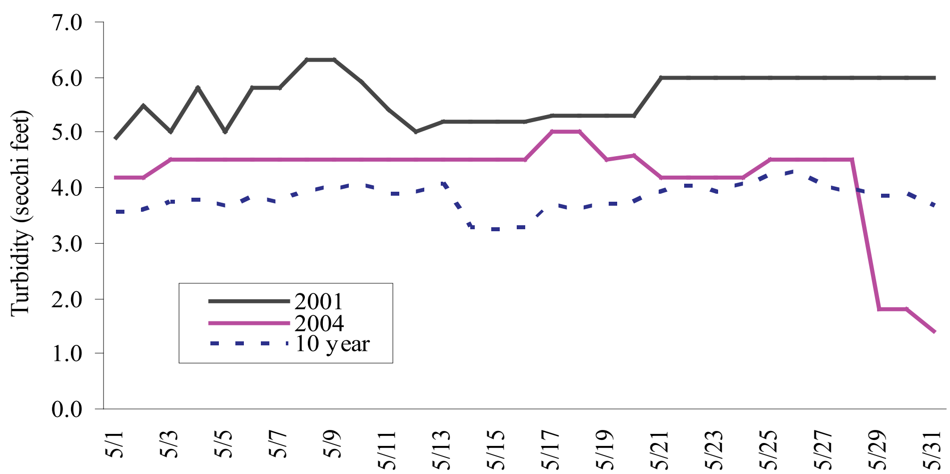


Figure 13. Turbidity in the forebay of Ice Harbor Dam during 2001 and 2004 and the 10-year average (measured by secchi disk readings).

DISCUSSION

During the planning phase of the study, we expected to collect and tag unclipped juvenile steelhead between the period that approximately 20-75% had passed the project based on the 9-year average observed at Lower Monumental Dam. As a result of low flows and the regional managers's decision to collect and transport the majority of fish, we began tagging after 40% of the steelhead run had passed the project. However, we were still able to tag approximately the middle third of the run and the sizes of those tagged were consistent with the run-at-large, thus providing estimates that were reasonably representative of the unmarked juvenile steelhead outmigrants.

One goal of this study was to spread out our releases of radio-tagged fish in order to have equal numbers of fish passing Ice Harbor Dam throughout any given 24-hour period. The percentage of fish entering the forebay of Ice Harbor Dam was slightly higher during daylight hours. The hour of passage at Ice Harbor Dam was fairly consistent during the study. There was a slight decline in fish passage in the predawn hours and an increase at night which most likely was a result of changing operations at the project.

The variation of spill treatment blocks did have a small effect on passage distribution and fish passage metrics at Ice Harbor Dam. Spill efficiency decreased during lower spill discharges experienced during the flat spill. A better test would have been to operate the project alternating bulk and flat spill patterns with similar spill discharges for each pattern. Previous studies have shown that the majority of juvenile yearling chinook salmon typically pass through the spillway with relatively few entering either powerhouse route (Eppard et al. 2000). There was a tendency for forebay residence times to decrease with bulk spill operations. This is most likely attributable to increased flow through the spillway. Tailrace egress was longer for fish passed during flat spill operations and proved to be statistically significant for the 50th percentile of fish, although the difference is measured in a couple of minutes and probably is not biologically significant.

Survival estimates indicate that a large portion of the mortality associated with migrating juvenile steelhead appears to occur prior to passage at Ice Harbor Dam and between the mouth of the Snake River and Port Kelley. We can effectively attribute 17% of our total mortality to the Caspian Tern colony on Crescent Island. Steelhead are particularly susceptible to predation by birds; Collis et al. (2001) found that greater than 15% of the PIT-tagged steelhead entering the Columbia River estuary in 1998 were later found on Rice Island, which at the time was the home of the largest Caspian Tern colony in western North America. Crescent Island harbors the second largest Caspian Tern colony in western North America and large populations of gulls while nearby islands support burgeoning populations of cormorants and pelicans. About 530 breeding pairs attempted to nest at the Crescent Island tern colony in 2004, approximately 9% fewer pairs than in 2003. Based on preliminary estimates, nesting success at the Crescent Island tern colony was fair this year (0.62 fledglings raised per breeding pair), although slightly higher than productivity at this colony last year (Collis et al. 2004). The last detection of radio-tagged fish subsequently found on Crescent Island indicated that, at a minimum, terns foraged from the tailrace of Lower Monumental Dam to Irrigon, OR, a distance of nearly 130 km.

The high percentage of fish transported in 2001 and 2004 had another important consequence: the overall abundance of Snake River juvenile salmonids below Lower Monumental Dam likely was exceptionally low compared to previous years, and the majority of these fish were PIT-tagged fish that were diverted back into the river. Only a small percentage of unmarked Snake River fish were subjected to the poor migratory conditions faced by migrants passing downstream though the hydropower system. This may have influenced predator/prey dynamics for the tagged fish and had a large influence on their survival. Extended travel times due to lower flows may have contributed to poor survival of juvenile salmonids by increasing their exposure time to predators and by extending their residence in reservoirs to periods with higher temperatures when predators were more active (Vigg and Burley 1991).

RECOMMENDATIONS

We recommend a continued effort to evaluate juvenile steelhead survival in the lower Snake River in order to identify areas of mortality. With the addition of a removable spillway weir at Ice Harbor Dam in 2005, we need to evaluate passage survival and the associated effects on juvenile steelhead behavior. It is also becoming apparent that the Crescent Island Caspian Tern colony is targeting juvenile steelhead at a much higher rate than other salmonids. We need to continue monitoring tern predation and consider alternatives to improve steelhead migration through the McNary pool.

ACKNOWLEDGMENTS

We express our appreciation to all who assisted with this research. We thank the U. S. Army Corps of Engineers who funded this research, and we particularly thank William Spurgeon (Lower Monumental Dam Project Biologist), Mark Plummer (Ice Harbor Dam Project Biologist), Brad Eby (McNary Dam Project Biologist), and Mark Smith, Marvin Shutters, and Rebecca Kalamasz (Walla Walla Environmental Analysis Branch) for their help coordinating research activities at Lower Monumental and Ice Harbor Dams, and the Ice Harbor Dam operators for their time and patience during fish releases. Monty Price and the staff of the Washington Department of Fish and Wildlife provided valuable assistance with collecting and sorting study fish. Carter Stein and staff of the Pacific States Marine Fisheries Commission provided valuable assistance in data acquisition.

For their ideas, assistance, encouragement and guidance, we also thank Thomas Ruehle, Scott Davidson, Ronald Marr, Byron Iverson, Tracy Eck, Mark Kaminski, Jeffrey Moser, Galen Wolf, and Douglas Dey, of the Fish Ecology Division, Northwest Fisheries Science Center, NOAA Fisheries Service.

REFERENCES

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998a. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile chinook salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences 55:781-787.

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998b. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile chinook salmon. Transactions of American Fisheries Society 127:128-136.

Axel, G. A., E. E. Hockersmith, M. B. Eppard, B. P. Sandford, S. G. Smith, and D. B. Dey. 2003. Passage and survival of hatchery yearling chinook salmon passing Ice Harbor and McNary Dams during a low flow year, 2001.

Report to U.S. Army Corps of Engineers, Contract W68SBV92844866, 37 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

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

Collis, K., D. D. Roby, and D. E. Lyonns. 2004. Caspian tern research on the lower Columbia River: final 2004 summary. Available at www.columbiabirdresearch.org (accessed 28 December 2004).

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

Eppard, M. B., G. A. Axel, and B. P. Sandford. 2000. Effects of spill on passage of hatchery yearling chinook salmon through Ice Harbor Dam, 1999. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Hockersmith, E.E., W.D. Muir, S.G. Smith, B.P. Sandford, N. S. Adams, J. M. Plumb, R.W. Perry, and D.W. Rondorf. 1999. Comparative performance of sham radio-tagged and PIT-tagged juvenile salmonids. Annual Report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA, Contract W66QKZ91521282, 25 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

Iwamoto, R. N., W. D. Muir, B. P. Sandford, K. W. McIntyre, D. A. Frost, J. G. Williams, S. G. Smith, and J. R. Skalski. 1994. Survival estimates for the passage of juvenile salmonids through dams and reservoirs. Report to Bonneville Power Administration, Project 93-29, Contract DE-AI79-93BP10891, 140 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

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

Muir, W. D., C. Pasley, P. Ocker, R. Iwamoto, T. Ruehle, and B. P. Sandford. 1995a. Relative survival of juvenile chinook salmon after passage through spillways at Lower Monumental Dam, 1994. Report to U.S. Army Corps of Engineers, Contract E86940101, 28 p. plus appendices. (Available Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, E. E. Hockersmith, S. Achord, R. F. Absolon, P. A. Ocker, B. M. Eppard, T. E. Ruehle, J. G. Williams, R. N. Iwamoto, and J. R. Skalski. 1996. Survival estimates for the passage of yearling chinook salmon and steelhead through Snake River dams and reservoirs, 1995. Report to Bonneville Power Administration, Contract DE-AI79-93BP10891, Project 93-29, and U.S. Army Corps of Engineers, Project E86940119, 150 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, R. N. Iwamoto, D. J. Kamikawa, K. W. McIntyre, E. E. Hockersmith, B. P. Sandford, P. A. Ocker, T. E. Ruehle, J. G. Williams, and J. R. Skalski. 1995b. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1994. Report to Bonneville Power Administration, Contract DE-AI79-93BP10891, Project 93-29, and U.S. Army Corps of Engineers, Project E86940119, 187 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, K. W. McIntyre, and B. P. Sandford. 1998. Project survival of juvenile salmonids passing through the bypass system, turbines, and spillways with and without flow deflectors at Little Goose Dam, 1997. Report to U.S. Army Corps of Engineers, Contract E86970085, 47 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, J.G. Williams, E. E. Hockersmith, and J. R. Skalski. 2001. Survival estimates for PIT-tagged migrant yearling chinook salmon and steelhead in the lower Snake and lower Columbia Rivers, 1993-1998. N. Am. J. Fish. Manage. 21:269-282.

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

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

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

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

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

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

NMFS (National Marine Fisheries Service). 2000. Federal Columbia River Power System Biological Opinion issued 21 December 2000.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. In N. C. Parker et al. (editors), Fish-marking techniques, p. 317-322. Am. Fish. Soc. Symp. 7.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. In N. C. Parker et al. (editors), Fish-marking techniques, p. 323-334. Am. Fish. Soc. Symp. 7.

Ryan, B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Methods to detect passive integrated transponder tags on piscivorous bird colonies in the Columbia River Basin. North American Journal of Fisheries Management 21:971-975.

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

Smith, S. G., W. D. Muir, E. E. Hockersmith, S. Achord, M. B. Eppard, T. E. Ruehle, J. G, Williams, and J. R. Skalski. 1998. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1996. Report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, Project 93-29, 60 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Smith, S. G., W. D. Muir, R. W. Zabel, D. M. Marsh, R. A. McNatt, J. G. Williams, and J. R. Skalski. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2003. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

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

Zabel, R. W., S. G. Smith, W. D. Muir, D. M. Marsh, J. G. Williams, and J. R. Skalski. 2002. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2001. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon. Project No. 1993-02900, 143 electronic pages, (BPA Report DOE/BP-00004922-1).

APPENDIX A

Assumptions for Survival Estimation

Model Assumptions

We used the single release (SR) model to estimate survival of radio-tagged juvenile steelhead from the tailrace of Lower Monumental Dam to the forebay of Ice Harbor Dam. We also used the SR model to estimate reach survival between Ice Harbor and McNary Dam using telemetry transects located at Sacajawea State Park (mouth of the Snake River), Port Kelley, the forebay of McNary Dam, and Irrigon, OR. Critical assumptions associated with the SR survival model that were evaluated using statistical tests include:

A1. All tagged fish have the same probability of being detected at a detection location.

Biological Assumptions

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

A2. The individuals tagged for the study are a representative sample of the population of interest.

A3. The tag and/or tagging methods do not significantly affect the subsequent behavior or survival of the marked individual.

A4. Fish that die at either a project or passing through a passage route at a project are not subsequently detected at a downstream array which is used to estimate survival for the project or passage route.

A5. The radio transmitters functioned properly and for the predetermined period of time.

Assumption Testing and Validation

Assumption A1

Radiotelemetry detection probabilities at Ice Harbor Dam were 100% with all fish that were seen below Ice Harbor being detected on the forebay entrance receivers.

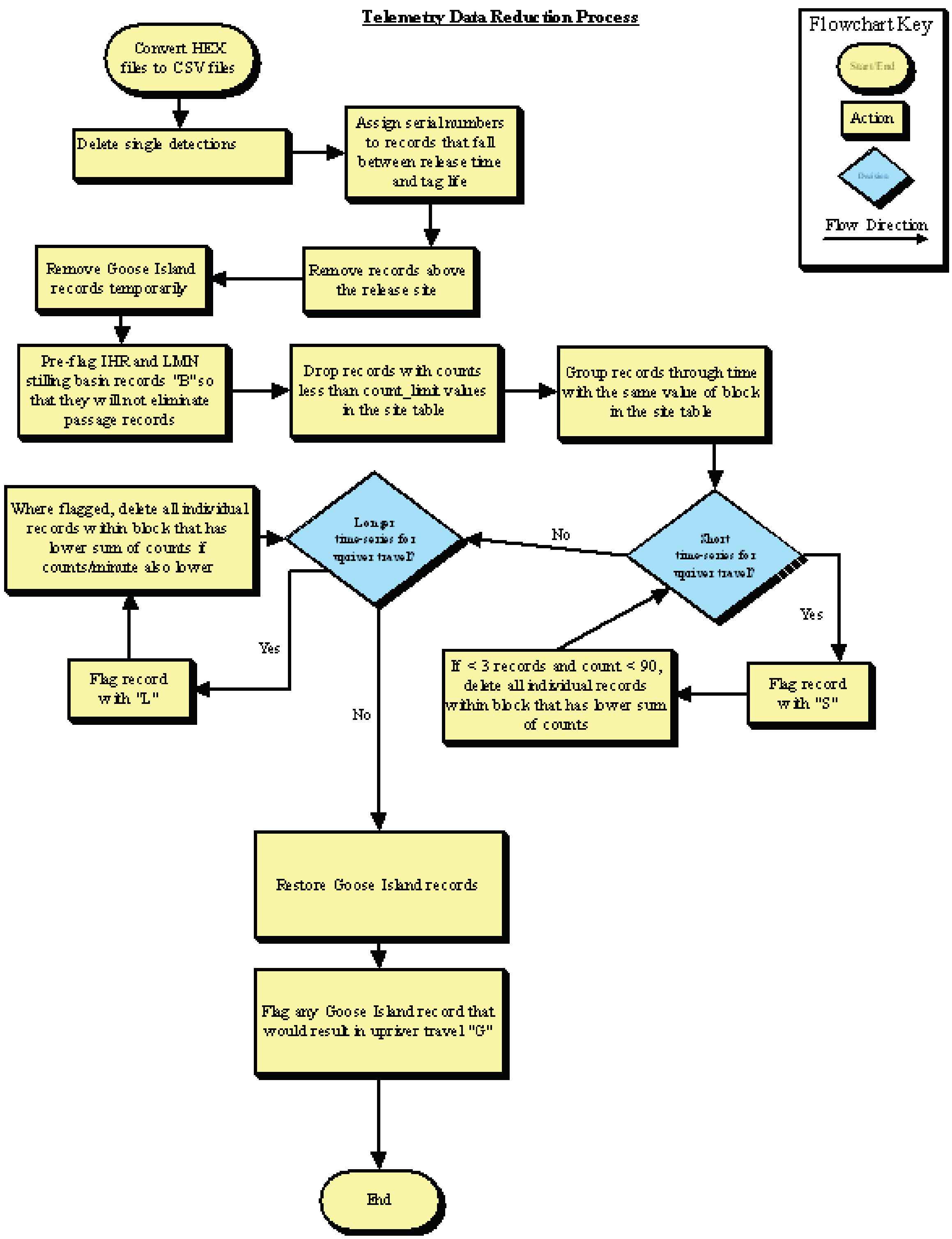
Assumption A2, A3, A4

Assumptions A2, A3, and A4 were not tested for validation in this study. However, previous evaluations have determine the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids (Adams et al. 1998 a, b; Hockersmith et al. 2003). The distance between Ice Harbor Dam and our first downstream detection array which was used for survival estimation (Irrigon) was 16 km. 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 which were more than 3.2 km downstream.

Assumption A5

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish and prior to release to assure that the transmitter was functioning properly. Tags which were not functioning properly were not used in the study. In addition, a portion of the radio transmitters from tagging mortalities throughout the study were tested for tag life by allowing them to run in river water and checked daily to determine if they functioned for the predetermined period of time. None of the tags tested for tag life failed prior to the preprogrammed shut down after 10 days.

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
Short time-series for upriver travel?
No
Yes
Flag record with "S"
If < 3 records and count < 90, delete all individual records within block that has lower sum of counts
Longer time-series for upriver travel?
Yes
Flag record with "L"
Where flagged, delete all individual records within block that has lower sum of counts if counts/minute also lower
No
Restore Goose Island records
Flag any Goose Island record that would result in upriver travel "G"
End