Development of Passage Structures for Adult Pacific Lamprey at Bonneville Dam, 2006

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Report of research by

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EXECUTIVE SUMMARY

Previous studies at Bonneville Dam have indicated that lamprey passage structures (LPSs) can aid passage of migrating adult Pacific lamprey *Lampetra tridentata*. A prototype LPS, which was operated during 2004-2005 in the Bradford Island Auxiliary Water Supply (AWS) channel, allowed adult lamprey to volitionally pass into the Bonneville Dam forebay. The first iteration of a lamprey collector at a fishway entrance was also fabricated and installed at Bonneville Dam in 2005. Our objectives in 2006 were to continue to modify and evaluate the performance of these structures.

In 2006, the LPS was bolted to the walls of the AWS channel, and its original configuration was changed to include dual ramps for improved lamprey collection. In addition, the new configuration featured a more commodious rest box that reduced the duration of continuous climbing by lamprey. Lamprey using the LPS were counted with a lamprey-activated counter. We also used half-duplex passive integrated transponder (PIT) detectors that were integrated into the LPS to examine passage of PIT-tagged fish. We surgically implanted adult Pacific lamprey with PIT tags and released them in the Columbia River approximately 3 km downstream from Bonneville Dam (n = 2,050).

We estimated that 38% of the lamprey that reached the top of the Bradford Island fishway used the AWS LPS. Seven percent of the PIT-tagged lamprey were detected in the LPS. In addition, 14% of the fish detected at The Dalles Dam were known to have used the LPS at Bradford Island. The median time lamprey required to pass through the LPS was 45 min, and 99% of the fish successfully exited the AWS LPS. When these results were compared to previous years of LPS operation, it was clear that the structural modifications made in 2006 improved lamprey collection, rate of passage, and passage success through this structure.

During its first full year of operation, 135 lamprey used the LPS collector at the downstream north entrance to the Washington-Shore fishway. This collector was modified in 2006 to provide less turbulent flows on the collector ramp. However, lamprey use of this structure was still low, indicating that further modification or better siting is needed. There was some evidence that fewer lamprey entered the collector during periods of high flow emanating from the Washington-Shore fishway entrance. A controlled experiment comparing high and low flow conditions at this site is needed to better evaluate the efficacy of the current collector design.

CONTENTS

INTRODUCTION

The ability to attract and guide movements of adult lamprey has applications worldwide. In the Pacific Northwest, the need for native lamprey conservation has stimulated research on migratory behavior of adult Pacific lamprey *Lampetra tridentata*. Pre-spawning lamprey that enter the Columbia River must pass four hydropower dams to reach the confluence of the Columbia and Snake Rivers and up to five additional dams to attain spawning areas in headwater streams. Providing safe passage routes for lamprey at these dams is challenging, but was identified as one of the highest priorities for Pacific lamprey recovery in the Columbia and Snake Rivers (CRBLTW 2005). Consequently, a better understanding of the factors that direct lamprey movement is critically needed.

After entering the Columbia River, adult Pacific lamprey encounter Bonneville Dam, the first mainstem hydropower dam at river kilometer 235. Here they have difficulty entering fishways, and those that successfully enter can be obstructed or delayed in flow-control areas near the top of fishways (Moser et al. 2002b; Figure 1).

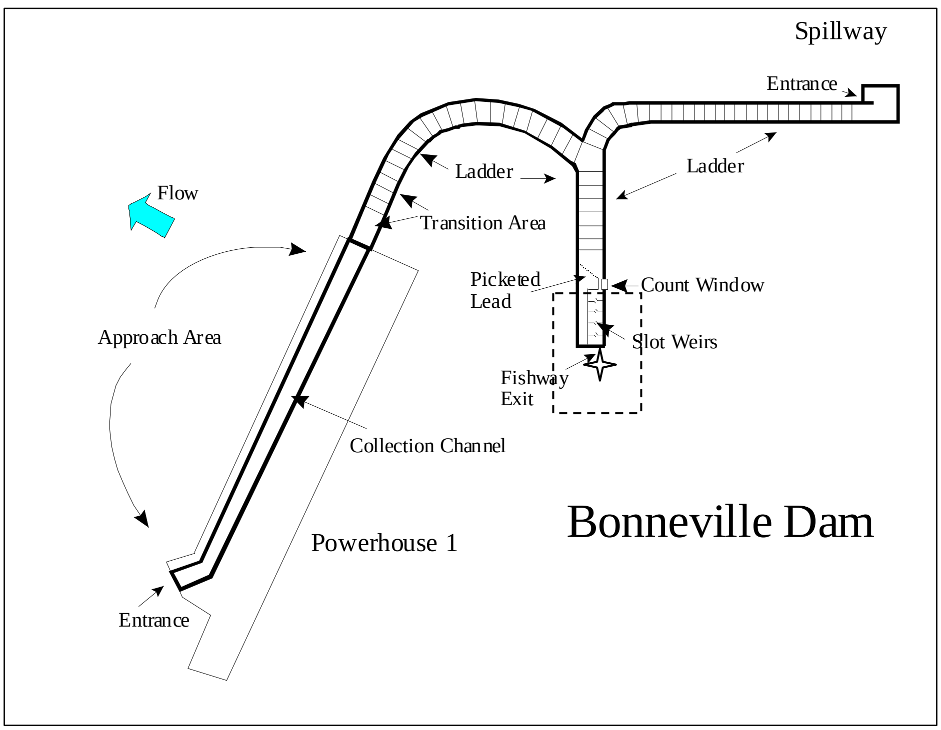

Figure 1. Schematic drawing of the Bradford Island fishway system at Bonneville Dam Powerhouse 1. The flow-control area at the top of the fishway is indicated in the dashed box. The star denotes the approximate AWS LPS exit location where lamprey pass into the forebay upstream from Powerhouse 1.

Serpentine weirs in the flow-control area present an obstacle to upstream movement, and lamprey routinely aggregate in the adjacent auxiliary water supply (AWS) channel (Figure 2). Lamprey enter the AWS channel through connecting diffuser gratings or via the picketed lead downstream from the count stations. There is no ready upstream outlet to the forebay from the AWS channel, and radiotelemetry results indicate that lamprey reside in the channel for 4 d on average and then typically fall back downstream (Moser et al. 2005).

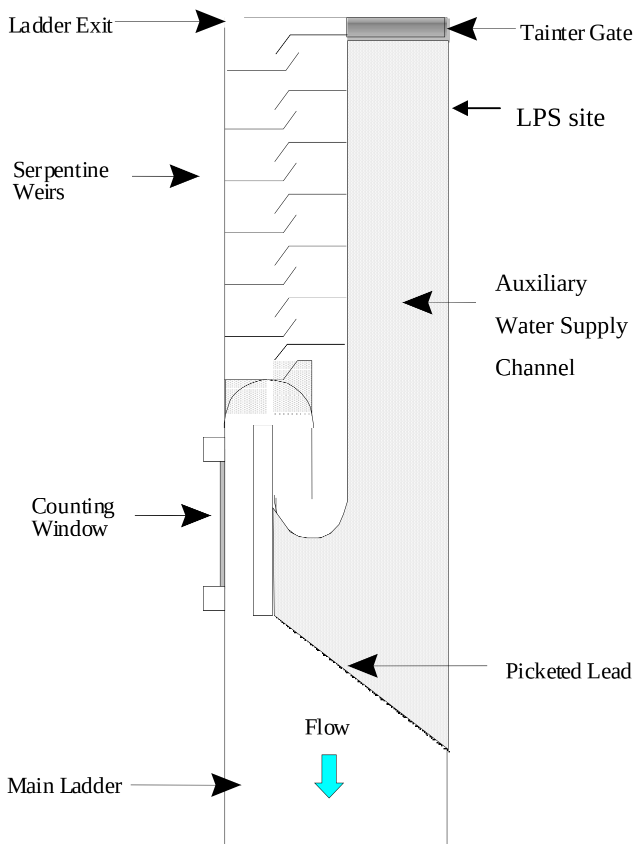

Figure 2. Detail of flow control area at the top of the Bradford Island fishway.

In 2002 we began development of a lamprey-specific fishway to aid lamprey passage from the Bradford Island AWS channel into the forebay of Bonneville Dam Powerhouse 1 (Figure 1). We conducted 2 years of testing on collector design, and in 2004 completed and installed the lamprey passage structure (LPS). The LPS allows lamprey to volitionally move from the AWS channel into the forebay. We developed a lamprey-activated counter and used half-duplex passive integrated transponder (PIT) technology to monitor lamprey passage events, determine rates of passage through the LPS, and evaluate overall LPS efficiency.

Evaluations of AWS LPS performance in 2004 and 2005 were promising. On average, 25% of the lamprey estimated to be at the top of the Bradford Island fishway used the LPS, and peak collection efficiency was 42% for marked lamprey released into the AWS channel. In addition, lamprey were typically able to negotiate the structure in less than 2 h with 94-96% passage success. However, results from detections of PIT-tagged lamprey in 2005 indicated that the median time required to find the LPS was over 1 d, and that collection efficiency could be improved. Lamprey also seemed to have the greatest difficulty climbing a relatively long, steep ramp in the LPS. When we tried reducing flow over this ramp in 2005, lamprey passage rate and efficiency did not improve.

Our first objective in 2006 was to make LPS structural modifications to improve lamprey passage success. Using detections of PIT-tagged fish in 2006, we were able to determine LPS collection efficiency, passage efficiency, and passage rate. These metrics were then compared to those from previous years of LPS operation. A second objective in 2006 was to evaluate a prototype lamprey entrance collector, which had been designed and fabricated in 2005. After the peak of the lamprey migration in 2005, the entrance collector was installed at the Washington-Shore fishway in the downstream north fishway entrance. In 2006, we assessed lamprey use of this collector during its first full season of lamprey migration by trapping lamprey at the top of the collector and by PIT-tag detection.

METHODS

Lamprey Passage Structures Tested

Auxiliary Water Supply Channel

We positioned the LPS at the upstream end of the Bradford Island AWS channel (Figure 2). In previous years the LPS had a single collector ramp along the west wall of the channel that was held in position by metal guides. In 2006, we added a collector ramp along the east wall of the channel and attached both ramps by bolting them to the wall (Figure 3). These dual collectors featured open ramps of sheet aluminum that extended from the bottom of the channel to the level of the first rest box at a 45° incline (Figure 4). A heavy rubber flange was fitted between the side of each ramp and the wall to help guide lamprey onto the ramp (see Moser et al. 2005).

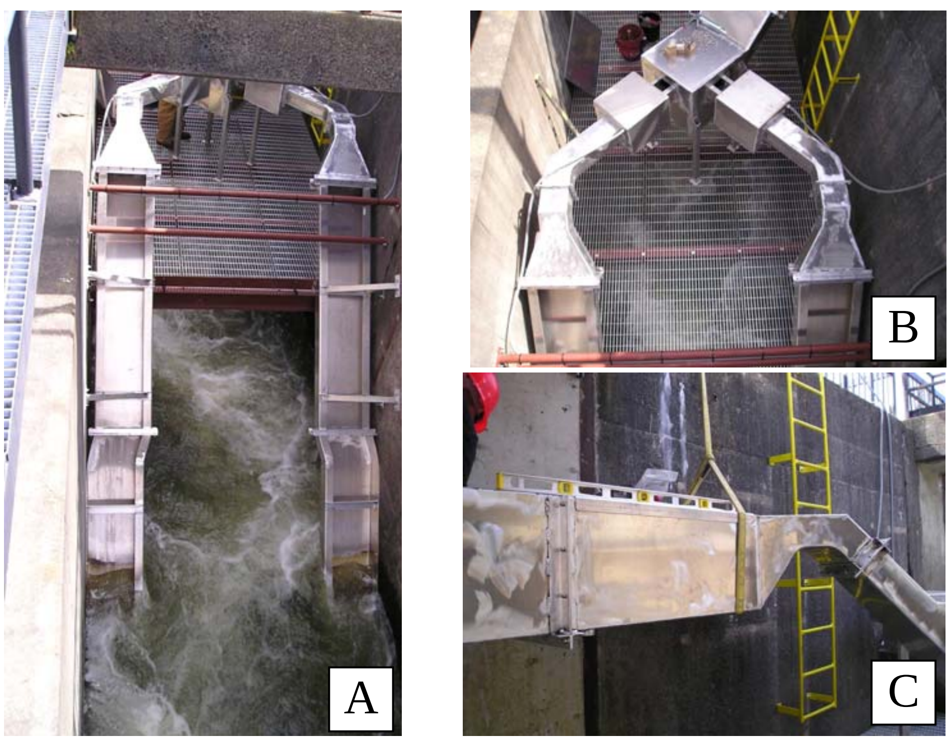

Figure 3. Photos of LPS installation in the Bradford Island AWS channel: A) dual collection ramps, B) access platform, and C) short ramp leading into large rest box.

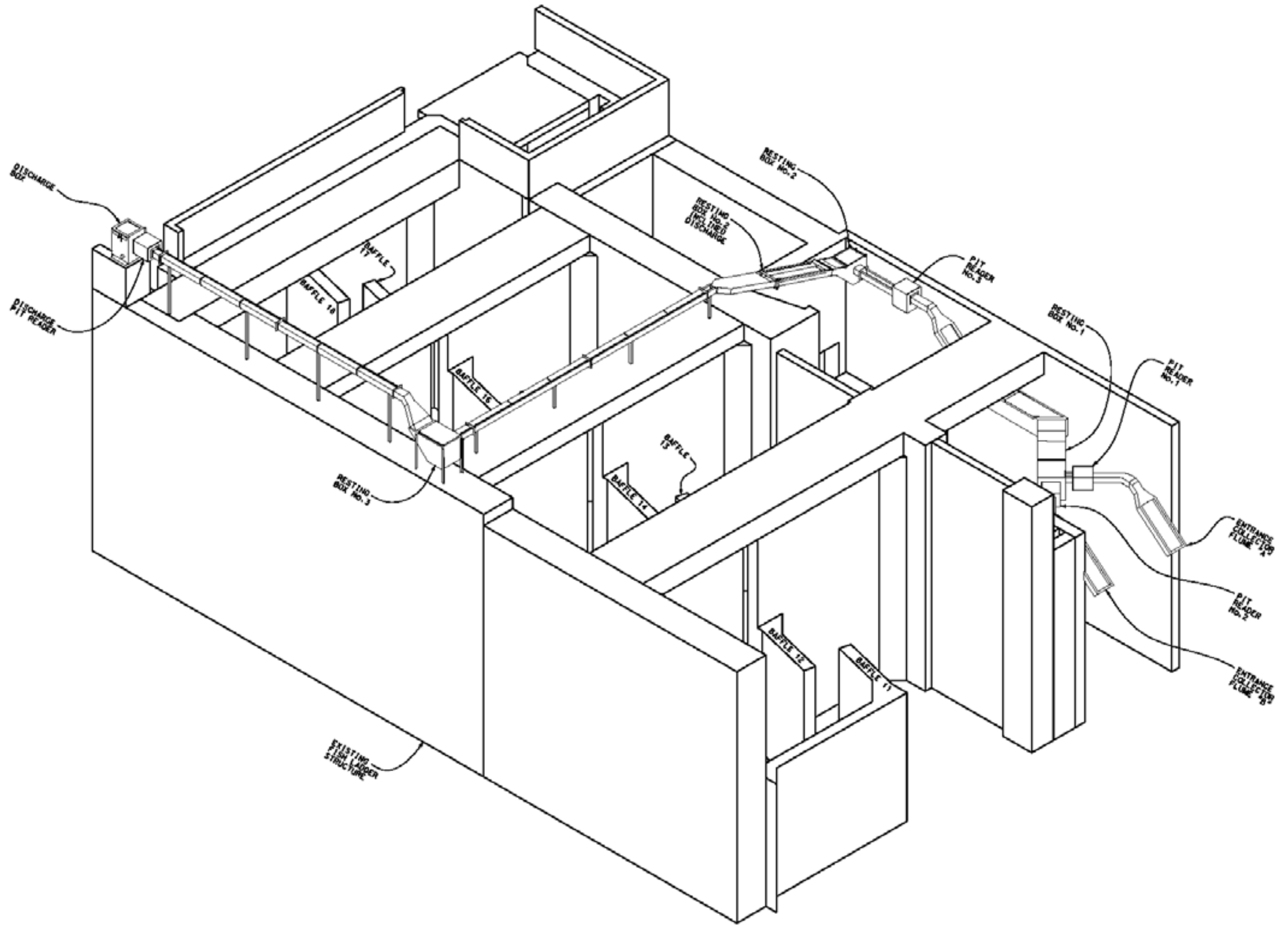

Figure 4. Schematic drawing of the AWS LPS (three dimensional view created by Michael Crump, U.S. Army Corps of Engineers).

After ascending either collector ramp, lamprey passed through a short (1.2-m) rectangular chute that emptied into a Rest Box 1 (Figure 5). The end of the chute was fitted with a funnel made of 1.2-cm plastic mesh to prevent lamprey from passing back down the LPS after entering the rest box. This "one-way valve" design was incorporated into the entry of each rest box.

The next section of the LPS was also modified in 2006. Instead of proceeding immediately up a steep ramp after leaving Rest Box 1 (Moser et al. 2008), lamprey passed up a short (1.4 m), 45° ramp, over a crested weir, and into a large (2.2 × 0.6 m) rest box (Figure 5). From this rest box they moved up another 1.4-m, 45° ramp, through a short horizontal chute and into Rest Box 2 (Figure 5). Thus, the single, long, steep ramp featured in the 2004-2005 design (Moser et. al 2006, 2008) was replaced with two shorter ramps separated by a large rest box.

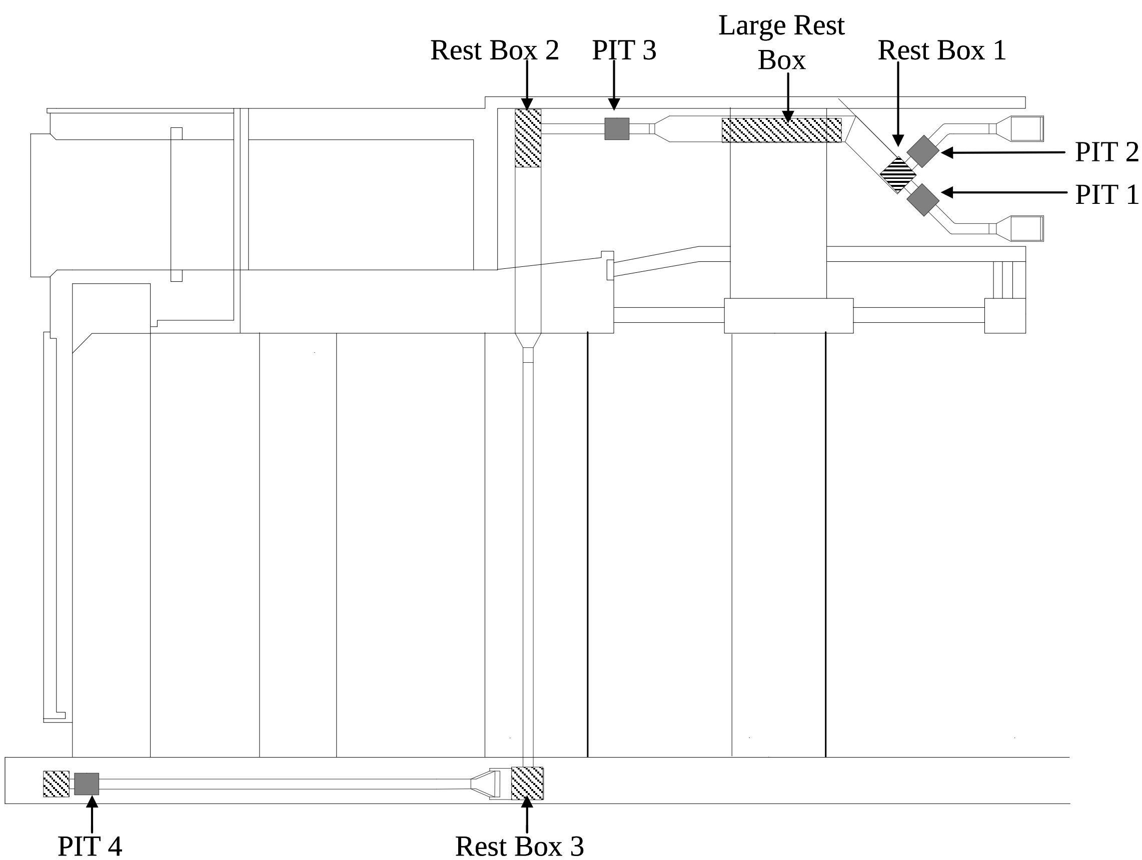

Figure 5. Schematic overhead view of AWS with rest boxes and PIT detector locations indicated.

The rest of the LPS was the same as in previous years (i.e., from Rest Box 2 upstream to the exit). Lamprey climbed an 18° ramp and passed through a long, closed rectangular tube before dropping into Rest Box 3 (Figure 5). They then encountered a short, 45° ramp before entering a long, closed tube that terminated at an upwelling box and exit slide (see Moser et al. 2006 for construction details).

The exit slide dropped lamprey into the forebay of Powerhouse 1 at a location approximately 10 m upstream from the exit of the Bradford Island fishway (Figure 1). Lamprey passing down through the exit slide were enumerated when they contacted a large paddle near the exit slide terminus (Figure 6). A limit switch attached to the paddle was wired to a palmtop computer, which assigned date and time to each passage record.

Figure 6. Lamprey-activated switch at the terminus of the LPS exit slide.

Columbia River water was supplied at the top of the LPS via a 10.2-cm diameter PVC pipe from two, 3-hp submersible pumps. Flow into the trap box was regulated to maintain a 3-cm depth on the ramps and approximately 10-cm depth in the closed tubes. Flow regulation was achieved by an upwelling box at the top of the LPS. At the LPS terminus, lamprey passed through a narrow opening in the upwelling box and then dropped onto the exit slide to the forebay of Powerhouse 1 (Figure 1).

Lamprey passage was monitored with a series of four, half-duplex PIT antennas integrated into the LPS design (Figure 7). A rectangular PVC sleeve was seamlessly inserted into the chutes leading to Rest Boxes 1, 2, and 4 (Figure 5). This was necessary because the aluminum chute itself would attenuate the PIT signal. Each PIT-tag detector was comprised of a loop antenna of 10-G multistrand wire (wrapped around the PVC sleeve), an outer aluminum housing that acted as a Faraday cage to shield the antenna, a detector, and a palmtop computer that logged the time and date of each detection to a 256-MB memory card. The detectors were synchronized by wiring them together.

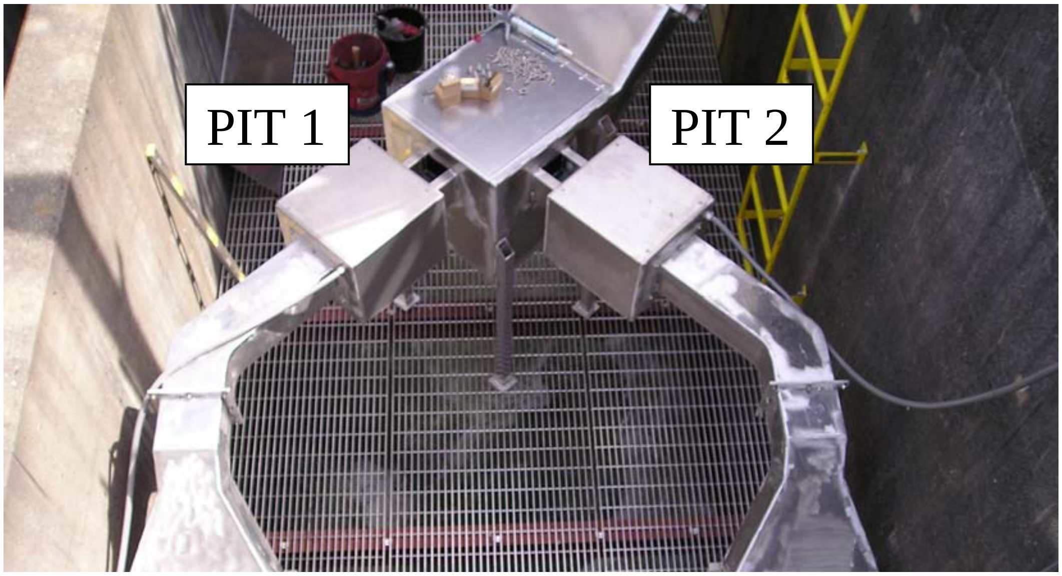

Figure 7. Shielded PIT antennas (PIT 1 and PIT 2 shown here) were seamlessly inserted in the chutes leading to rest boxes (Rest Box 1 shown here).

In 2005, we added a (half-duplex) PIT-tag detection antenna in the AWS channel (Moser et al. 2008); however, this antenna was removed in 2006 due to potential electromagnetic interference with the full-duplex detectors in the adjacent fishway. We moved the antenna to a position immediately upstream from the picket lead at the downstream end of the flow-control section of the Cascades Island fishway (Figure 8).

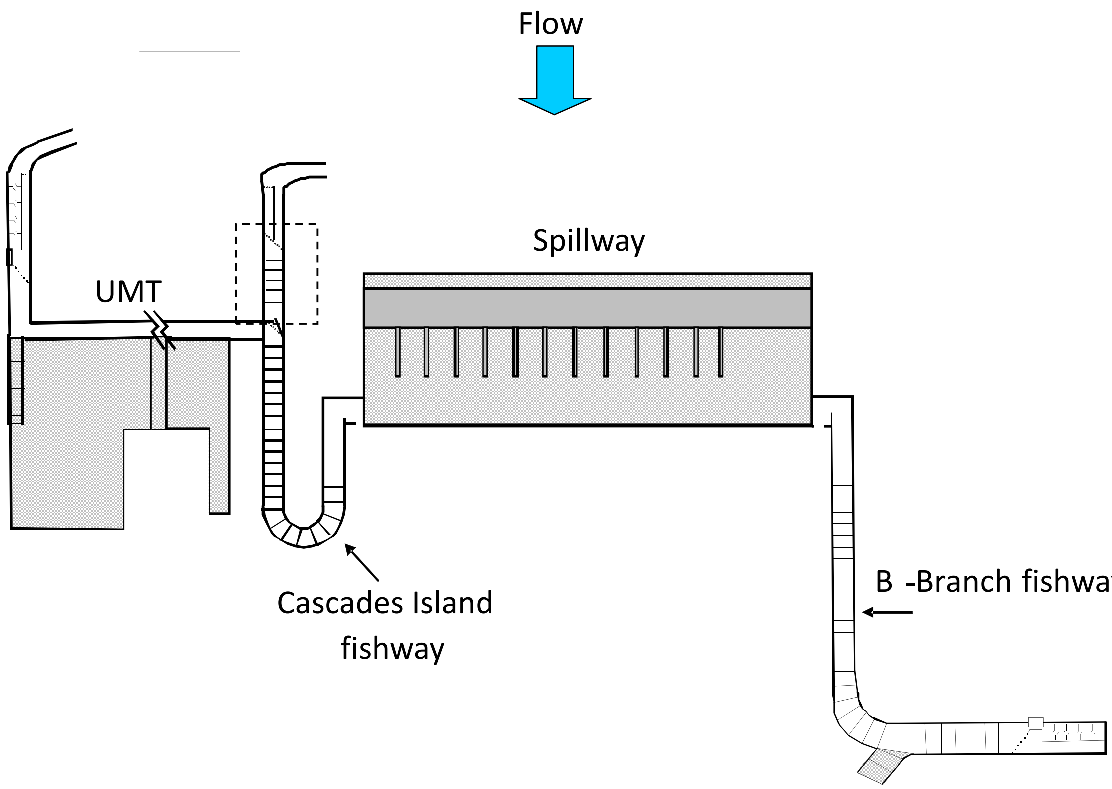

Figure 8. Location of the flow control area at the top of the Cascades Island fishway (denoted by dashed box).

This area is currently blocked off to salmon during most of the year. However, adult lamprey can gain access through the picket lead. We used PIT detections at this Cascades Island antenna to determine whether significant numbers of lamprey find their way into this area. This antenna was a 10 G multistrand wire loop positioned inside a 12.8- by 0.9-m rectangular PVC frame. The frame spanned the entire fishway channel and was supported in position approximately 15 cm from the bottom by clamping it to the existing walkway hand rail (Figure 9). The read range of this antenna was very limited (5 cm), so only lamprey that were traveling very close to the bottom or sides of the channel could be detected.

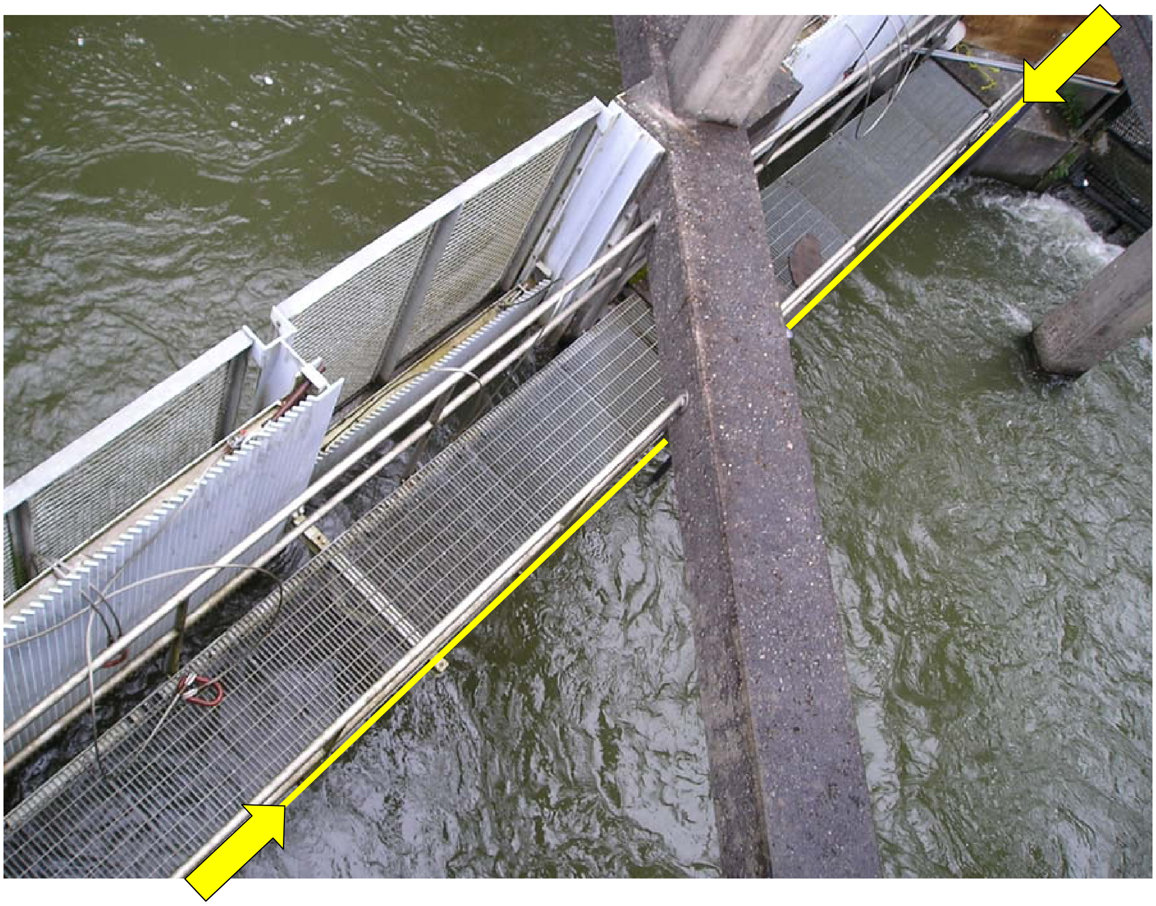

Figure 9. Top view of the Cascades Island PIT antenna site (arrows and connecting line) immediately upstream from the picket lead.

Washington-Shore Entrance Collector

The entrance collector was installed at the downstream north entrance to the Washington-shore fishway (Figure 10). This location was chosen because radiotelemetry studies have indicated that lamprey entrance efficiency at this location is consistently lower than at all other main entrances (Moser et al. 2005). To install the collector, a crane was used to attach a 10- by 15- by 1-cm steel hold-down beam to the collector base above the water surface (Figure 11). Current velocity emanating from the fishway entrance was then reduced so that the assembly could be lowered into place and seated on the vertical transition structure (Figure 11). The hold-down was then bracketed to the wall and jacked down from the top to create a seal with the transition structure.

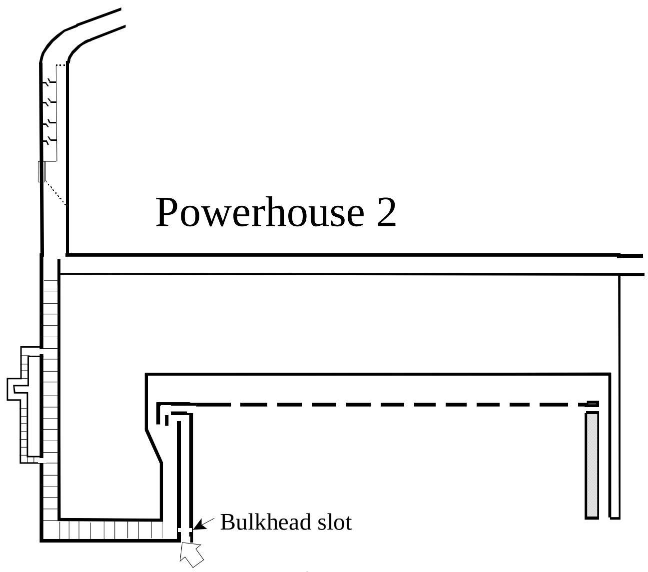

Figure 10. Diagram showing the location of a prototype entrance collector installed at the downstream north main entrance to the Washington-shore fishway.

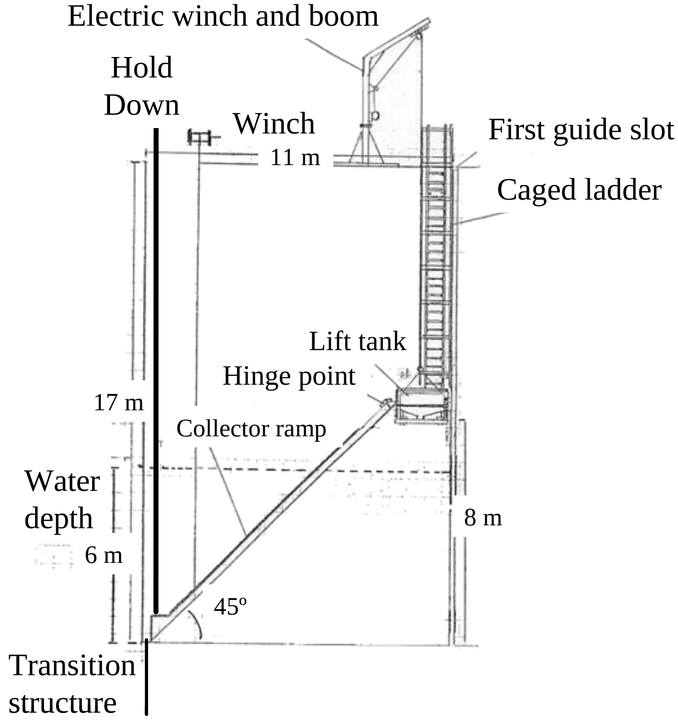

Figure 11. Side view (north wall) of the prototype entrance collector at the downstream Washington-shore fishway entrance.

The entrance collector ramp was of the same basic construction as in 2005 (Moser et al. 2008). It consisted of a 51-cm-wide, 12.6-m-long, closed aluminum ramp that lamprey entered at the top of the transition structure (Figure 12). In 2005, the ramp was open and was protected by a 5-cm bar grate to prevent sea lions from accessing lamprey on the ramp. In 2006, this bar grate was replaced with a solid sheet of aluminum to produce a closed ramp. This was done to reduce turbulent flows that were created when the ramp was submerged. After climbing up the 45-degree ramp, lamprey entered a 15.2- by 20.3-cm closed chute that passed through a PIT detection antenna (same construction as in the AWS LPS) and emptied into a 0.6- by 0.6- by 0.9-m trap box (Figure 12). The trap box was accessed daily by a caged ladder and could be hoisted to retrieve lampreys using an electric winch and boom (Figure 13). Lamprey in the trap were enumerated, measured, and released.

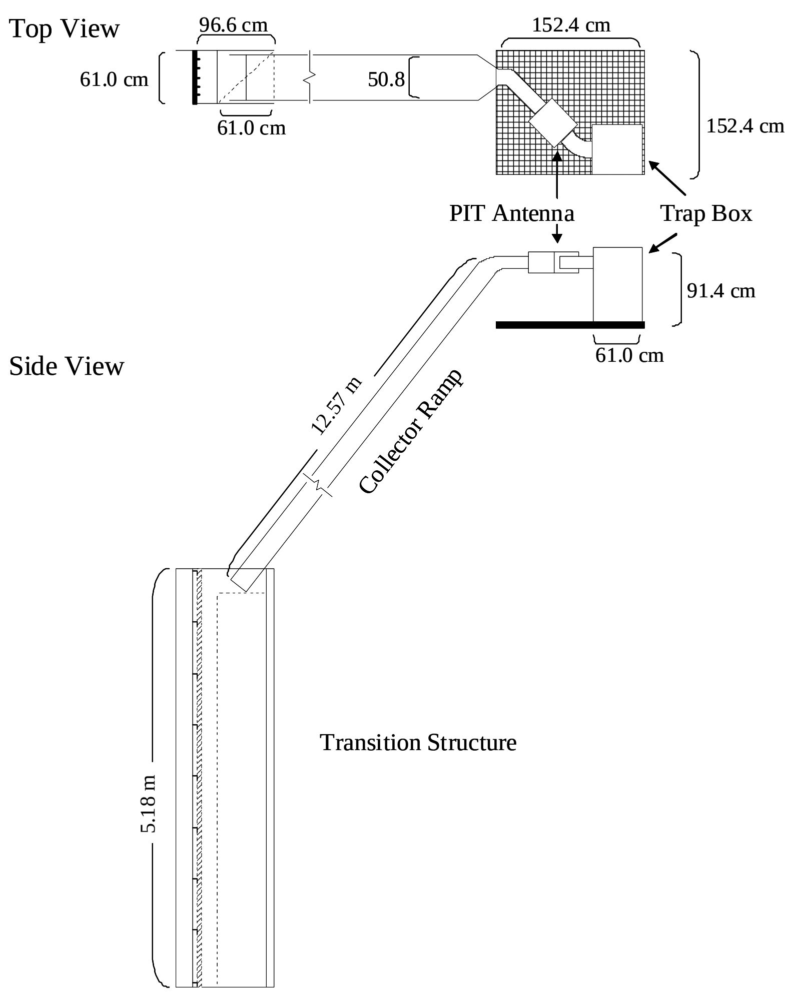

Figure 12. Schematic drawing illustrating dimensions of the entrance collector installed at the Washington-shore downstream north entrance.

Figure 13. Top view of the trap box at the terminus of the entrance collector.

Lamprey Collection and Tagging

We collected lamprey for PIT-tagging with two traps at the Bonneville Dam Adult Fish Collection and Monitoring Facility (AFF). Traps were deployed each night from approximately 2100 to 0700 PDT. Each morning trapped lamprey were transferred to a holding tank with flow-through Columbia River water.

After anaesthetizing lamprey using 60-ppm clove oil, we measured weight (nearest g), total length (nearest 0.5 cm), and girth at the insertion of the anterior dorsal fin (nearest mm) of each fish. We then made a 4-mm incision just off the ventral midline at a location even with the insertion of the anterior dorsal fin. A sterilized half-duplex PIT tag (3 × 32 mm) was inserted into the body cavity. We also tagged a small number of lamprey with both this half-duplex PIT tag and a sterilized full-duplex PIT tag by inserting the tags individually (full-duplex tag first).

Most PIT-tagged lamprey were released approximately 3 km downstream from Bonneville Dam at the Hamilton Island boat ramp. However, to test half-duplex detection efficiency at the downstream north entrance of the Washington-Shore fishway, we released 50 fish immediately downstream from this entrance along the Washington shoreline at the downstream end of the Boat Restriction Zone.

The number of tagged fish detected either in the entrance collector or the AWS channel LPS was compared to detections at PIT-tag monitors in the Cascades Island fishway (described above) and at other locations at Bonneville Dam and other lower Columbia and Snake River dams (see Daigle et al. 2008). In addition to determining passage routes, we were able to compute the time from release to first detection at each structure and the length of time lamprey required to pass between antennas in the LPS.

RESULTS

Lamprey Counts and Trapping

Counts at the LPS in the AWS channel were made from 19 May to 8 November 2006. During part of the day on 25-26 June, 21-23 July, and 12 August, the LPS counter malfunctioned. To avoid bias, visual counts made on those days were removed from analysis. Even with these days omitted, 15,046 lamprey were counted as they exited the LPS (Figure 14).

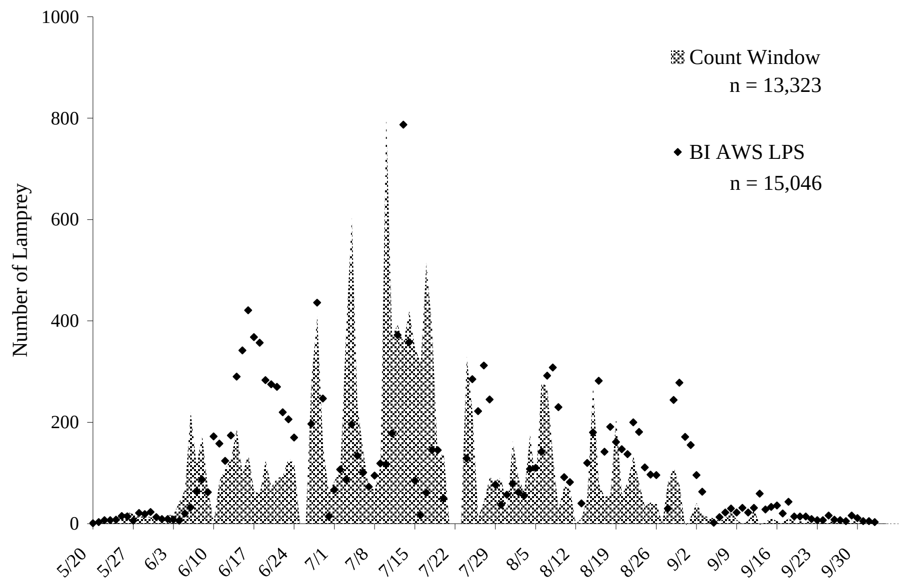

Figure 14. Number of lamprey counted at the Bradford Island count station (shaded area) vs. number counted at the Bradford Island AWS LPS exit slide (closed diamonds) during the periods of LPS counter operation in 2006.

From 18 May to 29 August we operated lamprey traps in the fishway at the Adult Fish Facility (AFF) and at the top of the entrance collector on the Washington shore. During this time, 3,031 lamprey were captured: 135 (4%) in the entrance collector (outside the Washington-Shore fishway entrance), and the remainder in the two AFF traps (located inside the Washington-Shore fishway). There was no difference in total length distribution between lamprey captured at the two locations: AFF traps (mean 67.0 cm, SD 4.8, range 52.0-83.0), and LPS collector trap (mean 66.1 cm, SD 4.7, range 52.0-77.0; Figure 15).

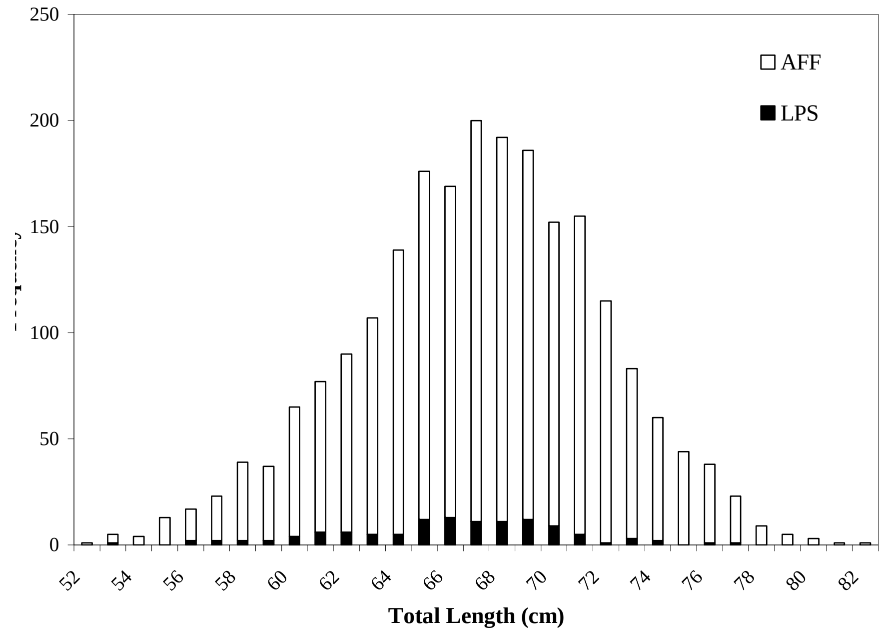

Figure 15. Size frequency (cm total length) of lamprey trapped at the Washington-Shore fishway as a function of trap location (open bars show Adult Fish Facility traps, dark bars show entrance collector).

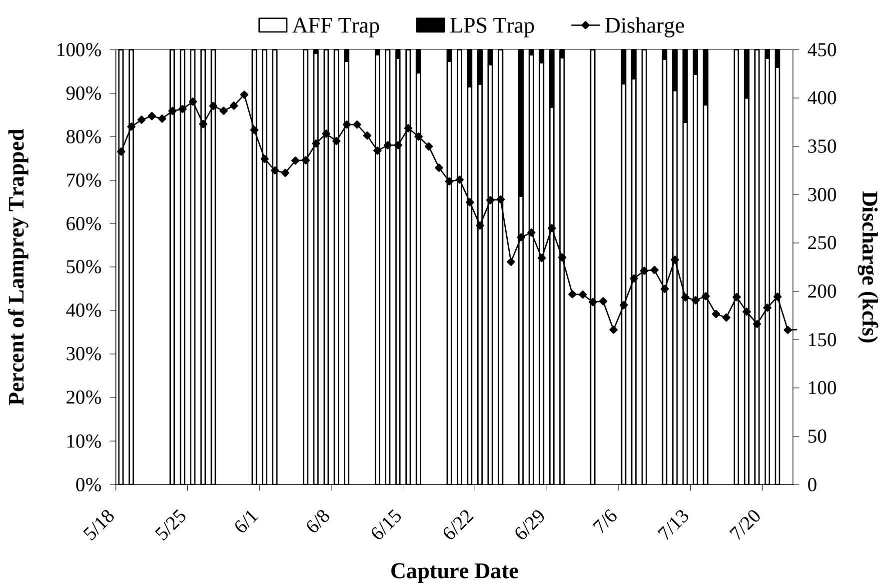

Figure 16. Percentage of lamprey trapped in the Washington-Shore fishway as a function of trap location (open bars = Adult Fish Facility, dark bars = entrance collector/LPS trap, diamonds = river discharge).

The percentage of lamprey caught in the entrance collector trap increased as river discharge (measured at the Bonneville Dam forebay) decreased (Figure 16). While it appeared that these variables were negatively correlated, the relationship between them was weak (r = -0.18). The highest catch occurred on the night of 26 June, when 30 lamprey were collected (Figure 16).

Lamprey Collection and Tagging

We tagged and released 2,050 lamprey with half-duplex PIT tags from 25 May to 29 August 2006. During this time, water temperature in the Bonneville Dam forebay ranged from 13.9 to 22.8°C. To avoid potential mortality due to handling stess, we did not trap lamprey between 24 July and 1 August, when water temperature exceeded 21°C (Ocker et al. 2001). Of 2,050 fish tagged, 2,000 were released 3 km below Bonneville Dam at the Hamilton Island boat ramp. The remaining 50 were released immediately downstream from the Washington-Shore fishway entrance on 23-29 August 2006. Of the 2,000 releases from the boat ramp, 20 were double tagged with both a full-duplex and half-duplex PIT tag on 27 June.

Auxiliary Water Supply Channel

Of the 2,050 PIT-tagged fish released downstream from Bonneville Dam in 2006, 144 (7%) were detected in the lamprey passage structure (LPS) at the Auxiliary Water Supply (AWS) channel. Two of these fish were double-tagged (10% of double-tagged sample). In addition, four PIT-tagged fish released in the AWS channel in 2005 were also detected in the LPS. These four fish were originally released between 21 June and 1 July 2005. All four passed through the AWS LPS between 15 and 20 June 2006.

We compared the number of fish detected at the Bradford Island LPS to the number detected at the adjacent Bradford Island fishway exit. There were 211 (10%) of the lamprey PIT-tagged in 2006 at the Bradford Island fishway exit, and 4 of them were double-tagged (20% of the double-tagged sample). One fish tagged and released downstream from Bonneville Dam in 2005 was also detected at this exit. This fish was released on 27 August 2005 and was detected once at the exit on 23 June 2006.

The time from release to first detection in the AWS LPS was extremely variable for tagged lamprey (range 1.5–54.4 d), and there was no indication that time of year affected this metric (Figure 17). Of the 136 fish detected at the upstream end of the AWS LPS collector ramps, 65% were first detected on the west collector ramp. Moreover, the tagged lamprey took slightly less time to find the west ramp (median 10.5 d) than they did to find the east ramp (median 13.5 d; Figure 17). Only two fish were detected at the top of both collector ramps. In both of these cases, the fish initially entered the west ramp, fell back out of the LPS, re-ascended the east ramp, and successfully passed through the LPS. One of these fish was later detected at the exit to John Day Dam.

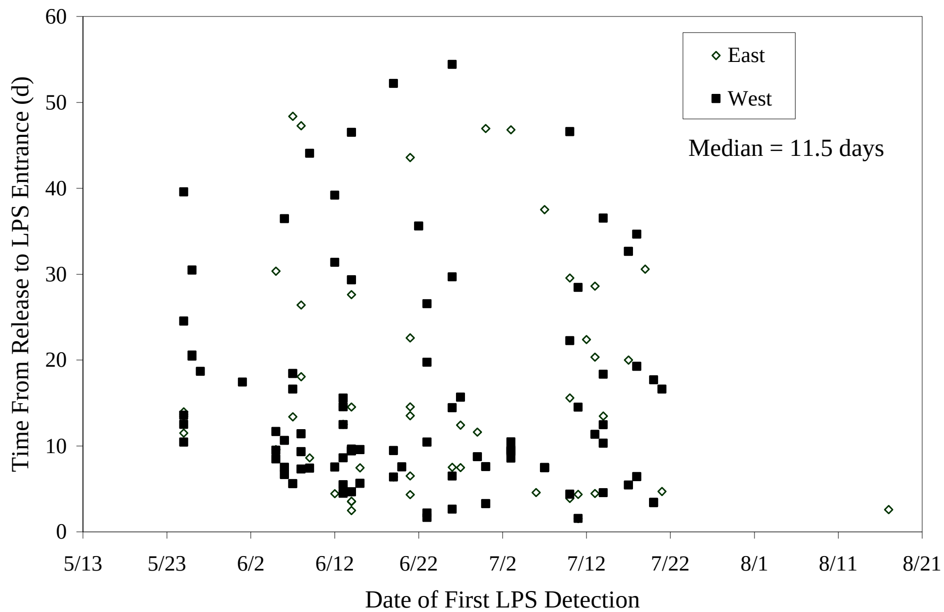

Figure 17. Time from lamprey release downstream from Bonneville Dam to first detection in the AWS LPS as a function of time of year. First detections that occurred on the east ramp are shown with open diamonds and those on the west ramp are closed squares.

To determine the time PIT-tagged lamprey required to pass through each section of the AWS LPS, we used only first passage attempts for the five fish detected moving downstream in the LPS. Two of these five fish passed all the way to the top of the LPS and then fell back. They were detected re-ascending it 4 days later. One of the five was detected at the top of the west collector ramp, fell back downstream, and was detected at the top of the east detector ramp 1 min later. This fish successfully negotiated the rest of the LPS. The remaining two fish were detected only at the top of the west collector ramp, presumably fell back downstream, did not re-ascend the LPS, and were not detected passing through a Bonneville Dam fishway exit. Interestingly, one of these fish was originally captured in the Washington-Shore fishway, was later detected at the Cascades Island fishway, and was then recaptured in the Washington-Shore fishway and released downstream from Bonneville Dam. It was then detected at the top of the west collector ramp but not detected thereafter.

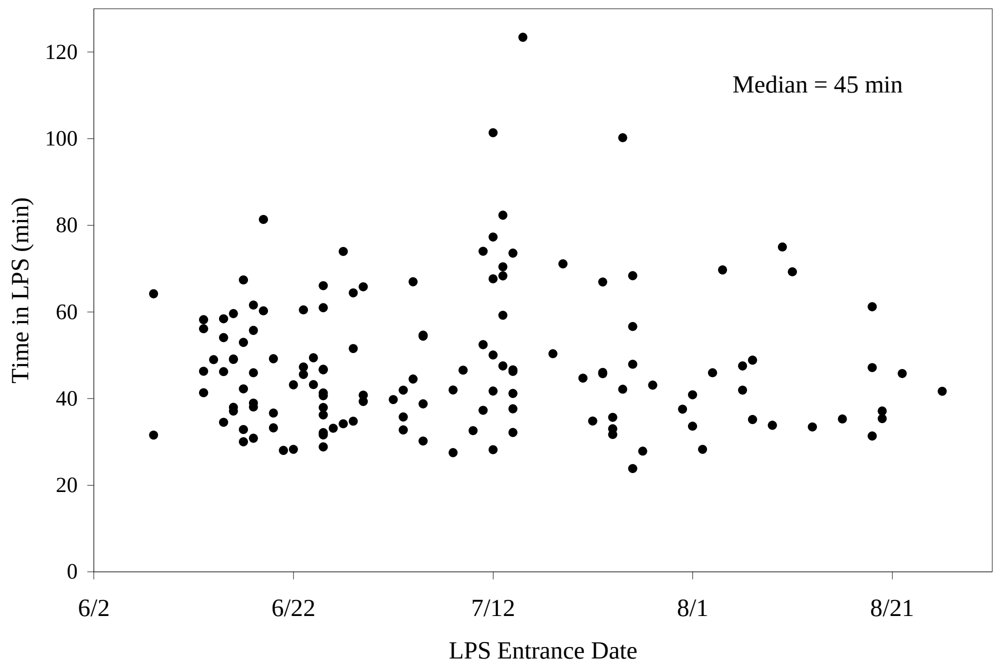

Figure 18. Time lamprey required to pass through the LPS as a function of time of year.

Median time from first detection at the top of the collector ramps (PIT 1 or PIT 2) to first detection at PIT 3 was 0.24 h (SD = 2.86 h; Table 1). This section included the newly divided steep ramp and the large rest box (Figure 5). Only three lamprey required more than 1 h to pass through this section. One of these fish passed in 100 min. The other two resided in this section for over 16 h and resumed migration the following day.

In contrast, lamprey required a median of 0.76 h to traverse the entire distance from the top of the collector ramp to the exit slide at PIT 4 (Table 1). The SD of travel time through the entire bypass was 2.87 h, but when we omitted three outliers that passed slowly through the divided ramp section, the SD was only 0.27 h.

All but two of the PIT-tagged fish detected in the LPS were detected at PIT 4 (Figure 7), indicating that 99% of those that entered the LPS successfully passed into the dam forebay. Of fish not detected at PIT 4, both were detected only at the top of the west collector ramp and apparently did not ascend above this point. They were not detected again on any half-duplex monitor at Bonneville Dam or any other Columbia River dam.

Table 1. Travel times (h) between PIT detectors for PIT-tagged lamprey that the LPS. PIT 1 and 2 were located at the top of each collector, PIT 3 was immediately after the divided steep ramp, and PIT 4 was at the LPS terminus (see Figure 5 for PIT detector locations).

	Lamprey passage time (h)		
	PIT 1 or 2 to 3	PIT 3 to 4	PIT 1 or 2 to 4
N	121	121	136
Median	0.24	0.52	0.76
Min	0.05	0.34	0.40
Max	27.95	1.83	29.78

Of the 136 lamprey detected at the LPS exit slide, 80 (59%) were subsequently detected by half-duplex monitors at upstream dams (The Dalles, John Day, and McNary). Fifteen of the 136 fish (11%) were detected at the Bradford Island fishway exit (which is located 10 m away from the exit slide). Median time from last detection in the LPS to last detection at the fishway exit was 1.1 h. Five of these fish (33% of those that passed into the fishway exit after LPS passage) were subsequently detected at upstream dams.

Cascades Island Flow Control Area

The PIT-tagged fish detected at the Cascades Island flow control area (n = 127) represented 6% of the fish tagged in 2006. Five of these fish were tagged with both half- and full-duplex PIT tags, comprising 10% of the double-tagged sample. We detected one additional fish originally PIT-tagged on 13 July 2005. Fish detected at the Cascades Island fishway detector took about the same median length of time to get to that point (12.5 d, SD 17.5, range 0.9-85.2) as lamprey detected in the AWS LPS.

Of the 127 lamprey detected at the Cascades Island flow control area, 46 (36%) were subsequently detected at a Bonneville Dam fishway exit and/or at upriver dams. Of these 46 fish, 32 (69%) were detected at the Washington-Shore fishway exit, 3 (7%) were detected at the Bradford Island fishway exit, 2 (4%) were detected in the Bradford Island LPS, and 9 (20%) passed via an unknown route and were later detected upstream. The median time to pass from the Cascades Island detector to the Washington-Shore fishway exit was 9.1 d (SD = 17.1, range = 1.1-64.2). The median time to pass from the Cascades Island detector to the Bradford Island fishway exit or AWS LPS was 17.8 d (SD = 10.4, range = 7.0-31.8). Thirty-one (24%) of the fish detected at the Cascades Island detector were later detected at upriver dams.

Washington-Shore Entrance Collector

Only 3 PIT-tagged lamprey were detected in the Washington-shore entrance collector. Two of these fish were detected in the collector during daytime and one during the night. The times from release downstream from Bonneville Dam to first detection in the collector were 3, 4, and 21 d. The two fish that found the collector first were also released on the same day (7 July) at the downstream site (Hamilton boat ramp). None of the fish released immediately downstream from the Washington-shore fishway entrance were detected in the entrance collector.

DISCUSSION

More lamprey were counted as they exited the LPS in the Bradford Island AWS channel in 2006 than in any other year of LPS operation (Table 2). In fact, more lamprey were counted exiting the LPS than were counted at the nearby Bradford Island count window. Visual counts generally represent approximately one-third of the total number of lamprey at the count window because most lamprey pass at night, when counts are not made. Therefore, we estimated that approximately 39,969 lamprey were at the top of the Bradford Island fishway during the study period. Roughly 38% of these fish used the LPS, a higher collection efficiency than in any other year (Table 2).

Table 2. Number of lamprey according to the Bradford Island count window, the expanded estimate at the top of the fishway, and exits from the LPS in the Bradford Island AWS channel over 3 years of LPS operation. Collection efficiency (%) in each year was estimated by dividing the number of fish exiting the LPS by the expanded estimate and multiplying this proportion by 100.

	Count station	Estimated total	Bradford Island LPS count	Collection efficiency (%)
2004	11,971	35,913	7,490	21
2005	10,257	30,771	8,889	29
2006	13,323	9,969	15,046	38

The large improvement in collection efficiency observed in 2006 was probably due to the addition of a second collection ramp. PIT-tagged lamprey were detected at both collector ramps, but more fish used the west ramp than the east ramp, and they generally took less time to find the west ramp. Preference for the west ramp may be due to AWS channel configuration downstream from the LPS (Figure 19). If lamprey contact and pass through the picket lead on the west wall of the AWS channel, they can move along the wall all the way up to the LPS collector. On the east side, fish have to negotiate a more circuitous route to find the collector on the east wall. In addition, an obsolete underwater wooden weir in the AWS channel just upstream from the picket lead may direct fish towards the west side of the channel (Figure 19).

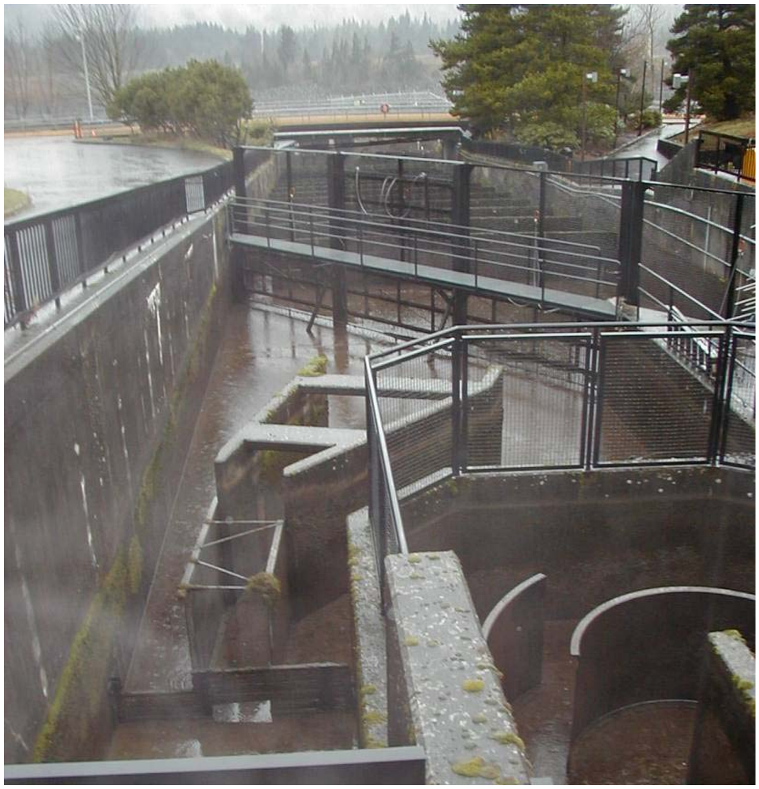

Figure 19. View looking downstream to the picket lead at the dewatered Bradford Island Auxiliary Water Supply channel. The west wall of the channel is located on the left in this photo.

Lamprey required over one week after release below Bonneville Dam to negotiate the fishways and find their way onto the LPS at Bradford Island. This was not surprising in light of the fact that PIT-tagged lamprey have been found to require a similar amount of time (median 9.6 d) to reach the exits of Bonneville Dam fishways (Daigle et al. 2008). Previous telemetry work has indicated that lamprey make multiple entries into the fishways, mill about in the tailrace, and exhibit relatively undirected movement while in the fishways (Moser et al. 2002a). This behavior contributes to the slow reported median rates of fishway passage (< 1 km/d) relative to median rates of reservoir passage (up to 16.2 km/d, Daigle et al. 2008).

After lamprey entered the LPS, their passage through it was remarkably rapid and successful. Median passage time through the entire structure was just 45 min for PIT-tagged lamprey. This was considerably less than LPS passage times in 2005 (median = 1.5 h) and 2004 (median = 1.1 h; Moser et al. 2006, 2008). In addition, 99% of fish that entered the LPS were detected at the exit slide. This was a slight improvement over LPS passage success in 2004 (96%) and 2005 (95%) (Moser et al. 2006, 2008).

We surmise that these improvements in LPS passage were related to changes in rest box and ramp construction made in 2006. Moser et al. (2008) noted that in 2005 most fish that fell back in the LPS did so at the longest (3.8 m) steep ramp (45°). In 2006, we divided this ramp into two shorter sections, separated with a large rest box (Figure 3C). The time tagged lamprey required to pass through this section in 2006 (14 min) was one quarter of that observed in 2005 (58 min). Thus, reducing the length of the steep ramp accounted for the entire difference in LPS passage times between years.

These results indicated that LPS modifications made in 2006 (dual ramps and shorter steep ramps) resulted in a structure that lamprey can traverse rapidly and with high passage efficiency. In addition, the structure is relatively maintenance-free. A guide to operation of this structure is included as an appendix to this report and should be consulted for details of operation, particularly during start-up in spring and decommissioning for winter (Appendix A).

Data from lamprey PIT-tagged in 2006 indicated that numbers of lamprey using the LPS were significant. For the first time we released large numbers of PIT-tagged lamprey (n = 2,050) below Bonneville Dam to determine whether improvements in overall lamprey passage could be attributed to LPS operation. Results indicated that 7% of the lamprey we released used the LPS to pass Bonneville Dam. This compares favorably with the number of lamprey detected at the traditional Bradford Island fishway exit (10%).

In addition, 59% of the lamprey that passed over Bonneville Dam via the LPS were subsequently detected at other upstream dams. In fact, lamprey that used the Bradford Island LPS represented 14% of all tagged lamprey that passed The Dalles Dam in 2006 (Daigle et al. 2008). This result indicates that use of the LPS did not prevent fish from proceeding upstream in a normal fashion. The LPS also provided a passage route for a few lamprey (n = 4) that we PIT-tagged in 2005 and that overwintered below Bonneville Dam.

Of the PIT-tagged lamprey that passed through the LPS, 11% were subsequently detected at the Bradford Island fishway exit. The exit slide drops lamprey into the Bonneville Dam forebay approximately 10 m to the east and upstream from the Bradford Island fishway exit. Lamprey may become disoriented during passage through the exit slide and fall back downstream after landing in the forebay. A third of these fallbacks into the fishway were later detected at upstream dams, indicating that they were able to resume upstream passage after their foray through the fishway exit. Efforts to provide a less disruptive exit from the LPS may help to reduce the fallback behavior we observed in both 2005 and 2006 (Moser et al. 2008).

A second objective in 2006 was to assess the efficacy of an entrance collector positioned outside of a main fishway entrance. Gaining entry to fishways at Bonneville Dam has historically been a bottleneck to adult lamprey passage (Moser et al. 2002a,b, 2005). An efficient collector positioned outside a main entrance could help lamprey to bypass this troublesome area and improve overall dam passage.

In 2005, we designed, fabricated, and installed a prototype entrance collector at the downstream north main entrance to the Washington-shore fishway. Due to difficulties encountered during installation, the structure was not operational until after the peak of lamprey migration. After this installation, we observed that the collector ramp created a persistent eddy, where water moved rapidly around the collector ramp. This reverse current, flowing up the submerged portion of the ramp, could disrupt lamprey use of the collector. Consequently, we modified the collector in 2006 to close over the open ramp and thereby eliminate the eddy effect. However, this change also forced lamprey to enter the collector only at its relatively small distal opening.

In 2006, we observed lamprey use of the entrance collector for an entire migration season. The results were disappointing in that only 135 lamprey were collected in the trap at the top of the collector. Of these, 3 had PIT-tags and represented less than 1% of the PIT-tagged population. Two of the three lamprey used the collector during the day, which is unusual for this nocturnally active fish. Perhaps closing the collector ramp produced an artificially low light condition on the collector during the day.

We also noted that the entrance collector seemed to be more effective during periods of low river discharge. In fact, over 20% of all lamprey collection at this structure in 2006 occurred on the day after river discharge fell below 250 kcfs. Perhaps lower velocities emanating from the fishway entrance, shorter submerged portions of the collector ramp, and reduced turbulence at the collector entrance resulted when discharge from the fishway entrance and tailrace elevation were low.

The entrance collector has potential for improving lamprey passage. In the future, we recommend that the collector ramp be opened to allow lamprey access along its entire submerged length. In addition, we recommend a systematic test of the effect of fishway entrance discharge on entrance collector efficiency. This will help identify the factors most important for lamprey attraction. Increased monitoring of precise lamprey positions as they approach this structure is also needed to help determine whether the collector ramp is sited in the most favorable location.

A broad range of variables stimulate lamprey movement (Daigle et al. 2006; Keefer et al. 2008). Further elucidation of these factors and their effects on lamprey movement is needed to improve LPS entrance collector design, particularly when lamprey are not aggregated near the collector and must be attracted to enter from afar.

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REFERENCES

CRBLTW (Columbia River Basin Lamprey Technical Workgroup). 2005. Critical uncertainties for lamprey in the Columbia River Basin: results from a strategic planning retreat of the Columbia River Lamprey Technical Workgroup. Report of the CRBLTW. Available at www.fws.gov/columbiariver/lampreywg/docs.htm (May 2009).

Daigle, W. R., C. A. Peery, S. R. Lee, and M. L. Moser. 2006. Evaluation of Adult Pacific Lamprey Passage and Behavior in an Experimental Fishway at Bonneville Dam. Report to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Daigle, W. R., M. L. Keefer, C. A. Peery, and M. L. Moser. 2008. Evaluation of Adult Pacific Lamprey Passage Rates and Survival Through the Lower Columbia River Hydrosystem: 2005-2006 PIT-Tag Studies. Report to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Keefer, M., W. R. Daigle, C. A. Peery, and M. L. Moser. 2008. Adult Pacific lamprey bypass structure development: tests in an experimental fishway Report to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Moser, M. L., A. L. Matter, L. C. Stuehrenberg, and T. C. Bjornn. 2002a. Use of an extensive radio receiver network to document Pacific lamprey (*Lampetra tridentata*) entrance efficiency at fishways in the lower Columbia River. Hydrobiologia 483:45-53.

Moser, M. L., P. A. Ocker, L. C. Stuehrenberg, and T. C. Bjornn. 2002b. Passage efficiency of adult Pacific lampreys at hydropower dams on the lower Columbia River, U.S.A. Transactions of the American Fisheries Society 131:956-965.

Moser, M. L., D. A. Ogden, D. Cummings, and C. A. Peery. 2006**.** Development and evaluation of a lamprey passage structure in the Bradford Island Auxiliary Water Supply Channel, Bonneville Dam, 2004. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Moser, M. L., D. A. Ogden, and C. A. Peery. 2005. Migration behavior of adult Pacific lamprey in the lower Columbia River and evaluation of Bonneville Dam modifications to improve passage, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Moser, M. L., D. A. Ogden, H. T. Pennington, W. R. Daigle, and C. A. Peery. 2008. Development of Passage Structures for Adult Pacific Lamprey at Bonneville Dam, 2005. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Ocker, P. A., L. C. Stuehrenberg, M. L. Moser, A. L. Matter, J. J. Vella, B. P. Sandford, T. C. Bjornn, and K. R. Tolotti. 2001. Monitoring adult Pacific lamprey (*Lampetra tridentata*) migration behavior in the lower Columbia River using radiotelemetry, 1998-99. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

APPENDIX

Lamprey Passage Structure Equipment and Maintenance

The lamprey passage structure (LPS) at the Bradford Island Auxiliary Water Supply Channel consists of two pumps that deliver water to the structure, the structure itself, and a counter that records lamprey passage events. The structure is operated from 15 May to 15 September each year and is relatively maintenance-free. Detailed below are instructions for start-up, in-season maintenance of the LPS and counter, specifications for the pump and counter, and procedures for winterization:

Start Up Instructions

1) Screw in all LPS drain plugs located in rest boxes.
2) Open valves to water lines and close valves that drain rest boxes.
3) Install and turn on both pumps.
4) Plug in palm pilot and connect it to event recorder (located at LPS terminus).

In-Season Maintenance Procedures

1) Conduct daily checks to insure that both pumps are delivering water to LPS.
2) Conduct weekly checks of accessible rest boxes to insure that there is no debris or dead lamprey in the boxes.
3) Conduct weekly downloads of counter. To do this, remove SD card. Download data to laptop computer. Re-insert SD card and restart counter.
4) Conduct monthly validation of counter. To do this, download counter and then observe ten lamprey passage events. Check counter data to confirm a 1:1 passage to count record.

Winterization Instructions

1) Turn off and remove pumps.
2) Turn off and remove palm pilot. Secure power cord and event recorder plug to insure that no moisture damage occurs.
3) Open drain plugs to drain rest boxes.
4) Close water line valves and open valves to drain rest boxes as needed.
5) Clean and inspect pumps and motors.

Pump and Counter Specifications

Pumps	Goulds Pump Model #75GS30 4" submersible well pump 75gpm
	Franklin Pump Motor Model #2343162604 3 hp 2.2KW 3Ph 230Volt
	Pump Panels C-H ECN5512BAE-E14 size 1 Overloads C-H 42011B-3 Acme Transformer for Panel 480 to 240 volt 6kva #T-2A-53329-1S
Counter	Allen-Bradley Counting Switch Oiltight limit switch Cat. No. 802T-HTP J series
	Operator head #40146-747-63
	Oregon RFID Time Stamp recorder.