Studies into Factors Limiting the Abundance of Okanagan and Wenatchee Sockeye Salmon

Columbia River Inter-Tribal Fish Commission Technical Report for BPA Project 2008-503-00

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ABSTRACT

A total of 850 sockeye salmon, *Oncorhynchus nerka*, were PIT tagged at Bonneville Dam in 2009. These fish were tracked upstream using detections at detection arrays within fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, Lower Granite, and Tumwater dams as well as in-river arrays in the Wenatchee basin. Upstream survival steadily declined as the migration progressed; Bonneville-Rock Island survival declined from as much as 90% for sockeye salmon passing Bonneville Dam during June to less than 80% during July. There was also a significant linear relationship between decreasing survival and increasing water temperature. The estimated stock composition of sockeye salmon passing Bonneville Dam was 82.6% Okanagan 15.1% Wenatchee, and 2.3% Snake.

The mean travel time of sockeye salmon between Bonneville and Rock Island dams was 12.7 days, indicating a mean travel speed of 38.2 km per day. Fish passing Bonneville Dam later in the migration traveled upstream faster than those earlier in the migration.

In the Okanagan Basin, a PIT tag detection array was installed upstream of Osoyoos Lake and an acoustic receiver network installed to detect VEMCO tags placed in 50 sockeye salmon trapped at Wells Dam. Of these fish, 25 were detected at Zosel Dam and 21 entered the north basin of Osoyoos Lake. High water temperatures and delays at Zosel Dam appeared to be implicated in the demise of the four fish not detected past Zosel Dam.

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INTRODUCTION

Sockeye salmon, *Oncorhynchus nerka,* is one of the species of Pacific salmon native to the Columbia River Basin. Prior to European settlement of the region, it is estimated the Columbia Basin supported an annual sockeye salmon run averaging over three million fish (Northwest Power Planning Council 1986, Fryer 1995). Since the mid-1800's, however, the sockeye salmon run has severely declined, reaching a low of fewer than 9,200 fish in 1995 before rebounding in recent years. The 2008 estimate of 213,607 sockeye at Bonneville Dam was the highest since 1959, with a mean escapement for the most recent four year period (2005-2008) of 87,000 fish (DART 2008, Fish Passage Center 2008).

The Columbia Basin sockeye salmon run was once composed of at least eight principal stocks (Fulton 1970, Fryer 1995). Today, only two major stocks remain (Figure 1); the first originating in the Wenatchee River-Lake Wenatchee

Figure 1. Map of the Columbia Basin showing fishery Zones 1-5 and 6, mainstem dams, and the two major sockeye salmon production areas.

System (Wenatchee stock) and second in the Okanagan[1] River-Osoyoos Lake System (Okanagan stock). A third remnant stock, comprising well under 0.1% of the run, returns to Snake River-Redfish Lake (Snake stock) and is listed under the Endangered Species Act.

The Okanagan sockeye run is the Columbia Basin's sole remaining transboundary salmon stock. The fish spawn in the Canadian portion of the Okanagan River, then rear in Osoyoos Lake, through which runs the border between the United States and Canada. This run has persisted despite one of the longest, most difficult migrations of any salmon stock in the world. The stock migrates 986 km between the spawning grounds and the ocean through one dam and a series of irrigation control structures on the Okanagan River as well as nine mainstem Columbia River dams. The production of this run is believed to be limited by upstream and downstream migration survival as well as habitat factors in the spawning and rearing areas (Fryer 1995; Hyatt and Rankin 1999, Hyatt and Stockwell 2010).

The Wenatchee stock spawns in tributaries to Lake Wenatchee and rears in the lake. This stock migrates 842 km through two Wenatchee River dams and seven mainstem Columbia River dams. Since the spawning grounds and lake are relatively pristine, the production of this run is believed limited by upstream and downstream survival as well as the low productivity of the oligotrophic Lake Wenatchee (Fryer 1995).

This study, funded by the Columbia Basin accords, seeks to expand our knowledge of factors limiting production of Okanagan and Wenatchee sockeye salmon stocks. This study expands upon previous work, funded by the Pacific Salmon Commission from 2006-2008, to examine upstream survival and timing by inserting Passive Integrated Transponder (PIT) tags in sockeye sampled at Bonneville Dam as part of the annual Pacific Salmon Commission (PSC)-funded sockeye stock identification project[2]. PIT tagged fish were detected at several upstream dam fish ladders with detection capability (McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams on the Columbia River, Ice Harbor and Lower Granite dams on the Snake River, and Tumwater Dam on the

[1] The Canadian spelling for Okanagan will be used throughout this document as opposed to the American spelling (Okanogan).
[2] In 2006-2008 we were also funded by the PSC to PIT tag Chinook salmon (Fryer 2007a, 2008a, 2009)

Wenatchee River) as well as at in-stream tributary antennas.

The fact that there are only two significant Columbia Basin sockeye salmon stocks passing through multiple Columbia River dams with PIT tag detection makes the species ideal for a PIT tag study. Determination of migration timing and mortality for other salmon and steelhead species is difficult since most tributaries are without detection facilities meaning that fish can escape undetected. The run timing of the adult Columbia Basin sockeye salmon migration is of particular interest because the migration timing has shifted to earlier in the year over the past 70 years (Fryer 1995, Quinn et al. 1997). A 1997 radio-tagging study also found high mortality of the latter portion of the run (Naughton 2005) as well as no difference in stock-specific migration timing. The radio tag study was conducted in an unusually high flow year that may not be typical of other years. Results of PIT tagging studies in 2006 and 2007 (Fryer 2007c, Fryer 2008b) concurred with the 1997 radio-tagging results (Naughton 2005) regarding higher mortality during the latter portion of the run.

In 2009, PIT tag detection antennas were installed by Washington Department of Fish and Wildlife (PTAGIS 2010) in natal streams in the Wenatchee Basin (Little Wenatchee and White rivers), making it possible to track Wenatchee sockeye to the spawning grounds. No similar detection system is available in the Okanagan Basin; therefore in 2009 a goal of this project was to fund the installation of PIT tag detection in the Okanagan Basin. To further investigate the mortality rate of Okanagan sockeye in the Okanagan Basin, in 2009 this project also established an acoustic network in the Okanagan basin and acoustic tagged sockeye salmon at Wells Dam.

For the Wenatchee stock, the project was to fund a hydroacoustic survey of Lake Wenatchee to initiate standardized smolt abundance estimation there for comparison with similar estimates already available for Okanagan sockeye in Lake Osoyoos. This estimate was to be used to estimate juvenile survival and will be compared to Wenatchee River smolt trap smolt estimates. A plan for further Wenatchee research was also to be developed as part of this project.

METHODS

Adult PIT and acoustic tag detection infrastructure

Lower Okanagan River (Canada) PIT tag detection

Biomark (through the Okanagan Nation Alliance (ONA)) was contracted with for the construction of an instream detection system in the lower Okanagan River in Canada. A site visit was completed April 8, 2009 with system installation scheduled for the fall with the assistance of ONA and CRITFC personnel.

Okanagan acoustic tag network

An acoustic tag network was deployed upstream of Wells Dam to monitor survival and timing of fish acoustically tagged at Wells Dam. The acoustic tag network was planned to consist of up to 12 VR5W receivers over the entire migration corridor upstream of Wells Dam. However, budget and contracting issues required scaling the system back to six receivers deployed between Zosel Dam and Okanagan River inlet to Osoyoos Lake (Figure 3). Monthly uploads of data were planned for the Osoyoos Lake acoustic receivers, with retrieval and uploading of observations from three receivers at Zosel Dam after all fish had passed. Data from these receivers were used to estimate mortality from Wells Dam to Zosel Dam and Osoyoos Lake as well as passage time.

Feasibility of PIT tag detection at McIntyre Dam

As part of the Lower Okanagan River PIT tag detection system, CRITFC worked with Biomark and the Okanagan Nation Alliance to determine the feasibility of PIT tag detection at McIntyre Dam. This dam had been a barrier to fish passage under all but the highest flows; since it's construction in 1954 but was modified during the summer of 2009 to allow passage of sockeye salmon.

Adult Sampling at Bonneville and Wells dams

Bonneville Dam

Sockeye salmon were sampled and tagged at the Adult Fish Facility located adjacent to the Second Powerhouse at Bonneville Dam (river km 235) in conjunction with the sampling of steelhead (*O. mykiss)* and summer Chinook salmon (*O. tshawytscha).* Sampling and tagging typically occurred between 0900 and 1500 hours four to five days per week. A picket weir diverts fish ascending the Washington Shore fish ladder into the adult sampling facility

collection pool. An attraction flow is used to draw fish through a false weir where they may be selected for sampling. Fish not selected and fish that have recovered from sampling then migrate back to the Washington Shore fish ladder above the picket weir.

Sockeye selected for tagging were examined for tags (including scanning for existing PIT tags), fin clips, wounds; and condition. They were measured for length, and four scales were removed for later age analysis (Fryer 2007b). PIT tags were inserted into the body cavity of the sockeye salmon using standard techniques (CBFWA 1999). The fish were scanned for the PIT tag number, which was stored in a Destron Fearing FS 2001 PIT tag reader. If there was no tag was detected, due to either the tag being shed or a malfunction, then no effort was made to implant another tag to eliminate the possibility of double tagging. Sockeye salmon were allowed to recover prior to release. All PIT tag and sampling information was uploaded to the Columbia Basin PIT Tag Information System (PTAGIS) database (www.ptagis.org).

PIT tagged sockeye salmon were detected by existing detection arrays in adult fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams on the Columbia River; Ice Harbor and Lower Granite dams on the Snake River; and Tumwater Dam on the Wenatchee River (Appendix 1) as well as several in-stream detection arrays. PIT tag detection data from these arrays are automatically uploaded several times daily to the PTAGIS database where it is immediately accessible to registered users of the site. If a tag was not detected after the fish was released, we considered it a shed tag and removed it from further analysis.

A PIT tag reader was supplied for use during Okanagan River spawning ground surveys and brood stock collection activities.

Wells Dam

Sockeye at Wells Dam were sampled at the west bank fish trap. At this location, fish were netted out of the trap and placed in a small anesthetic tank. Like at Bonneville Dam, sockeye were examined for tags (including PIT tags), fin clips, wounds, and condition. They were also measured for length and had four scales removed for later age analysis. All data were recorded onto datasheets.

Vemco© V9-2H acoustic tags were surgically implanted into the body cavities of 50 sockeye salmon. These tags were 29 by 9 mm and weighed 4.7 grams with a projected battery life of 132 days. Internal implantation followed methods of Langford et al. (1977) where an incision just smaller than the transmitter was made into the body cavity on the midline of the ventral surface halfway between the pectoral and pelvic fins. The transmitter was disinfected before placement into the body cavity. Once the transmitter was secured inside the fish, the body-wall incision was closed utilizing a single suture. Sterile non-reabsorbing suture was used.

Upstream Migration Analysis

Stock classification

Sockeye salmon stock determinations were made by the last detection point. Those individuals last observed at or upstream of Rocky Reach or Wells dams were classified as being Okanagan stock, those last observed at or upstream of Tumwater Dam were classified as Wenatchee stock, those last observed at or upstream of Ice Harbor or Lower Granite Dam were classified as being Snake River stock and those last observed downstream of these sites were considered as unknown and were also considered mortalities. The sole exception to this rule were those fish never detected after release, which were considered to have shed their tags and were subtracted from the number of fish tagged for subsequent analysis.

Escapement

Escapement to McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams was estimated as:

$$N = \sum_i \frac{B_i R_i}{T_i}$$

where N was the estimated escapement at a particular upstream dam, B_i is the weekly visual count passing Bonneville Dam in week i (DART 2008, Fish Passage Center 2008), T_i is the number of fish PIT tagged at Bonneville Dam in week i, and R_i is the number of PIT tag detections at the dam where escapement is being estimated of those fish tagged in week i.

Mortality

PIT tagged sockeye salmon that were lost on the upstream migration were recorded as mortalities. Mortality rates were computed by week of passage at Bonneville Dam between dams with detection capabilities and correlated with temperatures and flows at The Dalles Dam (for Bonneville to McNary mortality) and Priest Rapids Dam (for McNary to Rock Island mortality).

Detection Efficiencies

Any fish detected at an upstream dam should also be detected at lower dams (except at Bonneville, McNary, and Ice Harbor dams, which have navigation locks fish could pass through, thus bypassing PIT tag detection antennas). The percentage of PIT tagged sockeye salmon missed at each dam with PIT tag detection arrays was calculated; for example the percentage missed at Rocky Reach Dam was calculated as:

$$P = \frac{R_m}{R_d + R_m}$$

where R_m was the number of fish missed at Rocky Reach Dam but detected upstream at Wells Dam and R_d was the number of fish detected passing Rocky Reach Dam.

Compiled for placement in the appendix of this report was the probability of detection at the different sites, hereafter referred to as weirs, at dam fish ladders. PIT tag detection antennas in fish ladders are always located at a minimum of two weirs in relatively close proximity. Therefore, if a fish is detected at one weir, it should also be detected at the rest of the weirs in that same ladder. This allows a probability of detection at the individual weirs to be calculated by comparing it with other weirs in that same ladder. Detection probabilities were calculated as:

$$Pi = \frac{N_i}{Max(N_i)}$$

where N_i is the number of fish detected at a given weir and $Max(N_i)$ is the total number of fish detected by any weir in that ladder. An overall probability of detection was calculated as:

$$1 - \prod_i (1 - P_i)$$

Also calculated was the percentage of sockeye salmon using each ladder at dams with multiple ladders.

Migration timing and passage time

Run timing was estimated using the date and time of detection at the different dams. Migration rates were calculated between dam pairs as the time between the last detection at the lower dam and the first detection at the upper dam and correlated with temperatures and flows at The Dalles Dam (for Bonneville to McNary migration rates) and Priest Rapids Dam (for McNary to Wells migration rates).

The amount of time required to pass each dam was estimated as the difference between the first detection time at a dam and the last detection time at a dam.

Bonneville Stock composition estimates using PIT tag recoveries

The overall stock composition, P_i, for stock i (where i denotes the Wenatchee or Okanagan stock) at Bonneville Dam was estimated as:

$$P_i = \sum_j W_j * S_{ij}$$

where W_j is the proportion of the run passing Bonneville Dam in week j, and S_{ij} is the percentage of the run estimated in week j to belong to stock i based on upstream recoveries.

The stock composition estimated by PIT tag recoveries was compared with that estimated from two visual counts, the first estimating the Wenatchee stock abundance as the difference between the Rock Island and Rocky Reach Dam counts and the second using Tumwater Dam visual counts to estimate the Wenatchee stock abundance.

Okanagan and Wenatchee age and length-at-age composition

The age composition for the Okanagan and Wenatchee stocks was estimated as:

$$T_{i,j} = \sum_k A_{i,j,k} * W_k$$

where $T_{i,j}$ was the estimate for stock *i and age gro*up *j,* $A_{i,j,k}$ was the percentage of sockeye for stock i and age group j in week k (such that $\sum_j A_{i,j,k} = 1$) and W_k was the percentage of the run that passed Bonneville Dam in week k.

The variance was estimated as

$$Var(T_{i,j}) = \sum_k Var(A_{i,j,k}) * W_k^{\,2}$$

where

$$Var(A_{i,j}) = \frac{\sum_k A_{i,j,k}(1 - A_{i,j,k})}{n_{i,k}}$$

Night passage

Fish passing viewing windows at Columbia Basin dams are not always counted using the same time period. Fish passing Bonneville and McNary Dam fish viewing windows are counted by observers only from 0400 to 2000 hours Pacific Standard Time for 50 minutes of each hour and the counts expanded by a factor of 1.2. Video records of fish migration at Priest Rapids, Rock Island, Rocky Reach, and Wells dams are recorded 24 hours per day and subsequently reviewed to yield total counts of daily fish passage. In this study, night passage rates (where night is defined as 2000 to 0400 hours) were calculated by stock, for all dams passed, based on the last detection time for a given fish ladder. The last time at the uppermost weir was used as an approximation for passage time as this weir was closer to the fish counting window than the lower most weir (where the first detection would be made). This was the case at all weirs except at BO4 near the fish counting facility on the Washington shore at Bonneville Dam (Figure A1), where the distance between the upper-most and lower-most weirs is only about 25 meters.

Fallback

Fallback is defined as a fish that ascends a fish ladder into the reservoir above the dam, and then "falls back" to the tailrace of the dam either over the spillway or through the turbines, juvenile bypass facility, or adult fish ladders. Fallback determinations were made in two ways. The first determination of fallback was the detection of an adult sockeye salmon in a juvenile bypass system. However, on the Columbia River only Bonneville, John Day, and McNary dams have both juvenile bypass systems and PIT tag detection capabilities. Also, any sockeye salmon falling back over the spillway or through the turbines would not be detected. Therefore, sockeye salmon that had detection at an "upper" detection weir followed by detection at a "lower" detection weir that was separated by more than 2 hours were also considered to be fallbacks. At McNary and Bonneville dams, the upper weir was at the fish counting window, which is believed to detect all PIT tagged fish passing, while the lower weirs have lower passage efficiency for sockeye salmon[3]. At Priest Rapids, Rock Island, Rocky Reach, and Wells dams, there are only two weirs

[3] Figures showing the PIT tag detection array configurations for all mainstem Columbia Basin dams are in the Appendix. This information is also available at www.ptagis.org.

with PIT tag detectors in each fish ladder, so these two weirs were designated as the upper and lower detection weirs.

Acoustic trawl surveys for juvenile sockeye abundance

Night-time juvenile sockeye salmon densities in Osoyoos Lake were estimated by executing specialized acoustics and trawl based survey (ATS) methods. Several whole-lake transects covering depth strata from the lake surface to bottom were traversed with hydro-acoustics gear (Simrad or Biosonics sounders operating at 70-200 kHz) deployed from a boat at night (Hyatt et al. 1984). Acoustic signal returns from fish were digitally recorded for subsequent population estimates of the total number of targets comprising pelagic fish located between the lake's bottom and surface. Echo counting is frequently confounded by fish schooling behavior during short nights in May–July; therefore, the best estimates are normally obtained during ice-free periods in the fall to early spring. Fish density estimates, in combination with species composition and biological traits (length, weight, age) information from trawl catches, are used to determine numbers and biomass of juvenile sockeye salmon found in the lake. Data from multiple surveys may be used to estimate salmon mortality between consecutive seasonal intervals (fall-spring, spring-summer, summer-fall).

Fish bio-samples were collected using a small, mid-water trawl net (2m by 2m mouth opening, 7.5-m length). Haul depths were based on echo-sounding results that indicate depths at which juvenile sockeye or other pelagic fish were most likely to be caught.

Immediately upon capture, pelagic fish destined for laboratory analysis (biological traits, stomach contents etc…) were placed into a 90% solution of ethanol and then subsequently frozen. Random samples of up to 150 juvenile sockeye and/or kokanee were normally retained from each survey date between November 2009 and April 2010. Trawl segment duration was adjusted to shorter or longer times depending on catch success. Larger catches triggered short trawl sets (10-15 minutes) such that most fish remained in good condition upon trawl retrieval. Following random withdrawal of a sub-sample of fish from a large catch, all other trawl caught fish were released unharmed.

Wenatchee Stock Status Assessment

Available data were collected and tabulated and a meeting was held in Wenatchee on October 6, 2009.

RESULTS

Lower Okanagan River (Canada) PIT tag detection installation

CRITFC contracted Biomark (through the Okanagan Nation Alliance) to construct an instream detection system in the lower Okanagan River in Canada. A site visit was held April 8, 2009 with representatives from CRITFC, the British Columbia Ministry of the Environment, and ONA present. Following this visit, the decision was made to construct an instream detection system just downstream of Vertical Diversion Structure 3, approximately five kilometers upstream from Osoyoos Lake. The system was installed between November 2 and November 6, 2009 with a crew consisting of personnel from CRITFC, ONA and Biomark. The system covered 60' of the river bottom, leaving room for an additional 20' panel (Figure 2). To complete the antenna, ONA and Biomark installed the additional section on March 17, 2010.

Figure 2. PIT tag detection antenna immediately downstream of Vertical Diversion Structure 3 prior to installation of final panel, Oliver, British Columbia

Okanagan acoustic tag network installation and monitoring

Acoustic receivers were installed at Zosel Dam and at three upstream locations July 6 and 7, 2009 (Figure 3). We had initially planned on installing the Zosel Dam receivers immediately downstream of the dam but found that they had very

limited range when deployed at that site. Therefore, we installed just one receiver downstream off the middle of the dam, and then two more at a log boom just upstream of the dam (Figure 4). Data from Zosel Dam receivers were downloaded when they were removed on October 5.

Figure 3. Acoustic receiver sites at Zosel Dam and Osoyoos Lake in 2009.

Figure 4. Zosel Dam showing fish ladder entrances (indicated by orange arrows) and acoustic receiver sites (indicated by red Xs) in 2009 (Photo courtesy Confederated Tribes of the Colville Indian Reservation)

In Osoyoos Lake, one receiver was attached to the anchor holding the west navigation buoy off Haynes Point, while a second was attached to bridge abutment where Highway 3 crosses Osoyoos Lake (Figure 3). A third Canadian receiver was attached to a buoy and placed just upstream of where the Okanagan River flows into Osoyoos Lake (Figure 3).

Osoyoos Lake receivers were checked, but not downloaded on July 30. Data were downloaded on August 31 and October 5. It was discovered following the first download that the Osoyoos Inlet receiver was not functioning so it was replaced on September 10. On October 5, this receiver turned up missing, so it was replaced on October 6. Osoyoos Lake receivers were removed and data downloaded on November 20.

Feasibility of PIT tag detection at McIntyre Dam

McIntyre Dam was modified for fish passage in June, 2009 (Figure 5) and sockeye salmon were observed passing over the spillways. Based on the previous site visit (prior to the modifications), Biomark determined that it was possible to install antennas at McIntyre Dam that could detect passing PIT tagged fish at a projected cost of $70,000-$120,000.

Figure 5. McIntyre Dam with two spillways altered for fish passage.

Upstream Migration Analysis

Sample Size

A total of 850 sockeye salmon were sampled between June 3 and July 10, 2009. We halted sampling when PIT tag detections at Ice Harbor and Lower Granite dams indicated we had exceeded our permitted sample size of three ESA-listed Snake River sockeye salmon. Less than 3% of the sockeye run passed Bonneville Dam subsequent to the termination of sampling. Of the 850 fish sampled, a total of 838 sockeye salmon were released with working PIT tags (Table 1). The remaining 12 fish were either not PIT tagged, or were PIT tagged but the tags were not detected when scanned. An additional 31 fish were never

detected after release. These fish may have shed their tags, had defective tags, or died. It was also possible that sockeye salmon passed downstream without being detected as they often pass over the top of weirs in the fish ladder rather than through the underwater slots in those weirs where the antennas in the vicinity of the fish trap are located (Table A1). It is less likely that sockeye salmon pass upstream undetected as they must swim through antennas at fish counting windows, but data from 2006-2009 indicates it does happen (Table 2) particularly at dams with navigation locks that fish can pass through (Bonneville, McNary, Ice Harbor, and Lower Granite). PIT tag detection data were downloaded from www.ptagis.org on November 23, 2009.

Table 1. Number of PIT tagged sockeye salmon tracked at Bonneville Dam by date and statistical week in 2009.

Sampling Dates	Statistical Week	Sampled (n)	Number Tagged	Number Tracked
6/1,2,3,4,5	23	10	10	10
6/8,9,10,11,	24	75	75	74
6/15,16,17,18	25	200	199	196
6/22,23,24,25,26	26	275	271	259
6/29,30,7/1,2	27	196	190	178
7/6,7,8,9	28	94	93	90
	Total	850	838	807

Table 2. Percentage of PIT tagged fish by tag type not detected at dam detection sites as estimated from upstream detections in 2009 with comparison data for 2006-2008. *Navigation locks at these dams permit adult sockeye to bypass weirs equipped with pit-tag detectors.

Dam	2009	2008 (12.5mm tags only)	2007	2006	Mean
Bonneville*	0.6%	0.4%	2.1%	0.2%	0.8%
McNary*	5.0%	10.1%	6.5%	3.1%	6.2%
Priest Rapids	0.3%	0.3%	0.8%	0.0%	0.4%
Rock Island	2.6%	6.9%	6.8%	1.3%	4.4%
Rocky Reach	0.0%	0.2%	0.7%	12.3%	3.3%
Ice Harbor*	20.0%	0.0%			10.0%
Mean		3.0%	3.4%	3.4%	3.3%

Upstream Recoveries, mortality, and escapement:

Most of the tagged sockeye salmon that were not detected at Rock Island Dam were lost before reaching McNary Dam (Table 3, Figure 6). This reach of river is where the Zone 6 tribal fishery occurs, which was estimated to harvest 10,374 sockeye salmon (Table A2).

A total of five PIT tagged sockeye salmon were identified, out of approximately 2430 checked with hand-held scanners by the Okanagan Nation Alliance in Okanagan River brood stock collection and spawning ground survey activities.

Table 3. Percentage of PIT tagged sockeye salmon detected subsequent to tagging at upstream dams, estimated escapement from both PIT tags and visual means, and the difference between the PIT tag and visual escapement estimate in 2009.

Dam	Estimated percentage reaching dam	Estimated escape-ment using PIT tag data	Visual Dam count	Difference between PIT tag and visual estimate
Bonneville	100.0		173570	
McNary	85.7	148750	121672	22.3%
Priest Rapids	82.1	142486	153466	-7.2%
Rock Island	80.2	139142	162830	-14.5%
Rocky Reach	67.1	116454	133106	-12.5%
Wells	65.2	113170	134937	-16.1%
Tumwater	12.2	21212	16076	31.9%
Ice Harbor	1.8	3056	867	252.5%
Lower Granite	1.8	3056	1219	150.7%

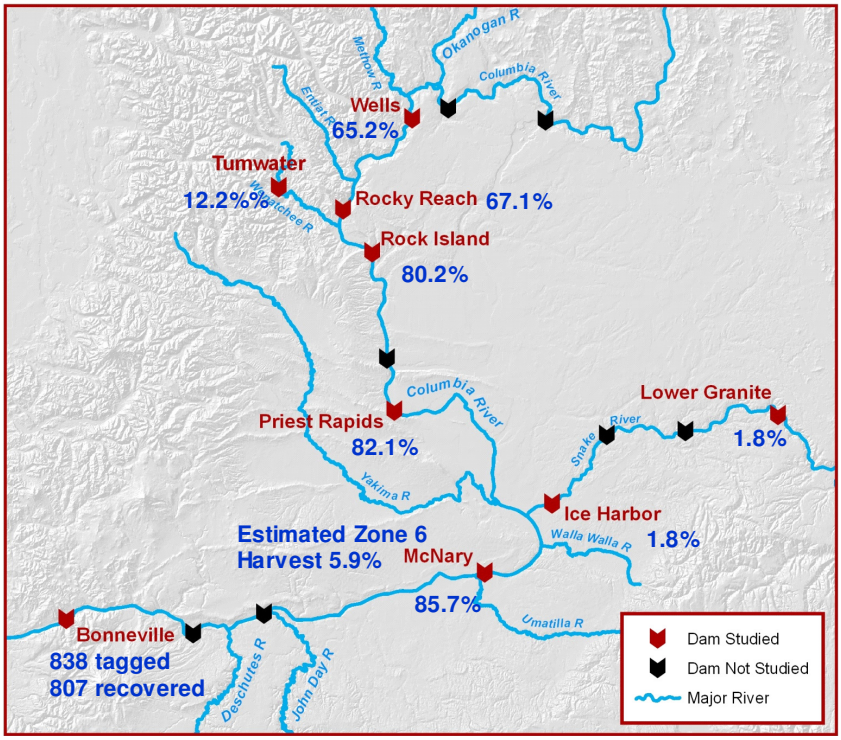

Figure 6. Map of the Columbia River Basin from Bonneville to Wells and Lower Granite dams showing the number of fish PIT tagged at Bonneville Dam, and the percentage of the run estimated to pass McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, Lower Granite, and Tumwater dams in 2009.

Using detections of fish PIT tagged by this program to estimate fish counts at dams resulted in greater variation from visual fish counts than in previous years. For instance, in 2008 estimates from this project were within 6.4% of the visual count at Priest Rapids, Rock Island, Rocky Reach, and Wells dams whereas, in 2009 these estimates differed by up to 16.1%. At McNary, Ice Harbor, and Lower Granite dams, it is possible for fish to use navigation locks to bypass fish ladders, thus avoiding both PIT tag detection and visual detection. At all of these dams, PIT tag estimates exceeded visual estimates of abundance; however, the magnitude of this difference was far greater than the percentage of sockeye estimated to have missed tag detection at these dams (Table 2).

The 2009 results were similar to 2006-2008 results where there were significant linear relationships between survival within specific river segments and the statistical week in which the fish were tagged with the fish tagged later in the migration exhibiting a lower survival rate (Table 4). In 2009, there was a significant linear relationship between statistical week tagged at Bonneville Dam and survival from Bonneville to Priest Rapids ($p=0.02$), but not with survival between Rocky Reach and Wells dams ($p=0.11$).

Table 4. Sockeye salmon survival through selected reaches by statistical week as estimated by PIT tag detections in 2009.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Rocky Reach-Wells
23	90.0%	90.0%	90.0%	100.0%
24	91.8%	90.4%	89.0%	98.4%
25	89.5%	88.4%	87.4%	100.0%
26	83.7%	79.3%	77.6%	95.2%
27	84.3%	79.1%	76.2%	96.6%
28	83.7%	80.2%	76.7%	96.8%
Composite	85.7%	82.1%	80.2%	97.0%

Bonneville to McNary survival significantly decreased with increasing temperatures at The Dalles Dam ($p=0.04$, Figure 7) as well as with decreasing flow ($p=0.05$). All three variables are highly correlated with absolute correlation coefficients ranging from 0.81-0.95.

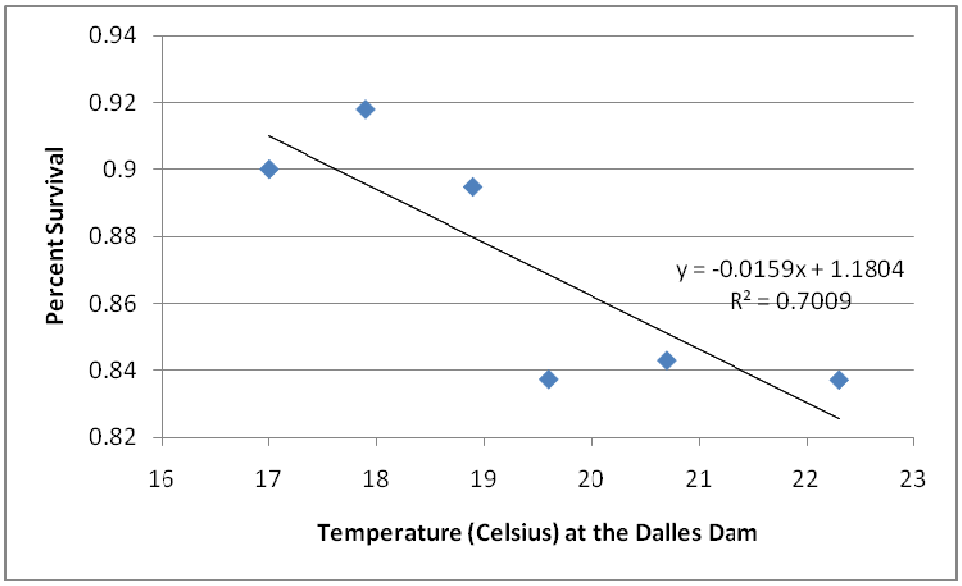

Figure 7. Figure showing the linear relationship between the survival of PIT tagged sockeye salmon from Bonneville to McNary Dam and mean water temperature at The Dalles Dam by statistical week in 2009.

Migration Timing and Passage Time

Sockeye salmon travel quickly upstream with a median travel time between Bonneville and Rock Island Dam of 12.7 days (Table 5). Sockeye salmon passing Bonneville Dam later in the migration travel upstream faster than those earlier in the migration. There is a significant (α=0.05) linear relationship between statistical week passing Bonneville Dam and passage time from Bonneville Dam to McNary, Rock Island, Rocky Reach, and Wells dams. The median difference in travel time from Bonneville Dam to all upstream mainstem dams was one day or less between the two major stocks (Table 6).

Table 5. Median sockeye salmon migration time and travel rates between mainstem dams as estimated by PIT tag recoveries in 2009.

Dam pair	Distance (km)	Median time (days)	Median travel time (km/day)
Bonneville-McNary	231	5.1	45.2
McNary-Priest Rapids	167	4.0	41.4
Priest Rapids-Rock Island	89	3.1	28.7
Rock Island-Rocky Reach	33	1.1	29.1
Rocky Reach-Wells	65	2.2	29.6
Rock Island-Tumwater	73	11.2	6.5
Bonneville-Rock Island	487	12.7	38.2
Bonneville-Tumwater	560	26.0	21.6
Bonneville-Wells	585	16.2	36.2

Table 6. Median adult sockeye salmon travel time in days between dam pairs by statistical week passing Bonneville Dam, the F-statistic for a linear regression between travel time and statistical week, and mean travel time by stock as estimated using PIT tags in 2009.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Bonneville-Rocky Reach	Bonneville-Tumwater	Bonneville-Wells	McNary-Rock Island	Rock Island-Rocky Reach	Rocky Reach-Wells
23	5.9	10.3	14.6	15.4	–	17.2	8.9	1.2	2.6
24	5.2	10.0	14.8	17.0	37.6	19.3	9.2	1.8	2.8
25	5.1	9.8	13.9	14.9	28.5	17.2	8.4	1.2	2.2
26	5.2	9.4	12.7	13.6	25.0	15.9	7.1	1.1	2.1
27	5.0	8.8	11.7	12.8	22.2	15.2	6.7	1.1	2.1
28	4.8	8.8	11.6	12.4	21.8	14.5	6.4	1.0	2.1
P-value	0.03	<0.01	<0.01	0.01	0.01	0.03	<0.01	0.08	0.10
Stock									
Okanagan	5.1	9.2	12.7	13.9	23.8	16.2	7.1	1.1	2.2
Wenatchee	5.1	9.8	13.7	13.0	26.0	15.6	8.0	1.1	2.8
Snake River	5.3	–	–	–	–	–	–	–	–
Unknown[4]	5.2	9.1	12.9	11.9	–	13.5	8.0	0.9	2.1

The median time between first detection and last detection was five minutes or less at all dams except for Bonneville, Lower Granite, and Tumwater dams (Table 7). At Bonneville Dam, many sockeye were detected in underwater orifices just upstream and downstream of the fish trap where sampling occurred. If these detections are excluded, the median time drops to 21 minutes. At Lower Granite Dam, all fish were trapped which likely resulted in increased passage times. At Tumwater Dam, all fish were trapped during the sockeye migration likely resulting in delays.

Table 7. Sockeye salmon median travel time from time of first detection at a dam to last detection at a dam and the percentage of sockeye salmon taking greater than 12 hours between first detection and last detection in 2009.

Dam	Median Passage Time (Minutes)	Taking more than 12 hours- (%)
Bonneville	58	5.7%
McNary	0	2.1%
Priest Rapids	5	1.2%
Rock Island	3	1.1%
Rocky Reach	2	1.5%
Wells	3	2.1%
Tumwater	159	41.4%
Ice Harbor	4	0.0%
Lower Granite	141	16.7%

[4] Unknown stock sockeye salmon are those that passed Bonneville but were not detected at Tumwater, Rocky Reach or Wells, or Ice Harbor or Lower Granite dams.

Stock composition estimates

The percentage of Wenatchee stock sockeye salmon was higher during the middle of the run when compared to the beginning and end with no significant linear relationship between weekly stock composition and statistical week (p=0.21, Table 8). The overall stock composition estimate was 15.1% Wenatchee, 82.6% Okanagan, and 2.3% Snake River. The Wenatchee/ Okanagan split was similar to that estimated using Rocky Reach Dam counts but varied greatly from that estimated using Tumwater Dam counts (Table 8).

A total of 30 adipose clipped sockeye salmon were PIT tagged. Of these, 10 were last detected in the Snake Basin (6 of which had ventral fin clips in addition to adipose fin clips), eight were last detected at Tumwater Dam, four were last detected upstream of Rocky Reach Dam, while one was not detected after Bonneville Dam[5].

Table 8. Weekly and composite sockeye salmon stock composition at Bonneville Dam as estimated by PIT tags in 2009 and a comparison to stock composition estimates estimated using visual dam counts.

Statistical Week and dates	Run Size	PIT Tag sample size	Percent Wenatchee	Percent Okanagan	Percent Snake River
23 (On or before June 6)	968	9	0.0%	100.0%	0.0%
24 (June 7-13)	8007	64	1.6%	98.4%	0.0%
25 (June 14-20)	42515	163	16.0%	84.0%	0.0%
26 (June 21-27)	64451	194	22.2%	74.7%	3.1%
27 (June 28-July 4)	46675	134	8.2%	88.1%	3.7%
28 (On or after July 5)	10954	62	11.3%	87.1%	1.6%
Composite	213564	9	15.1%	82.6%	2.3%
Standard Deviation			1.6	1.5	0.6
Visual Fish Counts at dams (using difference between Rock Island and Rocky Reach to estimate proportion Wenatchee)			17.8	79.9	
Visual Fish Counts at dams (Tumwater count to estimate the proportion Wenatchee)			9.6	88.1	

Okanagan and Wenatchee age and length-at-age composition

The 1.2 age class was predominant for all three stocks (Table 9). One-ocean sockeye salmon (age 1.1 and 2.1) were found predominantly in the Okanagan stock. For the Wenatchee stock, the age composition was similar

[5] Juvenile sockeye salmon are adipose clipped in Snake River and Lake Wenatchee hatchery programs.

whether estimated by PIT tag or by sampling at Tumwater Dam. However, this was not the case for the Okanagan stock where trap size selectivity, which was also observed in 2008 (Fryer 2008b), resulted in larger fish being over represented in the sample obtained at Wells Dam. Length-at-age estimates are found in Table 10.

Table 9. Age composition (%) of Columbia Basin sockeye salmon stocks as estimated by PIT tag recoveries as well as by sampling at Tumwater and Wells dams in 2009. Standard deviations are in parentheses.

		Age					
Stock/method	**Sample Size**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Bonneville sample	818	10.2 (1.0)	79.2 (1.4)	6.0 (0.3)	1.0 (0.8	3.6 (0.7	0.1 (0.1)
Wenatchee PIT tag estimate	87	0.8 (0.1)	75.9 (4.5)	22.5 (4.4)		1.0 (1.0)	
Wenatchee-Tumwater sample	384	0.6 (0.4)	76.6 (2.2)	18.0 (2.0)	0.3 (0.3)	4.1 (1.0)	0.3 (1.0)
Okanagan- PIT tag estimate[6]	504	7.4 (1.0)	86.4 (1.4)	0.7 (0.4)	2.3 (0.7)	3.2 (0.8)	
Okanagan-Wells sample	371	3.9 (1.0)	60.6 (2.8)	29.0 (2.6)		5.7 (1.3)	0.9 (0.5)
Snake River PIT tag estimate	12	26.3 (12.5)	73.7 (12.5)				

Table 10. Length-at-age composition of Wenatchee and Okanagan stock sockeye salmon estimated by PIT tag detection and sampling at Tumwater and Wells dams in 2009.

		Age					
Stock	**Statistic**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Bonneville mixed stock	Mean	39.9	49.5	56.9	42.5	50.4	56.5
	St. Dev.	1.9	2.7	2.9	1.9	3.1	2.1
	N	84	663	4	16	24	2
Okanagan (PIT tags)	Mean	39.0	51.0	57.1	40.4	52.3	53.0
	St. Dev.	2.2	2.7	2.6	2.6	2.7	-
	N	62	397	14	5	25	1
Okanagan (Wells Sampling)	Mean	40.1	53.4	57.8		54.3	58.2
	St. Dev.	1.9	2.3	2.4		2.4	2.1
	N	17	232	97		21	4
Wenatchee (PIT tags)	Mean	37.0	51.4	56.6		55.0	56.5
	St. Dev.	-	1.9	2.7		-	2.1
	N	1	65	20		1	2
Wenatchee (Tumwater Sampling)	Mean	41.5	53.6	59.3	45.0	54.2	55.0
	St. Dev.	3.5	2.4	2.9	-	2.8	-
	N	2	285	77	1	18	1

[6] The estimated Okanagan stock age composition determined from otoliths collected on the spawning ground (n=501) was .1=3.5%, 1.2=87.9%, 1.3=5.4%, 2.2 =3.3% (Kim Hyatt, personal communication).

In-river PIT tag detections

PIT tag antenna arrays were deployed in tributaries upstream of Tumwater Dam for the first time in 2009. These arrays were located on sockeye spawning grounds in the Little Wenatchee and White rivers, as well as on the Chiwawa River which is not considered a spawning area. Of the 87 sockeye salmon detected at Tumwater Dam, two were subsequently detected at Rocky Reach Dam. Of the remainder, 34 were detected at the White River, four at the Little Wenatchee, and two at the Chiwawa River (Table 11).

Table 11. Number of sockeye detected at Tumwater Dam by last detection site in the ladder, and subsequent detections in 2009.

		Number and percentage subsequently detected by site			
Tumwater Dam Antenna	**Total Last detected**	**Chiwawa River**	**Little Wenatchee**	**White River**	**Rocky Reach Dam**
Upper	64	2 (3.2%)	4 (6.4%)	32 (50.0%)	
Lower	23			2 (8.7%)	2 (8.7%)
Total	87	2 (2.3%)	4 (4.6%)	34 (39.0%)	2 (2.3%)

New PIT tag antenna arrays in the Entiat River (which flows into the Columbia River between Rocky Reach and Wells dams) also detected two sockeye salmon. One sockeye, with tag 3D9.1C2D0B7132, passed Wells Dam on July 15, before entering the Entiat where it was observed in the lower Entiat on July 19 and the middle Entiat on July 23. A second sockeye, with tag 3D9.1C2D0B8490 passed Rocky Reach Dam on July 16 and was detected in the lower Entiat between October 20 and 26.

Fallback

Estimated fallback (and reascension) rates for sockeye salmon ranged from 0.7% at Tumwater Dam to 33.3% at Lower Granite Dam (Table 12). However, the Lower Granite estimate is based on only 12 fish. Four PIT tagged sockeye salmon fell back through the John Day juvenile bypass system, while three sockeye at Bonneville Dam fell back through the juvenile bypass system.

Table 12. Estimated sockeye salmon fallback at mainstem Columbia River dams in 2009 as estimated by PIT tag detections.

Dam	**Sockeye (%)**
Bonneville	1.1
McNary	3.3
Priest Rapids	1.4
Rock Island	1.3
Rocky Reach	1.5
Wells	1.0
Tumwater	5.7
Ice Harbor	11.1
Lower Granite	33.3

Night Passage

Where there were a significant number of detections, Okanagan stock sockeye salmon passed dams at night (2000-0400 hours) at a higher rate than Wenatchee stock sockeye salmon (Table 13). The Bonneville Dam estimate of nighttime passage is likely biased low because tagging occurred between about 0900 and 1500 hours, and with a median passage time of 58 minutes from tagging to final detection at Bonneville Dam (Table 7), fish would be expected to pass the counting window prior to 2000 hours.

Table 13. Estimated sockeye salmon nighttime passage (2000-0400 standard time) in 2009 at mainstem Columbia River dams as estimated by PIT tag detections. An asterisk indicates fewer than five detections.

Dam	All Sockeye (includes unknown)	Okanagan Stock	Wenatchee Stock	Snake Stock
Bonneville	1.8	0.8	0.0	8.3
McNary-Oregon Shore	4.2	6.4	2.1	0.0
McNary-Washington Shore	5.4	6.8	2.6	0.0
Priest Rapids	2.2	3.4	0.0	NA
Rock Island	0.8	1.2	0.0	NA
Rocky Reach	4.1	5.4	0.0*	NA
Wells	12.1	12.1	50.0*	NA
Tumwater	8.0	0.0*	8.2	NA
Ice Harbor	0.0	NA	NA	0.0
Lower Granite	0.0	NA	NA	0.0
Mean McNary, Priest Rapids and Rock Island	4.8	6.6	2.4	NA

Acoustic Data Analysis

A total of 50 sockeye salmon were implanted with acoustic tags between July 6 and July 21, 2009 (statistical weeks 28-30). Of these, 25 were detected at Zosel Dam, 20 at Haynes Point, 20 at the Osoyoos Lake Bridge, and 13 at Osoyoos inlet (Table 14). Based on detections in Osoyoos Lake, no tagged fish were missed by acoustic receivers at Zosel Dam. However, there was one fish detected at the Osoyoos Bridge which was not detected at Haynes Point. Sockeye salmon were missed at the Osoyoos Lake inlet site; due to either a malfunctioning or missing receiver, detection data were only available between 8/23 and 9/7 and after 10/6.

Of the 21 fish that were detected in Osoyoos Lake, ten were last detected at the Osoyoos inlet and presumably moved upstream to spawn. One sockeye was observed at the Osoyoos inlet on 10/17 but last detected “downstream” at the Osoyoos Lake Bridge on 11/15. It is undetermined whether it spawned prior

to 10/17 before moving downstream, remained unspawned in the northern basin or spawned between 10/17 and 11/15 and then moved downstream bypassing detection at the Osoyoos inlet site.

The 50% of fish acoustic tagged at Wells Dam detected at Zosel Dam is similar to the 45.2% survival between those dams estimated by dam counts. (The Wells count was 134,937 while the Zosel count was 60,970 [DART 2010, FPC 2010]). Total harvest between Wells and Zosel dams was at least 15,867, or 11.8% of the Wells count (Table A2).

Survival of acoustic tagged sockeye salmon to Zosel Dam dropped from 58% for those fish tagged in week 28 to 20% for those tagged in Week 30 (Table 14). Survival from Zosel Dam to Haynes point was 88% for those fish tagged in Week 28, 100% for those tagged in Week 29, and 0% for those tagged in Week 30.

Of the 25 fish detected at Zosel Dam, 24 were detected at the East log boom receiver, 21 at the West log boom receiver, and nine at the downstream spillway receiver. All fish were last detected upstream of the dam, 21 at the West log boom receiver with the remaining four being the only fish that were solely detected at the East log boom receiver upstream of Zosel Dam. Of the nine fish generating 13 detections at the downstream spillway detector, 12 of the detections from eight different fish were simultaneously detected at the West log boom site. Seven of these eight fish were detected again within two minutes at the West log boom receiver. The only fish that was detected at the downstream spillway receiver that was not simultaneously detected at the West boom log receiver was subsequently detected in Lake Osoyoos.

Table 14. Number of sockeye salmon acoustic tagged at Wells Dam by date and week, and the number and percentage of acoustic tagged fish passing Zosel Dam, Haynes Point, Osoyoos Bridge, and Osoyoos inlet in 2009

Week	Dates	N	Passed Zosel Dam	Passed Haynes Point	Passed Osoyoos Bridge	Passed Osoyoos Inlet[7]
28	7/6,7,8	29	58% (17)	52% (15)	48% (14)	31% (9)
29	7/13,14	11	55% (6)	55% (6)	55% (6)	36% (4)
30	7/21	10	20% (2)	0%	0	0
All Weeks		50	50% (25)	42% (21)	40% (20)	26% (13)

The median travel time from Wells Dam to Zosel Dam was 36.1 days, with fish tagged earlier in July taking longer to reach Zosel Dam than fish tagged later (Table 15). The time spent between first and last detection at Zosel Dam was highly variable, ranging from 1 to 3,514 minutes (Figure 8). The four sockeye that were not detected after Zosel Dam had four of the longest seven delays at Zosel Dam, including the two longest delays. Tagged sockeye passed Zosel Dam in two groupings, the first consisting of seven fish, all tagged in Week 28, which passed between July 12 and July 18, and the second consisting of 18 fish passing between August 17 and 22. The sockeye which did not make it to Osoyoos Lake were four of the eight latest arriving fish at Zosel Dam. The bimodal distribution of Zosel sockeye passage correlates with temperature. Individual fish in the early group either passed prior to temperatures ascending to over 24C, or resumed when temperatures dropped below 22C. Visual counts of sockeye salmon passing up Zosel Dam fish ladders illustrate a similar multimodal distribution, with passage coming in two pulses in July and another in August. (Figure 9)

Table 15. Mean time in days for acoustic tagged sockeye to travel from Wells Dam to Zosel Dam, at Zosel Dam and between receiver sites in Lake Osoyoos.

Week tagged at Wells Dam	To Zosel Dam	At Zosel Dam	Zosel Dam to Central Basin	Central Basin to Osoyoos inlet	At Osoyoos Inlet
28	40.5	0.13	0.9	7.1	8.4
29	35.6	0.11	0.5	32.9	9.2
30	32.5	3.44	NA	NA	NA
All weeks	36.1	0.14	0.7	18.1	8.4

[7] Acoustic tagged fish likely were missed at the Osoyoos Lake inlet. The receiver initially deployed malfunctioned causing loss of data from installation through August 23, 2009. The replacement receiver disappeared after being downloaded on September 7, 2009 and was not replaced until October 6, 2009.

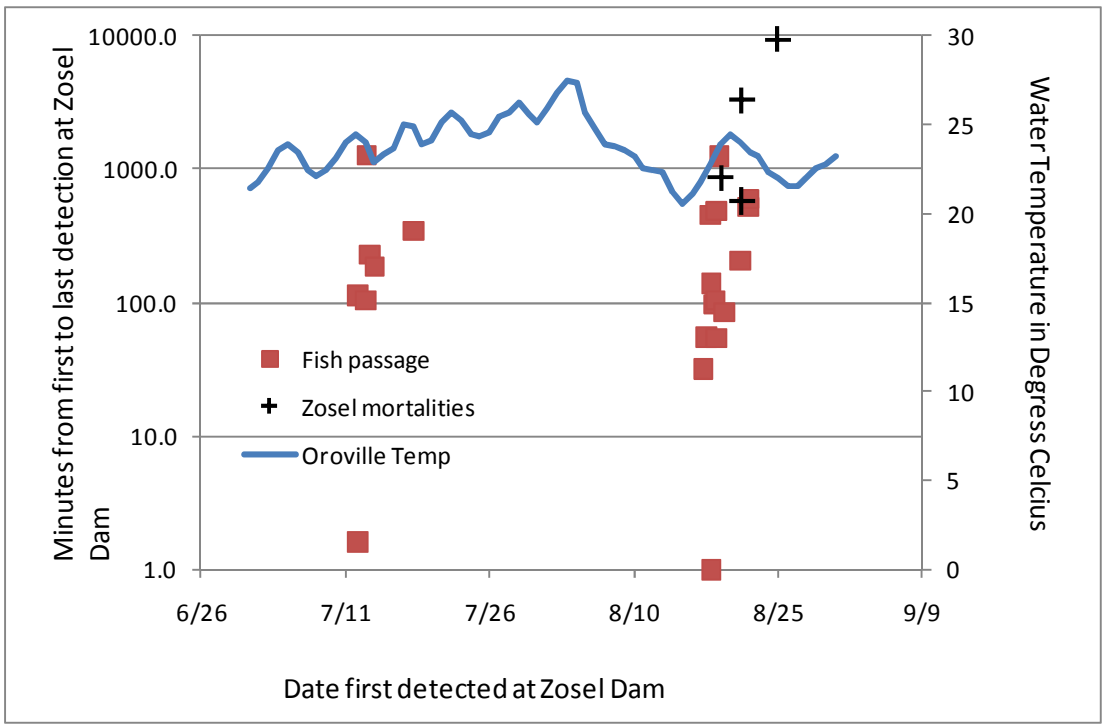

Figure 8. Oroville, WA water temperatures and timing and length of passage at Zosel Dam by date in 2009.

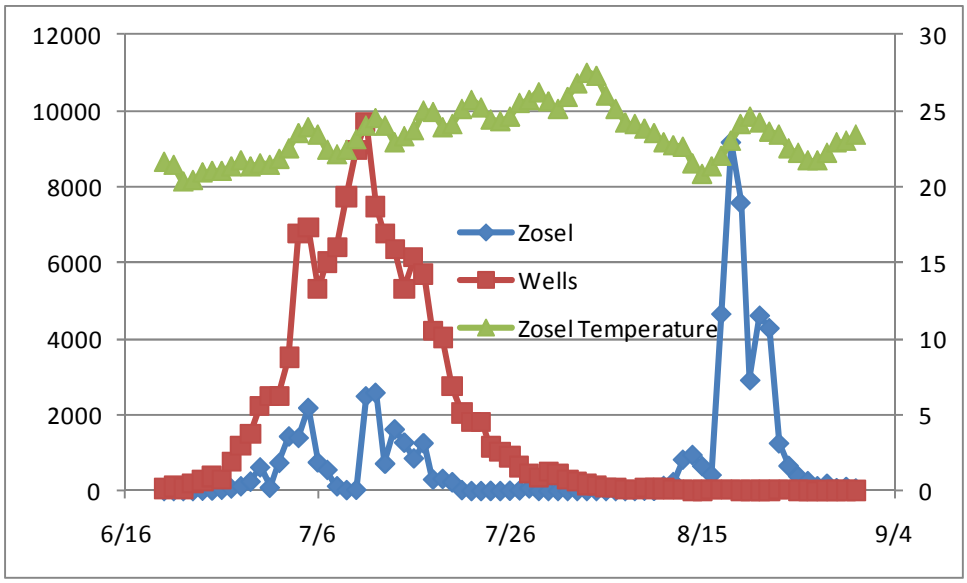

Figure 9. 2009 daily sockeye salmon passage at Zosel and Wells dams by date with water temperatures at Zosel Dam.

Acoustic Trawl Survey for juvenile abundance

Osoyoos Lake acoustic trawl surveys, funded by another project (Hyatt et al. 2010), were conducted between May 2009 and February 2010 to estimate

juvenile sockeye abundance (Table 16). Although planned, no similar surveys funded by this project were conducted for Lake Wenatchee sockeye as necessary permits arrived too late. The Lake Wenatchee survey will be conducted in 2010.

Table 16. Estimates of juvenile sockeye salmon abundance from Osoyoos Lake acoustic trawl surveys between May 2009 and February 2010.

Date	Estimated number of juveniles
18-May-09	10,202,000
20-Jul-09	9,787,000
24-Aug-09	7,880,000
28-Sep-09	6,994,000
23-Nov-09	7,253,000
10-Feb-10	7,724,000

Wenatchee Stock Assessment Status

A meeting was held on October 6, 2009 to bring together researchers working with Wenatchee sockeye salmon regarding why Wenatchee sockeye salmon abundance has not rebounded as Okanagan sockeye abundance has in recent years. Attending were Joe Miller (Chelan PUD), Todd Pearsons (Grant PUD), Keely Murdoch (YIN), Jeff Fryer (CRITFC) and, from WDFW, Andrew Murdoch, Todd Miller, and Mike Tonseth. Four primary issues were raised affecting Wenatchee sockeye that were deemed worthy of further study:

1.) Effect of increasingly frequent rain on snow flood events which may scour sockeye salmon spawning in the White River.
2.) Productivity of Lake Wenatchee.
3.) Predation in Lake Wenatchee from a reputedly large bull trout population.
4.) Role of the downstream migration corridor in low smolt to adult survival rates when compared to Okanagan smolt.

Possible research that could be funded by this project in the future included:

1.) Acoustic trawl survey (ATS) for smolt abundance that is already planned beginning in 2010. This will allow for ATS based estimates of smolt abundance which can then be used to estimate spawner-smolt and smolt-adult survival that can then be compared directly to the Okanagan stock. Furthermore, this survey may also provide some measure of abundance of large piscivores such as bull trout.

2.) A study into spawning area preferences. Only 10-15% of sockeye salmon spawn in the Little Wenatchee Basin by comparison with 85-90% that spawns in the White Basin. However, spawning habitat is better and less vulnerable to flood scouring events in the former than the latter. This raises the question as to whether Little Wenatchee and White River stocks are genetically distinct, and what would happen if adults were collected at Tumwater Dam and released into the Little Wenatchee? Could this be used to build the Little Wenatchee stock? Genetics studies and spawner relocation are both possible studies for future years of this project.
3.) A habitat assessment (e.g. Hyatt and Rankin 1999) to determine potential carrying capacity of the Wenatchee system for sockeye production. This might include a benthic core sample from which analysis of paleo-fossils and stable isotopes might be used to estimate historical abundance variations of sockeye salmon.
4.) Collection of more water quality data.

The development of an acoustic network, similar to that being developed in the Okanagan, was not thought to be a high priority for Wenatchee sockeye salmon, though it could be useful for summer Chinook. If an acoustic network were developed, tagging could be moved from Wells Dam to Priest Rapids Dam where both stocks would be tagged. However, PIT tag data indicates low mortality from Priest Rapids to Wells and Tumwater dams, suggesting that collecting better data on fish movement and survival in this area would be of minimal value.

Participants all agreed that, at the present time, there were more opportunities to expand our knowledge of factors limiting the survival of Okanagan sockeye than for the Wenatchee stock. PIT tag detection at Zosel Dam, in particular, was judged as very important for sockeye as well as being of importance for Chinook and steelhead.

DISCUSSION

This study adds to results of previous studies using PIT tags to assess adult sockeye salmon migration, timing, escapement, Wenatchee and Okanagan stock age and length-at-age composition, mortality, fallback rates, and the weekly and total stock composition at Bonneville Dam. In addition, we installed an in-stream PIT tag detection array at Okanagan River Vertical Diversion Structure 3 and implemented an acoustic tagging and monitoring program for Okanagan sockeye salmon.

Wenatchee-Okanagan stock composition estimates produced by this study (15.5% Wenatchee and 84.5% Okanagan) differed from those using Tumwater and Rocky Reach dam counts (9.9% Wenatchee and 90.1% Okanagan, Table 8). One possible explanation for this difference is that we may not be getting a representative sample at the Bonneville Dam Adult Fish Facility. Data from Wenatchee sockeye salmon PIT tagged as juveniles suggests this may be the case. Exactly 60.4% of 293 Wenatchee sockeye salmon PIT tagged as juveniles, and then detected at Bonneville Dam fish ladders in 2009, were detected on the Washington shore. However, counts from that station suggest that 69.6% of all sockeye actually passed the station. This suggests that Wenatchee stock sockeye salmon may have disproportionately used the Oregon shore ladder where they were not subject to tagging. This would also suggest that Okanagan sockeye salmon favored the Washington shore ladder in 2009.

Dam counts can also have problems. A total of 133,106 sockeye salmon were counted at Rocky Reach Dam, 16,076 at Tumwater Dam, and 162,830 fish at Rock Island Dam just downstream of these dams. This suggests that 9.2% of sockeye salmon disappeared between Rock Island Dam and the two upstream dams. However, PIT tag data puts this loss at 2.1%. In 2009, fisheries managers used the difference in counts between Rock Island and Rocky Reach dams to justify a sockeye fishery, even though review of Tumwater Dam video records subsequently indicated insufficient escapement to Tumwater for this fishery to occur with actual escapement of 16,034 fish compared to an escapement goal to Tumwater Dam of 27,000 (Andrew Murdoch, Washington Department of Fish and Wildlife, personal communication).

Seven sockeye salmon PIT tagged by this project were detected at both Rocky Reach and Tumwater dams. Five of these fish passed Rocky Reach (one

also passing Wells Dam) Dam before proceeding to Tumwater, while two were detected at, but likely did not pass, Tumwater Dam before proceeding upstream of Rocky Reach Dam. This suggests a low rate of straying for sockeye salmon as they pass through the hydrosystem.

As in 2008, there was not a significant linear relationship between run timing at Bonneville Dam and stock composition. In both 2006 and 2007, as well as in several years of past sockeye stock identification studies (e.g. Fryer 1995, 2006) using scale pattern analysis, there was a significant relationship between run timing and stock composition. These results suggested a higher percentage of the Wenatchee stock migrated in the early portion of the run and a higher percentage of the Okanagan stock migrated in the latter portion of the run.

The percentage of PIT tagged fish missed at McNary Dam, at 5.0%, was the highest among dams with significant numbers of detections. While it is possible some proportion of this is attributable to tagged fish being missed by detectors as they ascended weirs, it seems more likely that most sockeye salmon detection failures were due to ascent via navigation locks. In 2009, as in 2008, there was also a large disparity in visual dam counts, with McNary Dam estimating over 20% less passage than either Priest Rapids or Rock Island dams (both of which are located upstream of McNary Dam). These results also suggest significant bypass of fish through navigation locks at these dams. However, the dam count disparity is far greater than the percentage of missed PIT tagged fish.

As has been the case since 2006, the percentage sockeye salmon passing dams undetected (Table 2) was generally higher than it should have been given the high detection rates estimated at individual weirs (Table A1). At McNary, Bonneville, and Ice Harbor dams, fish can bypass the fish ladders by passing through navigation locks, however there are no locks at Priest Rapids, Rock Island, and Rocky Reach dams. At all fish ladders but the Rock Island right ladder (99.8%) the probability of pit tag detection based on detection rates at individual weirs was 100.0%. This suggests that sockeye salmon have some characteristic (e.g. a malfunctioning tag, a poorly placed PIT tag, or fish behavior), that allows them to escape detection at multiple weirs at a given dam.

Four PIT tags from sockeye salmon tagged by this project in 2009 were recovered at the Badger Island Pelican Colony in the McNary Pool, indicating

that pelicans are predators on adult sockeye salmon. Two of these fish were last detected after passing McNary Dam while two were not detected after Bonneville Dam, suggesting it is likely that these latter fish were captured downstream of McNary Dam. One of the recovered tags was from a smaller 37 cm one-ocean sockeye, however the other three were from larger two-ocean fish between 49.5 and 51 cm in length.

In 2008, this study found that sockeye salmon had a median delay of 4.6 days in passing Tumwater Dam (Fryer 2009). This was likely attributable to the 24 hour operation of the fish trap at Tumwater Dam. Fish were observed "stacking up" in the fish ladder below the trap (Keely Murdoch, Yakama Nation, personal communication), and it was evident that it was causing significant delays. The report (Fryer 2009), speculated that "it is possible that some sockeye salmon were not passing the Tumwater Dam due to the passage delays – 7.6% of those sockeye salmon detected at Tumwater Dam were last detected at the lower detection site suggesting that these fish turned around and went downstream and were not detected again". In 2009, changes in operation of the fish trap at Tumwater Dam likely resulted in the observed decline of median delay to just 159 minutes. However, 41.4% of sockeye still take more than 12 hours to pass Tumwater Dam suggesting that trap-operations continue to influence adult fish behavior.

In-stream detection arrays at sites upstream of Tumwater in 2009 allowed testing of the hypothesis that many fish did not pass Tumwater Dam (Table 11). Since 59.6% of fish last detected at the upper Tumwater Dam fish ladder antenna (Antenna A1 at www.ptagis.org) were subsequently detected upstream, compared to only 8.7% for those fish last detected at the lower Tumwater Dam fish ladder antenna (Antenna A2 at www.ptagis.org), it appears that there were significant numbers of sockeye that did not pass upstream. Presumably, some additional sockeye salmon last detected at A2, besides the two previously noted, may have passed A1 undetected so the percentage of sockeye last detected at the A2 that passed upstream was estimated as:

$$x = \frac{A_i}{A_{us}} = \frac{0.087}{0.563} = 0.155$$

where A_i is the percentage of sockeye detected at the lower antenna subsequently detected upstream (8.7%), and A_{us} is the percentage of tagged fish last detected at the upper antenna subsequently detected upstream.

Both antennas A1 and A2 are downstream of fish trapping facilities at Tumwater Dam. Once fish are trapped and counted, they cannot be detected again without falling back over the dam and re-ascending the fish ladder. Given that 16,076 sockeye were counted passing over Tumwater Dam, the number of sockeye actually reaching the fish ladder can be estimated as the total number of PIT tagged fish detected at Tumwater Dam (87) divided by the estimated number of PIT tagged fish passing upstream (all sockeye last detected at A1 plus 15.5% of those fish last detected at A2), resulting in an estimate of 20,703 with an estimated 4,628 fish reaching the fish ladder, but not passing over it.

All of the five sockeye estimated to have fallen back over Tumwater Dam were subsequently last detected at A1 so presumably did make it upstream.

Additional PIT tag detection antenna arrays are scheduled for installation in the Wenatchee Basin both upstream and downstream of Tumwater Dam in 2010 and 2011 to improve information on fish movement in the basin. If in place in 2009, such arrays might have provided information on what became of sockeye salmon last detected at A2 that apparently did not pass upstream of Tumwater Dam.

This project is also developing a more limited PIT tag antenna array in the Okanagan Basin, beginning with VDS 3 for 2010 and Zosel Dam for 2011. These arrays will supplement information generated by the acoustic tagging and detection network funded by this project. Acoustic tag data in 2009 suggested high mortality from Wells Dam to Zosel Dam. This mortality most affected later migrating fish. Additional mortality from Zosel Dam to the Osoyoos Lake Central Basin appeared to be aggravated by high temperatures and passage delays at Zosel Dam. Mortality could not be estimated between the Central Basin and terminal spawning area due to problems with maintaining the receiver at the north end of Osoyoos Lake. The acoustic network will be expanded in 2010, focusing on fish movement downstream of Zosel Dam since that is where 2009 results indicated most mortality occurred.

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APPENDIX

Table A1. Probability of detection at PIT tag detectors by weir at mainstem Columbia Basin fish ladders, and the overall probability of detection, for sockeye salmon in 2009.

Dam, site, and tag type[t]	Weir and probability of detection at weir											Overall Detection Probability
Bonneville	**N**	**1**	**2**	**3**	**4**							
BO4-12.5	718	99.9	98.6	99.4	99.3							100.0
BO1-12.5	82	100.0	100.0	100.0	100.0							100.0
McNary		**1**	**2**	**288**	**287**	**286**	**284**	**283**	**282**	**280**	**279**	
MC1-12.5	313	99.0	99.3	9.1	10.4	12.7	12.1	11.1	12.4	14.3	11.4	100.0
		1	**2**	**3**	**312**	**311**	**309**	**308**	**306**	**305**	**303**	
MC2-12.5	333	100.0	100.0	100.0	7.5	6.0	4.5	7.2	5.7	5.4	5.1	100.0
P. Rapids		**3**	**7**									
East-12.5	521	99.6[8]	99.8									100.0
		3	**5**									
West-12.5	**120**	100.0	99.2									100.0
R. Island		**1-2**	**3-4**									
Left-12.5	149	100.0	99.3									100.0
		5-6	**7-8**									
Middle-12.5	89	91.0	100.0									100.0
		09-0A	**0B-0C**									
Right-12.5	379	95.5	83.9									99.3
R. Reach		**1-2**	**3-4**									
12.5	535	99.6	100/0									100.0
Wells		**1-2**	**3-4**									
Left-12.5	246	99.6	100									100.0
		5-6	**7-8**									
Right-12.5	280	100	99.6									100.0
Tumwater		161	162									
12.5	87	100.0	100.0									100.0

[c] Fish bypass this weir when the Priest Rapids adult fish trap is in operation.

Table A2. Harvest by fishery for Columbia Basin sockeye salmon in 2009.

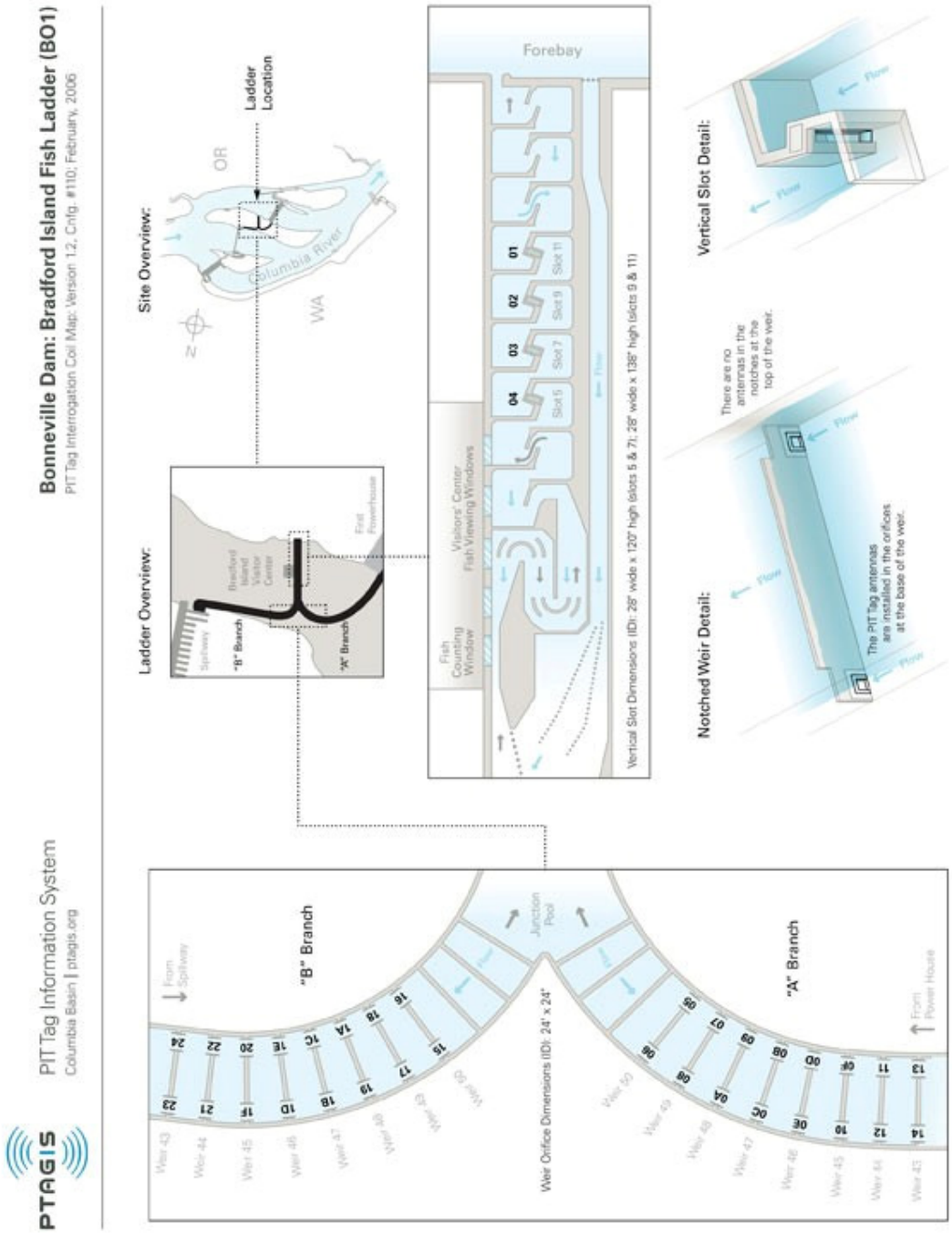
Location	Fishery Type	Source		Totals
Zone 1-5	Commercial	TAC	236	
	Sport	TAC	909	
	Non-retention mortality in shad fisheries	TAC	0	
				1145
Zone 6	Commercial	TAC	7021	
	Ceremonial and Subsistence	TAC	3353	
				10,374
Lake Wenatchee	Sport (2285 harvested, 57 released)	WDFW		2,228
Priest Rapids to Chief Joseph Dam	Sport	WDFW		1,345
Wells Pool/Okanagan River (US)	Sport	WDFW (D. Beich)		1,425
Okanagan River	Colville Tribe Tangle Net	CTCIR		168
Okanagan River	Colville Tribe Purse Seine			14,255
Chief Joseph Dam Tailrace	Colville Snag Fishery	CTCIR		6
Upstream of Lake Osoyoos	Okanagan tribal	ONA		1,653

Table A3. Distribution of sockeye salmon by fish ladder for dams with multiple fish ladders as estimated by PIT tag detections in 2009.

Dam	Right Bank[9]	Left Bank	Center
Bonneville	92.3%	7.0%	0.7%
McNary	51.5%	48.5%	
Priest Rapids	81.2%	18.8%	
Rock Island	61.4%	24.1%	14.4%
Wells	53.2%	46.8%	

[9] Right or left is determined by looking downstream at the dams, thus the right bank at Wells would be the west bank, at McNary it would be the Washington shore.

Figure A1. PIT Tag detection configurations in adult fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, and Wells dams. All images provided by PTAGIS (2007) and available at http://www.ptagis.org. Reprinted with permission.



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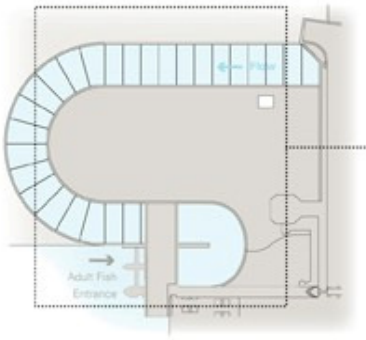
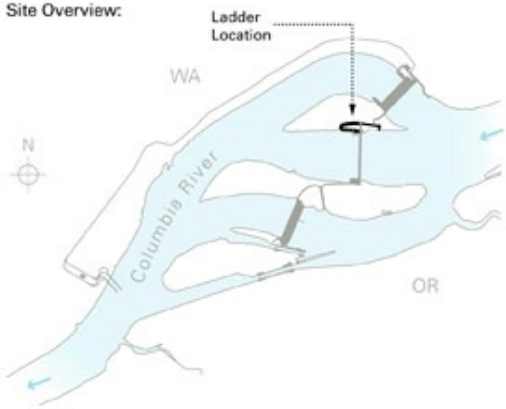
Bonneville Dam: Cascades Island Fish Ladder (BO2)

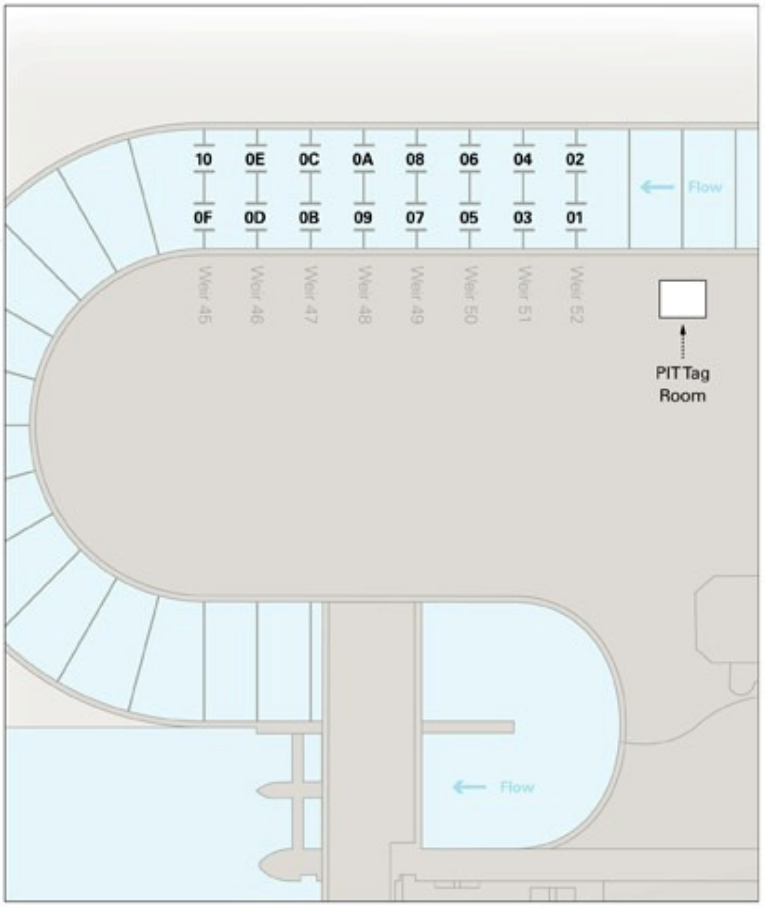
PIT Tag Interrogation Coil Map: Version 1.1, Cnfg. #100; February, 2002
Orifice Dimensions: 24" wide x 24" high

Ladder Overview:



Site Overview:





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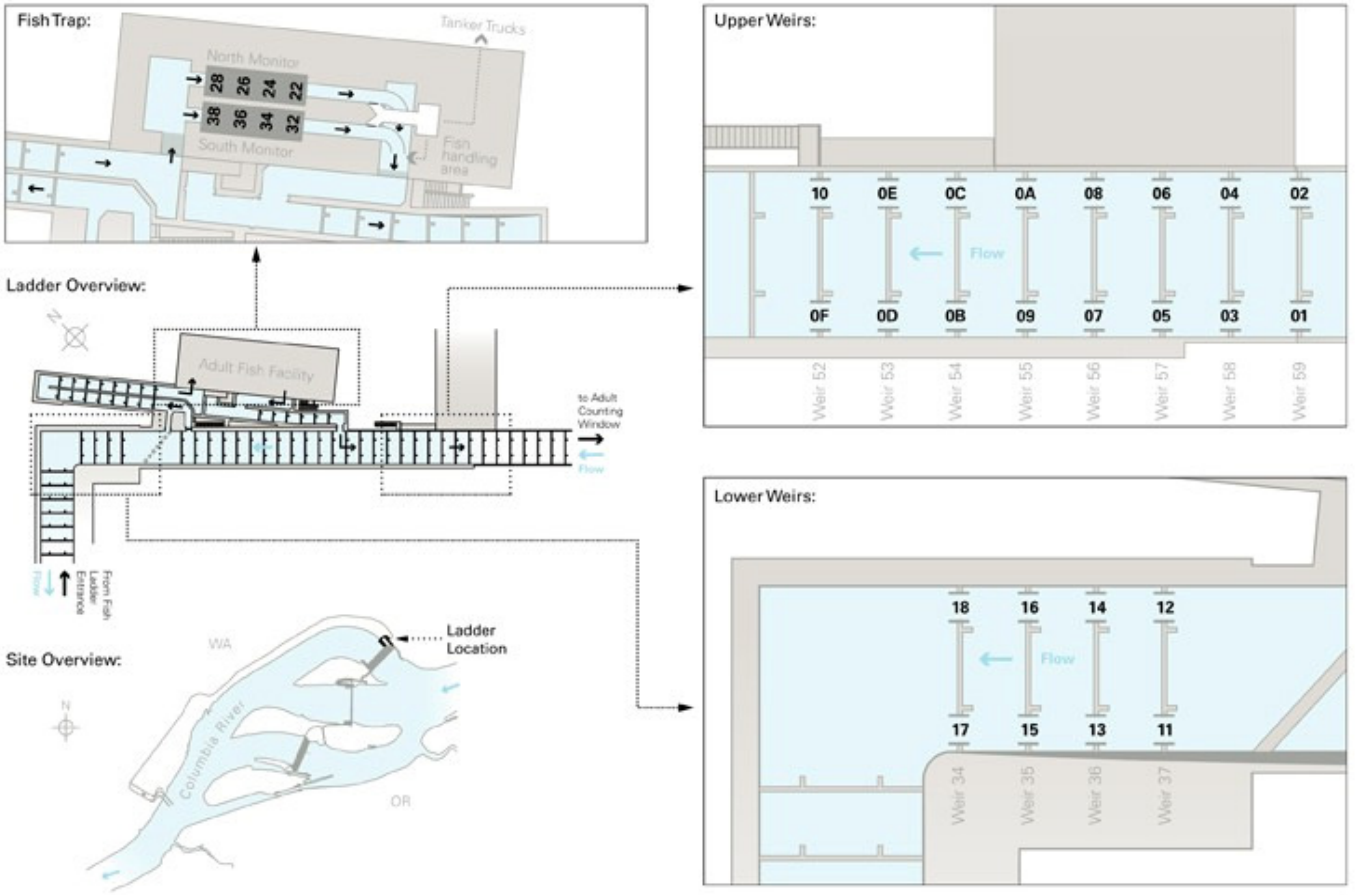
Bonneville Dam: Washington Shore Fish Ladder and AFF (BO3)

PIT Tag Interrogation Coil Map: Version 1.2, Cnfg. #110; Revised December, 2003
Orifice Dimensions: 18" wide x 18" high



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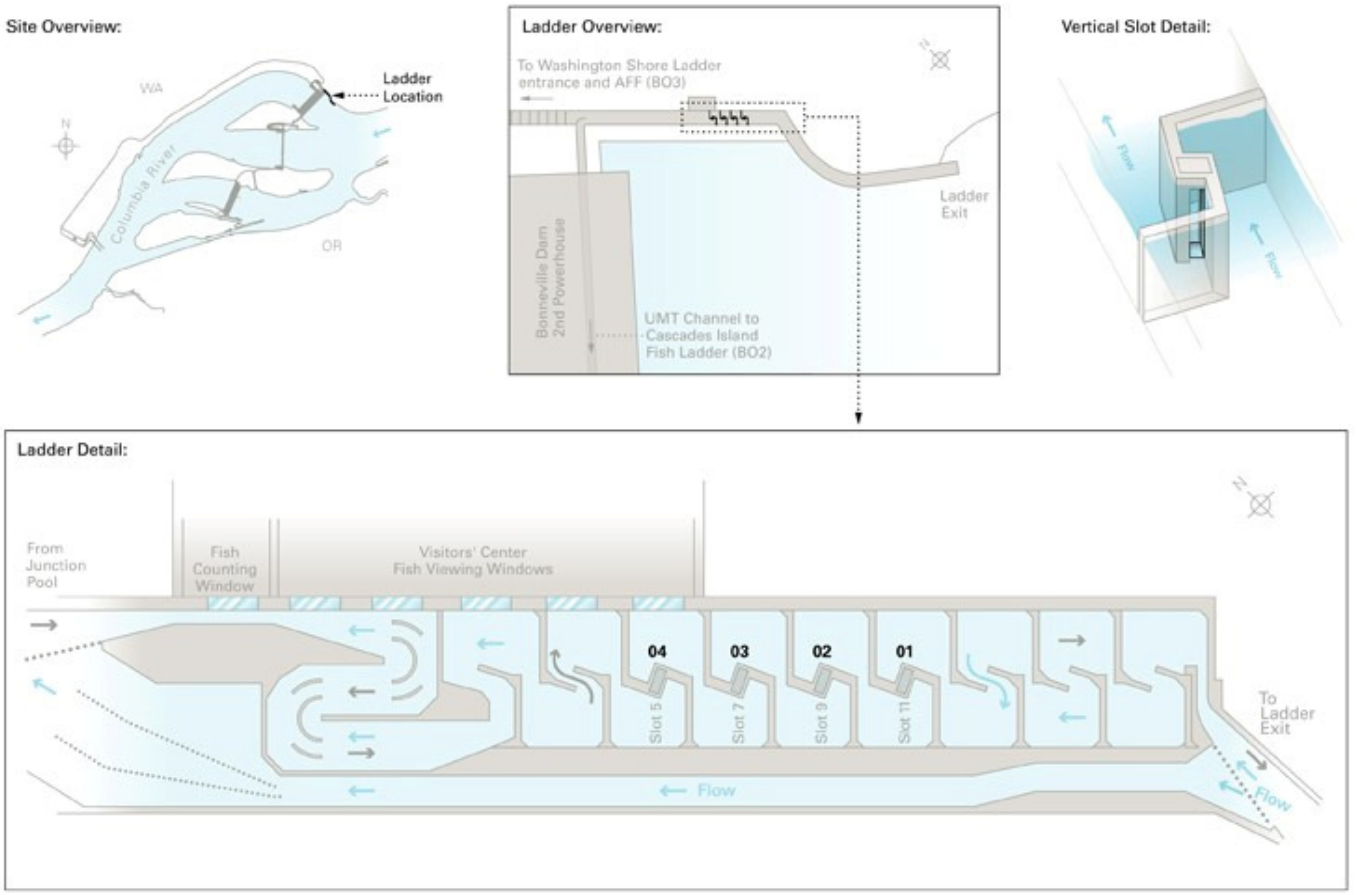
Bonneville Dam: Washington Shore Ladder Vertical Slots (BO4)

PIT Tag Interrogation Coil Map: Version 1.0, Cnfg. #100; Created March, 2005
Antenna Dimensions (ID): 28" wide x 120" high (slots 5 & 7); 28" wide x 138" high (slots 9 & 11)



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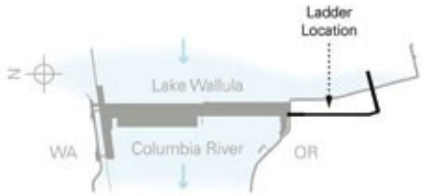
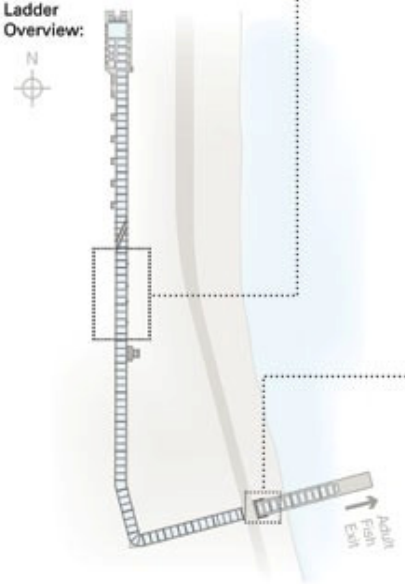
McNary Dam: Oregon Shore Ladder (MC1)

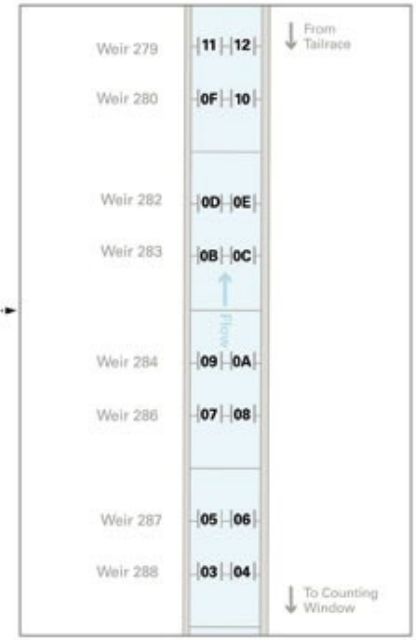
PIT Tag Interrogation Coil Map: Version 1.2, Cnfg. #100; February 2002

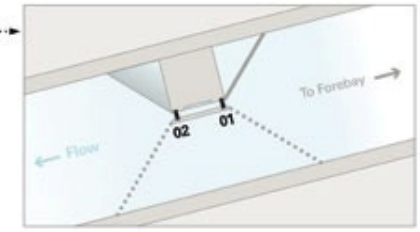
Site Overview:



Ladder Overview:

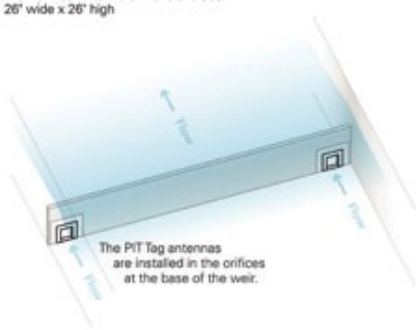






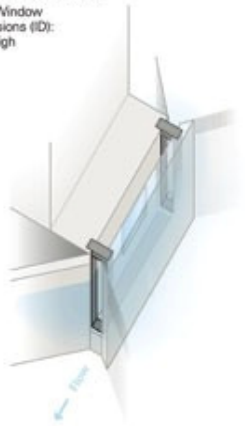
Overflow Weir Detail:

Weir Orifice Antenna Dimensions (ID):
26" wide x 26" high



Counting Window Detail:

Adult Counting Window
Antenna Dimensions (ID):
20" wide x 62" high



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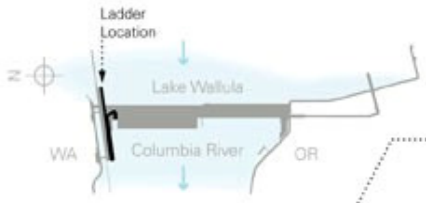
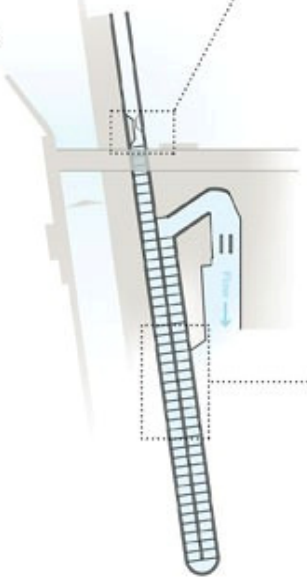
McNary Dam: Washington Shore Ladder (MC2)

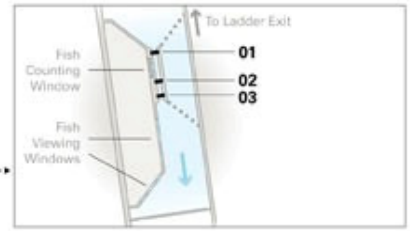
PIT Tag Interrogation Coil Map: Version 1.1, Cnfg. #120; Revised March, 2006

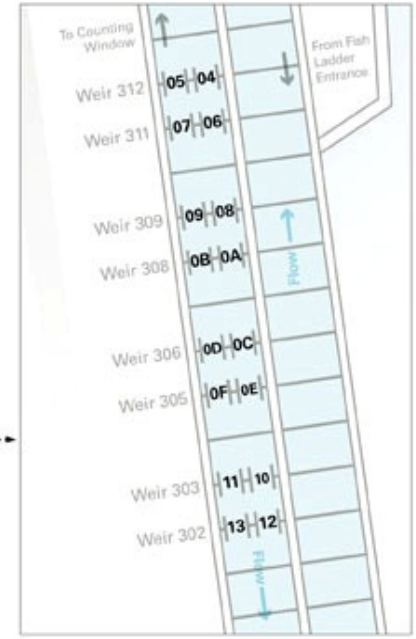
Site Overview:



Ladder Overview:

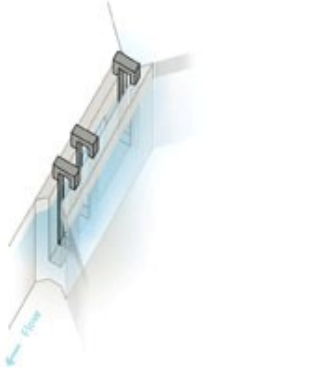






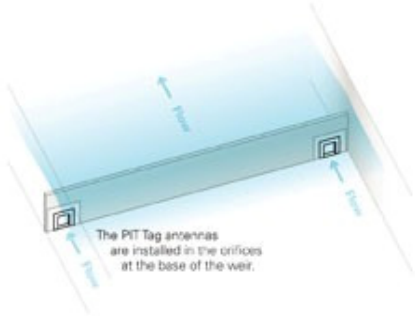
Counting Window Detail:

Adult Counting Window Antenna Dimensions (ID): 20" wide x 62" high



Overflow Weir Detail:

Weir Orifice Antenna Dimensions (ID): 21" wide x 23" high



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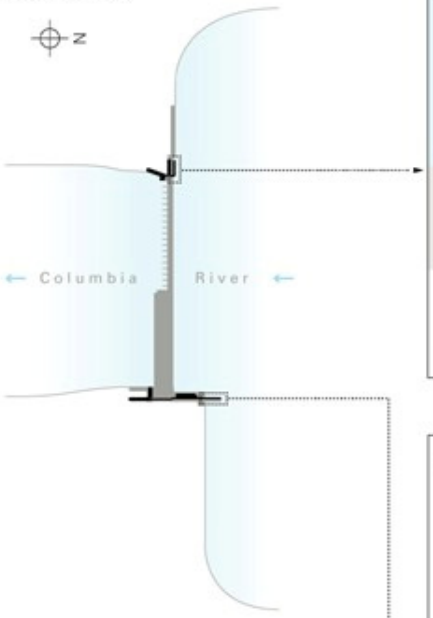
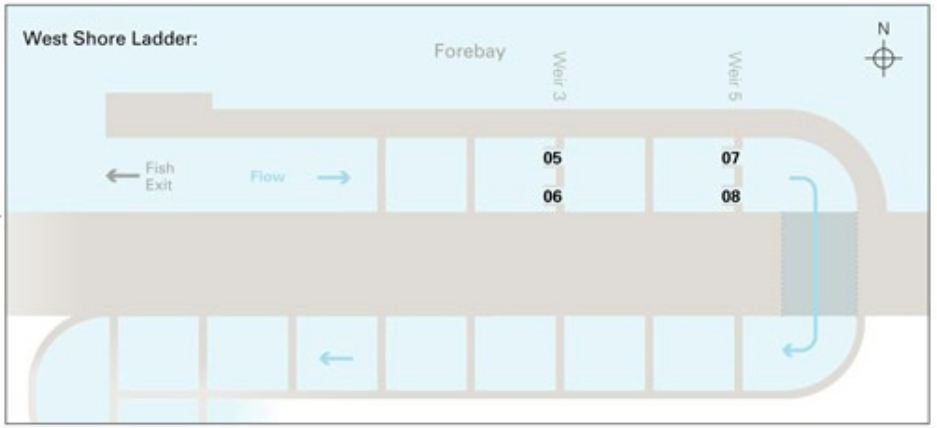
Priest Rapids Dam Fish Ladders (PRA)

Interrogation Coil Map Revised: May, 2003 v.1.0, Cnfg. #100

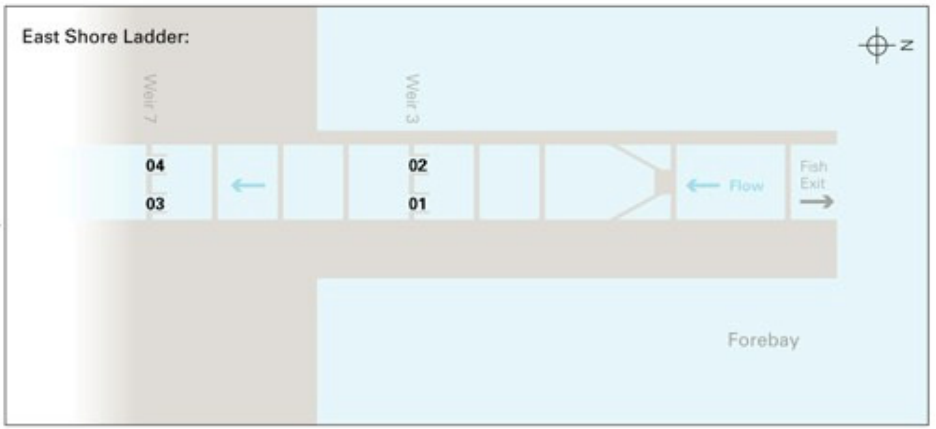
Site Overview:



West Shore Ladder:



East Shore Ladder:



PIT Tag Antenna Dimensions
two antennas per weir

West Shore (Right) Ladder
- Weir 3: 22.5" wide x 43.0" high (ID)
- Weir 5: 22.0" wide x 50.0 high (ID)

East Shore (Left) Ladder
- Weir 3: 24.0" wide x 55.0" high (ID)
- Weir 7: 24.5" wide x 45.0" high (ID)

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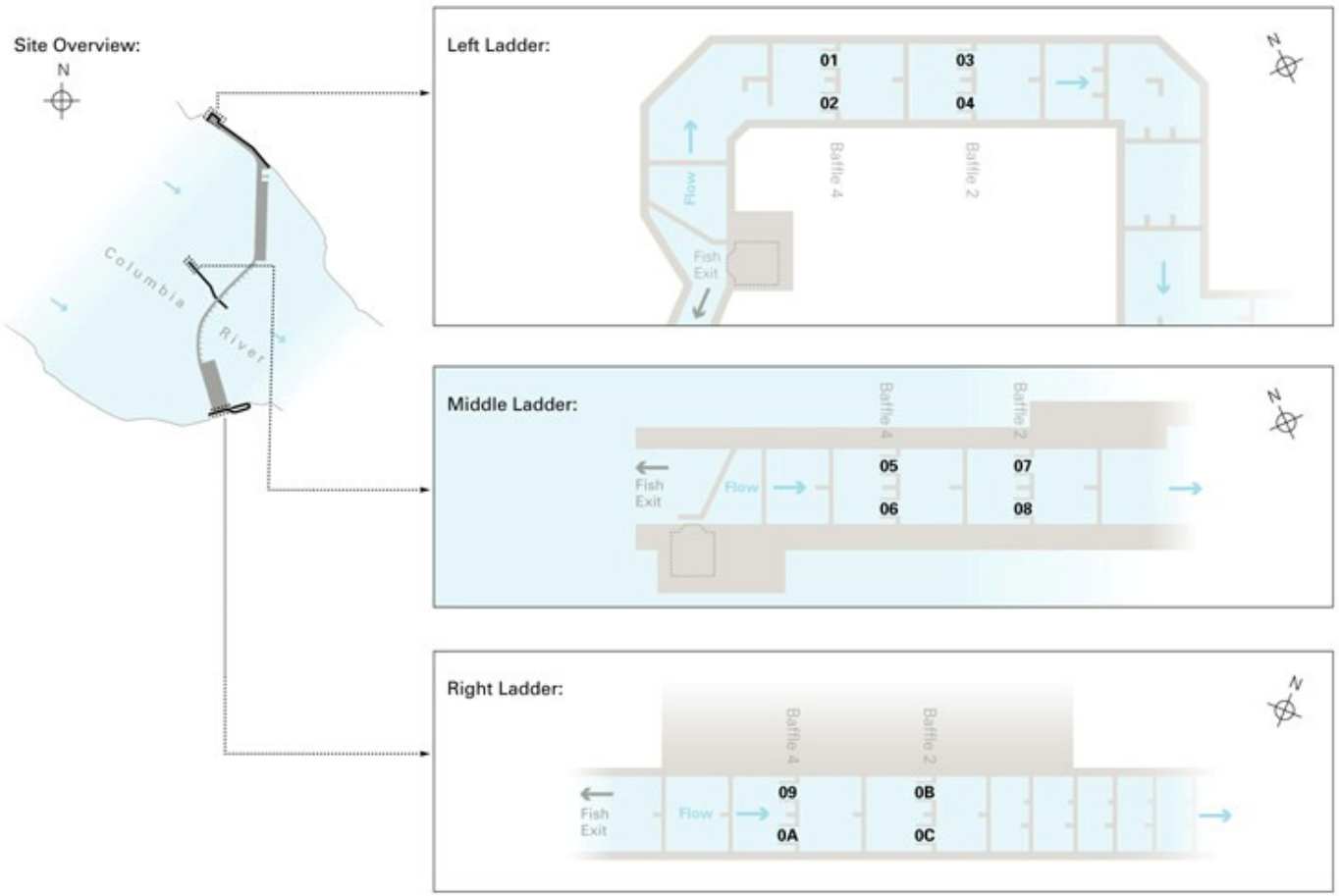
PIT Tag Information Systems
Columbia Basin

Rock Island Dam Fish Ladders (RIA)

Interrogation Coil Map Revised: May, 2003 v.1.0, Cnfg. #100
PIT Tag Antennae Dimensions: 21.5" wide x 36.5" high (ID)



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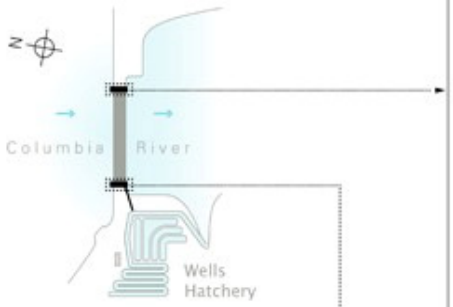
PIT Tag Information Systems
Columbia Basin

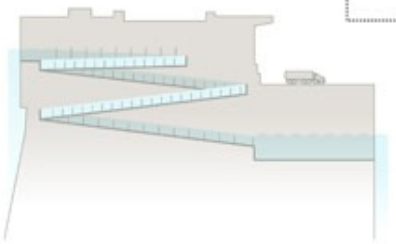
Wells Dam Fish Ladders (WEA)

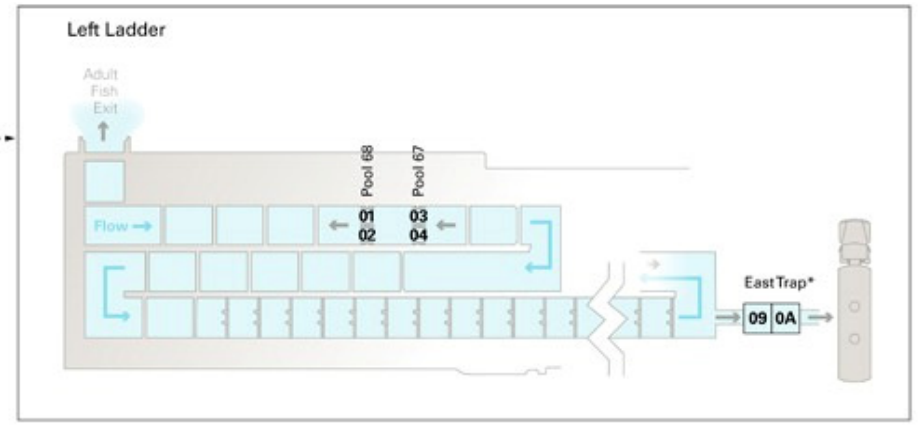
PIT Tag Interrogation Map: Version 1.1, Cnfg. #110; Revised June, 2004
Ladder Orifice Dimensions: 21" wide x 34.5" high

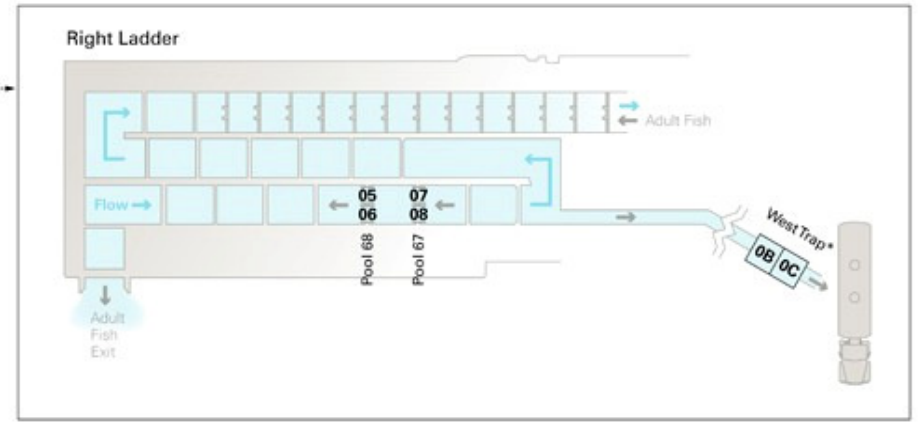
Site Overview:



Elevation View:







*Trap fish are removed to the hatchery or trucked off-site.