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CRITFC
TECHNICAL REPORT 08-02

Use of PIT tags to determine upstream migratory timing and survival of Columbia Basin sockeye salmon in 2007

Jeffrey K. Fryer

January 31, 2008

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ABSTRACT

A total of 509 sockeye salmon, *Oncorhynchus nerka*, were PIT-tagged at Bonneville Dam in 2007 and tracked upstream using detections at mainstem dam fish ladders. Based on these detections, upstream survival steadily declined as the migration progressed; Bonneville-Rock Island survival declined from over74% for sockeye salmon passing Bonneville Dam during June to less then 68% during the first two weeks of July. There was also a significant linear relationship between decreasing survival and increasing water temperature. The estimated stock composition of sockeye passing Bonneville Dam was 85.3% Okanogan and 14.7% Wenatchee.

Sockeye salmon mean travel time between Bonneville and Rock Island dams was 14.6 days, indicating a mean travel speed of 33.2 km per day. Fish passing Bonneville Dam later in the migration traveled upstream faster than those earlier in the migration.

Mark-recapture techniques were used to estimate sockeye salmon abundance at upstream dams. These techniques estimated up to 14.7% more fish at McNary Dam but at all other dams estimated 21.9% to 32.1% fewer sockeye salmon than indicated by visual dam counts. Estimated rates of sockeye salmon falling back over the dams after ascending and then reascending ranged from 0.2% at McNary Dam to 3.0% at Priest Rapids 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 white 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, this sockeye salmon population has severely declined. The estimated number of sockeye salmon passing Bonneville Dam over the most recent four year period (2004-2007) averaged 64,400 fish per year, though as recently as 1995-1998, the mean escapement was only 24,900 per year (DART 2007, Fish Passage Center 2007). The 2007 estimate of 24,376 sockeye salmon at Bonneville Dam was the lowest since 1999.

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 Okanogan River-Osoyoos Lake System (Okanogan 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 Okanogan run is the Columbia Basin's sole remaining transboundary stock. The fish spawn in the Canadian portion of the Okanogan 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 Okanogan 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).

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).

Since both stocks are believed to be limited, at least in part, by upstream survival, this study was proposed to examine upstream survival and timing by inserting Passive Integrated Transponder (PIT) tags in sockeye sampled at Bonneville Dam as part of our annual Pacific Salmon Commission (PSC)-funded sockeye stock identification project[1]. These PIT tags were then detected at upstream dam fish ladders with detection capability (McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams on the Columbia River and Ice Harbor and Lower Granite dams on the Snake River).

The fact that there are only two significant Columbia Basin sockeye salmon stocks makes the species ideal for a PIT tag study because it is easier to determine migration timing and mortality since there are not multiple tributaries

[1] In both 2006 and 2007 we were also funded by the PSC to PIT tag Chinook salmon (Fryer 2007a, 2008)

without detection facilities where fish can escape undetected. The run timing of the adult Columbia Basin sockeye salmon migration is of particular interest because the migration has become earlier over the past 70 years (Fryer 1995, Quinn et al. 1997), and a 1997 radio-tagging study 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 this study from 2006 (Fryer 2007c) concurred with Naughton (2005) regarding higher mortality during the latter portion of the run, but differed in finding that there was stock-specific migration timing.

METHODS

Sampling

Sockeye salmon were sampled at the Adult Fish Facility located adjacent to the Second Powerhouse at Bonneville Dam (river km 235) in conjunction with steelhead *O. mykiss* and summer Chinook salmon *O. tshawytscha*. Sampling typically occurred between 0900 and 1500 four to five days per week. The facility uses a picket weir to divert 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 then can 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 sampling were examined for tags (including scanning for existing PIT tags), fin clips, wounds, and condition, measured for length, and four scales removed for later age analysis and measurement for our stock identification project (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 recorded. If no tag was detected due to either the tag being shed or a malfunctioning tag no effort was made to implant another tag to eliminate the possibility of double tagging. 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 PIT tag 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, as well as at several tributaries and hatcheries in the Columbia Basin (Appendix 1). PIT tag detection data was uploaded to the PTAGIS database, where it is accessible to registered users of the site. We also supplied a PIT tag reader to the Okanagan National Alliance to use on their Okanogan River spawning ground surveys and brood stock collection activities. If a tag was not detected after release, we considered it as a tag shed and removed it from further analysis.

Stock classification

Sockeye salmon stock determinations were made by last detection point. For example, those individuals last observed at Rocky Reach or Wells dams

were classified as being Okanogan stock, those last observed at Rock Island Dam (but not observed at Rocky Reach or Wells dams) were classified as Wenatchee stock, while those last observed downstream of Rock Island were considered as unknown and were also considered mortalities. (Note that this will overestimate the proportion of the Wenatchee stock since any mortality of Okanogan-stock fish that occurs between Rock Island and Rocky Reach dams will be considered as a Wenatchee-stock sockeye salmon.) 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.

Escapement

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

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

with variance:

$$Var(N) = \sum_i \frac{Var(B_i) R_i^{\,2}}{T_i^{\,2}}$$

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 2007, Fish Passage Center 2007), 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.* For $Var(B_i)$, it was assumed that visual fish counts at Bonneville Dam are within 5% of the true count at α=0.05 (Fryer 1995).

Mortality

PIT-tagged sockeye salmon that were lost on the upstream migration (with the exception of those “lost” between Rock Island and Rocky Reach dams, which were considered to be Wenatchee stock) 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 McNary Dam and Ice Harbor where it is possible that a fish

could use the navigation locks). 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.

Also 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 placed 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.

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 Okanogan 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 *i* estimated to belong to stock *i* based on upstream recoveries.

The stock composition estimated by PIT tag recoveries was compared with that estimated by scale pattern analysis, visual interpretation of scale patterns, as well as by visual fish counts at dam fish ladders. Two visual counts are available, 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 count to estimate the Wenatchee stock abundance.

Okanogan and Wenatchee age and length-at-age composition

The age composition for the Okanogan 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 at Columbia Basin dams are not always counted using the same time period. Fish at Bonneville and McNary dam fish ladders are counted by observers only from 0400 to 2000 Pacific Standard Time for 50 minutes of each hour and the counts expanded by a factor of 1.2. Fish passing Priest Rapids, Rock Island, Rocky Reach, and Wells dams are recorded 24 hours per day and

the video later reviewed. Night passage rates (where night is defined as 2000 to 0400) were calculated by stock for all dams passed based on the last detection time for a given fish ladder. The last time detected was used as an approximation for passage time as the upper most weir was closer to the fish counting window than the lower most weir (where the first detection would be made) at all weirs except at BO4 near the Washington shore fish counting facility (Figure A1). (And at BO4, the distance between the upper most and lower most weirs is only about 25 meters.)

Fallback

There were two methods of determining fallback, which is defined as a fish that ascends a fish ladder into the reservoir above the dam, then "falls back" to the downstream side of the dam either over the spillway or through the turbines. The first was if an adult sockeye salmon was subsequently detected in the juvenile bypass system following upstream passage. However, on the Columbia River only Bonneville, John Day, and McNary dams have both juvenile bypass systems and PIT tag detection capability. Also, any sockeye salmon falling back over the spillway or through the turbines would not be detected. Therefore, I also considered sockeye salmon that had a detection at an "upper" detection weir followed by a detection at a "lower" detection weir that was separated by more than 2 hours as possible fallbacks. At McNary and Bonneville dam, the upper weir was that at the fish counting window (which is believed to detect all PIT-tagged fish passing) while the lower weirs were PIT tag detectors at lower weirs which have a lower passage efficiency for sockeye salmon[2]. At McNary and Bonneville dams, sockeye salmon that were detected at multiple ladders were also examined as possible fallbacks since "lower" detection weirs did not prove to detect sockeye very well. At Priest Rapids, Rock Island, Rocky Reach, and Wells dams, there are only two weirs with PIT tag detectors in each fish ladder so these two weirs were designated as the upper and lower detection weirs.

[2] Appendix 1 gives PIT tag detection array configurations for all mainstem Columbia Basin dams except Rocky Reach Dam. This information is also available at www.ptagis.org.

RESULTS

Sample Size

A total of 508 sockeye salmon were PIT-tagged between May 29, 2007 and July 13, 2007 (Table 1) with one fish being recaptured thus resulting in a total sample size of 509. This compares to 550 sockeye salmon sampled for our stock identification study.

Table 1. Number of PIT tagged sockeye salmon tracked at Bonneville Dam by date and statistical week in 2007.

Dates	Statistical Week	Sampled (n)	Tagged (n)	Tracked (n)
5/29,30,31	22	4	4	4
6/4,5,6,7,8	23	28	27	27
6/11,12,13,14,15	24	104	103	95
6/18.19.20.21.22	25	156	133	121
6/25,26,27,28,29	26	151	141	128
7/2,3,4,5	27	92	86	83
7/13	28	15	15	12
	Total	550	509	470

Upstream Recoveries, mortality, and escapement:

PIT tag detection data was obtained from www.ptagis.org on November 7, 2007. Of the total PIT tag sample size of 509, 470 fish were detected subsequent to release while one died in the recovery tank and two were found dead against a grate immediately downstream of the exit from the recovery area. The latter two fish died during days when shad were being forced out of the recovery area and we suspect that these fish may have inadvertently been forced out with the shad prior to full recovery. The remaining 36 fish either shed their tags prior to detection at the Bonneville Dam, or did not pass Bonneville Dam PIT tag detectors. Most of the fish that were not detected at Rock Island Dam were lost between Bonneville and McNary dams (Table 2, Figure 2). This stretch of river is where the Zone 6 tribal fishery occurs, which was estimated to harvest 1,414 of the 4,308 sockeye estimated to have been lost between Bonneville and McNary dams. A total of 10 PIT-tagged sockeye salmon, out of 730 scanned, were detected by the Okanagan Nation Alliance in Okanogan River brood stock collection and spawning ground survey activities.

Table 2. Percentage of PIT-tagged sockeye salmon detected subsequent to tagging at upstream dams, the estimated mortality, and the percentage missed at mainstem Columbia Basin dams with PIT tag adult detection capability in 2007.

Dam	Estimated percentage reaching dam	Percent lost en route	Percent "missed" by PIT tag detectors at dam
Bonneville	100.0		2.1
McNary	84.0	16.0	6.5
Priest Rapids	77.4	7.9	0.8
Rock Island	73.4	5.2	6.8
Rocky Reach	62.2	NA	0.7
Wells	609	NA	NA

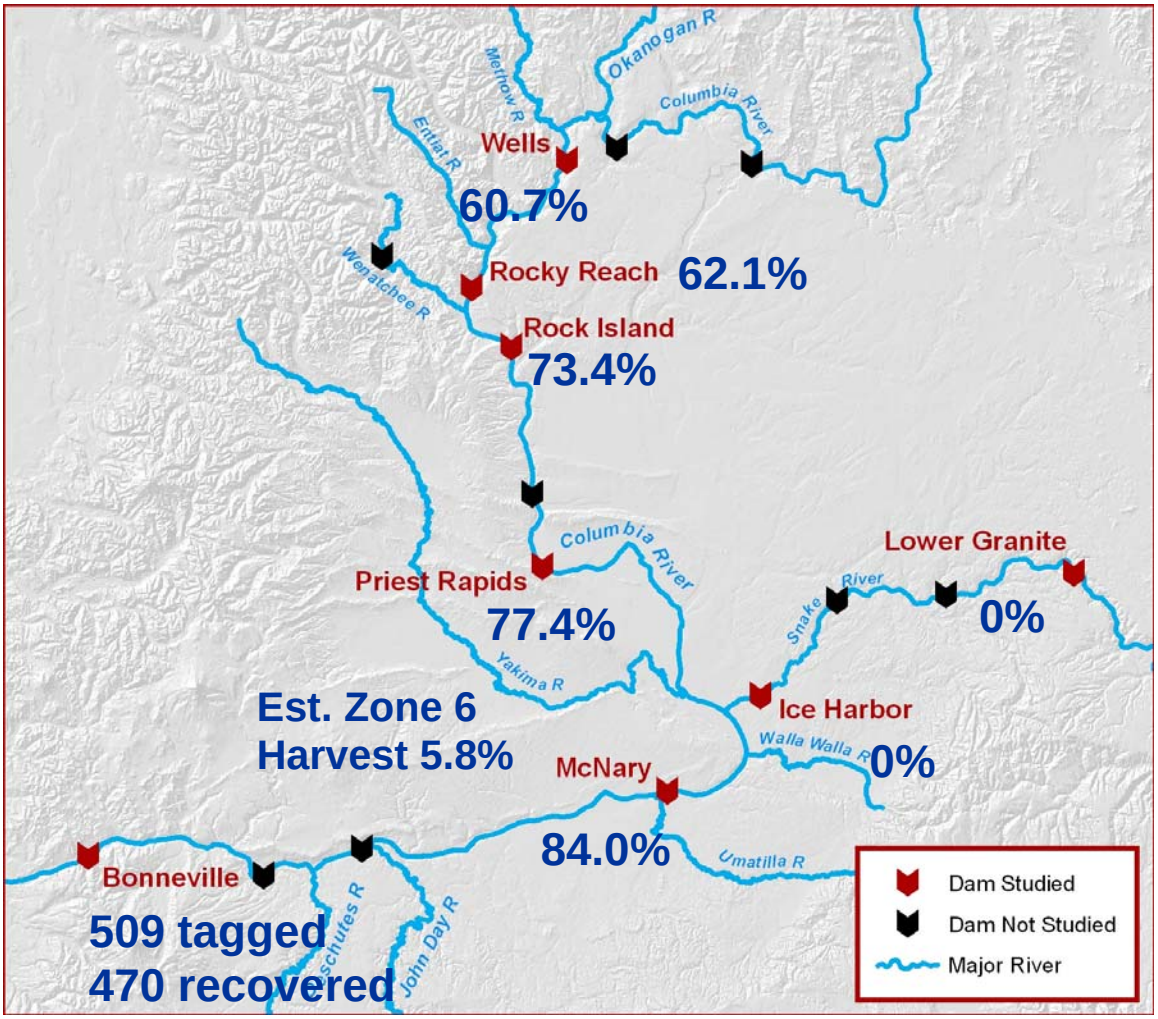

Figure 2. Map of the Columbia River Basin from Bonneville to Wells and Lower Granite dams showing the number of fish PIT-tagged at Bonneville Dam, and the percentage of the run estimated to pass McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, and Lower Granite dams in 2007.

Similar to 2006, sockeye salmon tagged at Bonneville Dam later in the migration had lower rates of survival to McNary, Priest Rapids, and Rock Island dams than fish tagged earlier in the migration (Table 3). However, these later migrating fish had higher survival rates between Rocky Reach and Wells dams which was also similar to 2006.

Table 3. Sockeye salmon survival through selected reaches by Statistical Week as estimated by PIT tag detections in 2007.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Rocky Reach-Wells
22-23	83.9%	77.4%	74.2%	91.3%
24	88.4%	84.2%	74.7%	93.9%
25	89.3%	83.5%	77.7%	97.3%
26	85.9%	82.0%	81.3%	100.0%
27	80.7%	71.1%	67.5%	98.1%
28	58.3%	41.7%	41.7%	100.0%
Composite	84.0%	77.4%	73.2%	97.7%

Rock Island and McNary dams had the largest number of fish passing upstream undetected at 6.8 and 6.5%, respectively (Table 2). Navigation locks provide a plausible means of passage that would avoid detection for McNary Dam but no such locks exist at Rock Island Dam. No estimate could be made for Wells Dam, although all 10 fish recovered on the spawning grounds were detected at Wells Dam. Data on the detection probability of individual weirs within ladders is found in Table A1, while data on the distribution of fish between ladders is found in Table A2.

Using PIT tag detections to estimate escapement at mainstem dams results in estimates that deviate from visual fish counts by 12.5% or more (Table 4). Visual fish counts at McNary Dam estimated fewer fish than those estimated using PIT tags, while Priest Rapids, Rock Island, Rocky Reach, and Wells dam visual fish counts all estimate a greater abundance than PIT tags. Unlike visual fish counts, PIT tag counts do not have the problem of more sockeye salmon being counted at an upstream dam than a downstream dam. In 2007, like 2006, the visual sockeye salmon count at Rock Island Dam was greater than that of any downstream dam.

The largest difference between the visual fish count and the escapement estimated from PIT tags was at Wells Dam. Some corroboration of the PIT tag estimate can be found from the count obtained from video recorded at Zosel

Dam on the Okanogan River upstream of Wells Dam. This count, of 17,708, is 15.7% greater than that at Wells Dam. Since Zosel Dam does not have any PIT tag receivers it is not possible to estimate escapement from PIT tag data.

Table 4. Sockeye escapement at McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams as estimated from both PIT tag recoveries and dam counts, and the difference between the two estimates in 2007.

Dam	Estimate	Standard Deviation	Visual Fish Count	Difference
McNary	20,868	277	18198	14.7%
Priest Rapids	19259	261	26465	-21.9%
Rock Island	18.249	248	25122	-27.4%
Rocky Reach	15,341	209	20683	-25.4%
Wells	15,131	206	22282	-32.1%

Bonneville to McNary survival significantly decreases with increasing temperatures (p=0.015, Figure 3), but not with increasing flow (p=0.296) or week of migration (p=0.113). All three variables are highly correlated with absolute correlation coefficients ranging from 0.83-0.96. McNary to Rock Island survival shows no significant relationship with statistical week passing McNary Dam (0.198), Priest Rapids Dam flow (0.962) or temperature (p=0.195).

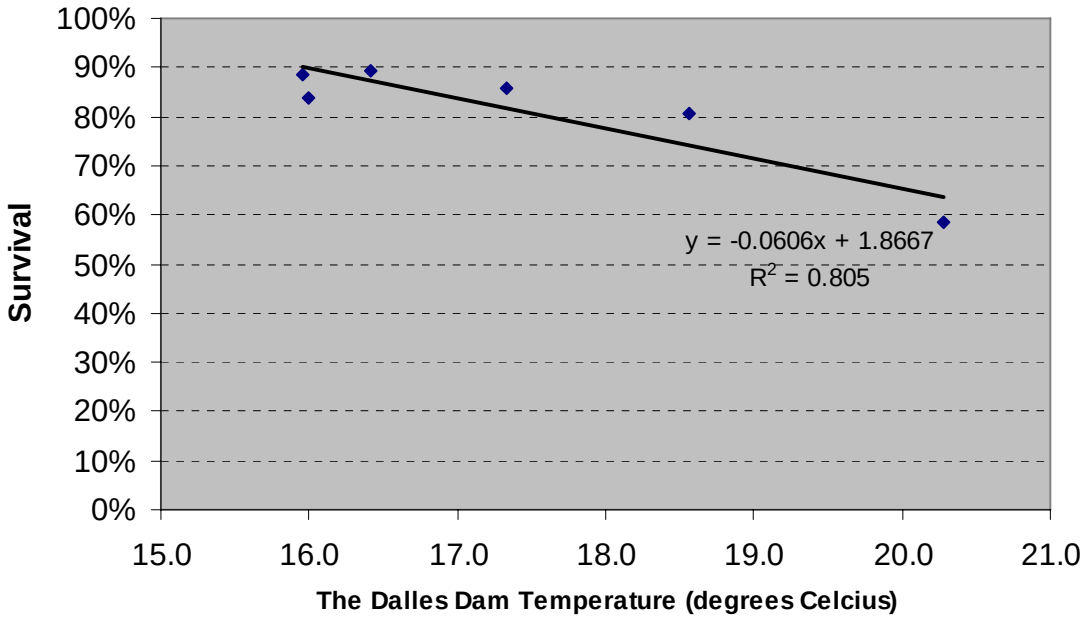

Figure 3. Figure showing the linear relationship between the survival of PIT-tagged sockeye salmon from Bonneville to McNary Dam and mean water temperature at The Dalles Dam by statistical week in 2007.

Migration Timing and Passage Time

Sockeye salmon travel quickly upstream, with a median travel time between Bonneville and Rock Island Dam of only 13.9 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 for Bonneville-Rock Island and Priest Rapids-Rock Island, but all other relationships tested in Table 6, with the exception of Rocky Reach to Wells, are significant at the α=0.10 level. The median travel time for Wenatchee stock fish is greater than that for Okanogan stock fish for those dam pairs that both stocks pass (Table 6).

Table 5. Median sockeye salmon migration time and travel rates between mainstem dams as estimated by PIT tag recoveries in 2007.

Dam pair	Distance (km)	Median time (days)	Median travel time (km/day)
Bonneville-McNary	231	4.9	47.3
McNary-Priest Rapids	167	4.8	34.3
Priest Rapids-Rock Island	89	3.6	24.5
Rock Island-Rocky Reach	33	1.6	21.3
Rocky Reach-Wells	65	2.3	28.2
Bonneville-Rock Island	487	13.9	35.1
Bonneville-Wells	585	17.9	32.8

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 2007.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Bonneville-Rocky Reach	Bonneville-Wells	McNary-Priest Rapids	Priest Rapids-Rock Island	Rock Island-Rocky Reach	Rocky Reach-Wells
23	5.8	13.8	18.2	21.7	26.1	7.9	5.0	1.9	2.8
24	5.1	11.6	16.9	17.9	21.3	6.1	4.8	2.0	2.7
25	4.9	9.8	14.0	15.0	17.9	4.9	4.0	1.2	2.3
26	4.9	9.2	12.2	13.6	16.0	4.2	3.0	1.2	2.2
27	4.8	8.9	12.1	13.8	16.7	4.1	2.9	1.6	2.3
28	4.5	8.1	12.1	14.1	15.9	3.8	3.2	1.7	2.1
F-Statistic	0.01	<0.01	0.01	0.11	0.07	0.01	0.01	0.93	0.07
Stock									
Okanogan	4.8	9.7	13.1	15.1	17.8	4.7	3.4	1.6	2.3
Wenatchee	5.2	11.1	16.0	NA	NA	5.4	4.3	NA	NA
Unknown[3]	4.9	11.5	NA	NA	NA	5.5	NA	NA	NA

[3] Unknown stock sockeye salmon are those that were not detected at Rock Island Dam and are likely mortalities on the upstream migration.

The median time between first detection and last detection is less than two hours at all dams except Bonneville Dam (Table 7.)

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 2007.

Dam	Median Passage Time (Minutes)	Taking more than 12 hours- (%)
Bonneville	103	15.8
McNary	0	1.8
Priest Rapids	6	2.4
Rock Island	4	1.2
Rocky Reach	3	1.2
Wells	3	1.7

Stock composition estimates

The percentage of Okanogan stock sockeye salmon at Bonneville Dam steadily increased as the run progressed while the Wenatchee portion of the run decreased (Table 8). The overall stock composition estimate of 14.7% Wenatchee and 85.3% Okanogan was similar to that estimated using dam counts (Table 8).

Of the 13 adipose clipped sockeye PIT salmon tagged at Bonneville Dam, and presumed to be from either a Wenatchee hatchery program or a Skaha Lake (which is located just upstream of Osoyoos Lake) reintroduction program, only one was last detected at Rock Island Dam (and thus classified as Wenatchee stock), while eight were last detected at Wells Dam (and thus classified as Okanogan stock), with the four remaining sockeye last detected downstream of Rock Island Dam and thus considered unknown.

Table 8. Weekly and composite sockeye salmon stock composition at Bonneville Dam as estimated by PIT tags in 2007 and a comparison to stock composition estimates estimated using visual dam counts.

Statistical Week	n	Percent Wenatchee	Percent Okanogan
22-23	27	0.0	100.0
24	95	32.4	67.6
25	121	22.3	77.7
26	128	7.7	92.3
27	83	5.4	94.6
28	12	0.0	100.0
Composite	470	14.7	85.3
Visual Fish Counts at dams-(using difference between Rock Island and Rocky Reach for Wenatchee estimate)		17.7	82.3
Visual Fish Counts at dams -(Tumwater count as Wenatchee estimate)		18.1	81.9

Okanogan and Wenatchee age and length-at-age composition

Age composition estimates based on upstream PIT tag detections differed considerably from those estimated from scales from sockeye salmon collected at Wells and Tumwater dams (Table 9). Many of these differences are not significant due to large standard deviations resulting from small sample sizes in the Wells sample and the small number of PIT tagged fish classified as being from the Wenatchee stock. However, even taking this into consideration, the Okanogan age composition estimates were significantly different ($p<0.001$). PIT tags indicated that the proportion of Age 1.1 sockeye in the Okanogan stock was 42.4%, while our Wells sample indicated 11.4%. Conversely, the PIT tag estimate for Age 1.3 portion of the run was 2.9%, compared to 33.5% for the Wells sample. This suggests that the trap used for sampling is not efficient at capturing smaller (one-ocean) sockeye salmon, which was something suspected, but not confirmed, by Douglas PUD biologists (Shawn Bickford, Douglas County Public Utility District, e-mail personal communication, December 3, 2007.) Length-at-age estimated by the two methods are similar, with mean lengths not differing by more than 1.0 cm for estimates where 10 or more PIT-tagged fish were recovered (Table 10).

Table 9. Age composition (%) of Wenatchee and Okanogan stock sockeye salmon in 2007 as estimated by upstream detection of PIT tags (with standard deviations in parentheses) as well as by sampling at Tumwater and Wells dams.

	Age					
Estimate	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Wenatchee PIT tag	12.1 (17.2)	28.0 (30.1)	33.3 (31.2)	1.8 (8.3)	17.2 (19.7)	7.6 (15.4)
Wenatchee-Tumwater	0.3 (0.3)	8.1 (1.4)	42.8 (2.7)		32.8 (2.6)	15.9 (2.0)
Okanogan-PIT tag	42.4 (3.3)	38.4 (3.1)	2.9 (1.3)	5.8 (1.8)	10.0 (2.0)	3.6 (0.6)
Okanogan-Wells Dam	11.4 (2.0)	34.7 (6.8)	33.5 (7.3)	0.5 (0.3)	16.3 (5.9)	3.6 (3.4)

Table 10. Length-at-age composition of Wenatchee and Okanogan stock sockeye salmon in 2007 as estimated by upstream detection of PIT tags as well as by sampling at Tumwater and Wells dams.

		Age					
Stock	**Statistic**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**
Bonneville mixed stock	Mean	39.6	51.0	57.4	42.3	52.3	57.9
	St. Dev.	2.8	3.0	2.8	2.0	3.1	2.4
	N	201	162	60	32	56	15
Okanogan (PIT tags)	Mean	39.6	50.9	56.7	42.3	51.5	57.5
	St. Dev.	3.0	3.0	3.0	2.0	2.7	4.9
	N	134	96	10	18	27	2
Okanogan (Wells sampling)	Mean	39.5	53.2	57.6	43.5	54.1	61.0
	St. Dev.	2.5	3.2	2.4	3.5	2.6	-
	N	41	40	20	2	18	1
Wenatchee (PIT tags)	Mean	40.4	51.8	57.8	41.5	52.5	58.3
	St. Dev.	3.6	2.8	2.4	-	4.1	1.1
	N	4	11	24	1	7	6
Wenatchee (Tumwater Sampling)	Mean	42.5	52.0	57.3		52.4	56.8
	St. Dev.	-	3.2	2.2		3.1	2.5
	N	1	35	165		121	59

Fallback

Estimated fallback rates for sockeye salmon ranged from 0% at Bonneville to 3.3% at Wells Dam (Table 11).

Table 11. Estimated sockeye salmon fallback at mainstem Columbia River dams in 2007 as estimated by PIT tag detections.

Dam	**Sockeye (%)**
Bonneville	2.7
McNary	0.2
Priest Rapids	3.0
Rock Island	1.2
Rocky Reach	1.0
Wells	2.7

Night Passage

Okanogan stock sockeye salmon passed dams at night (2000-0400) at a higher rate than Wenatchee stock sockeye salmon (Table 12). The Bonneville Dam estimate of night time passage is likely biased low due to the fact that tagging occurred between about 0900 and 1500. If a “night” passing sockeye salmon at one dam is more likely to pass subsequent dams at night, our time of sampling could bias low all nighttime passage estimates. However, among the sockeye salmon that did pass at night, there did not appear to be a tendency for fish to pass multiple dams at night (Table 13).

Table 12. Estimated sockeye salmon nighttime passage (2000-0400 standard time) in 2007 at mainstem Columbia River dams as estimated by PIT tag detections

Dam	All Sockeye (includes unknown)	Okanogan Stock	Wenatchee Stock
Bonneville	2.0	2.4	0.0
McNary-Oregon Shore	5.0	6.0	3.8
McNary-Washington Shore	6.1	6.9	3.7
Priest Rapids	5.4	6.1	1.8
Rock Island	4.3	4.8	1.8
Rocky Reach	8.8	8.8	NA
Wells	15.2	15.2	NA
Mean McNary, Priest Rapids and Rock Island	5.1	5.8	2.5

Table 13. Number of dams passed at night (2000-0400 standard time) by PIT-tagged Okanogan and Wenatchee sockeye salmon in 2007.

Total Dams passed at night	Okanogan	Wenatchee	Unknown
1	90	5	5
2	17	0	0
3	1	0	0

DISCUSSION

This study demonstrates the feasibility of using PIT tags to assess adult sockeye salmon migration, timing, escapement, Wenatchee and Okanogan stock age and length-at-age composition, mortality, fallback rates, and weekly and total stock composition at Bonneville Dam.

Stock composition estimates produced by this study were consistent with those estimated using upstream dam counts. However, both estimates do not allow classification of sockeye salmon at Bonneville Dam that do not appear at Rock Island Dam, which made up of 27.8% of the run. Our estimate of 14.7% Wenatchee and 85.3% Okanogan assumes that these presumed mortalities have a similar classification. Scale pattern studies that we have conducted over the past 22 years (Fryer 2007b) do offer stock composition estimates at Bonneville Dam unaffected by this potential bias, however scale pattern analysis suffers from insufficient sample size of some age classes and often high estimates of variability.

Our stock composition estimate is also likely biased because we classified all sockeye detected at Rock Island Dam, but not Rocky Reach or Wells dams as Wenatchee stock. It is likely that some of these fish were in fact Okanogan fish that were mortalities. This likely explains at least a portion of the 13.9% of the Wenatchee stock that were estimated to be of Age 1.1 or 2.1. This is an age class that we have almost never seen in our Wenatchee known stock in the 22 years of the stock identification study (although we did see one Age 1.1 fish out of 400 sampled at Tumwater Dam in 2007), but which frequently observed for the Okanogan stock.

As in 2007, the results of this study differ from those of Naughton (2005) with respect to run timing. Naughton found that there was no difference in run timing between the two stocks, while we found a significant relationship between run timing and stock composition, with a higher percentage of the Wenatchee stock migrating in the early portion of the run. This finding was similar to what we have found in most years of our stock identification study (e.g. Fryer 1995, 2006). A later migrating Okanogan stock, combined with a higher mortality for later migrating fish suggests that the Okanogan stock has higher upstream migration mortality than the Wenatchee stock. Indeed, combining our weekly stock

composition and mortality rates results in 87.2% of the Bonneville-Rock Island mortality being allocated to the Okanogan stock with the remainder allocated to the Wenatchee stock; resulting in an estimated stock composition at Rock Island Dam of 84.6% Okanogan and 15.4% Wenatchee stock. This compares to a Bonneville Dam stock composition of 85.3% Okanogan and 14.7% Wenatchee (Table 8).

PIT tags provide an easier, much cheaper, and less intrusive method of monitoring the upstream migration than radio tags used in past studies (e.g. Naughton (2005). However, PIT tags may not provide the same data that can be collected in a radio tag study. For example, PIT tag detectors are not installed at all mainstem dams, nor are they present in many tributaries. However, new detection sites, particularly at dams, are continually being added. Ultimately, it seems likely all dams in the Columbia Basin with upstream passage facilities will be wired with PIT tag detectors. Key dams for sockeye salmon would be Tumwater Dam on the Wenatchee River and would be Zosel Dam on the Okanogan River near the Canadian border. PIT tag detection capability at Zosel dam would allow mortality to be estimated on the reach from Wells Dam to Lake Osoyoos, where mortality is believed to be high.

The percentage of sockeye salmon passing dams undetected (Table 2), though small, was generally higher than it should have been given the high detection rate estimated at individual weirs (Table A1). At all fish ladders, overall detection based on individual weirs was 100% with the exception of the Rock Island center right at 99.3%, the Wells Dam Right ladder at 99.4%, and the Rocky Reach ladder at 95.3%. This suggests that a small number sockeye salmon have some characteristic (e.g. a malfunctioning or poorly placed PIT tag or some behavior), that allows them to escape detection at multiple weirs at a given dam. Conversely, the percentage missing Rocky Reach Dam was less than expected based on individual weir detection rates.

During the week of July 2, we had four sockeye mortalities which resulted in us being unable to sample sockeye salmon from July 6 through July 12. Two of these sockeye salmon were found impinged on a grate immediately downstream of the recovery area. We suspect that these fish were forced out of the recovery area prematurely with shad that do not self-release and thus must be forced out manually. Of the remaining two mortalities, one fish was in poor

condition when it entered the anesthetic tank while the other never recovered from the anesthetic. Until this year, mortalities have been very low from our sockeye sampling program averaging well under one per year.

Another problem which we encountered in 2007 was an increase in the number of sockeye salmon that were PIT tagged, but not detected after PIT tagging. In 2006, we had 20 such fish, while in 2007 we had 39 such fish. We had a similar increase in Chinook salmon undetected after release from 1 in 2006 to 20, most of which were jacks which are similar in size to sockeye salmon. We suspect that these "missing" Chinook and sockeye salmon lost their tags immediately after tagging, but they could also have swam downstream without going through PIT tag detectors located in the vertical slots (which sockeye do not tend to use). Leading some credence to this latter theory is the fact that 11.2% of PIT tagged sockeye salmon passed the Oregon shore counting station at Bonneville Dam, compared to only 2.3% in 2006. This suggests that sockeye moved downstream after tagging at a much higher rate than in 2006.

In 2008, detection data will be more closely monitored to detect possible tagging errors. We also will allow sockeye to recover in a small recovery tank where they are not vulnerable to premature release as could have happened in 2007. The smaller recovery tank can also be scanned for possible shed tags which is impossible in the larger recovery area used in 2007. Finally, we plan to set up a computerized video system (FishTick by Salmonsoft) to record our sampling, including the PIT tagging. FishTick will accept as input the PIT tag signal and imprint this on the video when the fish is scanned after tagging. This will allow us to review fish not detected after release to ensure that proper tagging procedures were correctly applied.

This project will be benefited by the installation of a PIT tag detector at Tumwater dam on the Wenatchee River in 2008. This will allow for a better estimate of the fate of fish which pass Rock Island Dam but not Rocky Reach Dam. We also suspect that we would find that some sockeye salmon detected at Rocky Reach or Wells dams ultimately fall back over the dams and end up in the Wenatchee River (where they may be detected at Tumwater Dam).

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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 2007.

Dam and site	Weir and probability of detection at weir											Overall Detection Probability
Bonne-ville	**N**	**1**	**2**	**3**	**4**							
BO4	395	99.2	100.0	99.7	98.7							100.0
BO1	50	100.0	100.0	100.0	98.0							100.0
McNary		**1**	**2**	**288**	**287**	**286**	**284**	**283**	**282**	**280**	**279**	
MC1	192	98.9	100.0	19.3	20.8	26.0	22.4	22.4	23.4	13.5	29.2	100.0
		1	**2**	**3**	**312**	**311**	**309**	**308**	**306**	**305**	**303**	
MC2	181	98.9	100.0	97.8	7.8	8.8	4.4	8.8	10.5	3.3	12.7	100.0
Priest Rapids		**3**	**7**									
East	317	95.9[a b]	99.7									100.0
		3	**5**									
West	**58**	98.3	100									100.0
Rock Island		**1-2**	**3-4**									
Left	59	100.0	100.0									100.0
		5-6	**7-8**									
Middle	59	98.3	100.0									100.0
		09-0A	**0B-0C**									
Right	205	97.2	64.9									99.0
Rocky Reach		**1-2**	**3-4**									
	249	76.3	80.3									95.3
Wells		**1-2**	**3-4**									
Left	137	97.1	100.0									100.0
		5-6	**7-8**									
Right	154	100.0	99.6									99.4

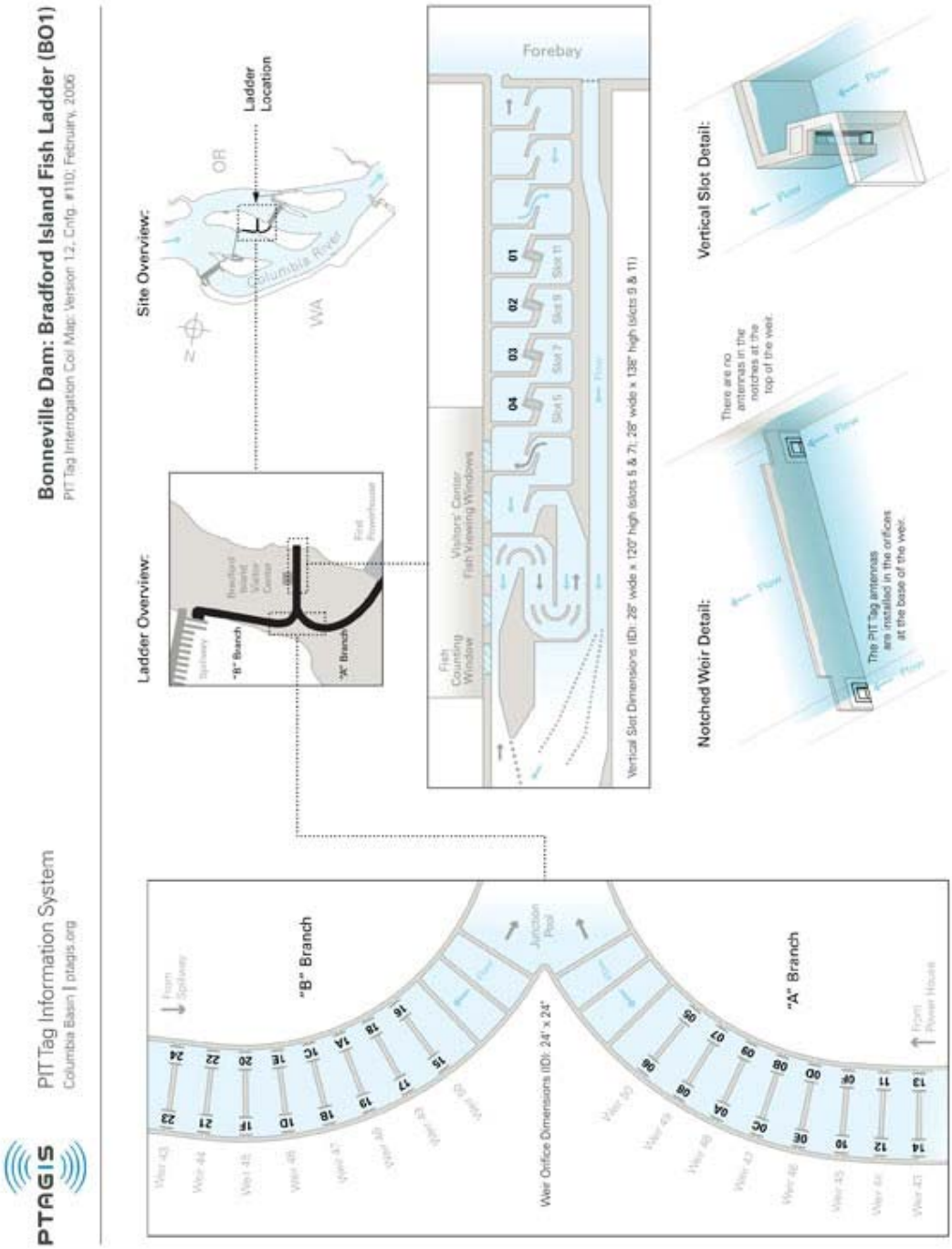
[a] Fish bypass this weir when the Priest Rapids adult fish trap is in operation.

Table A2. Distribution of sockeye salmon by fish ladder for dams with multiple fish ladders as estimated by PIT tag detections in 2007.

Dam	Right Bank[a]	Left Bank	Center
Bonneville	88.7%	11.3%	
McNary	51.5%	48.5%	
Priest Rapids	15.5%	84.5%	
Rock Island	64.1%	17.9%	17.9%
Wells	47.1%	52.9%	

[a] 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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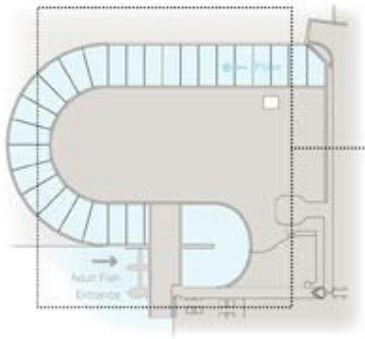
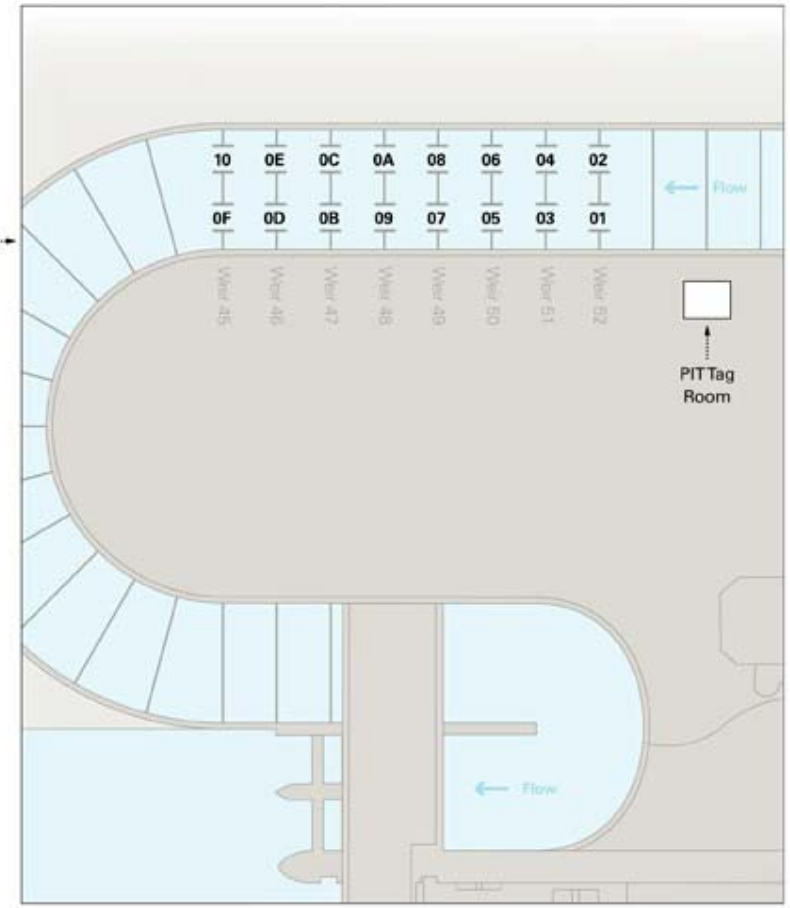
Bonneville Dam: Cascades Island Fish Ladder (BO2)

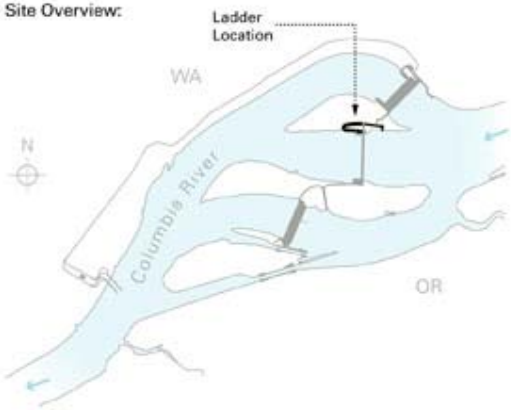
PIT Tag Interrogation Coil Map: Version 1.1, Cnfg. #100; February, 2002
Orifice Dimensions: 24" wide x 24" high

Ladder Overview:





Site Overview:



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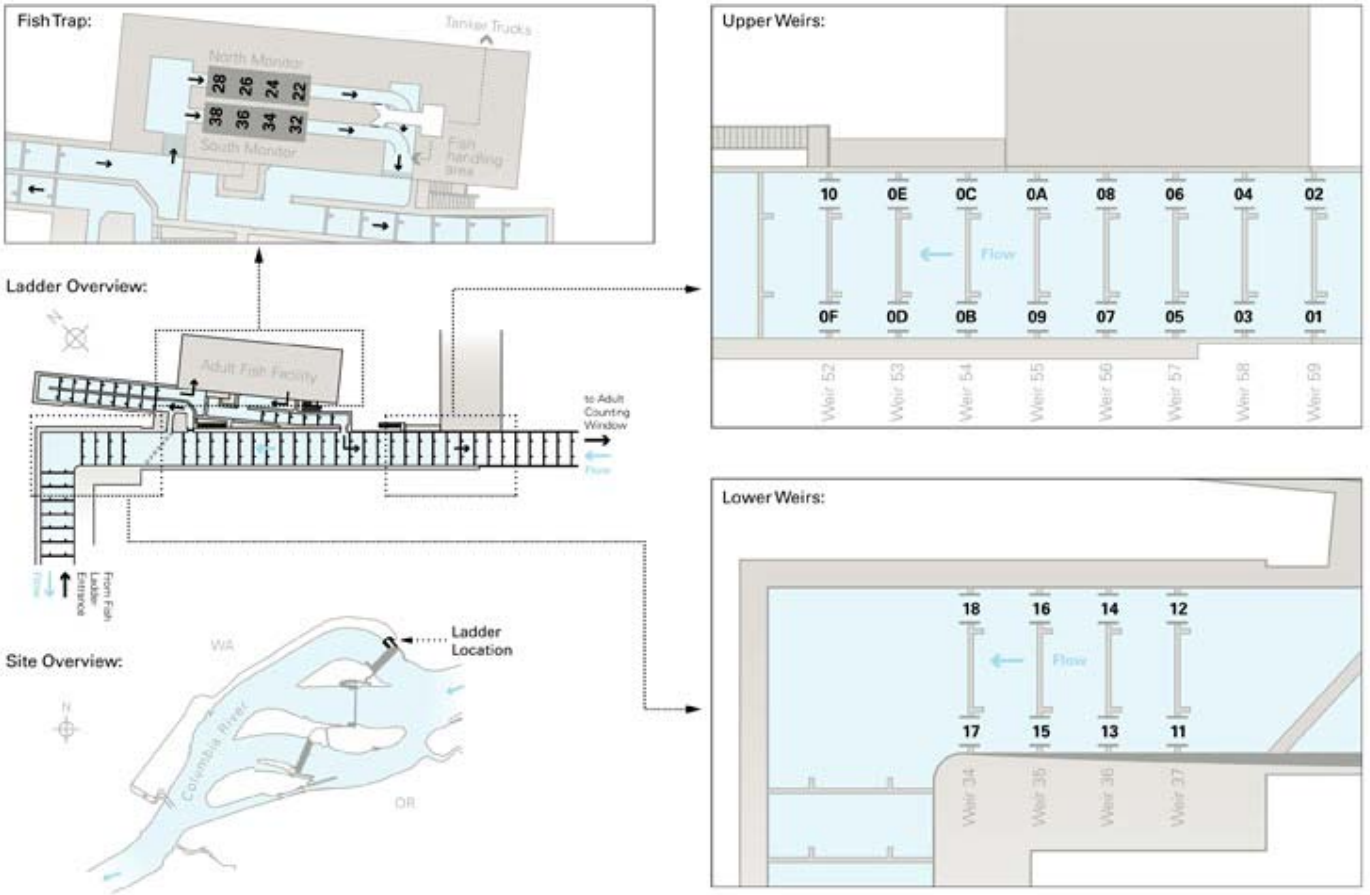
Bonneville Dam: Washington Shore Fish Ladder and AFF (BO3)

PIT Tag Interrogation Coil Map: Version 1.2, Cnfg. #110; Revised December, 2003

Orifice Dimensions: 18" wide x 18" high



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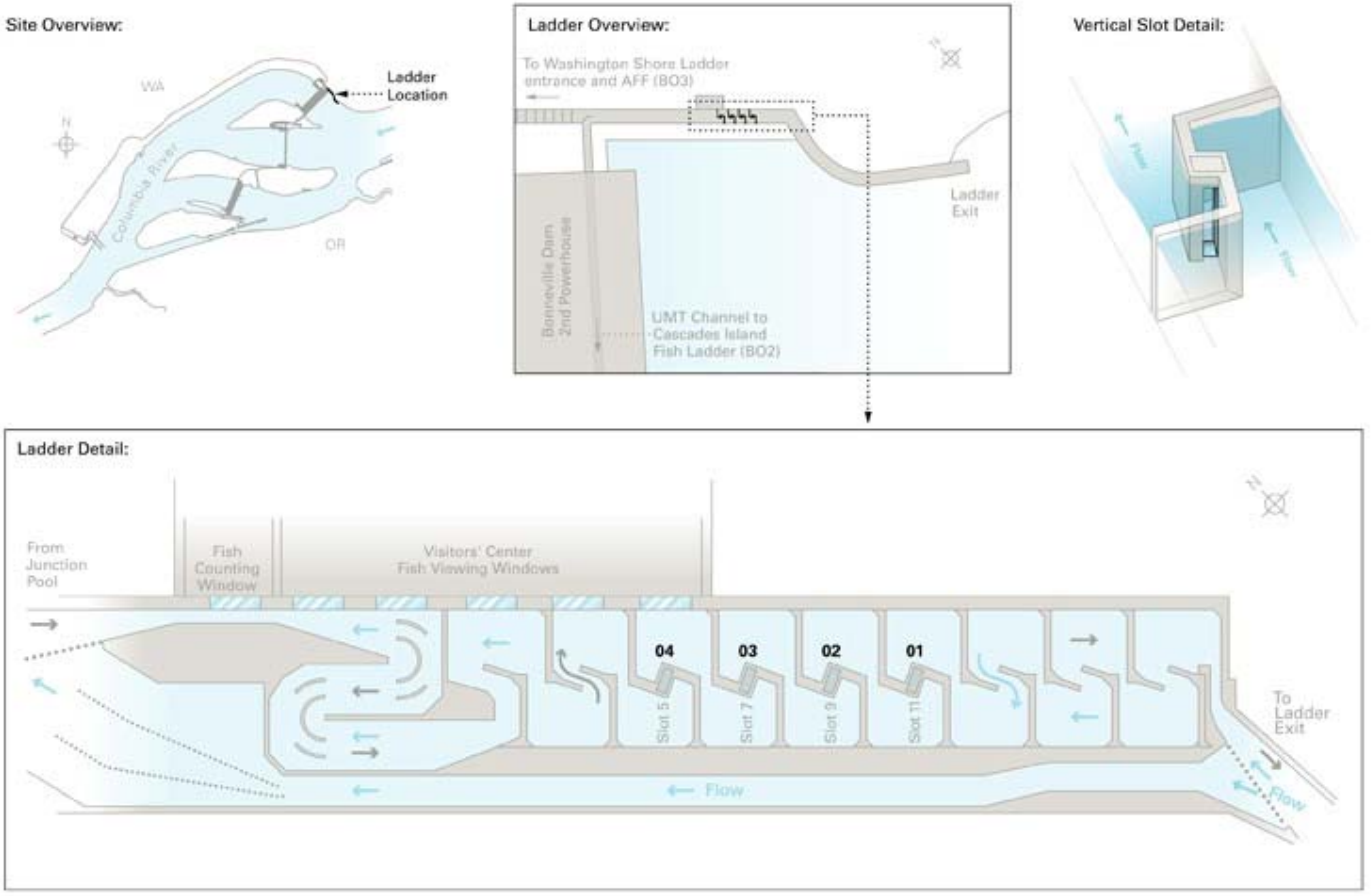
Bonneville Dam: Washington Shore Ladder Vertical Slots (BO4)

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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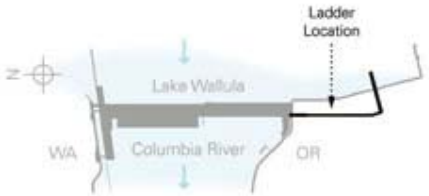
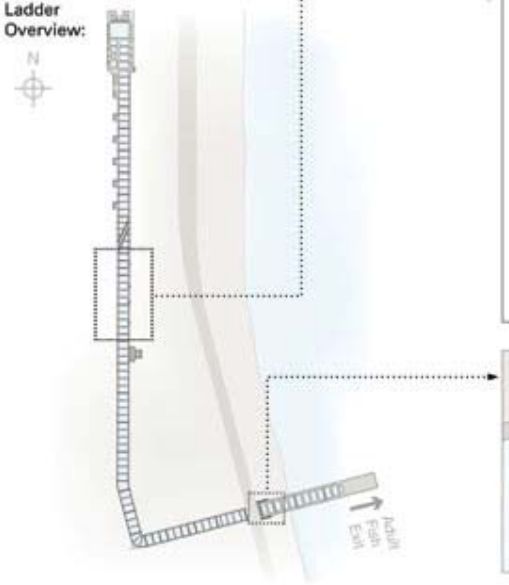
McNary Dam: Oregon Shore Ladder (MC1)

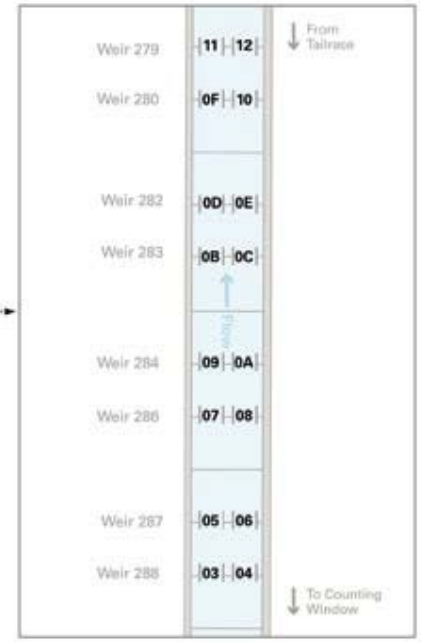
PIT Tag Interrogation Coil Map: Version 1.2, Cnfg. #100; February 2002

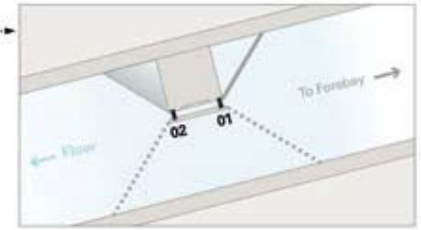
Site Overview:



Ladder Overview:

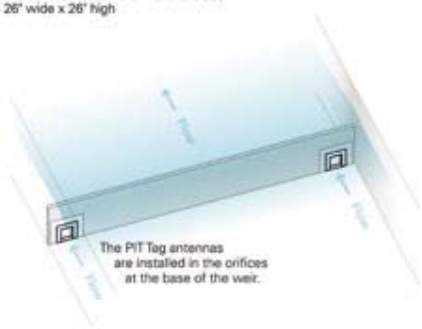






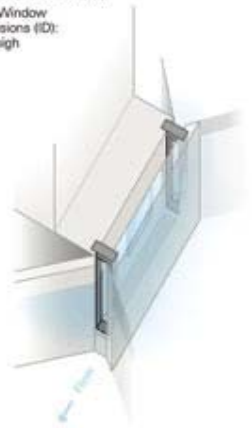
Overflow Weir Detail:

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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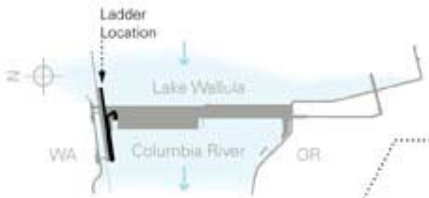
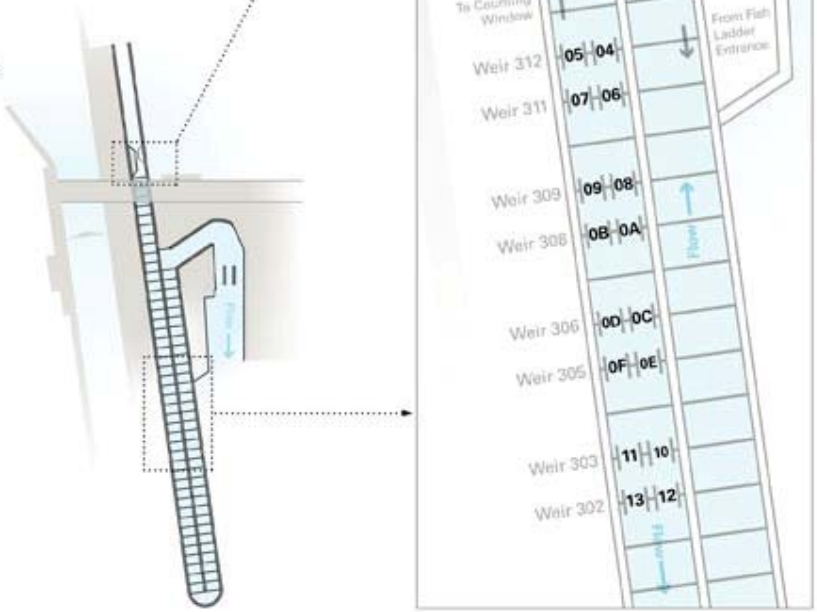
McNary Dam: Washington Shore Ladder (MC2)

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

Site Overview:

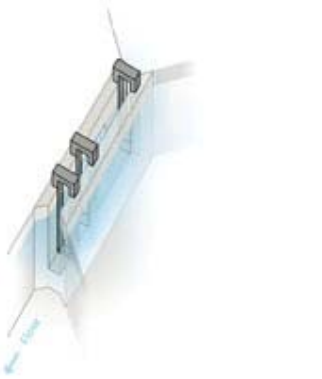


Ladder Overview:



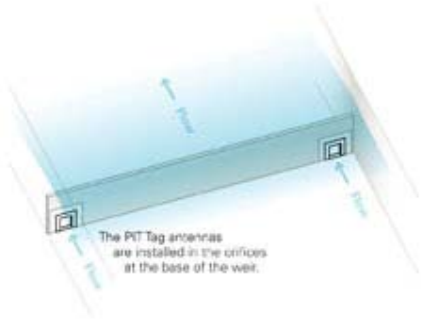
Counting Window Detail:

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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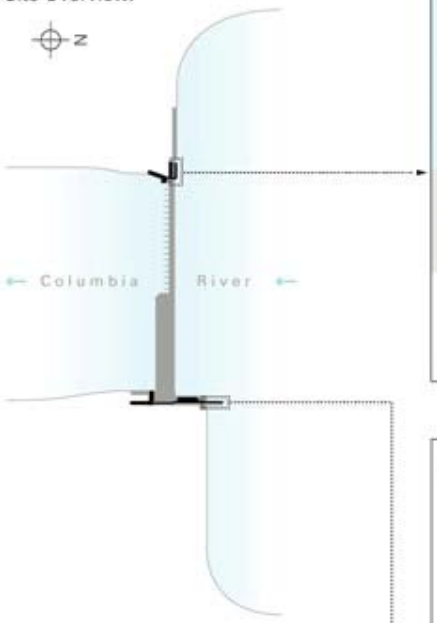
Priest Rapids Dam Fish Ladders (PRA)

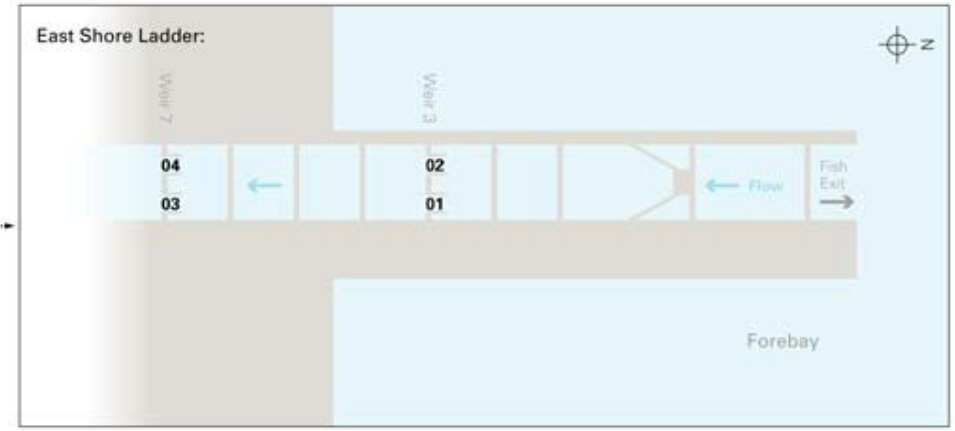
Interrogation Coil Map Revised: May, 2003 v.1.0, Cnfg. #100

Site Overview:



West Shore Ladder:

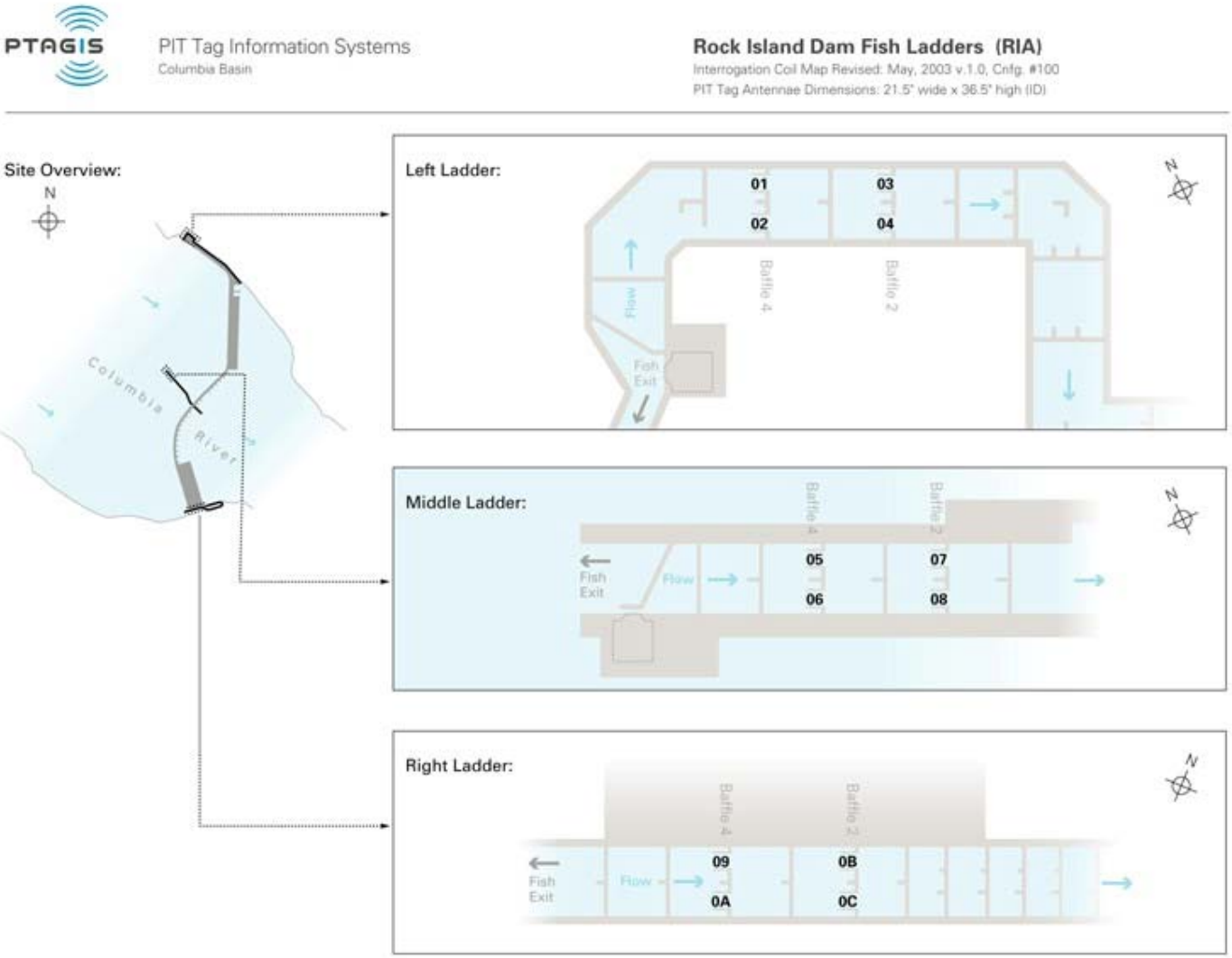
East Shore Ladder:



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)
Site Overview:
N
Columbia River
Left Ladder:
01
02
03
04
Baffle 4
Baffle 2
Flow
Fish Exit
Middle Ladder:
05
06
07
08
Right Ladder:
09
0A
0B
0C

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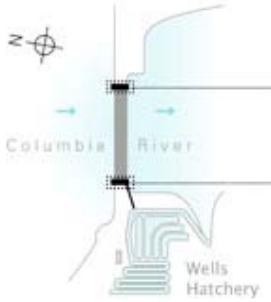
PIT Tag Information Systems
Columbia Basin

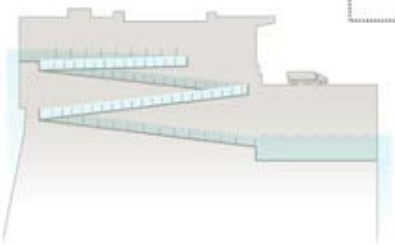
Wells Dam Fish Ladders (WEA)

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

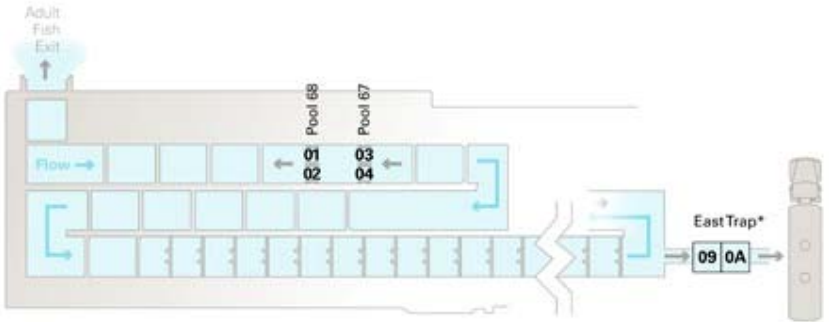
Site Overview:



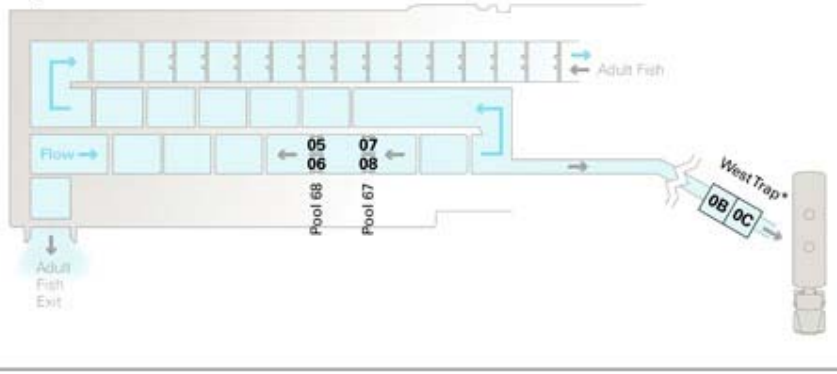
Elevation View:



Left Ladder



Right Ladder



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