Passage of Radio-tagged Adult Pacific Lamprey at Yakima River Diversion Dams

2012 Annual Report

Andy Johnsen, Mark C. Nelson, Daniel J. Sulak, Cal Yonce, and R.D. Nelle

U.S. Fish and Wildlife Service
Mid-Columbia River Fishery Resource Office
Leavenworth, WA

On the cover: Pacific lamprey code 69 attempting to climb the closed headgate in the right fishway at Prosser Dam, April 30, 2012. Photograph by Cal Yonce, USFWS.

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PASSAGE OF RADIO-TAGGED ADULT PACIFIC LAMPREY
AT YAKIMA RIVER DIVERSION DAMS
2012 ANNUAL REPORT

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Final Report

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Abstract- The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Pacific Northwest. Information about Pacific lampreys in the Yakima River is very limited. Several irrigation diversion dams exist on the Yakima River that may prevent or delay the upstream migration of adult Pacific lampreys; however, the total impact of these dams on adult Pacific lamprey migration and spawning is not known. We used radio telemetry to determine approach timing, residence time, fishway routes, other passage routes, and migration rates at the diversion dams on the lower Yakima River. Wanawish, Prosser, Sunnyside, and Wapato dams were equipped with multiple antenna telemetry stations. Seven additional stations were established to monitor tributaries and the boundaries of the study area. Seventy-six Pacific lampreys, collected from lower Columbia River dams in summer 2011, were radio-tagged and released near Wanawish and Prosser Dams on October 4, 2011 and March 28, 2012. Seventy-four lampreys made upstream movements with sixty-eight approaching at least one dam. Overall passage success at the dams varied from a low of 39% at Sunnyside Dam to a high of 62% at Wanawish Dam. Only two lampreys passed all four dams. All passage events occurred in October and April-June. At all four dams combined, the average residence time for lampreys that passed in the fall was 5.45 d with a fishway passage time of 2.2 h. Lampreys that passed in the spring had an average residence time of 23.7 d and a fishway passage time of 3.4 h. Fall passage occurred during discharges between 500 and 2,500 ft^3/s. Average discharge during spring passage events was highest at Wanawish with 8,300 ft^3/s and lowest at Prosser Dam with 5,200 ft^3/s. The majority (78%) of passage occurred when water temperatures were between 12 and 15 °C. The average migration rate between dams was 10.1 km/day with most movements past stations occurring at night. Fishway entrance velocities at all four dams ranged between -4.61 and 10.09 ft/s. To date, our results indicate the diversion dams on the Yakima River are impeding the upstream migration of Pacific lampreys. We suggest several different modifications that may increase lamprey passage including a lamprey passage system (LPS), reduced fishway velocities, and modifications to fishway entrances.

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Introduction

The Pacific lamprey *Entosphenus tridentatus* is an anadromous fish native to the Columbia River Basin and many of its tributaries, including the Yakima River (Patten et al. 1970). Over the last decade the number of adult Pacific lampreys returning to the Yakima River has been minimal, with counts at Prosser Dam (river kilometer 75) ranging from 0 to 87 individuals per year (DART 2011). These low counts are consistent with the declines observed at Columbia River dams (Kostow 2002, DART 2011). Several factors including construction and operation of hydroelectric and diversion dams, river impoundment, water withdrawals, stream alteration, habitat degradation, elevated water temperatures, pollution, and ocean conditions have likely contributed to this decline (Luzier et al. 2011).

Telemetry studies of Pacific lamprey movements within the Columbia River have documented that hydroelectric dams cause major delays and difficulties for the upstream migration of Pacific lampreys, resulting in less than half of tagged fish successfully passing upstream through the fishways (Moser et al. 2002, Johnson et al. 2009, Keefer 2009). Several diversion dams exist in the Yakima River Basin and may be impediments for adults migrating to suitable spawning areas, however, details on upstream migration, timing, spawning, and distribution of Pacific lamprey in the Yakima River are not well understood. Results from the pilot year of this study indicate dam passage success rates as low as 25%, however, the sample size was small and more detailed information about passage and residence time at the dams is needed (Johnsen et al. 2011).

The objective of this multi-year radio telemetry study is to determine adult Pacific lamprey passage at the Yakima River diversion dams, including approach timing, residence time downstream of dams, passage routes, time in the fishways, total time spent at the dams, and migration rates between dams. In addition, areas where Pacific lamprey over-winter and spawn in the Yakima River will be located if possible. Information from this study will help guide management recommendations for improving passage at the dams in the Yakima River.

This annual report presents the results of our study for the 2011 migratory year, from September 13, 2011 through August 31, 2012. Because of the increased interest and urgency for actions to conserve Pacific lamprey we also make some preliminary recommendations in this report.

Background

Similar to summer steelhead *Oncorhynchus mykiss*, Pacific lamprey enter freshwater a year prior to spawning, migrate upstream to overwinter, and then access spawning tributaries or areas the following spring. It is thought Pacific lampreys do not home to their natal streams, unlike many anadromous fishes, but instead may utilize the “suitable river strategy” in which returning adults are attracted to streams inhabited by larval lamprey or ammocoetes (Waldman et al. 2008). Recent genetic studies indicate Pacific lampreys are panmictic (Goodman et al. 2008 and Docker 2010) and support the hypothesis of no natal homing in Pacific lamprey. Adults typically return to the Columbia

River from February to June (Kostow 2002) and begin to arrive at McNary Dam (67 kilometers downstream of the Yakima River confluence) in early June with the peak of migration in late July or early August (DART 2011). During a migratory year, lampreys are not observed at Prosser Dam until mid to late August and only a few are counted through the fall. Most of the returning adults are observed the following spring with the majority counted during April and May (DART 2011). However, radio telemetry studies conducted in tributaries such as the John Day River (Bayer et al. 2000), the Willamette River (Clemens et al. 2011), and the Methow River (Nelson et al. 2009) found that Pacific lamprey entered these spawning tributaries in late summer and completed about 85% of their migration to spawning areas before overwintering. Thus it appears there has been a shift in migration timing in the Yakima River that differs from other tributaries and may be related to temperature differences between the Yakima and Columbia rivers. During July and August, temperatures in the lower Yakima River are on average almost 4 °C higher than in the Columbia River (mean 23.8 °C vs. 20.0 °C, 2002 to 2009 data-USBOR 2011; DART 2011). This appears to create a thermal barrier that either encourages lampreys to migrate past the Yakima River and continue upstream in the Columbia River or discourages lampreys from entering the Yakima River until later in the fall after temperatures equilibrate. Lampreys may also be overwintering in the Columbia River and entering the Yakima River the following spring. Radio-tagged Pacific lampreys translocated to the Yakima River exhibited the same migratory behavior as those that entered the river naturally (Johnsen et al 2011), supporting both the hypothesis of no natal homing and shifted migration timing within the Yakima River.

Investigation of the potential thermal barrier and its effect on lamprey migration in the Yakima River is beyond the scope of our current study. However, because it appears to shift the majority of the migration to the spring, we designed our study to test passage at the dams during both the fall and spring of the lamprey migration year. Accordingly, we tagged and released a portion of our study fish in the fall and held the others over winter before tagging and releasing them in the spring in order to mimic both the timing of the "natural" run and the condition of the lampreys during their migration in the Yakima River.

Methods

Study Area

The Yakima River flows for 344 km, from the headwaters at Keechelus Lake in the Cascade Mountains to the confluence with the Columbia River at river kilometer (rkm) 539, and drains an area of approximately 15,941 km^2 (Figure 1). Annual mean discharge at the Kiona Gage Station (rkm 48.1) is 3,479 cubic feet per second (ft^3/s) (range 1,293 – 7,055 ft^3/s), with the highest daily mean discharge of 59,400 ft^3/s recorded on December 24, 1933 and the lowest daily mean discharge of 225 ft^3/s recorded on April 4, 1977 (USGS 2011). The main tributaries include Satus Creek, Toppenish Creek, Naches River, Taneum Creek, Teanaway River, and Cle Elum River.

A complex irrigation network, managed in large part by the U.S. Bureau of Reclamation, makes the Yakima River Basin one of the most intensely irrigated areas in the United States, and has served to make it a leading producer of tree and vine fruit as well as other diverse agricultural products. Six lakes and reservoirs, with a total active storage capacity of 1.07 million acre-feet, hold the spring and summer snowmelt in the mountains for delivery to irrigation districts between April and October (Fuhrer et al. 2004). Irrigation water is distributed throughout the network via rivers, creeks, and man-made canals. Irrigation diversion dams include Wanawish, Prosser, Sunnyside, Wapato, Roza, and Easton on the Yakima River and Cowiche and Wapatox on the Naches River (Figure 1).

Surface water diversions are equivalent to about 60% of the mean annual stream flow from the basin (Fuhrer et al. 2004). In spring, the stream flow reflects the quantity of water stored in the mountain snowpack, while during the dry summer months it reflects the quantity of water released from the basin's storage reservoirs. During summer, return flows from irrigated land account for 50 to 70% of the flow in the lower Yakima River (Fuhrer et al. 2004).

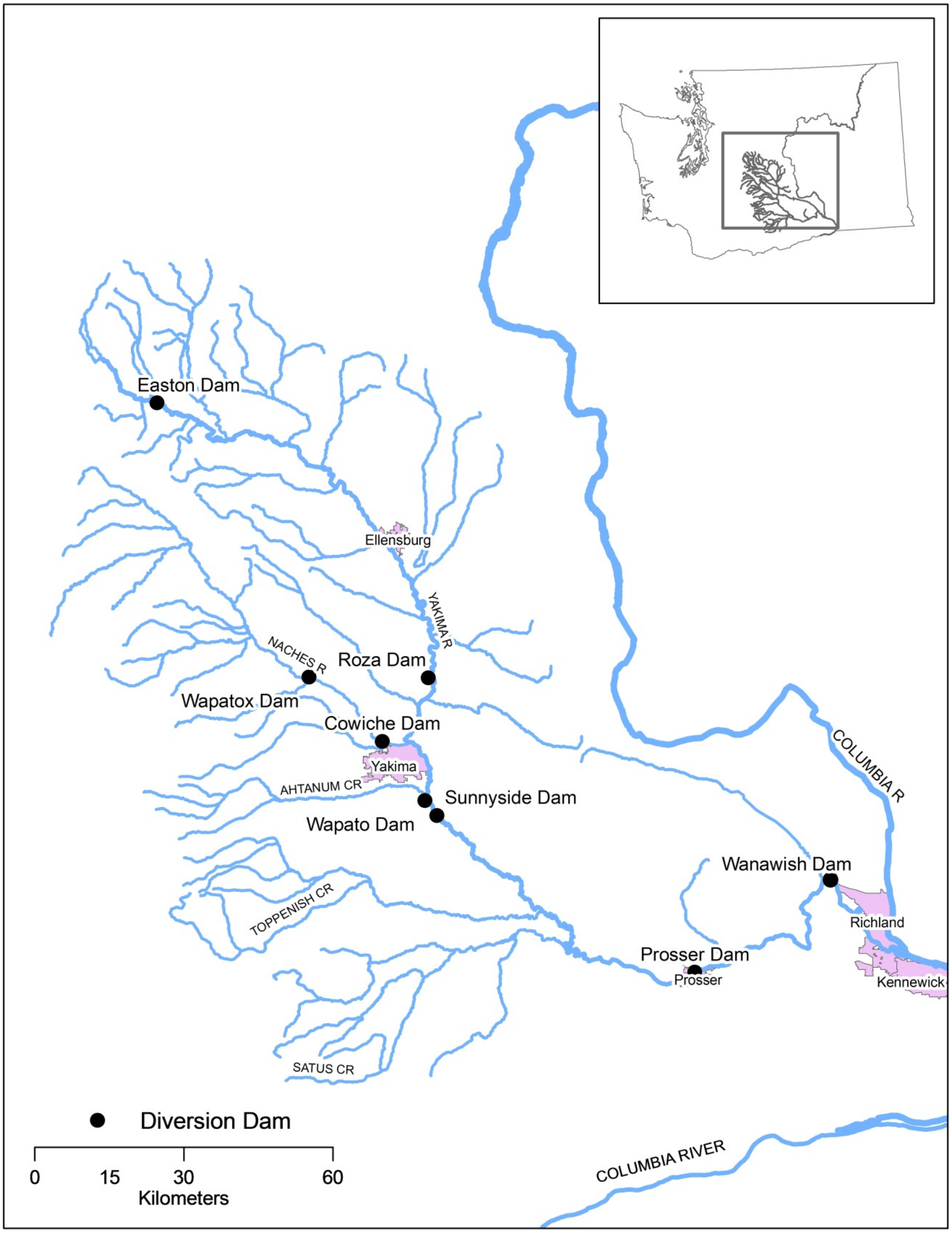

Figure 1. Map of the Yakima River watershed, showing the locations of the major diversion dams.

Fixed Stations

Fixed telemetry stations were set up at six diversion dams, in three tributaries, at the outfall of an irrigation diversion, and near the mouth of the Yakima River (Figure 2). The basic layout at a diversion dam consisted of aerial antennas that monitored downstream of the dam, the face of the dam, and upstream of the dam. Underwater antennas monitored pools at the entrance, middle, and exit of each fishway. Aerial antennas were four element Yagi-type and underwater antennas were constructed of coaxial cable with 100 mm of the inner wire bared at the end. Hanging antennas were added to the arrays during the spring of 2012 and were the same design as the underwater antennas except they were suspended above the waterline. Aerial antennas were mounted on masts, underwater antennas were suspended on chains, and hanging antennas were zip-tied to rails and posts. Data recording telemetry receivers (Lotek SRX-400A), equipped with an antenna switching unit (Grant Engineering Hydra) programmed on a "master-slave" cycle, were housed in a metal box at each station. AC power, when available, was used to charge the external 12v battery that powered the receiver at each diversion station. Solar panels were used as a back-up power system in case AC power was lost and as the primary power source at stations with no available AC power.

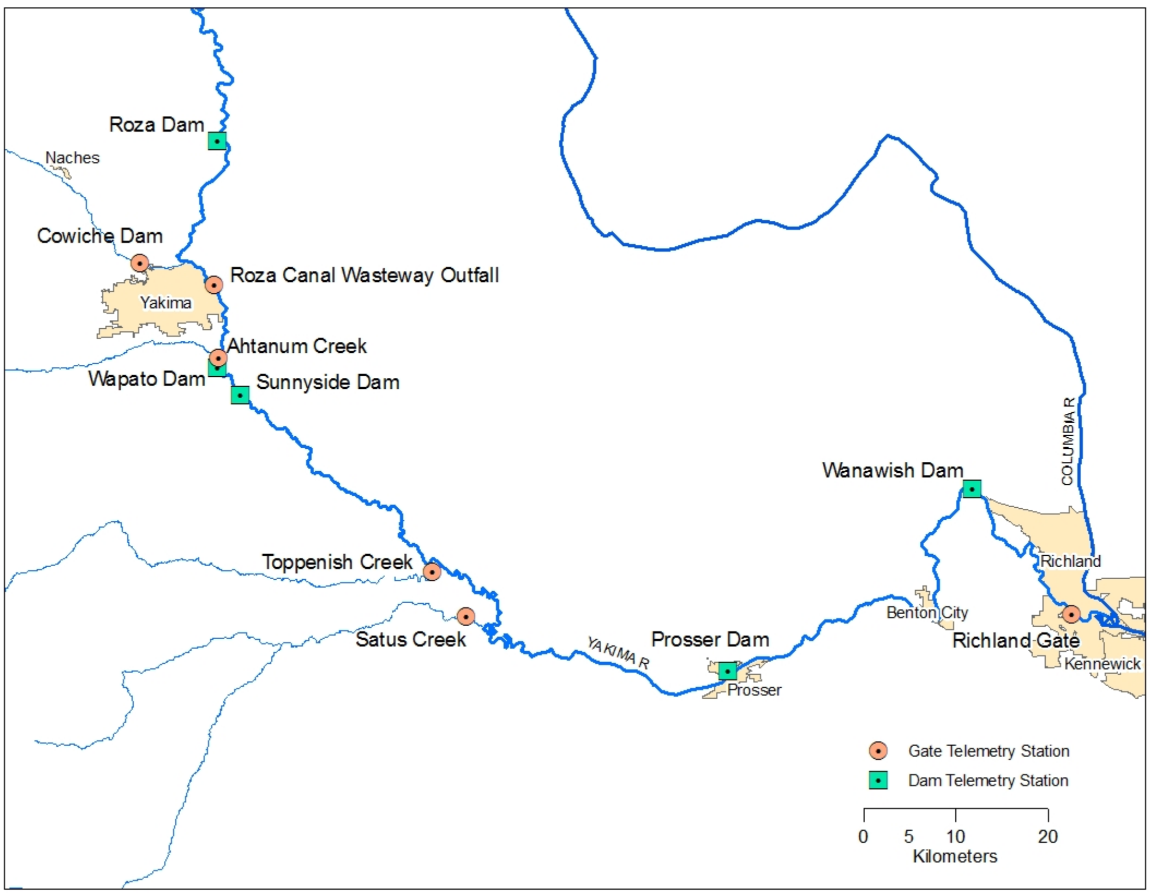

Figure 2. Map of the lower Yakima River basin showing the locations of fixed telemetry stations in 2012.

Wanawish Dam

Wanawish Dam, constructed in 1892 at rkm 29 near Horn Rapids, is a rock filled timber crib dam with a concrete face. It is 160 m long and approximately 2 m high and diverts water into canals on both banks of the river. Fishways, consisting of an entrance pool and 4 vertical slot pools, are located on each bank at the dam, with the fishway exit near the mouth of each canal (Figure 3). Each entrance pool has a high flow and low flow gate that were operated in relation to river flow. Both fishways at the dam had one aerial antenna facing downstream, one upstream, and one across the face of the dam. Underwater antennas were located at the entrance, middle, and exit pool of each fish ladder, as well as the entrance to the irrigation canal on river left. Hanging antennas were placed in the entrance of the right bank irrigation canal and in each corner where the face of the dam meets the bank (Figure 3).

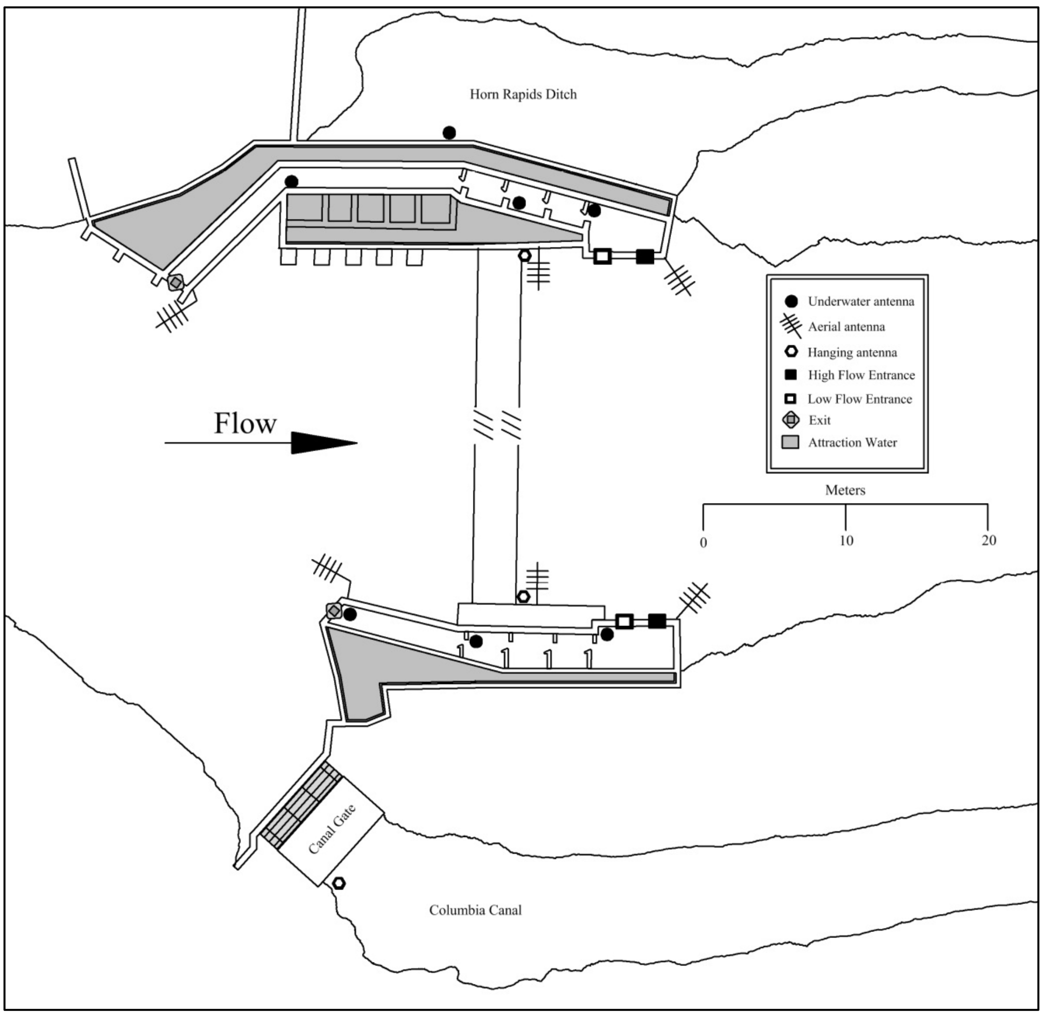

Figure 3. Locations of telemetry antennas on right and left bank fishways at Wanawish Dam, 2011 to 2012.

Prosser Dam

Prosser Diversion Dam, constructed in 1904 by private interests and now operated by the U.S. Bureau of Reclamation, is located at rkm 75. The facility consists of a concrete weir structure (2.7 m tall, 201 m long), an irrigation canal (1,500 ft^3/s capacity) on the left bank, an adult sampling facility (in the right bank fishway), three vertical slot type fishways (one on the right bank and two mid-river "islands" on the dam), and a juvenile bypass and sampling facility (downstream at the canal screen structure). The left island entrance pool has four gates: two high flow and two low flow. The center island fishway entrance pool has high flow and low flow gates on each side. The right bank fishway has an upper entrance with high and low flow gates and a lower entrance with one high/low flow gate (USBOR 2011). The right bank fishway had one aerial antenna monitoring downstream and one upstream; underwater antennas were located at the high water entrance, low water entrance, middle, and exit pools of the fish ladder. A hanging antenna was placed near an outflow pipe located at the most downstream end of the dam (Figure 4). The center island fishway had one downstream aerial antenna and two upstream aerial antennas (combined as one unit); underwater antennas were at both entrance pools and the exit pool of the fish ladder. Hanging antennas monitored where the face of the dam met the left and right sides of the island (Figure 4). The left island fishway was equipped with aerial antennas monitoring upstream, downstream, and across the face of the dam to the left and right of the island; underwater antennas were located within the entrance, middle, and exit pool of the fish ladder. Hanging antennas were placed on the outside of each fish ladder entrance gate and where the face and the left side of the island meet (Figure 4).

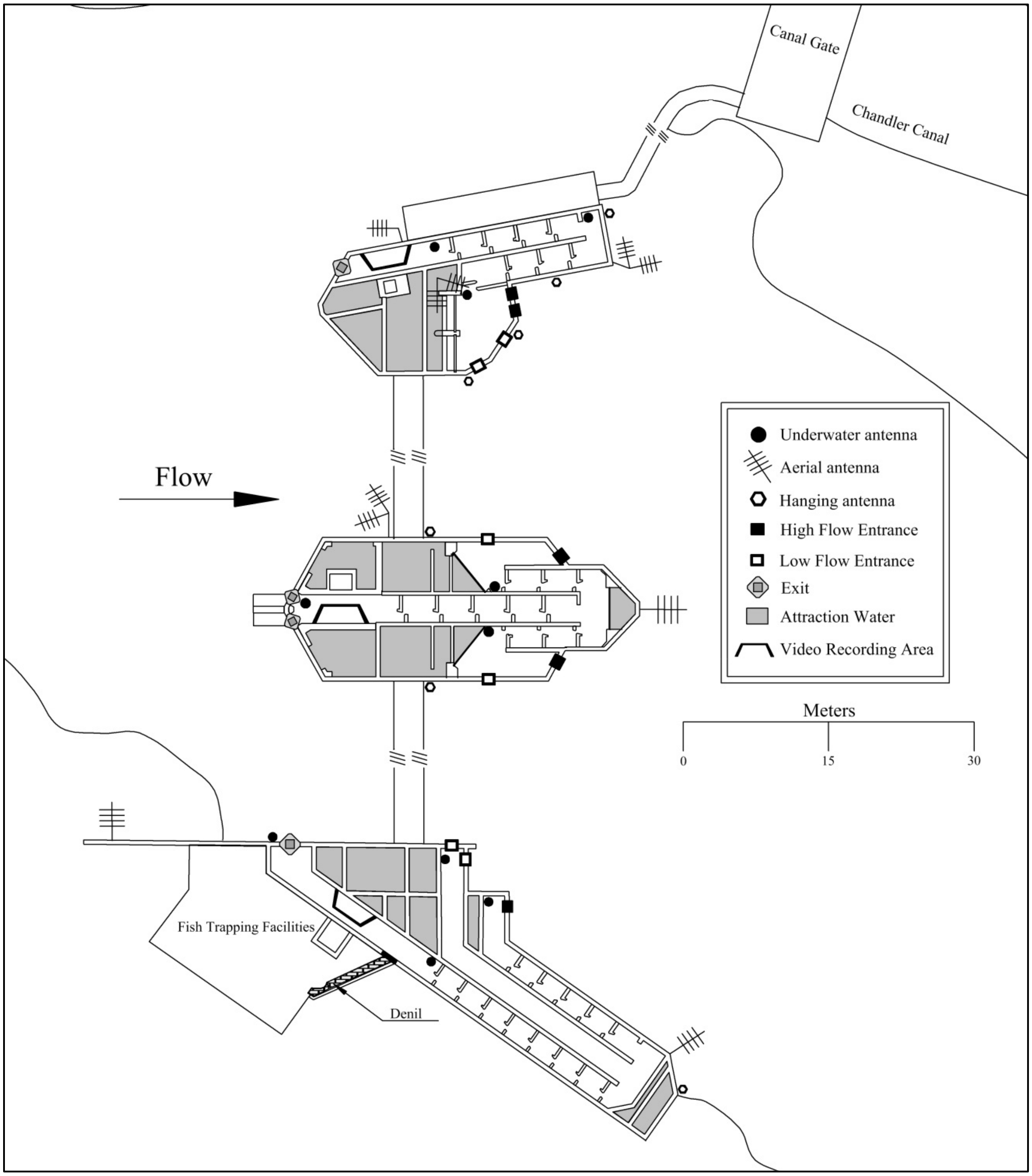

Figure 4. Locations of telemetry antennas on right, center, and left fishways at Prosser Dam, 2011 to 2012.

Sunnyside Dam

Sunnyside Diversion Dam, located at rkm 167, was completed in 1907. It is a concrete ogee weir with embankment wing and a canal (1,320 ft^3/s capacity) on the left bank. The structural height is 2.4 m and the weir crest length is 152 m (USBOR 2011). Fish passage facilities consist of three stair step ladders, one on each bank and one near the center of the dam. The left and right bank fishways have one high flow and one low flow gate. The center island has two high flow and two low flow gates; one located on each side. The left bank fishway had one upstream aerial antenna and two downstream aerial antennas (combined as one unit); underwater antennas were located in the entrance, center, and exit pool of the fish ladder. Hanging antennas monitored the sluiceway and the corner where the structure met the face of the dam (Figure 5). The center island fishway was equipped with a total of four aerial antennas: two (combined as one unit) monitored downstream and two monitored upstream on either side; underwater antennas were located in both entrance pools and a middle pool of the fish ladder. Hanging antennas were placed in the corners of the island and the face of the dam (Figure 5). The right bank fishway was equipped with three aerial antennas: one downstream, one across the face of the dam, and one upstream; underwater antennas were located in the entrance, middle, and exit pools of the fish ladder. One hanging antenna monitored where the right bank structure and the face of the dam met (Figure 5).

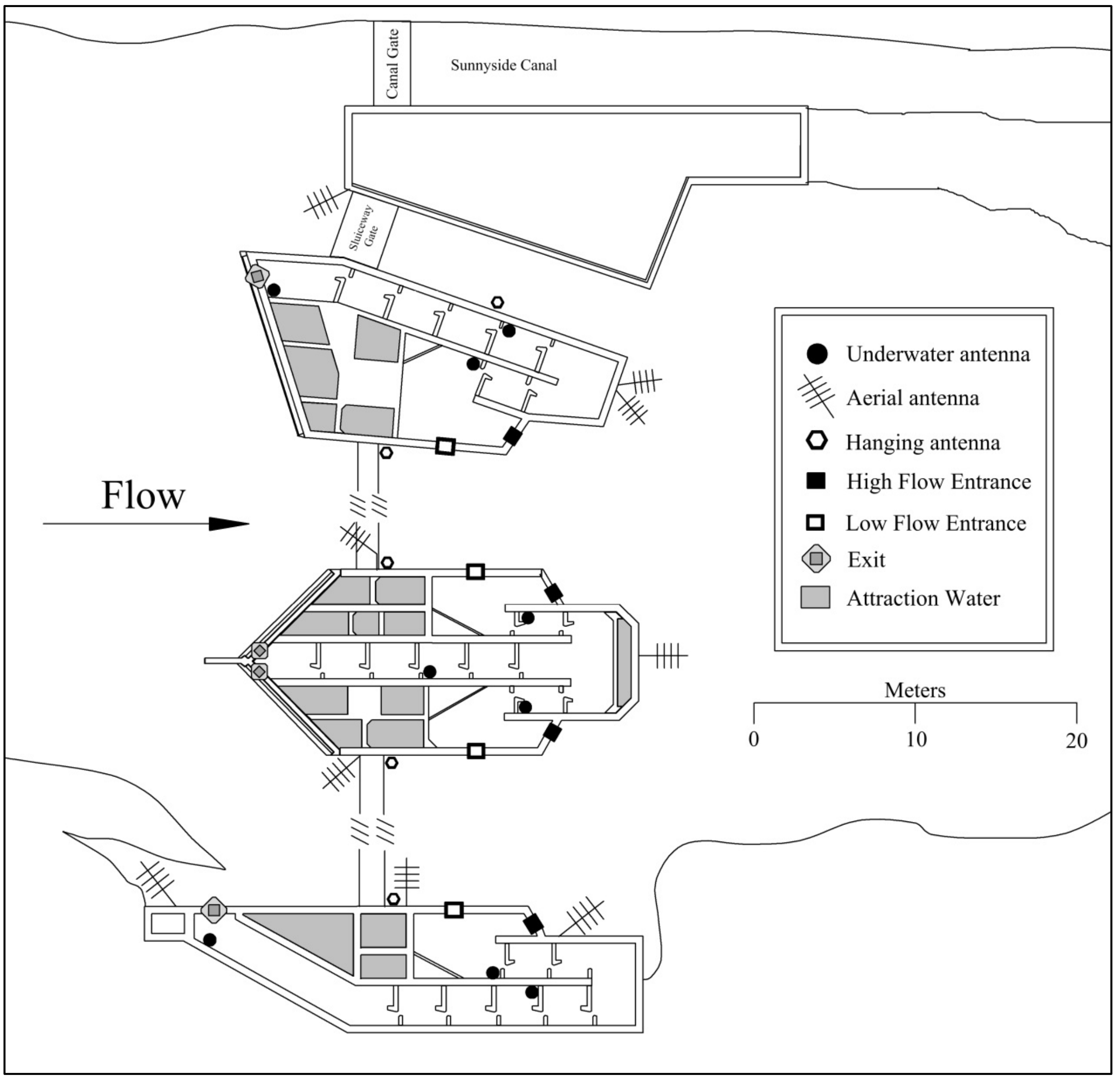

Figure 5. Locations of telemetry antennas on the right, center and left bank fishways at Sunnyside Dam, 2011 to 2012.

Wapato Dam

Wapato Dam (rkm 171.5) consists of two separate structures in two channels connected by a natural island. The west channel structure has one fishway located on a center island with a diversion canal on the right bank. The east channel structure has fishways on both the center island and on the right bank. All the fishways consist of serpentine vertical slot pools with high and low flow gates in the entrance pool. The east channel structure center island was equipped with three aerial antennas: one downstream, one upstream, and one monitoring the face on the river left side of the island. Underwater antennas were located in the entrance, middle, and exit pools of the fish ladder. A hanging antenna was located on the right side of the island near the face of the dam (Figure 6). The right bank of the east channel structure utilized three aerial antennas: one downstream, one upstream, and one across the face of the dam. Underwater antennas were positioned in the entrance, middle, and exit pools of the fish ladder. One hanging antenna was placed in the corner where the face and left bank structure met (Figure 6). The west channel structure was equipped with four aerial antennas: one downstream, one upstream, and one across the face of the dam on either side of the center island. Underwater antennas were located in the entrance, middle, and exits pools of the fish ladder (Figure 7).

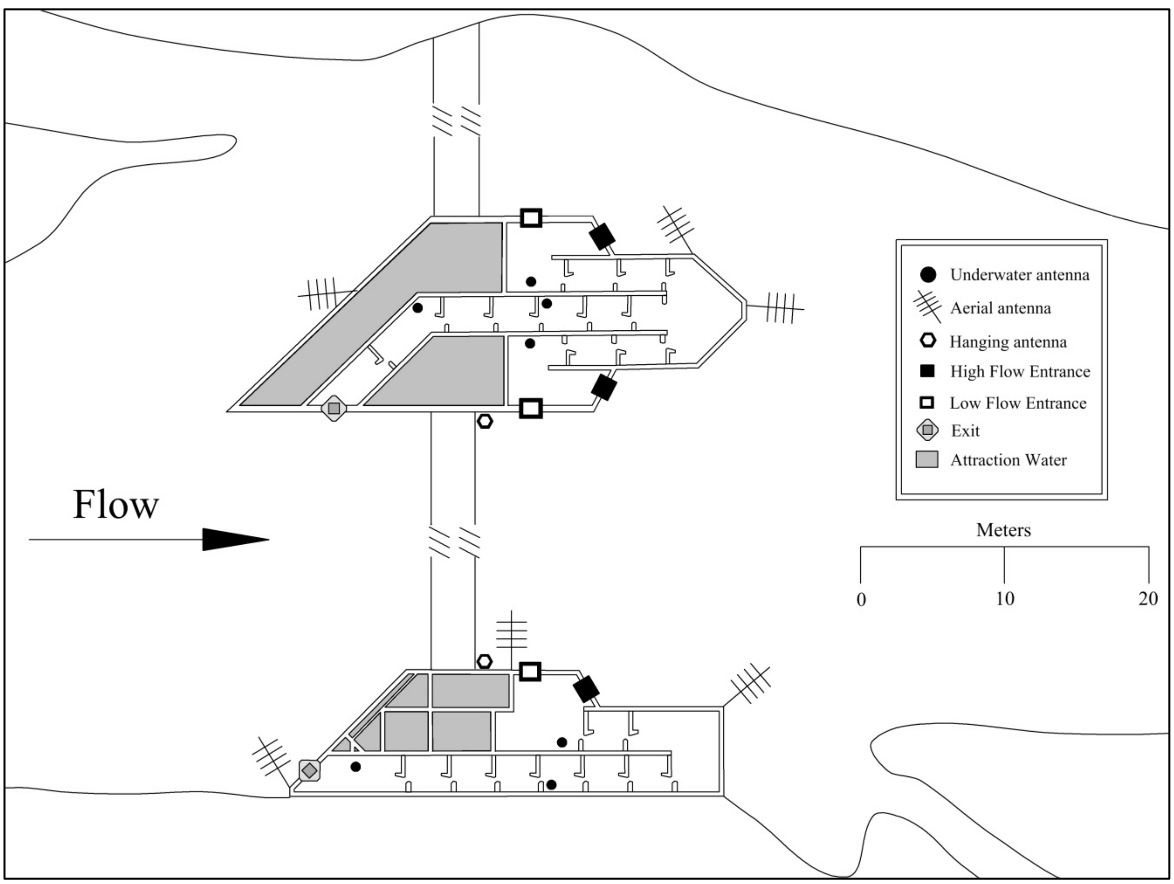

Figure 6. Locations of telemetry antennas on the left island and right bank of the east structure of Wapato Dam, 2011 to 2012

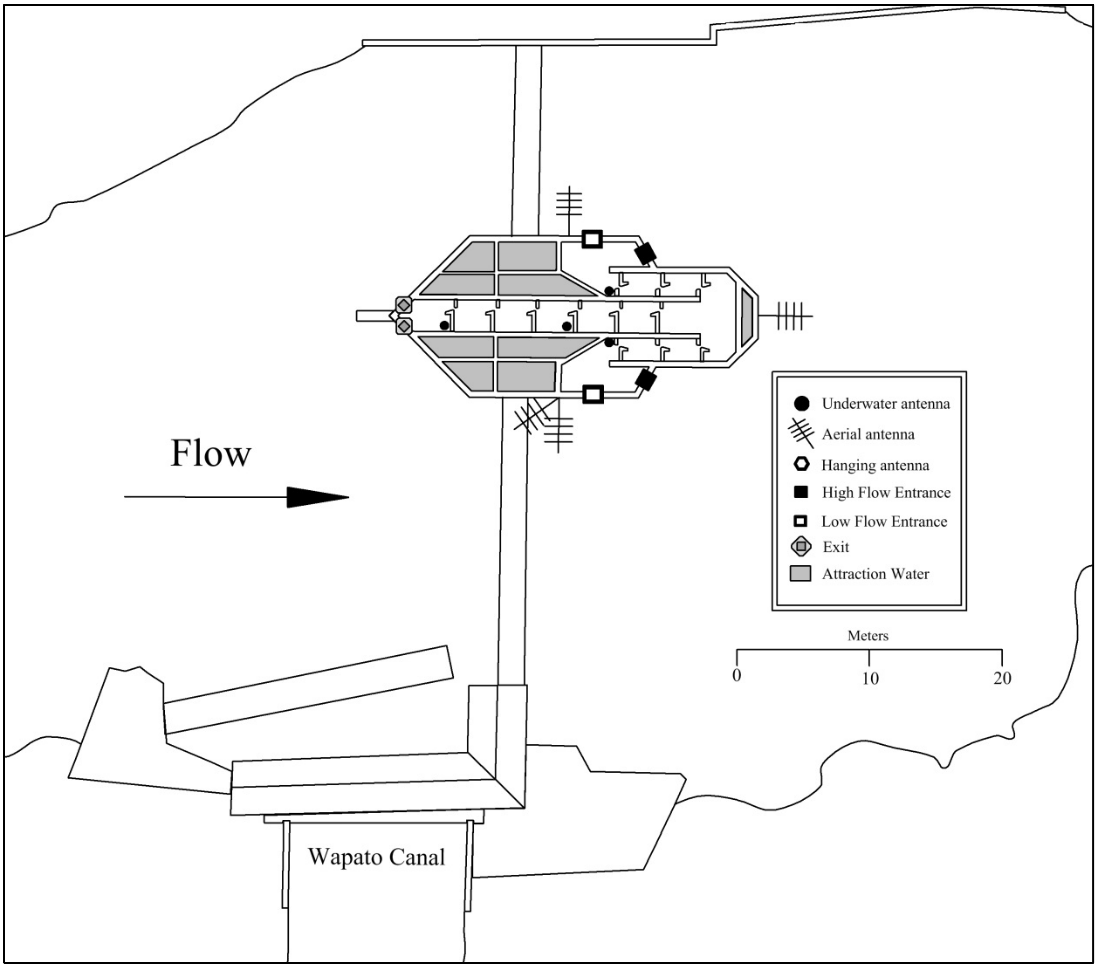

Figure 7. Locations of telemetry antennas on the center island of the west structure of Wapato Dam, 2011 to 2012.

Cowiche Dam

Cowiche Dam (rkm 6) on the Naches River is a concrete ogee spillway structure. It is approximately 65 m in length, with a 1.5 m crest, a 6.4 m ogee spillway, and a 6.4 m apron (George and Prieto 1993). A fish ladder consisting of vertical slot pools is located on the river left of the dam. A diversion canal and fish screen is located on the river right portion of the dam. The dam was equipped with three aerial antennas: one downstream, one across the face of the dam, and one upstream (Figure 8).

Roza Dam

Roza Dam (rkm 205) was originally built in 1939 and is operated by the U.S. Bureau of Reclamation. It is a concrete weir with a movable crest structure. The dam stands 20.4 m tall and is 148 m in length (USBOR 2011). Water is diverted into an irrigation canal on the river right of the dam. The fishway utilizes a vertical slot pool design with entrances on both banks. These entrances merge into a single ladder on the left bank. A simple telemetry station consisting of one downstream antenna was installed at Roza Dam to detect if any tagged Pacific lampreys migrated that far upriver (Figure 2). No solar power backup was utilized at Roza Dam.

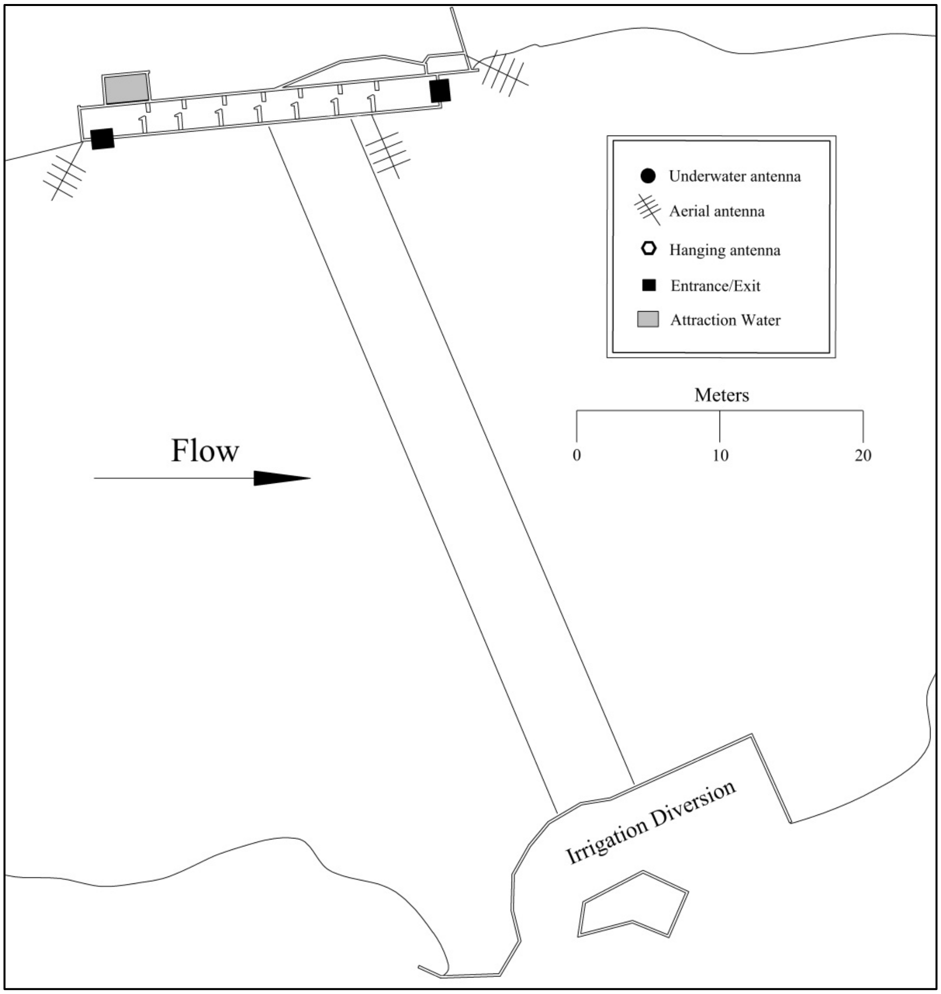

Figure 8. Locations of telemetry antennas on Cowiche Dam, 2011 to 2012.

Gate Stations

"Gate" stations were set up to determine if any tagged lampreys left the study area or entered tributaries (Figure 2). A station near the mouth of the Yakima River (rkm 6.9) was set up to determine if Pacific lamprey moved downstream to the Columbia River. This fixed station consisted of one aerial antenna aimed across the river, a SRX400A receiver, and a car battery charged by AC power provided by the landowner. Gate stations were also set up on Satus and Toppenish creeks to determine movement into these tributaries. These stations each had one antenna facing upstream and one facing downstream combined together as one unit. The receivers at these stations were powered by solar panels. A station using solar power and a single downstream facing antenna monitored movement into Ahtanum Creek (Figure 2). A station at the Roza irrigation canal wasteway outfall near the city of Yakima (rkm 182) was also set up to aid in upstream migration detections. This station was equipped with a single upstream facing antenna and was AC powered.

Telemetry Data Analysis

For descriptive purposes, the definitions of *left* and *right* were referenced to the downstream or river flow direction, and applied to the river banks as well as the island fishways at the dams. *First approach* was defined as the first detection recorded on an aerial antenna at a fixed telemetry station. *Below dam residence* was calculated as the difference between the first downstream detection at the dam and the first detection of entry into the fishway during a passage event. *Below dam residence* was further separated into three segments based on activity: *fall residence*, *over-winter*, and *spring residence*. *Fall residence* was defined as the time a lamprey spent actively moving at a dam in an attempt to pass. *Over-winter* was calculated as the time of inactivity during the winter months in which a lamprey did not move or attempt to pass a dam. *Spring residence* was calculated as the difference between when movement commenced after the over-winter period and when a lamprey either entered a fishway on a passage event or moved downstream from the dam. *Fishway passage* was calculated as the elapsed time between the first fishway entrance detection and the last fishway exit detection during a passage event. *Above dam residence* was defined as the difference between the last fishway exit detection and the last upstream aerial antenna detection at the dam. Diurnal movements were described as occurring either during day or night hours. Civil twilight, as noted at the town nearest to each dam (www.sunrisesunset.com), was used to differentiate between day and night hours. *Migration time* was calculated as the difference between the last detection as the lamprey moved from one station to the first detection at the next station. *Migration rate* was as defined the distance between stations divided by migration time.

Collection

Adult Pacific lampreys were supplied by the Yakama Nation Fisheries Program from lampreys collected at Bonneville Dam, The Dalles Dam, and John Day Dam on the lower Columbia River between June 24 and August 18, 2011. Fish were captured in funnel traps at the picketed leads of the fish counting stations on both sides of the dams and transported to the Yakama Nation Prosser Hatchery facility and held until tagged. All were injected with 0.15 cc of Oxytetracycline to prevent the spread of disease (Patrick Luke, Yakama Nation Fisheries Program, pers. comm.). Holding facilities consisted of flow-through metal stock tanks supplied with river and/or well water.

Radio Transmitter Implantation

Implantation surgeries took place in the spawning shed at the Yakama Nation Prosser Hatchery facility. The surgical procedure was modified from methods described in Moser et al. (2002) and Nelson et al. (2007). Tools and transmitters were chemically disinfected with Benz-All®. Fish were anesthetized in a bath of 80 ppm tricaine methanesulfonate (MS-222) buffered with sodium bicarbonate to match the pH of the river water. After 8 to 10 minutes the fish was removed from the bath and total length (mm), interdorsal base length (mm), girth (mm), and weight (g) were measured and recorded. The lamprey was then placed on a cradle made from PVC pipe and the head and gills were immersed in a 15 L bath of 40 ppm of buffered MS-222. Wet sponges were placed in the cradle to prevent the lamprey from sliding and to assist in incision placement. Using a number 12 curved blade scalpel, a 25 mm incision was made 1 cm off the ventral midline with the posterior end of the incision stopping in line with the anterior end of the first dorsal fin. A catheter was inserted through the incision and out the body wall approximately 4 cm posterior to the incision. The antenna was threaded through the catheter and the individually coded radio transmitter (Lotek NTC-6-2, 9 x 30 mm, 4.3 g, 441 d battery life or Lotek NTC-4-2L, 8 x 18 mm, 2.1 g, 162 d battery life) was inserted into the incision. Using a 19 mm needle the incision was then closed with 3-4 braided absorbable sutures. The lamprey was then transferred to a holding tank until release.

Release

Release dates were chosen in an attempt to mimic the movements of the natural run in the river. Release sites were located upstream and downstream of both Wanawish Dam and Prosser Dam. Release sites were chosen by accessibility and relative close proximity to each dam. Individuals were chosen for each release site by removing them from the holding tank at random. The code of each fish was then recorded prior to release.

Tracking

Fixed telemetry stations were downloaded on a weekly schedule. Test beacons were activated during downloads at each station to ensure the antennas and receivers were operating and recording properly. In addition to the data recorded at fixed stations, mobile tracking was opportunistically conducted to determine exact locations at the dams as well as approximate locations between the dams. Mobile tracking was conducted by foot, truck, boat, and airplane.

Temperature

Stream temperatures were monitored at Wanawish, Prosser, Sunnyside, and Wapato dams. Electronic data loggers (HOBO® U22 Water Temp Pro v2, Onset Computer Corp.) were calibration checked for accuracy with an NIST-tested thermometer and only units that agreed to within 0.2 °C were deployed. The data loggers were housed in perforated PVC pipe (40 mm dia.) and tethered to wire cable suspended into the river from one fishway at each dam. Data loggers were programmed to record once every hour. Data were downloaded into a shuttle, offloaded, and saved to a desktop computer. Mean, minimum, and maximum daily water temperatures were calculated with the Hoboware® Pro software package.

Discharge

Stream discharge was obtained from the USBOR Pacific Northwest Region Hydromet website (http://www.usbr.gov/pn/hydromet/yakima/yakwebarcread.html). Average daily flow (QD) was queried for the Yakima River stations at Kiona (KIOW), Prosser (YRPW), and Parker (PARW). Discharge is reported in ft^3/s.

Velocity

Velocities at the entrances to the fishways were measured during weekly downloading of the telemetry stations. Measurements were taken when the velocity meter was available for use and when time allowed. Velocities were measured using a Marsh McBirney Flo-Mate™ 2000 portable flow meter. The sensor and mount were attached to an extension pole so measurements could be taken from the deck of the dam. Measurements occurred on the downstream side of all open entrances to the fishways. The meter was placed approximately 0.5 m into the water column, though this varied between fishways and levels of discharge. Three measurements were taken and the median velocity was recorded in feet per second (ft/s). For analysis purposes, each island fishway had velocities of all its open gates averaged and reported as one. Statistical analyses of entrance velocities were performed using a single factor analysis of variance. The field measurements of entrance velocity are recorded in Appendix B.

Results

Tagging

Tagging and release occurred during two time periods; one in the fall 2011 and the other in the spring 2012. For the fall releases, a total of 42 adult Pacific lampreys were radio tagged September 13-15, 2011 (Table 1). Weights ranged from 356 to 825 g (mean 509.5 g), lengths from 624 to 780 mm (mean 685 mm) and girths from 100 to 135 mm (mean 116.5 mm). For the spring release, 35 lampreys were tagged on March 21-22, 2012 (Table 2). Weights ranged from 276 to 499 g (mean 361.8 g), lengths from 532 to 687 mm (mean 595.7 mm), and girth ranged between 95 and 123 mm (mean 106.2 mm) (Figures 9 and 10).

Holding

Lampreys tagged in the fall were held for 3 weeks before release. Lampreys tagged in the spring were held for one week. One lamprey shed its tag during the fall holding period. No mortalities occurred during holding.

Releases

Fall release- A total of 41 tagged lampreys were released on October 4, 2011. Five were released from the left bank 1.2 km upstream of Wanawish Dam; sixteen were released 0.45 km downstream of the dam, eight on each bank (Figure 11). The upstream release location was in a slow water area consisting of submerged grasses and an undercut bank. The downstream release locations were in areas consisting of various sized cobbles. Sixteen lampreys were released on the left bank 0.30 km downstream of Prosser Dam amongst large boulders in a slow, deep pool. Four lampreys were released 1.1 km upstream of the dam on the right bank in a slow water area with boulders and floating debris (Figure 12).

Spring release- A total of 35 Pacific lampreys were released on March 28, 2012 at the same locations used in the fall. Seven lampreys were released on each side of the river downstream of Wanawish Dam and four were released upstream of the dam. Thirteen tagged fish were released downstream of Prosser Dam and 4 upstream of the dam.

Table 1. Weight, total length, girth, dorsal base length, and release location of radio-tagged adult Pacific lampreys released in the Yakima River on October 4, 2011.

Code	Total Length (mm)	Weight (g)	Girth (mm)	Dorsal Base Length (mm)	Release Location
4	710	587	135	34	Wanawish Left d/s
11	669	570	122	35	Wanawish Left d/s
21	644	377	103	26	Wanawish Left d/s
27	780	665	128	44	Wanawish Left d/s
18	642	420	108	30	Wanawish Left d/s
22	654	466	115	45	Wanawish Left d/s
35	662	425	110	35	Wanawish Left d/s
43	657	450	115	38	Wanawish Left d/s
6	715	571	128	47	Wanawish Right d/s
7	726	644	125	40	Wanawish Right d/s
10	724	525	113	43	Wanawish Right d/s
14	716	581	123	36	Wanawish Right d/s
19	675	444	105	45	Wanawish Right d/s
23	661	473	119	38	Wanawish Right d/s
28	719	598	124	44	Wanawish Right d/s
12	664	475	118	55	Wanawish Right d/s
13	720	825	127	38	Wanawish u/s
20	700	479	114	39	Wanawish u/s
32	669	464	119	32	Wanawish u/s
45	669	445	112	31	Wanawish u/s
40	660	461	111	40	Wanawish u/s
5	732	596	115	44	Prosser d/s
9	739	647	125	41	Prosser d/s
15	678	476	113	39	Prosser d/s
17	653	392	105	50	Prosser d/s
26	690	514	116	34	Prosser d/s
29	703	530	122	44	Prosser d/s
31	649	420	109	38	Prosser d/s
34	754	676	127	55	Prosser d/s
37	640	437	111	29	Prosser d/s
39	719	558	119	41	Prosser d/s
41	687	470	113	39	Prosser d/s
42	684	470	116	36	Prosser d/s
8	680	544	119	41	Prosser d/s
16	732	600	124	47	Prosser d/s
33	666	468	118	31	Prosser d/s
46	683	540	120	35	Prosser d/s
30	675	475	114	34	Prosser u/s
38	624	367	104	29	Prosser u/s
36	632	356	100	31	Prosser u/s
44	684	462	109	38	Prosser u/s
24	668	456	121	34	shed during holding

Table 2. Weight, total length, girth, dorsal base length, and release location of radio-tagged adult Pacific lampreys released in the Yakima River on March 28, 2012.

Code	Total Length (mm)	Weight (g)	Girth (mm)	Dorsal Base Length (mm)	Release Location
56	571	327	98	20	Wanawish Left d/s
67	572	315	102	18	Wanawish Left d/s
69	625	408	109	30	Wanawish Left d/s
71	620	348	97	40	Wanawish Left d/s
78	595	391	112	30	Wanawish Left d/s
85	622	387	106	30	Wanawish Left d/s
88	605	354	106	27	Wanawish Left d/s
55	542	297	105	12	Wanawish Right d/s
59	589	352	104	22	Wanawish Right d/s
60	625	445	113	18	Wanawish Right d/s
61	562	395	123	18	Wanawish Right d/s
65	638	377	103	30	Wanawish Right d/s
68	600	349	116	34	Wanawish Right d/s
77	602	371	103	25	Wanawish Right d/s
57	561	352	115	30	Wanawish u/s
72	532	276	95	17	Wanawish u/s
89	555	320	102	15	Wanawish u/s
82	553	293	98	15	Wanawish u/s
62	610	405	112	27	Prosser d/s
63	687	499	117	40	Prosser d/s
64	598	354	107	30	Prosser d/s
66	592	362	102	32	Prosser d/s
75	612	427	112	25	Prosser d/s
76	646	444	110	34	Prosser d/s
79	582	323	105	27	Prosser d/s
81	635	401	110	23	Prosser d/s
83	655	434	110	32	Prosser d/s
84	585	337	101	21	Prosser d/s
86	580	322	101	24	Prosser d/s
87	593	329	100	22	Prosser d/s
58	575	305	95	25	Prosser d/s
70	592	332	97	27	Prosser u/s
73	555	290	100	23	Prosser u/s
74	600	340	115	26	Prosser u/s
80	582	403	115	32	Prosser u/s

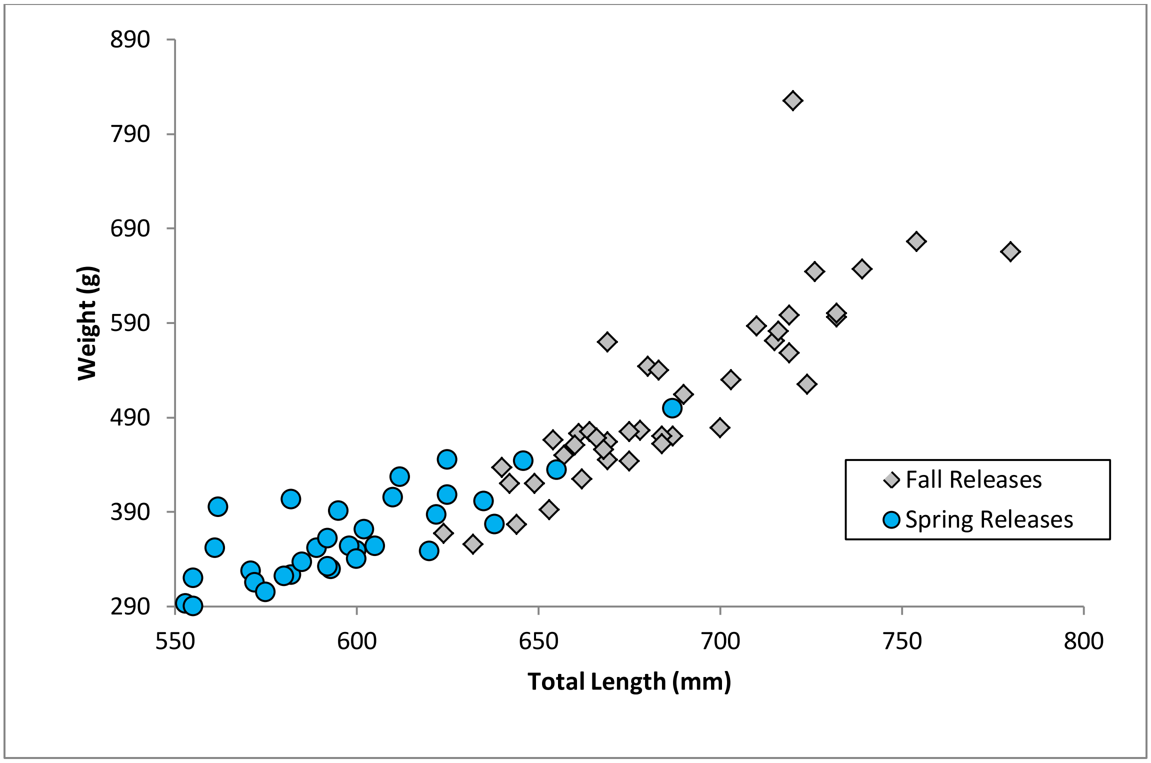

Figure 9. The lengths and weights of radio-tagged Pacific lampreys released into the Yakima River on October 4, 2011 and March 28, 2012.

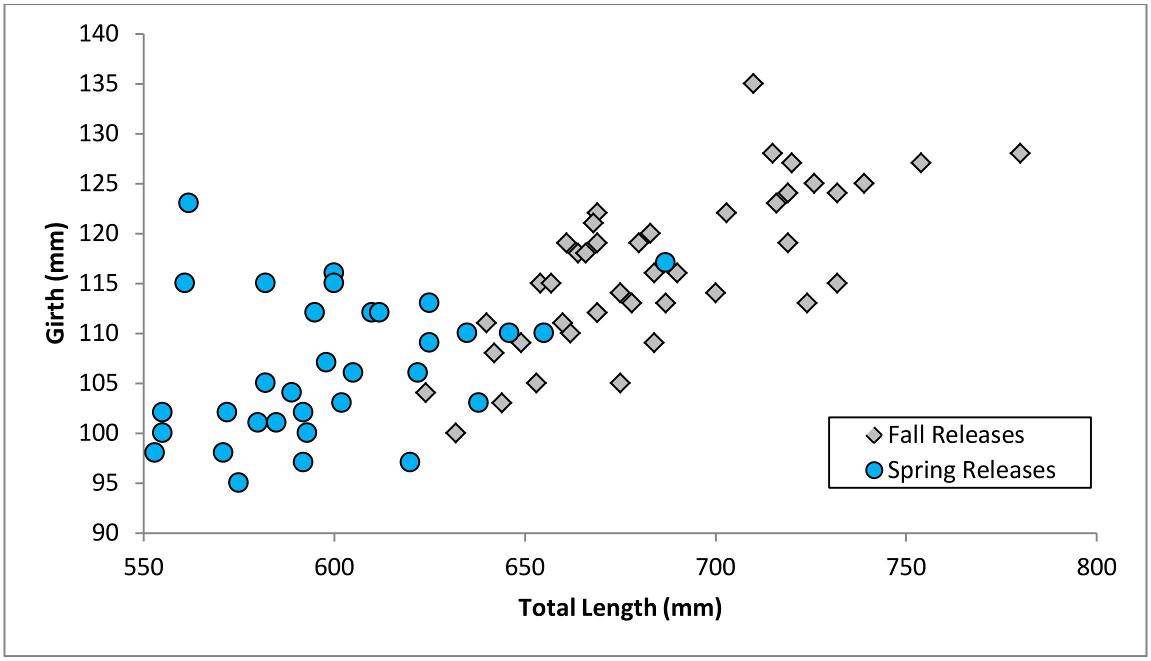

Figure 10. The girths of radio-tagged Pacific lampreys released into the Yakima River on October 4, 2011 and March 28, 2012.

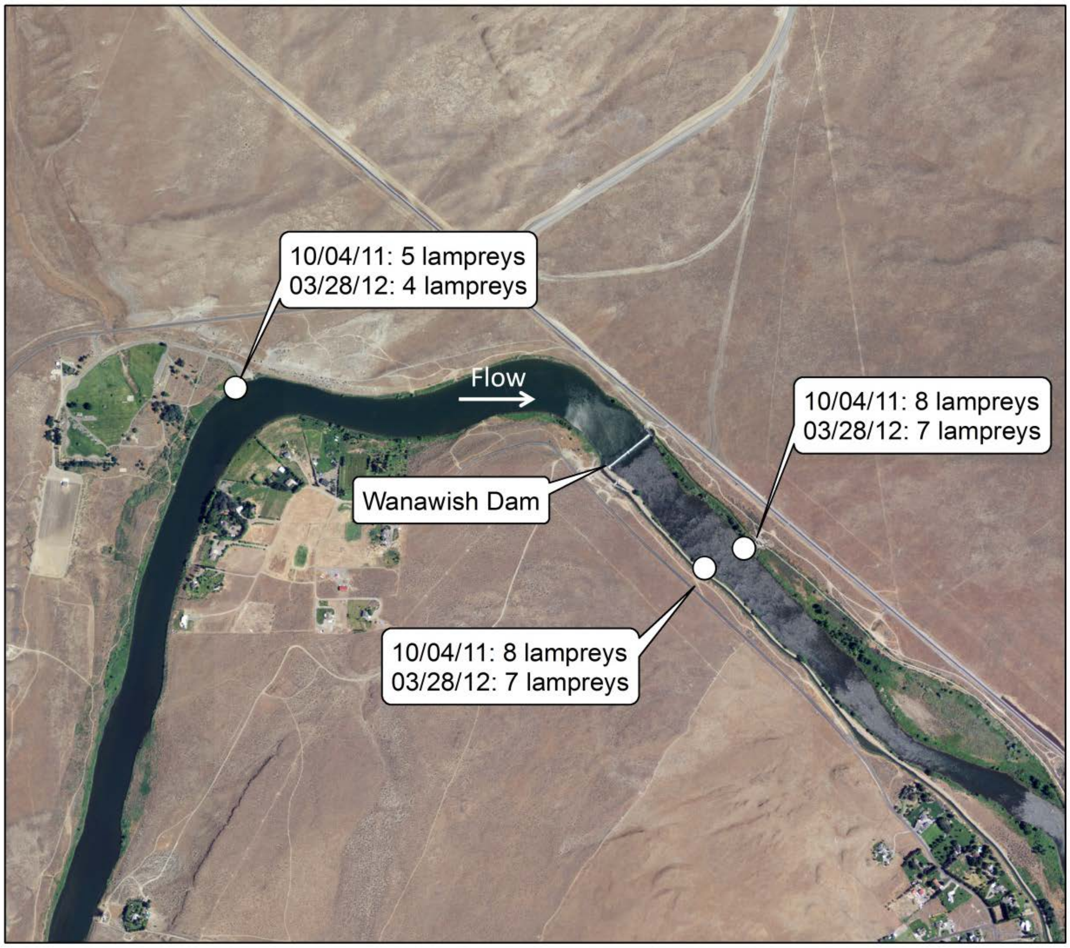

Figure 11. Aerial photograph showing the release locations of radio-tagged adult Pacific lampreys in the vicinity of Wanawish Dam on October 4, 2011 and March 28, 2012.

Figure 12. Aerial photograph showing the release locations of radio-tagged adult Pacific lampreys in the vicinity of Prosser Dam on October 4, 2011 and March 28, 2012.

Movements
A total of 73 (96%) Pacific lampreys moved upstream from their release sites. Two moved downstream from their release sites and one never moved. The tag of this latter individual was later determined to be on the bank, indicating either predation or scavenging had occurred. First approaches of a dam were made between October 4, 2011 and July 7, 2012. A total of thirteen lampreys resided at the dams through the winter. The movements of radio-tagged lampreys at each dam are described in the following sections.

Wanawish Dam
First approach of fall release- Sixteen tagged lampreys were released downstream of the dam on October 4 and first approach detections of individuals ranged from October 4 to December 20, with a second pulse from January to April 2012 (Table 3). Nine lampreys (56%) approached in October, one individual approached in December, five (31%) approached in the following spring, and one moved downstream from its release location. Detections of first approaches were on the downstream aerial antennas, with 62% near the left bank while the rest were near the right bank.

First approach of spring release- Fourteen tagged lampreys were released on March 28 and detections of first approach of individuals at the dam ranged from March 28 to April 24, 2012. One hundred percent of the spring released lampreys were detected approaching the dam.

Below Dam Residence- Total residence time below Wanawish Dam ranged from two hours and forty-five minutes to nearly 219 days (Table 3). Ten lampreys approached the dam before overwintering. Three passed the dam in October and had an average fall residence of 8 days (range 0.11-13.1 d). The remaining seven had an average fall residence of 12 days (range 1.7-19.7 d) before they stopped actively moving. These lampreys remained at the dam throughout the winter before continuing their upstream migration. Overwinter residence averaged 132 days, though one lamprey only overwintered for 55.5 days. Spring residence time of fall released lampreys averaged 33.9 days (range 21.3-50.9 d) for those who passed the dam and 58.1 days (range 29-82 d) for those that were unsuccessful in migrating past the dam. Successful spring released lampreys had an average residency time of 30.8 days (range 23-50 d) (Figure 13). All twenty-nine lampreys that approached Wanawish Dam were detected on each side of the dam at least once (Figure 14). Holding areas for lampreys were not localized to a pool or corner of the dam and instead were distributed across the width of the river, most commonly in middle of the river close to the face of the dam and along the banks just downstream of the dam. The mortality of one lamprey was indicated at Wanawish Dam on May 4 when code 19 stopped moving. On May 10 it was detected out of the river on the right bank 250 m downstream of the dam, but recovery of the transmitter was not possible and it is unknown if the lamprey was depredated or scavenged.

Table 3. Wanawish Dam approach and residence data: first and last detection dates and total number of days that adult radio-tagged Pacific lampreys resided below the dam before entering a fishway or moving downstream, October 2011 through August 2012.

Code	1st Station Detected	1st Detection Date	Last Detection Date	Days	Enter Fishway?
11	Left Bank	10/04/11 19:34	05/07/12 16:18	215.9	No
35	Left Bank	10/04/11 19:51	10/04/11 22:36	0.1	Yes
22	Left Bank	10/04/11 19:57	10/15/11 21:25	11.1	Yes
6	Left Bank	10/04/11 22:26	04/21/12 22:01	200	Yes
12	Right Bank	10/10/11 19:35	10/23/11 21:04	13.1	Yes
27	Left Bank	10/10/11 21:29	05/16/12 20:24	219	Yes
19	Left Bank	10/15/11 19:34	05/04/12 00:51[A]	201	No
4	Left Bank	10/18/11 19:46	04/22/12 20:58	187.1	Yes
18	Right Bank	10/22/11 19:21	04/15/12 21:33	176.1	No
14	Right Bank	12/20/11 22:45	04/23/12 00:15	124.1	Yes
21	Left Bank	02/24/12 03:34	05/06/12 09:01	72.2	No
7	Left Bank	02/26/12 02:05	05/18/12 02:23	82	No
43	Left Bank	03/17/12 13:53	04/27/12 15:50	41.1	No
23	Left Bank	03/17/12 14:32	05/18/12 05:06	61.6	No
60	Right Bank	03/28/12 16:01	04/23/12 00:09	25.3	Yes
65	Right Bank	03/28/12 20:03	04/24/12 01:26	26.2	Yes
71	Left Bank	03/28/12 20:18	05/08/12 22:53	41.1	Yes
88	Left Bank	03/28/12 20:41	05/17/12 18:50	49.9	Yes
69	Left Bank	03/28/12 21:00	04/21/12 21:18	24	Yes
78	Left Bank	03/28/12 23:51	04/22/12 20:38	24.9	Yes
28	Left Bank	03/31/12 14:15	04/21/12 22:06	21.3	Yes
77	Right Bank	04/01/12 18:45	04/24/12 21:30	23.1	Yes
68	Right Bank	04/10/12 20:40	04/22/120 8:28	11.5	No
59	Right Bank	04/12/12 19:39	05/14/12 19:04	31.9	Yes
55	Right Bank	04/21/12 21:31	08/21/12 00:37[B]	121.1	No
67	Left Bank	04/22/12 21:21	05/19/12 18:19	26.9	No
61	Right Bank	04/23/12 03:41	04/25/12 22:46	2.8	No
85	Left Bank	04/24/12 02:58	unknown	unk	Yes
56	unknown	unknown	05/28/2012 22:39	unk	Yes

[A] last date of movement

[B] date radio tag battery died

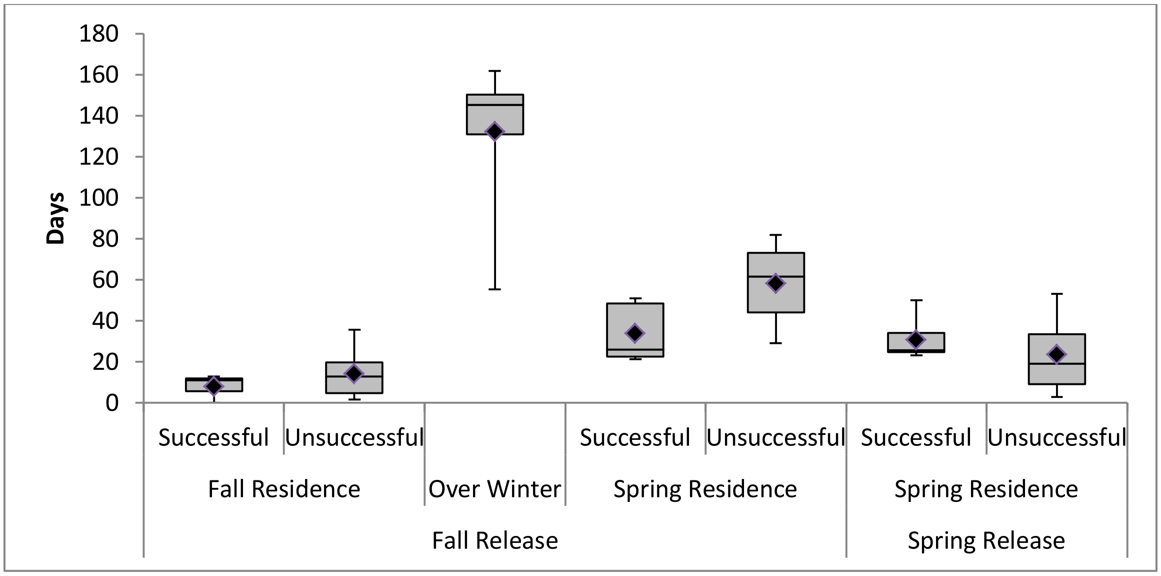

Figure 13. Periods of below dam residency for radio-tagged Pacific lampreys at Prosser Dam that were successful and unsuccessful in passing upstream of the dam, October 2011 through July 2012. Box plots show median and quartiles. The diamonds indicate the means.

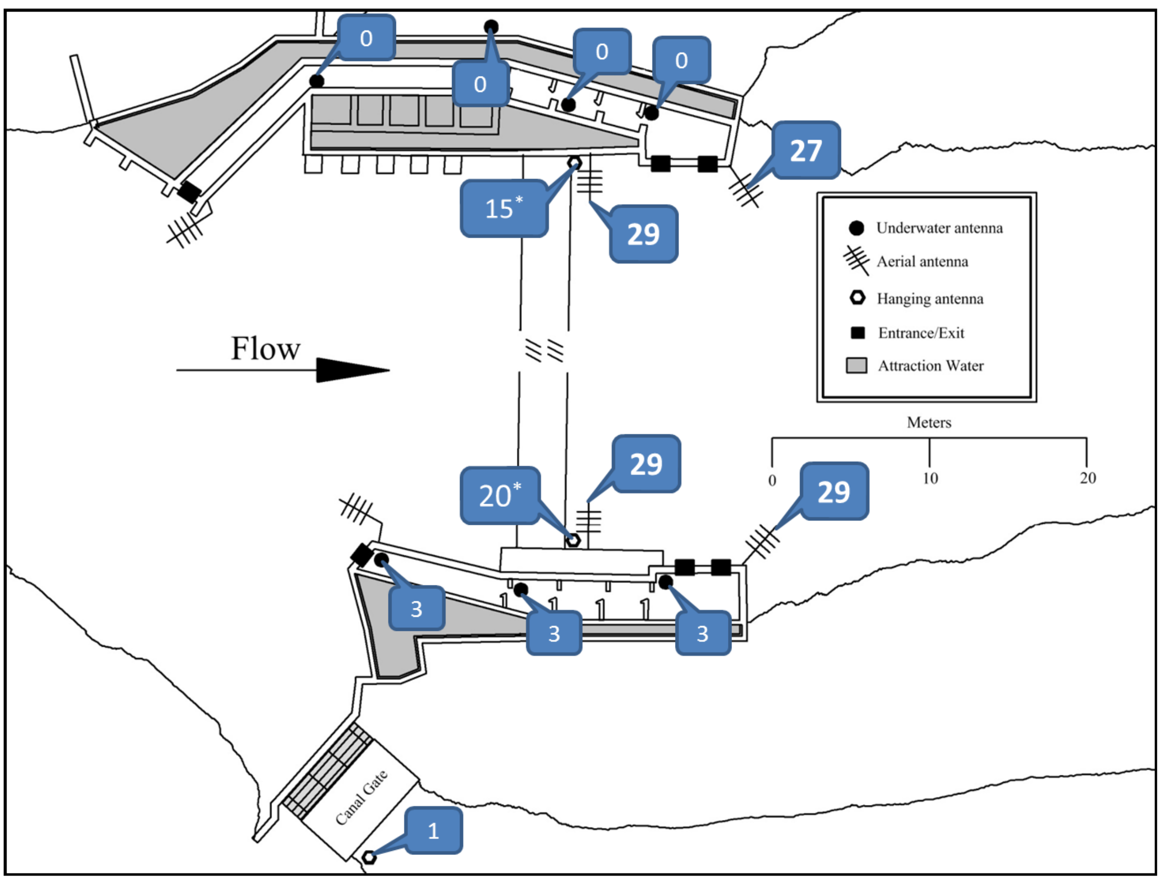

Figure 14. Number of radio-tagged Pacific lampreys detected on downstream and in-ladder antennas at Wanawish Dam, October 2011-July 2012. Antennas with a (*) were installed on March 27, 2012.

Fishway Passage- Of the 29 Pacific lampreys that approached the dam, 18 (62%) were ultimately successful in passing upstream (Table 4). Three fall released lampreys passed Wanawish Dam in October and five were successful in the spring months for a total fall release success rate of 53%. Ten of the fourteen spring released lampreys passed, for a success rate of 71%. All passage events took place in October, April, and May; half of which occurred between April 21 and 24. The right bank fishway was definitively used by three lampreys. Two lampreys were last detected passing the dam on the left bank antennas but there were no detections on the antennas within the fishway. The remaining 13 were detected passing the dam on the river right station. Data suggest that these individuals did not use the fishway but instead climbed over the dam using a ledge in between the fishway and the face of the dam (Figure 15). Passage time within the fishway ranged from 0.03 to 0.27 hours. The time it took to pass the dam using the ledge ranged from 0.18 to 2.98 hours (average 1.08 hours). Nine lampreys never passed the dam and instead moved back downstream. One individual remained at the dam until the transmitter battery died near the end of the study period. The status of that lamprey is not known.

Table 4. Wanawish Dam fishway data: dates of entry, exit and total time in fish ladder or passage area, and water temperature at passage for radio-tagged adult Pacific lampreys from October 2011 to July 2012.

Code	Release Site/Period	Fishway or Area	Entered Ladder or Area	Exited Ladder or Area	Time in Ladder or Area (hr)	Temp °C
35	WAN Fall Dn	L. Bank	10/04/11 22:36	10/05/11 02:45	4.15	15.4
22	WAN Fall Dn	Ledge	10/15/11 21:25	10/15/11 22:39	1.23	14.0
12	WAN Fall Dn	Ledge	10/23/11 21:04	10/23/11 22:08	1.07	14.0
69	WAN Spr Dn	Ledge	04/21/12 21:18	04/21/12 21:36	0.3	11.9
6	WAN Fall Dn	Ledge	04/21/12 22:01	04/21/12 22:27	0.43	11.9
28	WAN Fall Dn	R. Ladder	04/21/12 22:06	04/21/12 22:20	0.23	11.9
78	WAN Spr Dn	Ledge	04/22/12 20:38	04/22/12 21:36	0.97	13.3
4	WAN Fall Dn	Ledge	04/22/12 20:58	04/22/12 21:26	0.47	13.3
60	WAN Spr Dn	Ledge	04/23/12 00:09	04/23/12 00:28	0.32	14.3
14	WAN Fall Dn	R. Ladder	04/23/12 00:15	04/23/12 00:17	0.03	14.3
65	WAN Spr Dn	Ledge	04/24/12 01:26	04/24/12 01:53	0.45	14.7
77	WAN Spr Dn	Ledge	04/24/12 21:30	04/24/12 21:41	0.18	14.7
71	WAN Spr Dn	Ledge	05/08/12 22:53	05/08/12 23:09	0.27	13.3
59	WAN Spr Dn	L. Bank	05/14/12 19:04	05/14/12 19:32	0.47	15.1
27	WAN Fall Dn	Ledge	05/16/12 20:24	05/16/12 23:23	2.98	16.4
88	WAN Spr Dn	R. Ladder	05/17/12 18:50	05/17/12 19:06	0.27	15.3
56	WAN Spr Dn	Ledge	05/28/12 22:39	05/28/12 23:03	0.4	14.5
85	WAN Spr Dn	Ledge	unknown	05/13/12 15:06	unk	13.9

Figure 15. The ledge on the right bank of Wanawish Dam that it appears most Pacific lampreys used to pass upstream. The flow is approximately 5,500 ft^3/s in the left picture and 10,500 ft^3/s on the right. The entrance to the fishway is just out of the picture on the left hand side.

Discharge-

Pacific lampreys passed Wanawish during two distinct discharge levels. The three that passed in October 2011 did so at flows below 2,600 ft^3/s. Lampreys passing during the spring months did so at flows between 6,610 and 10,400 ft^3/s. The majority of passage events occurred during periods of increasing discharge (Figure 16).

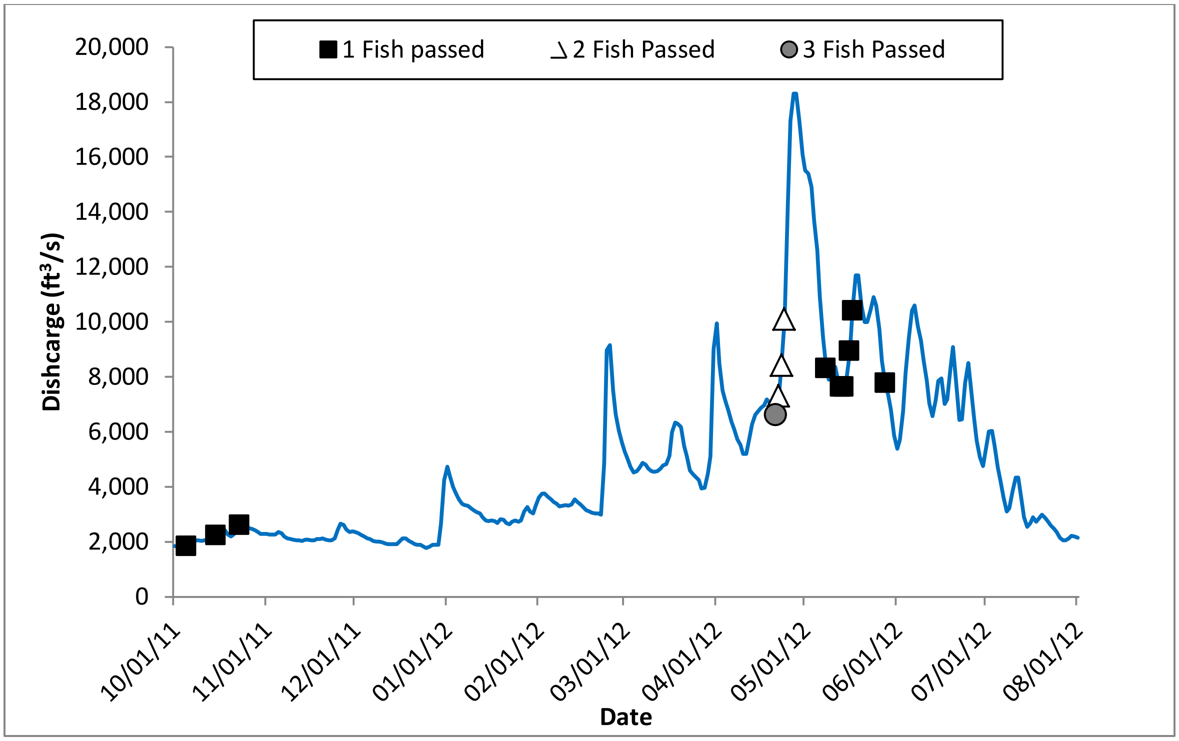

Figure 16. Graph showing the discharge and passage timing of radio-tagged Pacific lampreys at Wanawish Dam on the Yakima River, October 2011 through July 2012.

Velocity at Fishways- Fishway entrance velocities were recorded between April 5 and August 7, 2012 (Figure 17 and Appendix B). Velocities for the right bank fishway ranged between -0.81 and 6.92 ft/s. Several negative velocities were recorded for both fishways. The left bank fishway was inoperable during most of the study period. Its velocities are therefore representative of the velocity of the river as it passes the fishway entrance and not those of the fishway itself.

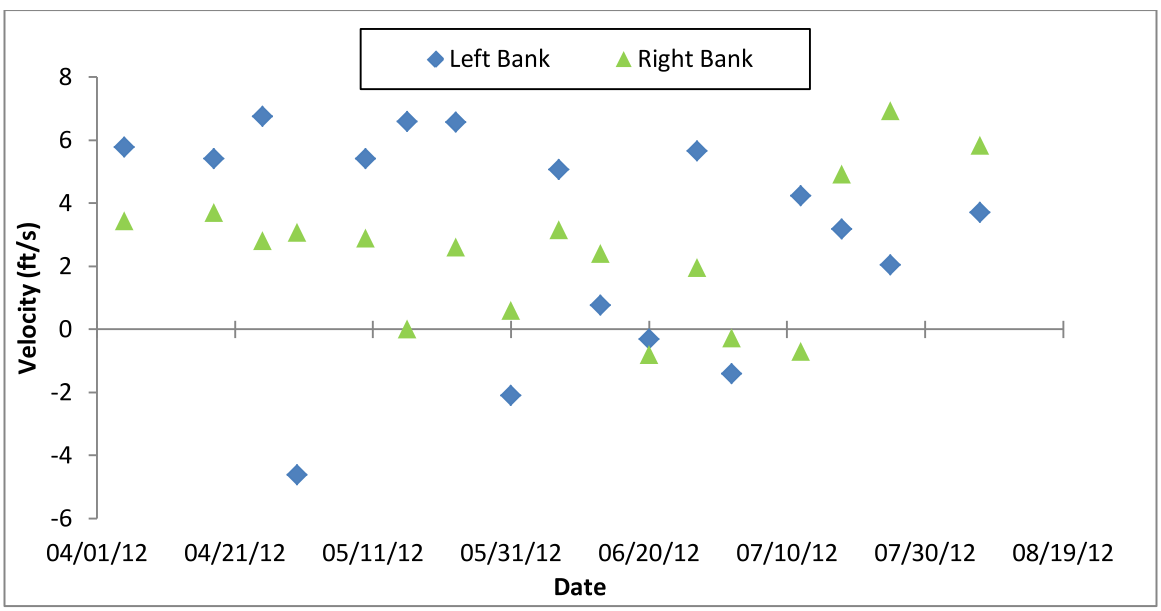

Figure 17. The entrance velocities at Wanawish Dam fishways between April and August, 2012.

Temperature- Water temperatures of the Yakima River were recorded at Wanawish Dam between October 1, 2011 and September 1, 2012 (Figure 18). Daily averages varied from 0 to 25 °C. Lamprey passage occurred during daily mean temperatures of 11.9 to 16.4 °C with the majority (78%) passing between 13.4 and 14.7 °C (Figure 18, Table 4). In the fall, water temperatures rapidly declined to less than 10 °C after the last lamprey passed the dam and movements below the dam generally ceased for the remainder of the fall.

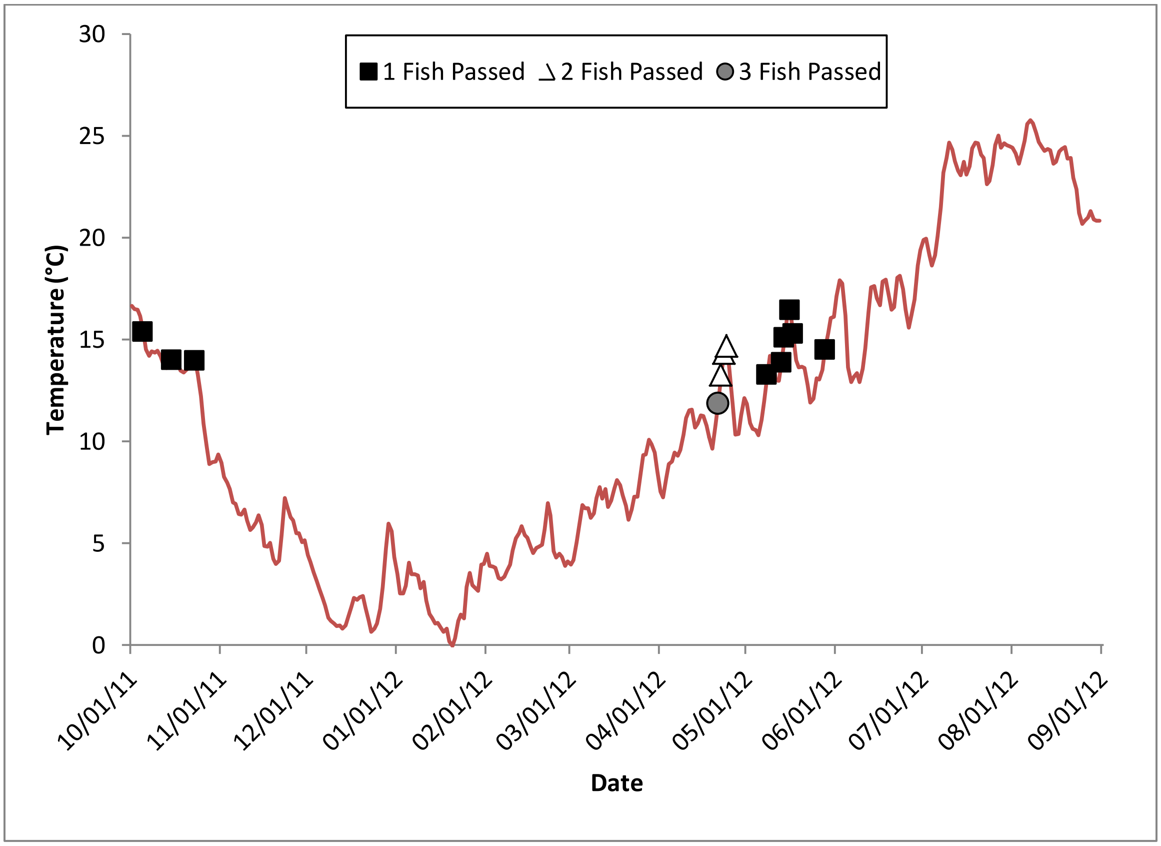

Figure 18. Average daily water temperatures of the Yakima River and dates of lamprey passage at Wanawish Dam between October 1, 2011 and September 1, 2012.

Above Dam Residence- On May 10, one lamprey (code 71) was detected in the right bank Columbia Irrigation District Canal after it had passed the dam. It stayed approximately 20 m downstream of the canal entrance for 58.1 days. It then exited through the upstream end of the canal and continued its upstream movement. No other lamprey resided more than a few minutes at the dam once it had successfully passed upstream of it.

Prosser Dam

First Approach- Pacific lampreys from both releases downstream of Prosser Dam began to approach on the evening of their release (Table 5). Twenty-eight of the 29 lampreys released downstream of the dam were detected approaching it. Twelve fall released lampreys first approached between October 4 and November 24, 2011 before overwintering. The remaining four approached between February 22 and May 28, 2012. Spring released lampreys approached the dam between March 28 and May 20, 2012. One spring released lamprey never approached the dam and instead moved downstream from the release site. Of the five lamprey released upstream of Wanawish Dam in the fall, one approached Prosser Dam in October. Three others overwintered before approaching between March 17 and April 11. Only one of the four lampreys released upstream of Wanawish in the spring approached Prosser Dam. It did so on April 7. Fifteen (83%) of those lampreys that successfully passed Wanawish Dam migrated upstream to Prosser Dam and approached it. One fall released lamprey approached on October 15, while the rest of the approaches from both release groups occurred between March 17 and May 28. Prosser Dam therefore had an overall approach rate of 84%. First approaches were made near the left bank 62% of time and the right bank 34% of the time. Only two lampreys were first detected on the downstream antenna on the center island.

Below Dam Residence- Average fall residence for lampreys that were successful in passing Prosser Dam was 0.5 days (Figure 19). Three lampreys approached the dam in the fall and moved downstream before over-wintering. These lampreys all spent less than two hours at the dam before moving downstream. Lampreys that remained at the dam and were unsuccessful in passing during the fall had an average fall residence of 23.5 days (range 24-77 d). These individuals stopped moving and over-wintered at the dam for an average of 120 days (range 87-152 d). Fall released lampreys that began moving again in the spring and ultimately passed Prosser Dam resided at the dam for an average of 45.8 days while those that were unsuccessful resided for an average of 59.4 days. Spring released lampreys had the most variable residence times at Prosser Dam: Lampreys that passed in the spring had an average residency of 27.4 days (range 0.04-93 d) while those that did not pass averaged 81.6 days (range 12-130.3 d) of residency at the dam.

Table 5. Prosser Dam approach and residence data: first and last detection dates and total number of days that adult radio-tagged Pacific lampreys resided below the dam before entering a fishway or moving downstream, October 2011 through August 2012.

Code	1st Station Detected	1st Detection Date	Last Detection Date	Days	Entered Fishway?
16	Left Island	10/04/11 19:46	10/04/12 20:16[C]	0.02	Yes
29	Right Bank	10/04/11 20:02	10/04/11 20:20	0.01	No
39	Right Bank	10/04/11 20:25	10/4/11 21:51[C]	0.06	Yes
8	Right Bank	10/04/11 20:26	10/05/11 22:46	1.1	Yes
42	Right Bank	10/04/11 20:33	10/04/11 22:06	0.06	No
17	Center Island	10/04/11 20:40	04/23/12 22:34	202.1	No
46	Right Bank	10/04/11 20:40	10/12/11[B]	7	No
26	Right Bank	10/04/11 21:14	5/29/12 23:39	238.1	Yes
9	Right Bank	10/04/11 21:22	10/04/11 21:23	0.00	No
31	Right Bank	10/04/11 22:41	10/17/11[B]	12	No
41	Right Bank	10/05/11 04:45	04/15/12 12:03	193.3	No
34	Right Bank	10/15/11 20:28	10/15/11 21:57	0.06	Yes
35	Right Bank	10/15/11 20:57	03/22/12[A]	158	No
13	Right Bank	10/21/11 21:32	10/22/11 06:04	0.4	Yes
37	Left Island	02/22/12 06:18	05/16/12 08:00	84.1	No
15	Left Island	03/17/12 00:23	06/03/12[A]	78	No
12	Left Island	03/17/12 20:26	06/03/12 23:00	78.1	No

Table 5 Continued

Code	1st Station Detected	1st Detection Date	Last Detection Date	Days	Entered Fishway?
40	Left Island	03/17/12 20:56	05/08/12 21:01	52.0	Yes
20	Left Island	03/25/12 23:55	06/05/12 11:29	71.5	Yes
66	Left Island	03/28/12 20:50	05/29/12 22:15	62.1	Yes
76	Left Island	03/28/12 22:10	06/29/12 22:41	93	Yes
63	Right Bank	03/29/12 01:10	08/06/12 07:45	130.3	No
75	Left Island	03/29/12 21:46	07/25/12[B]	117	No
33	Left Island	03/30/12 21:10	05/09/12 22:24	40.1	Yes
22	Right Bank	03/31/12 03:57	06/30/12 04:34	91	No
84	Left Island	03/31/12 05:18	04/12/12 20:30	12.6	Yes
58	Left Island	04/02/12 21:12	07/25/12 20:21	114	No
86	Left Island	04/03/12 02:35	07/12/12 04:59	100.1	No
83	Left Island	04/03/12 18:27	04/10/12 22:56	7.2	Yes
79	Left Island	04/05/12 02:15	04/22/12 22:33	17.9	Yes
89	Left Island	04/07/12 22:12	04/10/12 18:58	2.9	Yes
81	Left Island	04/09/12 22:37	06/09/12[A]	60	No
32	Left Island	04/11/12 02:32	05/15/12 23:38	34.9	Yes
5	Left Island	04/22/12 04:29	05/13/12 21:19	21.7	Yes
87	Left Island	04/23/12 12:43	08/25/12 18:04	124.2	No
28	Left Island	04/23/12 23:37	04/24/12 00:29	0.04	Yes[D]
69	Left Island	04/24/12 01:58	04/24/12 02:51	0.04	Yes
4	Left Island	04/25/12 00:05	07/14/12 22:11	80.9	Yes
78	Left Island	04/25/12 00:43	06/02/12 01:22	38	Yes
6	Center Island	04/28/12 00:18	05/08/12 21:25	10.9	Yes
14	Right Bank	05/01/12 02:25	06/01/12 22:08	31.8	Yes
77	Left Island	05/01/12 02:50	05/28/12 23:59	27.9	Yes
65	Left Island	05/08/12 21:19	08/03/12 14:27	86.7	No
59	Right Bank	05/19/12 00:22	05/31/12 00:05	12	No
85	Left Island	05/20/12 05:35	06/02/12 01:07	12.8	Yes
27	Left Island	05/28/12 12:09	06/29/12 22:28	32.4	Yes
62	Left Island	06/02/12 23:53	07/25/12[B]	52	No
60	Left Island	04/30/120 4:32	05/25/12 11:10	25.3	No

[A] last date of movement
[B] date tag was recovered
[C] last detection before power failure
[D] entered and went up left fishway on 4/24 when headgate was closed and backed down 1 hour later

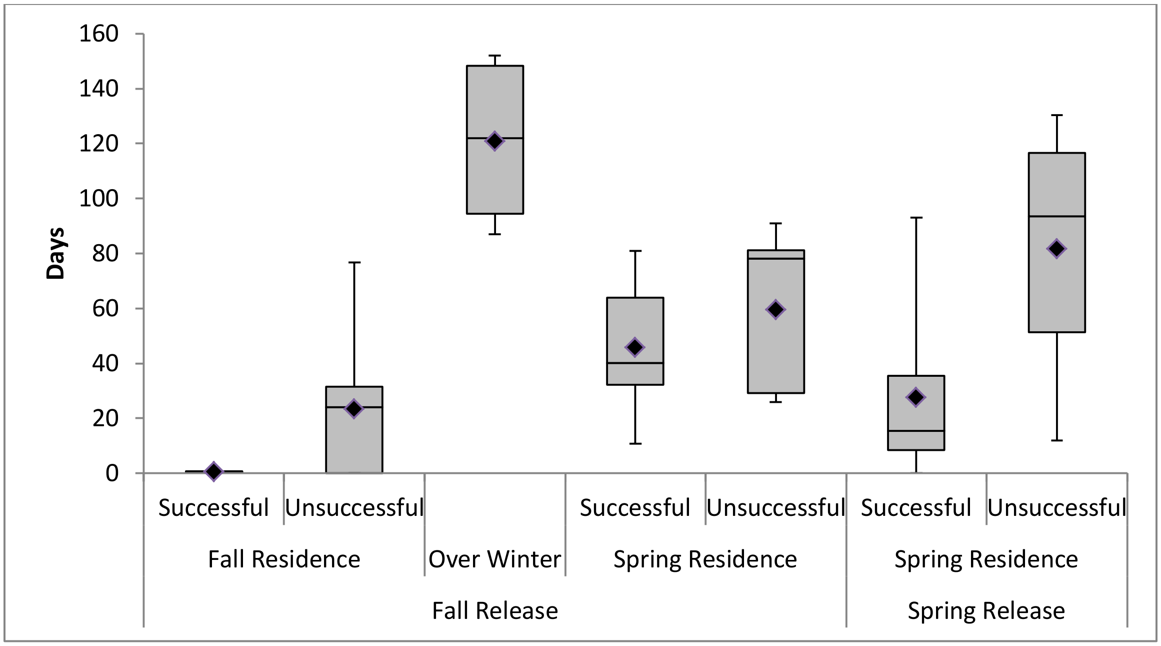

Figure 19. Periods of below dam residency for radio-tagged Pacific lampreys at Prosser Dam that were successful and unsuccessful in passing upstream of the dam, October 2011 through July 2012. Box plots show median and quartiles. The diamonds indicate the means.

Lampreys were detected on all three stations at Prosser Dam while they searched for upstream passage with the greatest number occurring on the left island antennas (Figure 20). Unlike at Wanawish Dam, lampreys spent little time near the face of Prosser Dam during holding periods or daylight hours, residing instead just downstream of the bedrock ledge the dam was built upon. The greatest concentration occurred in a pool along the left bank (Figure 21). This area included a boulder filled pool and areas of whitewater coming off the face of the dam. Pacific lampreys were consistently detected in this area during both day and night hours. Night observations during July showed tagged lampreys attempting to climb over the dam using the bedrock at face of the dam along the left bank (Figure 22). High velocities over the dam and the overhanging crest prevented these lampreys from being successful in their attempts.

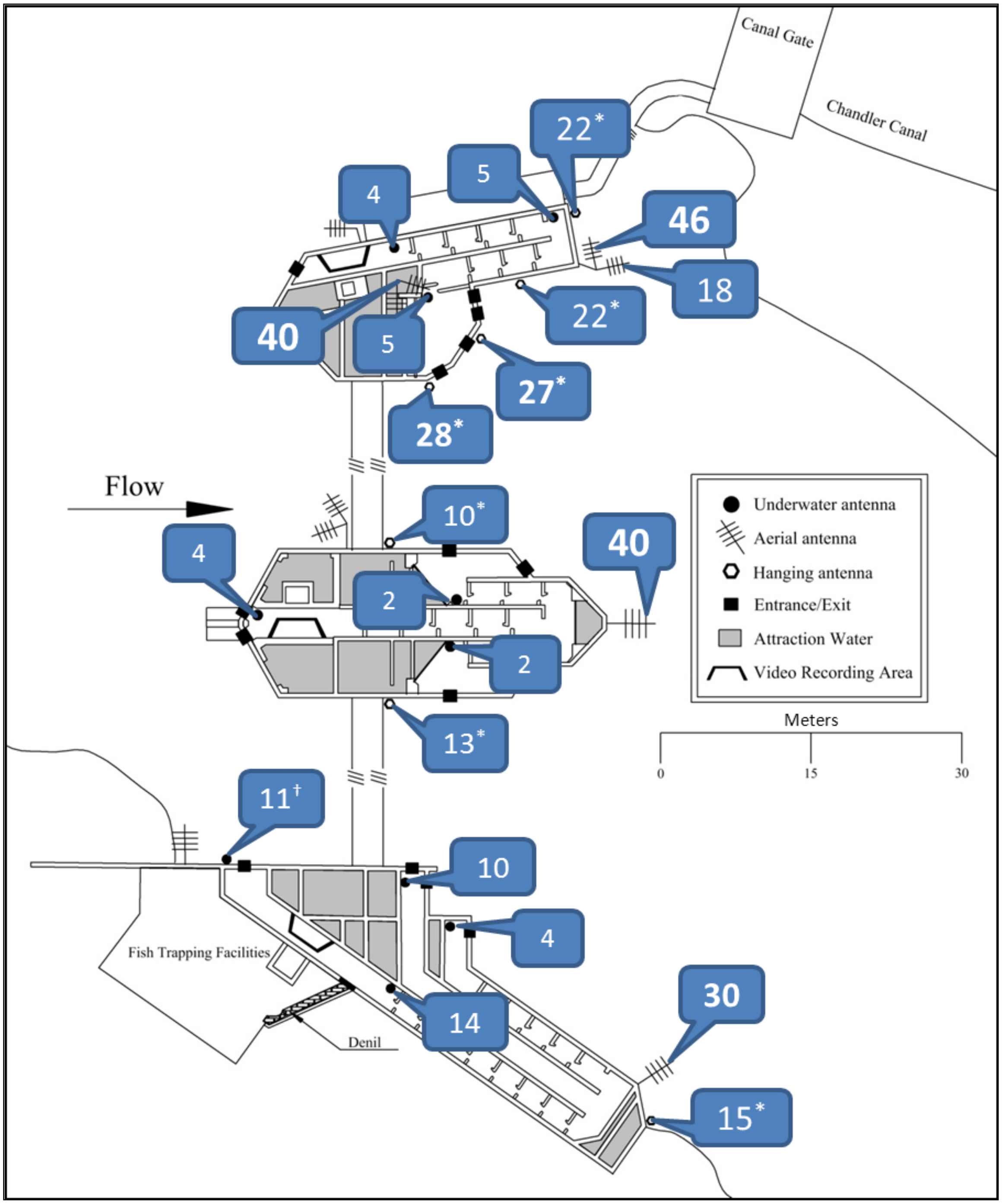

Figure 20. Number of radio-tagged Pacific lampreys detected on downstream and in-ladder antennas at Prosser Dam, October 2011-July 2012. † indicates two additional lampreys were not detected but were detected upstream by mobile tracking. Antennas with a (*) were installed on March 27, 2012.

Four tags were recovered at Prosser Dam. On October 12, 2011 a tag was recovered left of river center downstream of the dam. The tag was in a grassy area with approximately 5 cm of water covering it. The antenna appeared to have bite marks in it, but it is not known if predation or scavenging occurred. On October 17, 2011 a deceased radio-tagged lamprey was found in the drain pipe of the trap tank in the adult salmonid trapping facility on the right bank. This drain empties into the river along the bank downstream of the fishway. It is assumed that the lamprey swam up the 4 inch PVC drain pipe as it was not detected moving up the fishway. On July 25, 2012, two tags were recovered from the left bank downstream of the dam. Both were on the bank above the waterline in areas of grass and mud. Neither showed teeth marks, however, their presence on dry land indicate some type of predation or scavenging had occurred. Three lampreys ceased moving and were still at the dam at the end of the study period. It was determined from several foot tracking occasions that these individuals were in the river but visual observations of the lamprey or tag were not possible and their fates are not known.

Figure 21. Pool and whitewater along the left bank of Prosser Dam where the majority of Pacific lampreys held during the day and night hours.

Figure 22. Radio-tagged Pacific lampreys (circled in red) attempting to climb over Prosser Dam by way of the dam face and exposed bedrock, July 3, 2012.

Fishway Passage- A total of 23 tagged lampreys passed Prosser Dam, for an overall passage success rate of 48%. Five lampreys (22%) passed in October, two of which used the right bank fishway during adult salmonid trapping operations. Both lampreys successfully moved up the ladder and around or through the picket gate used to direct salmon into the denil and trapping facility. The remaining eighteen (78%) passed the dam between April 10 and July 14. Thirteen of the 23 (57%) passage events occurred in the right bank fishway (Table 6). Four lampreys used the center island fishway and four were known to have used the left island fishway. An additional two lampreys passed the dam during a power outage and we deduced they used the left fishway: Prior to losing power both were detected on the left island antennas; video recorded two lampreys in the fishway that night; both tagged lampreys were detected upstream of the dam the next day during mobile tracking. Passage time for Prosser Dam fishways ranged between 0.55 and 29.48 hours with an average of 5.05 hours (Table 6). One lamprey (code 69) entered the right bank fishway on April 24 at which time the fishway headgate was closed due to high flows. It remained near the headgate for several days attempting to pass (Figure 23). On May 2 it moved downstream within the ladder and was detected on the underwater center antenna near the gate blocking the entrance to the denil. The gate was lifted between May 6 and May 8 while the denil was in operation. On May 10, code 69 was foot tracked and located in the body of water beneath the denil. This area collects spillage from the denil but has no entry or exit for fish when the denil is not operating. Code 69 remained in this location for the remainder of the study as it had no way to exit. A lamprey also entered the left island fishway on April 24. The headgate in this fishway was also closed. Code 28 remained in the fishway for approximately an hour before returning downstream. It entered the fishway a second time on June 19 for approximately an hour and a half before once again returning downstream. On July 1 it moved downstream from the dam.

Table 6. Prosser Dam fishway data: dates of entry and exit, total time in the fish ladder, and water temperature at passage for radio-tagged adult Pacific lampreys, October 2011 through July 2012.

Code	Release Site/Period	Fishway	Entered Ladder	Exited Ladder	Time in Ladder (hr)	T °C	Video?
16	PRO Fall Dn	Left	10/04/11[A]	10/05/11[A]	unk	15.6	yes
39	PRO Fall Dn	Left	10/04/11[A]	10/05/11[A]	unk	15.6	yes
8	PRO Fall Dn	Right	10/05/11 22:46	10/05/11 23:28	0.71	15.1	no
34	PRO Fall Dn	Right	10/15/11 21:57	10/15/11 23:18	1.34	13.6	no
13	WAN Fall Up	Center	10/22/11 06:04	10/22/11 15:25	9.36	13.3	yes
89	WAN Spr Up	Right	04/10/12 18:58	04/10/12 23:15	4.29	10.6	no
83	PRO Spr Dn	Right	04/10/12 22:56	04/11/12 02:45	3.82	10.6	no
84	PRO Spr Dn	Right	04/12/12 20:30	04/13/12 07:06	10.6	10.7	no
79	PRO Spr Dn	Right	04/22/12 22:33	04/23/12 00:47	2.23	12.5	no
40	WAN Fall Up	Right	05/08/12 21:01	05/09/12 00:10	3.15	12.9	no
6	WAN Fall Dn	Right	05/08/12 21:25	05/09/12 03:20	5.92	12.9	no
33	PRO Fall Dn	Right	05/09/12 22:24	05/10/12 00:49	2.42	13.7	no
5	PRO Fall Dn	Right	05/13/12 21:19	05/14/12 01:48	4.48	13.2	yes
32	WAN Fall Up	Left	05/15/12 23:38	05/16/12 00:55	1.28	15.4	no
77	WAN Spr Dn	Center	05/28/12 23:59	05/29/12 02:56	2.95	14.0	no
66	PRO Spr Dn	Center	05/29/12 22:15	05/30/12 04:50	6.58	14.8	no
26	PRO Fall Dn	Center	05/29/12 23:39	05/31/12 05:08	29.48	14.8	yes
14	WAN Fall Dn	Right	06/01/12 22:08	06/02/12 03:06	4.97	15.8	yes
85	WAN Spr Dn	Right	06/02/12 01:07	unknown	unk	17.0	yes
78	WAN Sp rDn	Right	06/02/12 01:22	unknown	unk	17.0	no
27	WAN Fall Dn	Left	06/29/12 22:28	06/29/12 23:24	0.93	17.8	yes
76	PRO Spr Dn	Left	06/29/12 22:41	06/29/12 23:14	0.55	17.8	yes
4	WAN Fall Dn	Left	07/14/12 22:11	07/14/12 23:09	0.97	22.3	yes

[A] exact time of day unknown due to power outage

Figure 23. Radio-tagged Pacific lamprey code 69 attempting to exit the right bank fishway at Prosser Dam by climbing the closed headgate, April 30, 2012.

Discharge-
River discharge at Prosser Dam varied between 588 and 18,705 ft^3/s. In October 2011, three tagged lampreys passed the dam at flows of 1,460 ft^3/s or less. The other successful lampreys passed between April and July when flows ranged from 1,080 to 11,750 ft^3/s (Figure 24). Passage occurred primarily on increasing flows or during transitions between decreasing and increasing flows.

Velocity at Fishways- Velocities at the Prosser Dam fishway entrances were recorded between April 5 and August 7, 2012 (Figure 25 and Appendix B). Velocities varied between -0.9 and 9.5 ft/s. All three fishways had average velocities between 4 and 6 ft/s and did not differ significantly (p=0.21). Due to river conditions on several occasions, measurements were not taken at the Prosser Dam right bank upper fishway entrance. Large differences between the upper and lower fishways during the peak period of passage led us to analyze these two entrances separately.

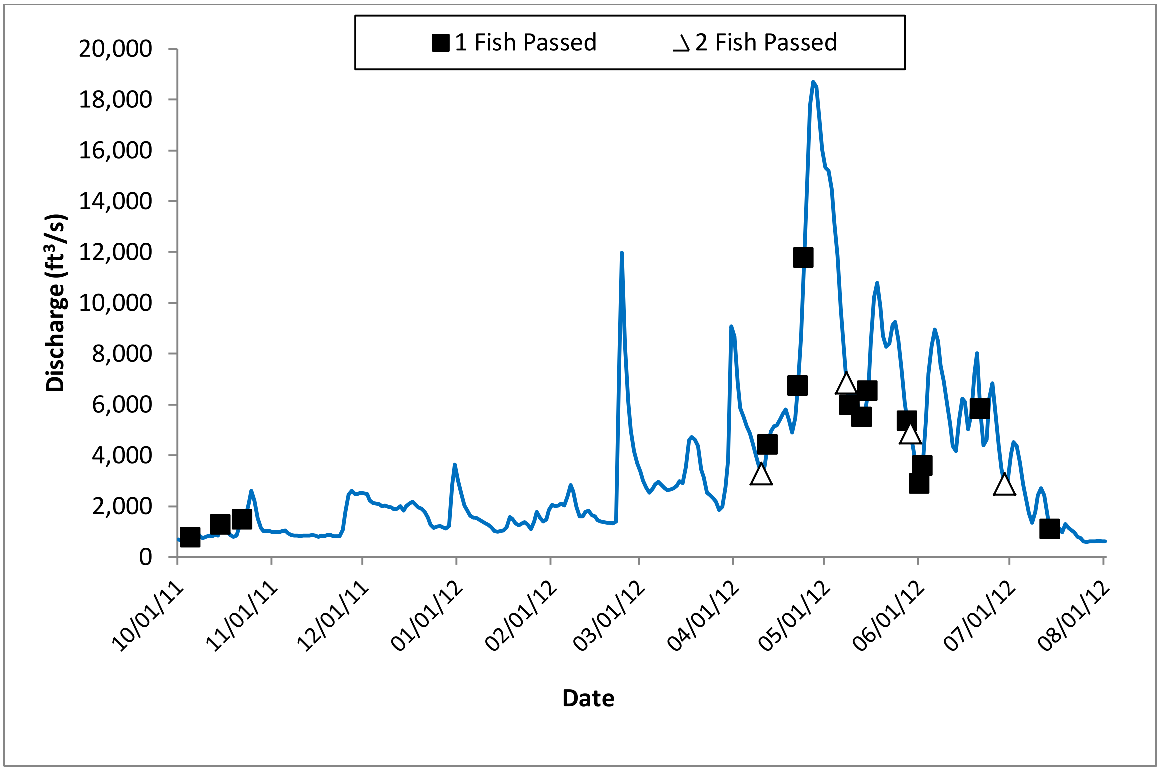

Figure 24. Graph showing the discharge and passage timing of radio-tagged Pacific lampreys at Prosser Dam on the Yakima River, October 2011 through July 2012.

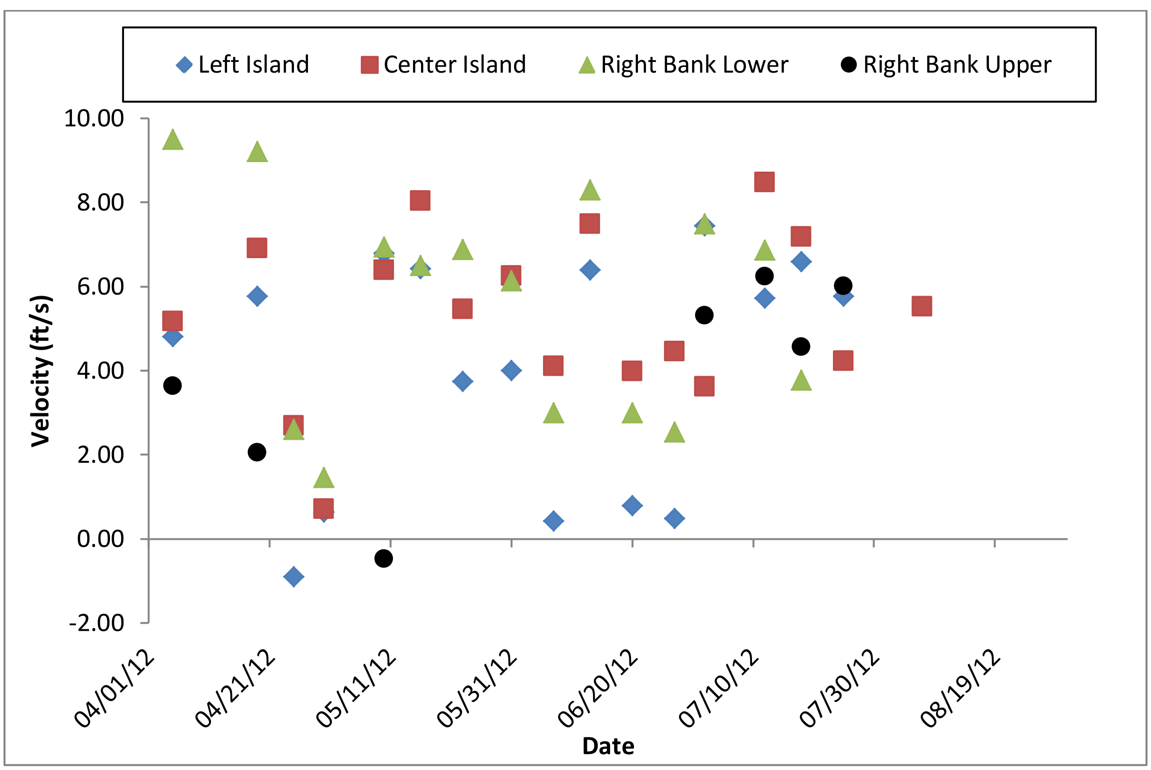

Figure 25. The entrance velocities at the Prosser Dam fishways between April and August, 2012.

Temperature- River water temperature was recorded at Prosser Dam from October 1, 2011 to September 1, 2012 (Figure 26). Daily averages ranged from 0.3 °C to 24 °C. The majority of tagged lampreys passed the dam at mean daily water temperatures between 12 °C and 15 °C, however, the last lamprey passed at 22.3 °C. In the fall after the 3 lampreys passed the dam water temperatures decreased rapidly and passage ceased for the winter.

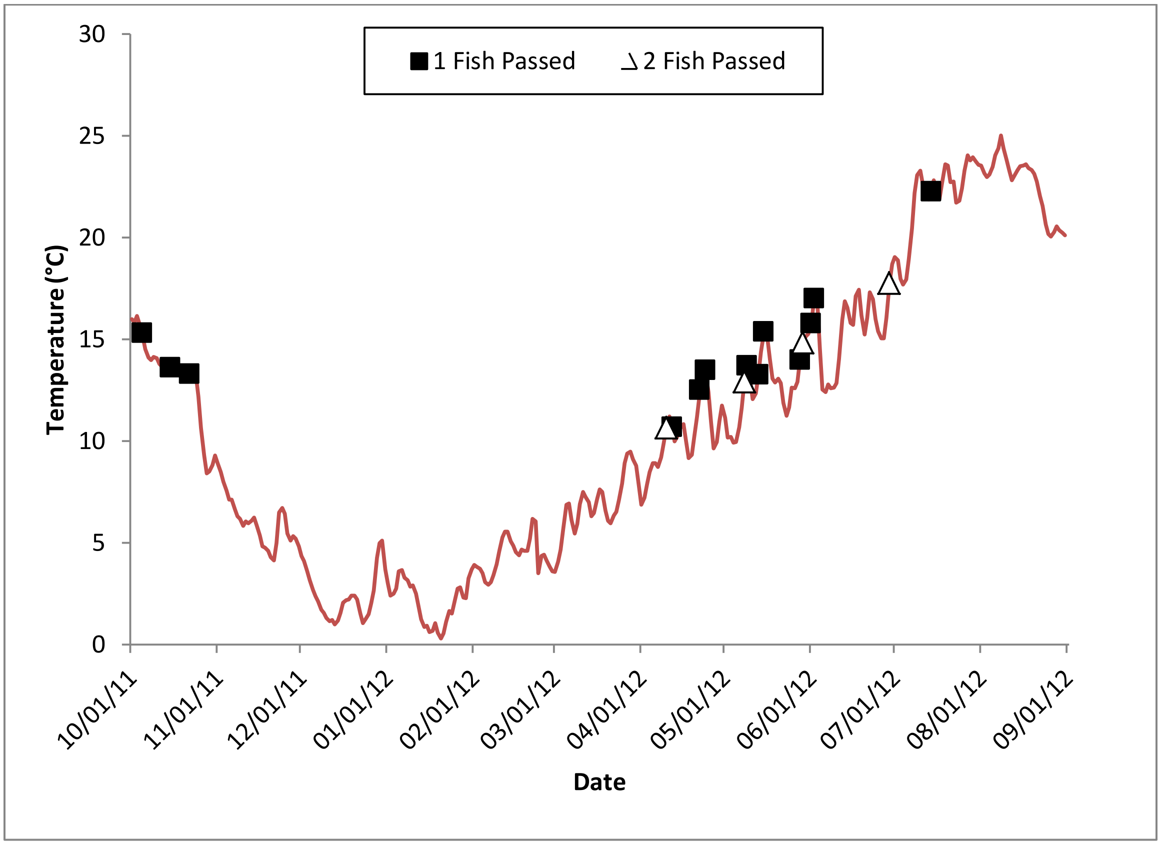

Figure 26. Average daily water temperatures of the Yakima River and dates of radio-tagged lamprey passage at Prosser Dam, October 2011 through August 2012.

Above Dam Residence- The lampreys that successfully passed Prosser Dam spent little time in the vicinity before continuing their migration. Two individuals spent 3.33 and 16.83 hours respectively while the rest spent less than 10 minutes before moving upstream.

Video counts of lampreys at Prosser Dam- Between August 22, 2011 and July 1, 2012 a total of 41 lampreys were observed on the video recorders within the fishways at Prosser Dam, 10 of which were radio-tagged. Thirteen tagged lampreys passed that were not detected on the video counts (Table 6 and Figure 27). Video recording was not operational for the time periods of March 31-April 2 and also April 23-May 7 and only one tagged lamprey passed Prosser Dam during these time periods. Thus during the times that the videos were recording, 12 of the 22 tagged lampreys (55%) were not observed or counted while passing in the fish ladders at Prosser Dam.

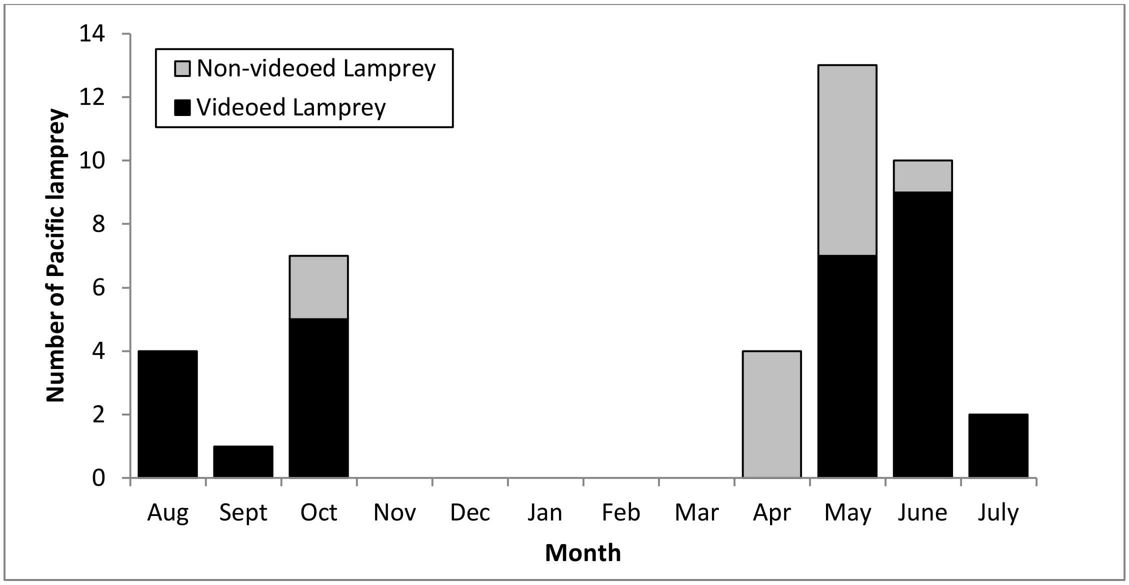

Figure 27. Video counts of upstream migrating adult Pacific lampreys at Prosser Dam, August 2011 to July 2012.

Sunnyside Dam

First Approach- The first detections at Sunnyside Dam were all on the aerial antennas of the center island station (Table 7). Thirty-one lampreys had either been released above Prosser Dam or had successfully passed above Prosser Dam and 18 (58%) migrated upstream to Sunnyside Dam. Three lampreys first approached the dam in October 2011. Approaches made during the spring months occurred from March 28 to July 3, 2012 with the majority in April (Table 7).

Below Dam Residence- Pacific lampreys that were successful in passing Sunnyside Dam had an average residency of 9.3 days before entering a fishway. The shortest residency occurred on June 16, 2012 and lasted just over 2.5 hours while the longest was 20.7 days (Table 7). The average residency time for those individuals who were not successful and ultimately moved downstream was 40 days (range 0.1 to 112.7 d). Only one lamprey (code 34) over-wintered at Sunnyside Dam. It attempted to find passage from its arrival on October 24 until December 29. It then over-wintered for 90 days until it began moving again on March 28. Its spring residence at the dam lasted for 81 days until June 17 when it stopped moving. It is not known if the tag was shed, the lamprey died, or it was still holding. Lampreys utilized holding areas across the width of the river downstream of the dam; however, the majority of lampreys used the area between the center island and the right bank for holding during daylight hours (Figure 28). A large log stuck on the face of the dam provided a break in the flow over the dam and lampreys were routinely detected beneath it.

Table 7. Sunnyside Dam approach and residence data: first and last dates of detection and number of days that radio-tagged adult Pacific lampreys resided below the dam before entering a fishway or moving downstream, October 2011 to August 2012.

Code	1st Station Detected	1st Detection Date	Last Detection Date	Days	Entered Fishway?
44	Center Island	10/16/11 01:32	10/23/11 20:04	7.8	Yes
38	Center Island	10/17/11 03:32	10/17/11 6:20	0.1	No
34	Center Island	10/24/11 04:10	06/17/12[A]	237	No
13	Center Island	03/28/12 01:16	05/24/12 04:00	57.1	No
30	Center Island	04/11/12 23:32	04/29/12 16:22	17.7	No
70	Center Island	04/14/12 06:04	06/15/12 02:17	61.8	No
73	Center Island	04/15/12 21:14	04/23/12 02:47	7.2	No
84	Center Island	04/22/12 17:31	06/06/12 02:14	44.4	No
83	Center Island	04/23/12 04:04	08/13/12 21:08	112.7	No
39	Center Island	04/24/12 03:18	06/21/12 16:23	58.6	No
8	Center Island	04/24/12 06:11	05/14/12 22:19	20. 7	Yes
79	Center Island	05/10/12 01:12	05/15/12 22:59	5.9	Yes
6	Center Island	05/17/12 02:24	05/28/12 00:53	10.9	Yes
36	Center Island	05/17/12 21:35	05/17/12 23:17	0.07	No
32	Center Island	06/03/12 22:50	06/17/12 22:28	14	Yes
14	Center Island	06/15/12 22:10	7/17/12[A]	30.1	No
77	Center Island	06/16/12 22:28	06/17/12 01:05	0.1	Yes
5	Center Island	07/03/12 07:05	07/09/12 00:43	5.7	Yes

[A] last date of movement

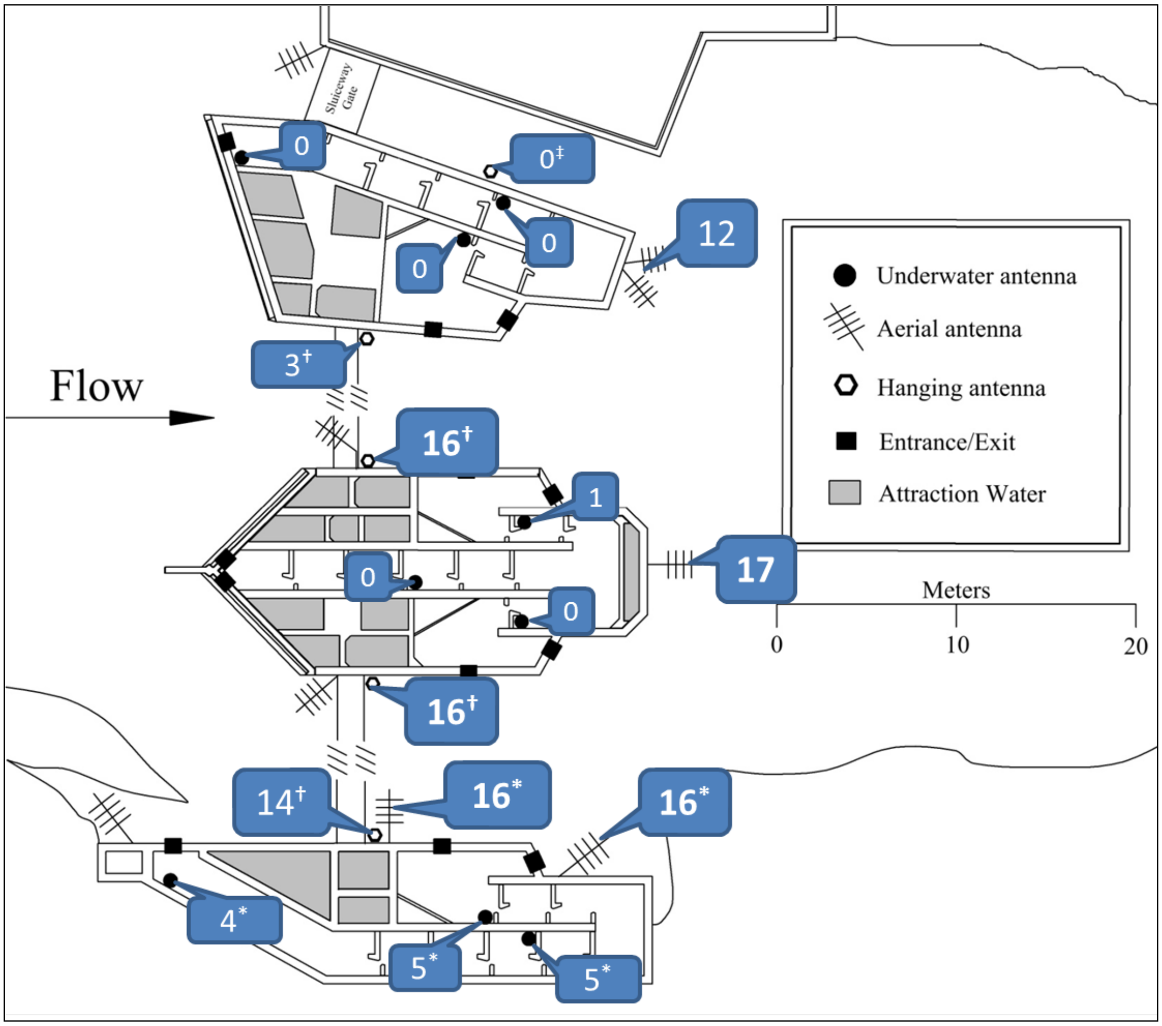

Figure 28. Number of radio-tagged Pacific lampreys detected on downstream and in-ladder antennas at Sunnyside Dam, October 2011-July 2012. Antennas with a (*) were installed on December 2, 2011. The † indicates antennas installed on April 5, 2012 and a ‡ indicates an installation date of April 30, 2012.

Fishway Passage- Seven of the eighteen (39%) lampreys that approached Sunnyside Dam successfully passed upstream using one of the fishways (Table 8). Of the fish released in the fall, 5 (42%) passed the dam while two (33%) from the spring release were successful. The first lamprey passed Sunnyside Dam on October 23, 2011, before the right bank fishway antennas were installed. Because it was not detected on any underwater antennas within the left and center island fishways, based on the data from aerial antennas we concluded it passed in the right bank fishway. Six lampreys passed upstream between May 14 and July 9, 2012; five using the right bank fishway and one using the center island fishway. Two lampreys were detected in the right bank fishway but did not successfully negotiate the ladder or pass the dam. Passage through the fishways ranged between 0.27 to 3.85 hours with an average of 1.09 hours.

Table 8. Sunnyside Dam fishway data: dates of entry and exit and total time in the fish ladder for radio-tagged adult Pacific lampreys from October 2011 to August 2012.

Code	Release Site/Period	Fishway	Entered Ladder	Exited Ladder	Time in Ladder (hr)	Temp °C
44	PRO Fall Up	Right	10/23/11 20:04[A]	10/23/11 21:14[A]	1.17	12.5
8	PRO Fall Dn	Right	05/14/12 22:19	05/14/12 22:35	0.27	11.9
79	PRO Spr Dn	Right	05/15/12 22:59	05/15/12 23:23	0.40	12.2
6	WAN Fall Dn	Right	05/28/12 00:53	05/28/12 01:39	0.77	12.3
77	WAN Spr Up	Right	06/17/12 01:05	06/17/12 01:50	0.75	14.6
32	WAN Fall Up	Right	06/17/12 22:28	06/17/12 22:58	0.50	14.6
5	PRO Fall Dn	Center	07/09/12 00:43	07/09/12 04:34	3.85	17.8

[A] based on center island aerial antennas

Discharge- Discharge at Sunnyside Dam ranged from a low of 586 ft^3/s on July 26, 2012 to a high of 18,924 ft^3/s on April 25, 2012. The one lamprey that passed in October did so at a discharge of 1,807 ft^3/s. The lampreys that passed in the spring did so at flows between 2,839 and 8,410 ft^3/s. The majority of passage events occurred during increases in the hydrograph (Figure 29).

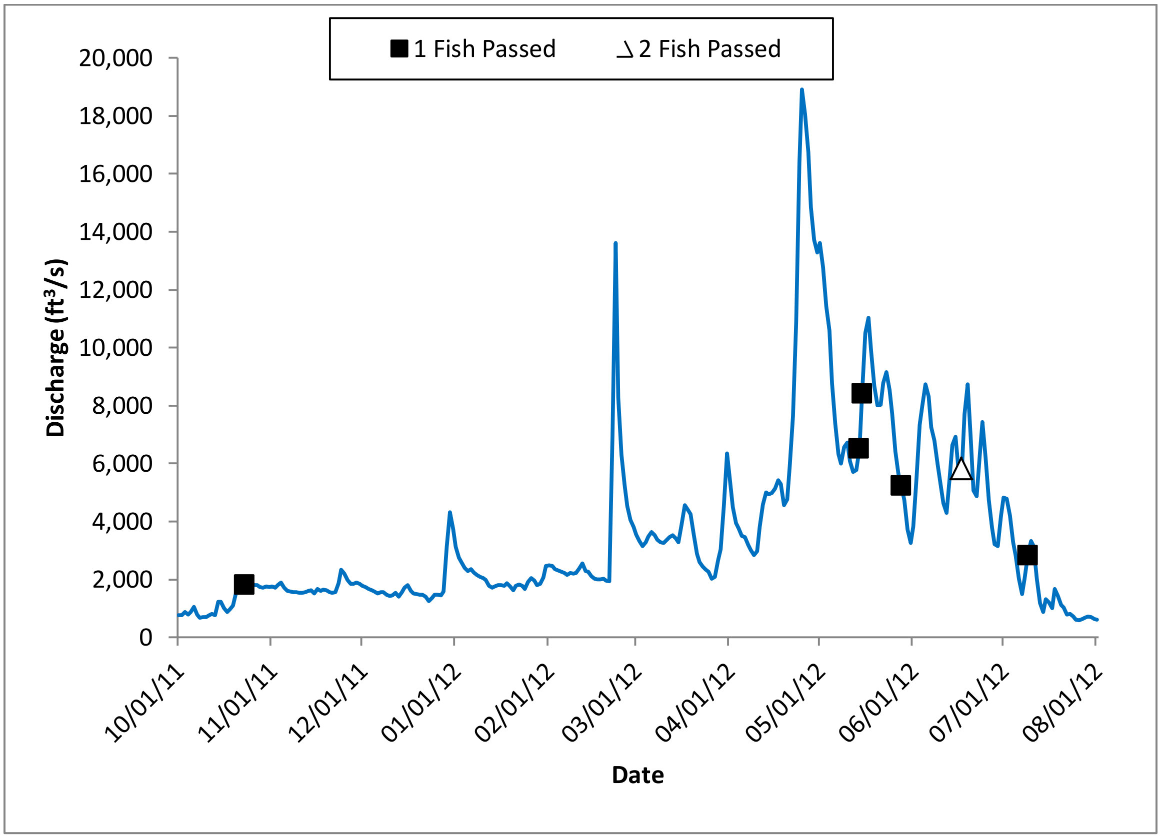

Figure 29. Graph showing the discharge and passage timing of radio-tagged Pacific lampreys at Sunnyside Dam on the Yakima River from October 2011 to August 2012.

Velocity at Fishways- Fishway entrance velocities were recorded at Sunnyside Dam between April 5 and August 7, 2012 (Figure 30 and Appendix B). Velocities at the dam ranged from -0.53 to 10.09 ft/s. The right bank fishway was the slowest with an average velocity of 4.7 ft/s. The center island fishway averaged 7.3 ft/s and the left island fishway had a slightly higher average of 7.5 ft/s. There were no significant differences between the left and center islands (p=0.5), however, the right bank velocities were significantly different than both the left and center island fishways (p=0.0005, p=0.01).

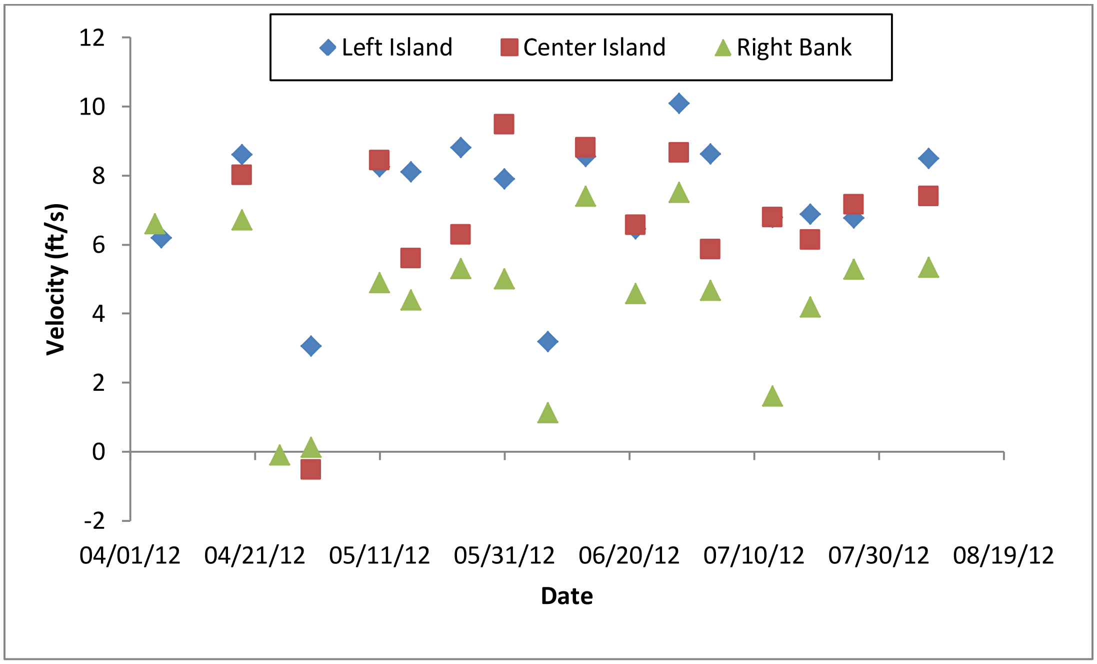

Figure 30. Entrance velocities at Sunnyside Dam fishways between April and August, 2012.

Temperature- Water temperature was recorded at Sunnyside Dam from October 1, 2011 through Sept 1, 2012 and mean daily temperature ranged from 0 to 18.3 °C (Figure 31). Six out of seven lampreys passed when temperatures were between 12 and 15 °C, including both fall and spring passage events. One lamprey passed the dam when the water temperature was 17.8 °C.

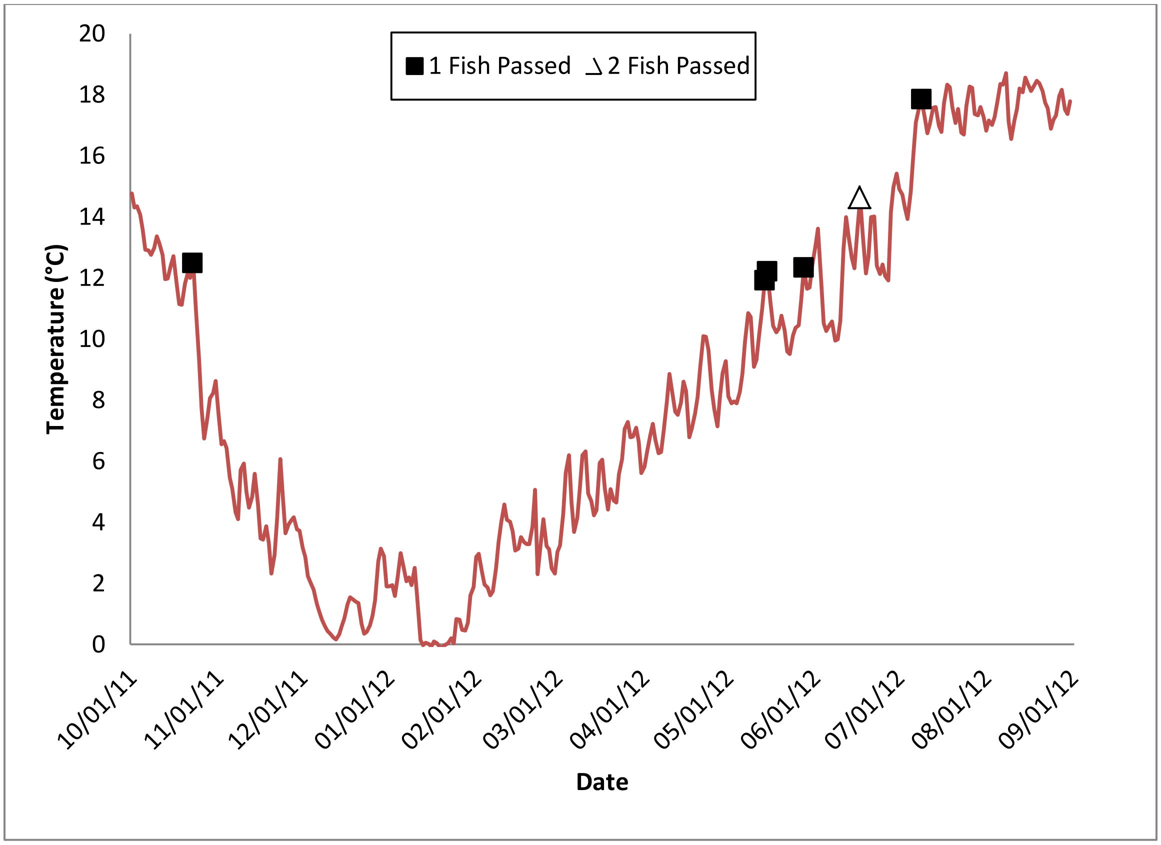

Figure 31. Average daily water temperatures of the Yakima River and dates of lamprey passage at Sunnyside Dam between October 1, 2011 and September 1, 2012.

Above Dam Residence- Only one lamprey was detected for more than a few minutes after successfully passing through Sunnyside Dam- code 5 spent 18.5 hours in the upstream vicinity of the dam before continuing its migration.

Wapato Dam

First Approach- All seven Pacific lampreys that passed Sunnyside Dam migrated upstream to Wapato Dam (Table 9). One approach occurred in the fall on November 2, 2011. The remaining six approached the dam in the spring between May 15 and July 11, 2012. Two approached using the west channel and five used the east channel. All of those in the east channel were first detected on the center island downstream aerial antenna.

Below Dam Residence- One lamprey (code 44) over-wintered at Wapato Dam in the east channel. Its fall residence at the dam lasted 26.1 days before it moved approximately 200 m downstream and over-wintered near a rock cross vane. On March 10, after an overwintering period of 102.6 days, it resumed actively trying to pass the dam. On June 5 it moved downstream and was subsequently detected passing downstream of Sunnyside as well. Its total residence time at Wapato was 216.34 days. The residence time of those that were successful in passing the dam ranged between 1.81 and 33.9 days with an average of 11.02 days. These fish were detected during daylight hours holding near the face of the dam as well as along the bank just downstream of the dam though antenna detections indicate movements occurred across the entire dam (Figures 32 and 33). Two lampreys were still residing at Wapato at the end of the study period, one in each channel.

It is not known whether these fish were holding, no longer alive, or if the tags had been shed. They were the last two fish detected approaching the dam.

Table 9. Wapato Dam approach and residence data: first and last dates of detection and number of days that radio-tagged adult Pacific lampreys resided below the dam before entering a fishway or moving downstream, October 2011 to August 2012.

Code	1st Station Detected	1st Detection Date	Last Detection Date	Days	Entered Fishway?
44	E. Center Island	11/02/11 09:13	06/05/12 17:27	216.3	No
8	E. Center Island	05/15/12 04:13	06/18/12 01:51	33.9	Yes
79	W. Center Island	05/17/12 02:57	05/18/12 22:18	1.8	Yes
6	E. Center Island	05/28/12 23:31	06/02/12 04:32	4.2	Yes
77	E. Center Island	06/17/12 23:32	06/22/12 03:33	4.2	Yes
32	E. Center Island	06/18/12 02:56	07/19/12[A]	30.9	No
5	W. Center Island	07/11/12 03:59	07/24/12[A]	12.8	No

[A] last date of movement

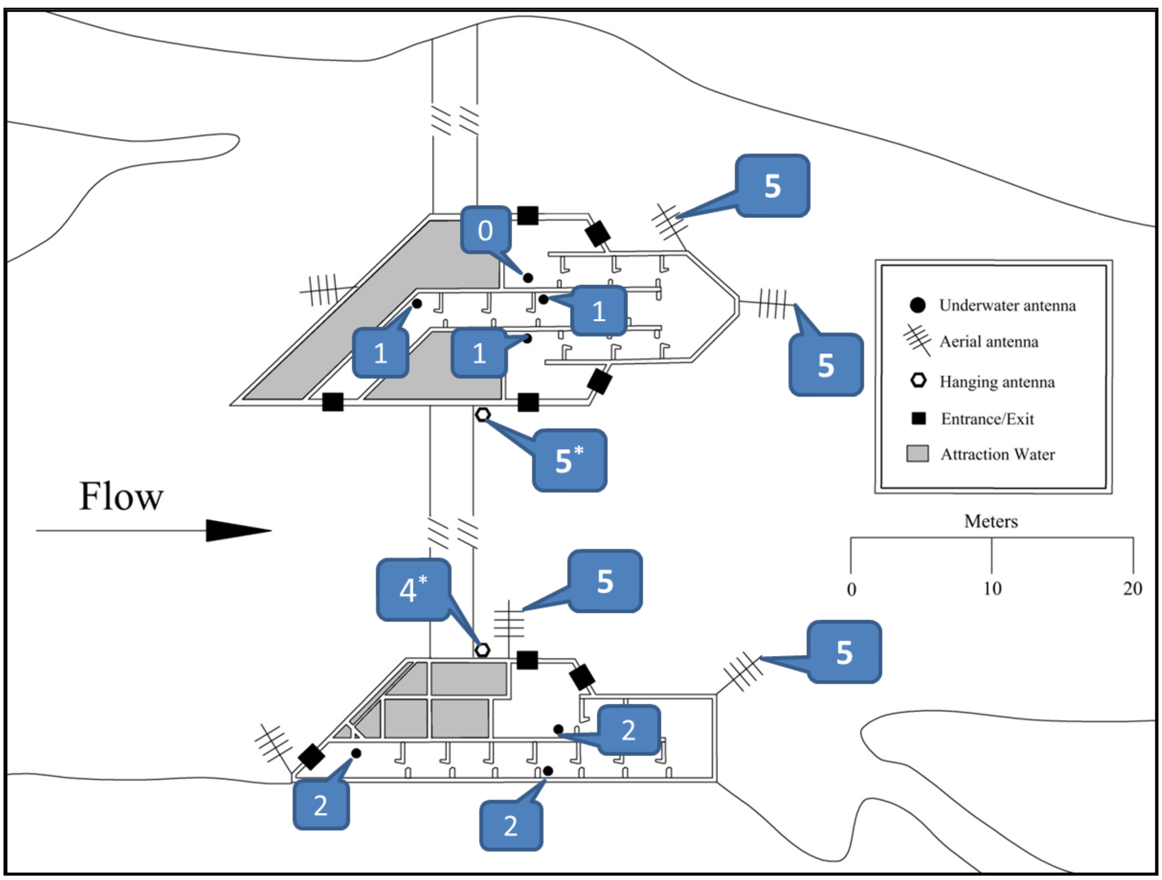

Figure 32. Number of radio-tagged Pacific lampreys detected on downstream and in-ladder antennas in the east channel at Wapato Dam, October 2011-July 2012. A (*) indicates an antenna installation date of April 5, 2012.

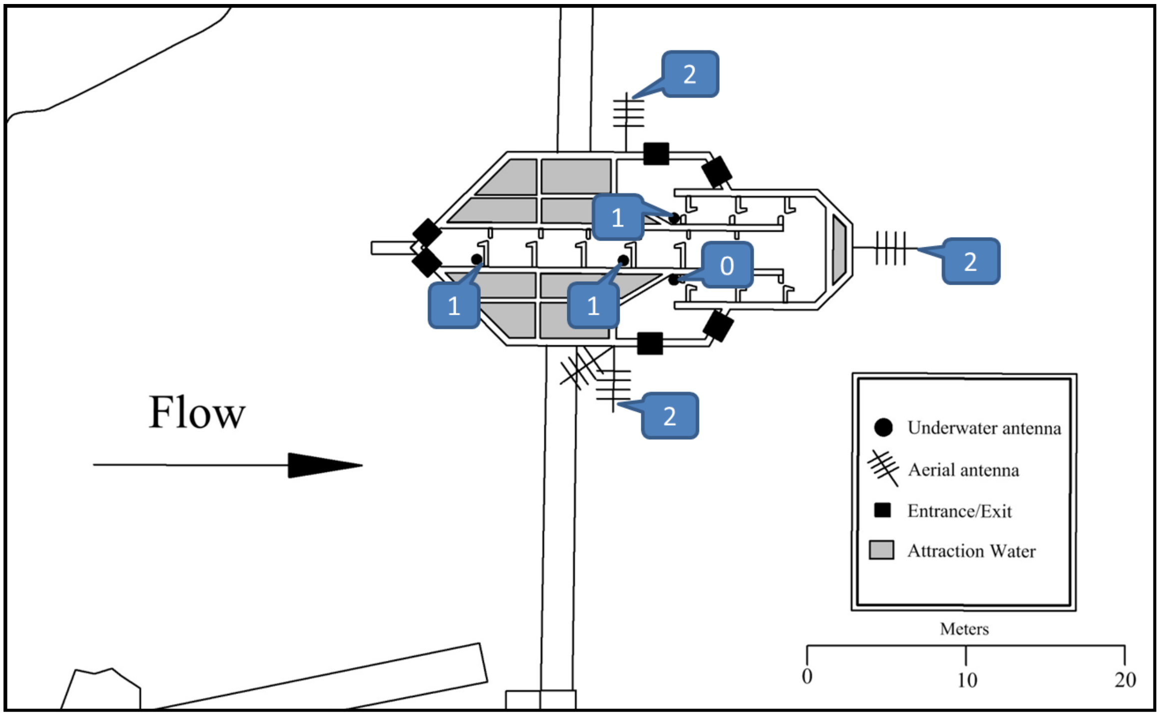

Figure 33. Number of radio-tagged Pacific lampreys detected on the downstream and in-ladder antennas in the west channel of Wapato Dam, October 2011-July 2012.

Fishway Passage- Of the seven Pacific lampreys that approached Wapato Dam, 4 (57%) successfully passed upstream using one of the fishways (Table 10). Two of the five fall-released lampreys were successful while both spring-released lampreys that made it to Wapato successfully passed it. No passage occurred during October of 2011. All passage events occurred between May 20 and June 22, 2012. One lamprey passed using the west channel island fishway, one passed in the east channel island fishway, and two lampreys passed in the east channel right bank fishway. Passage times for the lampreys in the east channel were 50 minutes or less while the lamprey that passed in the west channel took 1.4 days (Table 10).

Table 10. Wapato Dam fishway data: dates of entry and exit and total time in the fish ladder for radio-tagged adult Pacific lampreys from October 2011 to August 2012.

Code	Release Site/Period	Fishway	Entered Ladder	Exited Ladder	Time in Ladder (hr)	Temp °C
79	PRO Spr Dn	W. Center Island	05/18/12 22:18	05/20/12 08:31	34.22	10.2
6	WAN Fall Dn	E. Center Island	06/02/12 04:32	06/02/12 05:22	0.83	13.4
8	PRO Fall Dn	E. Right Bank	06/18/12 01:51	06/18/12 02:38	0.78	13.4
77	WAN Spr Dn	E. Right Bank	06/22/12 03:33	06/22/12 04:12	0.65	14.0

Discharge- Discharge at Wapato Dam ranged from a low of 586 ft^3/s on July 26, 2012 to a high of 18,924 ft^3/s on April 25, 2012. Lampreys that passed the dam did so during flows of 4,873-9,908 ft^3/s. Passage events all occurred after peak flows and like the other dams tended to be on an increase in the hydrograph (Figure 34).

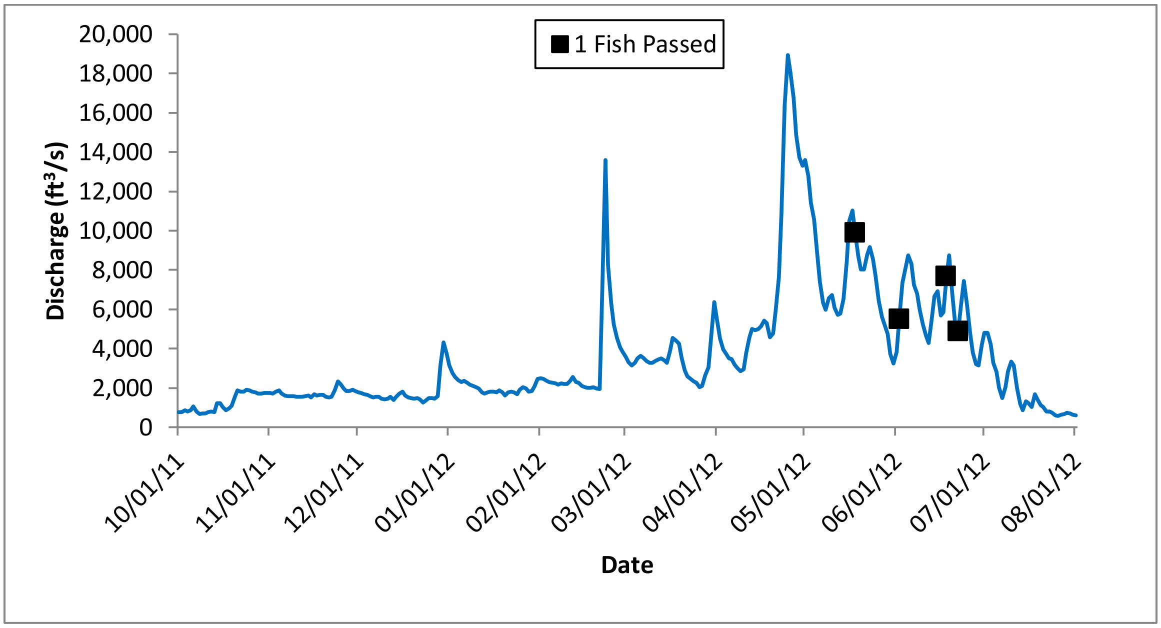

Figure 34. Graph showing the discharge and passage timing of radio-tagged Pacific lampreys at Wapato Dam on the Yakima River from October 2011 to August 2012.

Velocity at Fishways- Velocities at the Wapato Dam fishway entrances were recorded between April 6 and August 7, 2012 (Figure 35 and Appendix B). The differences in velocities between each fishway were significant (p=0.0004). The east channel center island fishway consistently had velocities below 3 ft/s. The east channel right bank and west channel center islands fishways were much more varied in their velocities. The highest velocity, 6.69 ft/s, occurred July 19 in the east channel right bank fishway while the lowest, 0.79, occurred in the west center island fishway on July 3, 2012. No negative velocities were recorded at Wapato Dam. Attraction water did not appear to be in operation at the east channel center island.

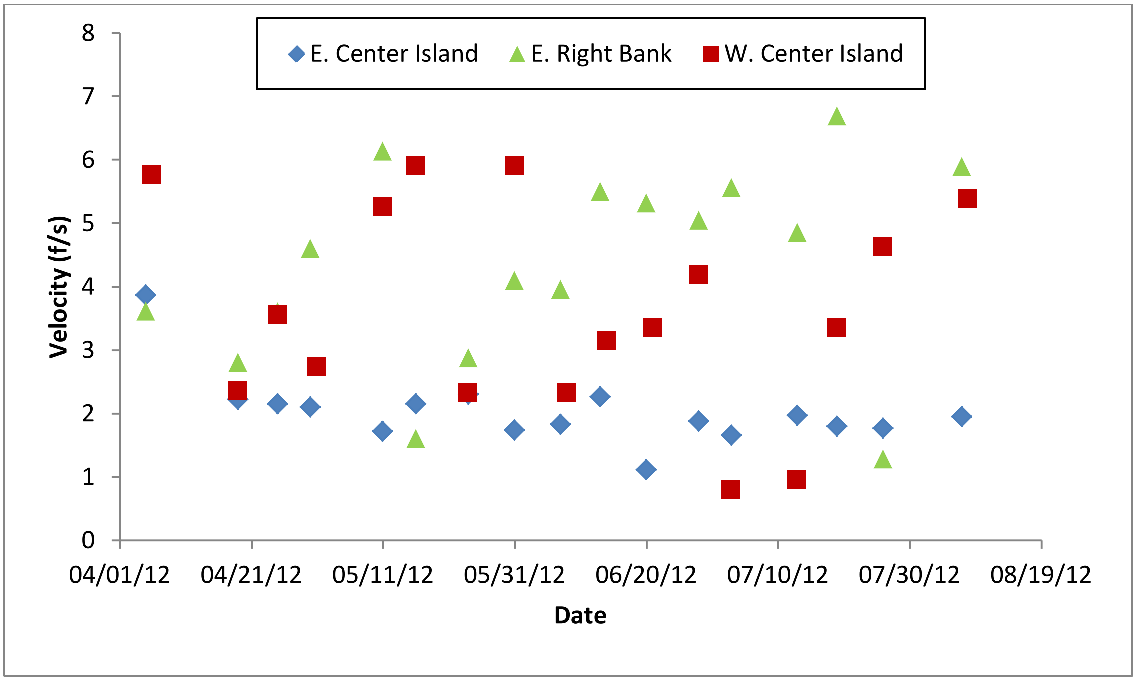

Figure 35. Entrance velocities at Wapato Dam fishways between April and August, 2012.

Temperature- River water temperatures were recorded at Wapato Dam between November 4, 2011 and September 1, 2012 (Figure 36). Temperatures were not available for the time period between June 8 and July 13, 2012. The average daily temperature varied from 0 to 18.1 °C. Lamprey passage occurred at temperatures between 13 and 15 °C with the exception of one passing at 10 °C. Two fish did pass during the time period when temperature data was not available. The temperatures during these passage events were determined using those from nearby Sunnyside Dam.

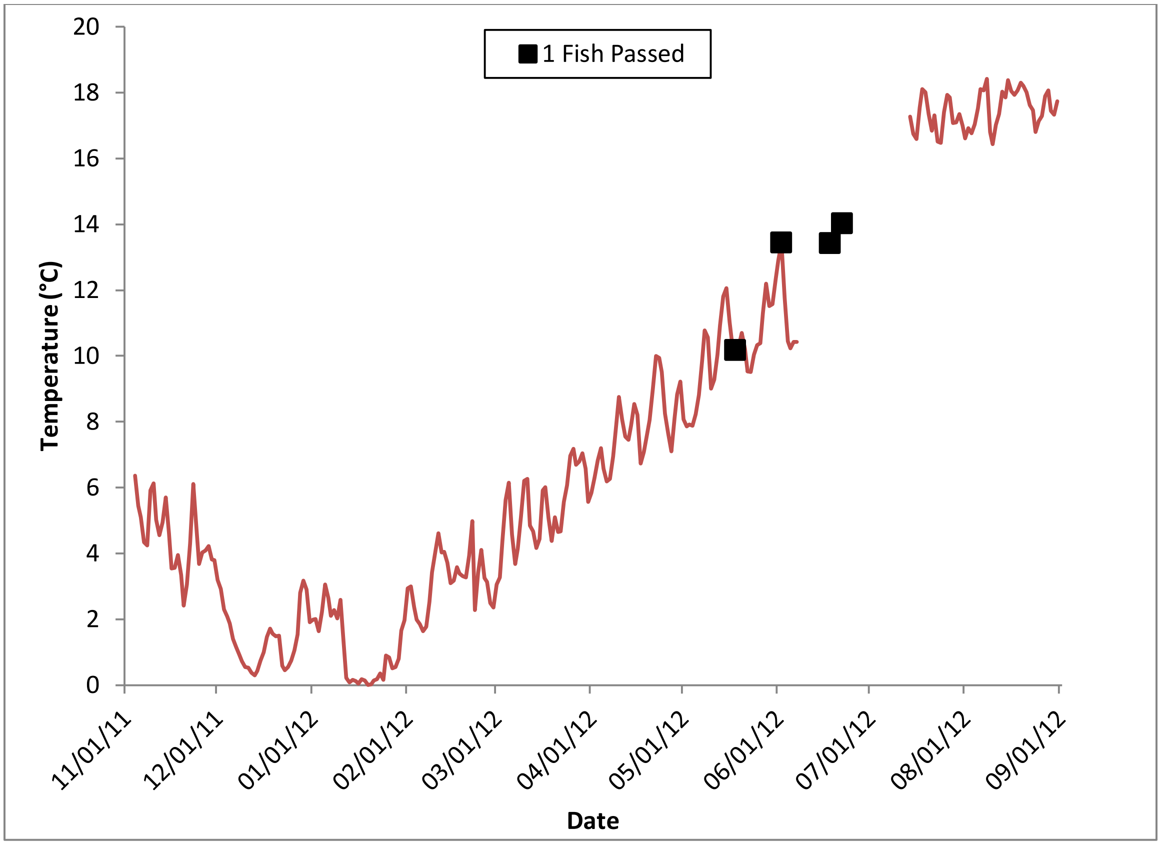

Figure 36. Average daily water temperatures of the Yakima River and dates of lamprey passage at Wapato Dam between November 4, 2011 and September 1, 2012. Data was not available for the time period between June 8 and July 13, 2012.

Above Dam Residence- The four lampreys that successfully passed Wapato Dam had above dam residence times between 32 minutes and 17 hours. There did not appear to be any correlation between fishway passage time and the length of above dam residence.

Diurnal Period of Movement

Upstream movements of Pacific lampreys past fixed stations occurred almost exclusively at night (Figure 37). First approaches to the dams and movements into the fishways both occurred at night with a frequency of greater than 75%. Lampreys initiating successful passage of a dam did so nearly all during night hours; only two entering a fishway during daylight hours. Both of these movements occurred within the last two hours of daylight. Movement downstream from the dams occurred evenly between day and night hours.

Figure 37. Diurnal periods that adult radio-tagged Pacific lampreys were active during downstream movement, upstream movement, and entry into fishways during the time period of October 2011 to August 2012.

Migration Rates between Stations

Fall Releases- Fall released Pacific lampreys had an average migration rate of 11.1 km/d (range 4 to 23 km/d) to move the 46.7 kilometers from Wanawish Dam to Prosser Dam. Migration rates for fall released lampreys between Prosser Dam and Sunnyside Dam- a distance of 92 km- averaged 7.7 km/day ranging from 1.8 to 12.7 km/day. The average migration rate for fall released lampreys between Sunnyside and Wapato dams (5 km) was 15.5 km/d, ranging from 4.2 to 30.9 km/d (Figure 38).

Spring Releases- Lampreys released in the spring migrated upstream from Wanawish Dam to Prosser Dam (46 km) at an average rate of 11.1 km/d (range 3.1 to 21.6 km/d). From Prosser Dam to Sunnyside Dam (91.4 km) lampreys averaged 7 km/d (range 4.9 to 9.9 km/d). The two spring released lampreys that migrated from Sunnyside Dam to Wapato Dam (5 km) averaged 5 km/d (range 4.1 to 30.9 km/d) (Figure 38).

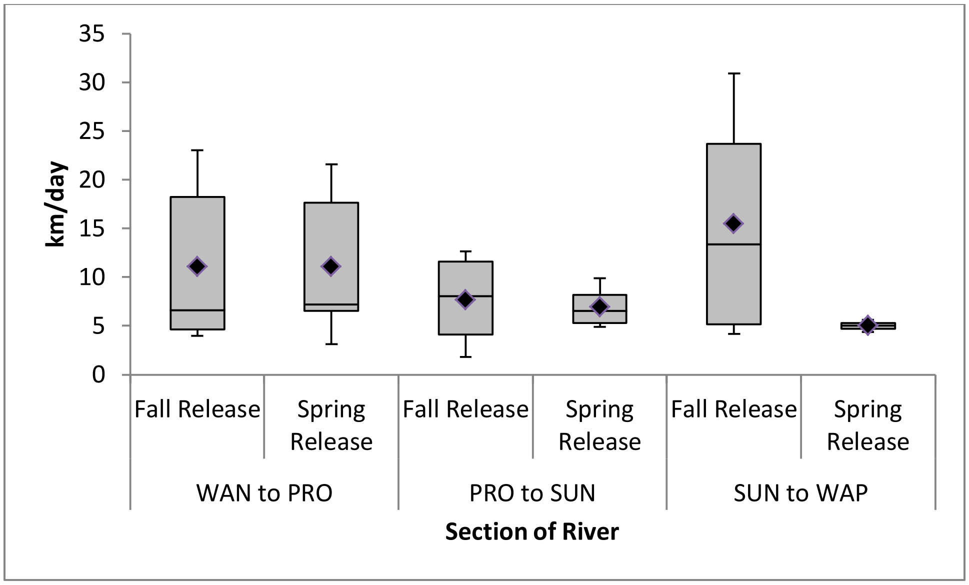

Figure 38. Kilometers traveled upstream per day by radio-tagged Pacific lampreys in the Yakima River, October 2011 to July 2012. Box plots show median and quartiles. The diamonds indicate the means.

Multiple Dam Passage

Lampreys having passed at least one dam had success rates of 39% at Prosser Dam, 50% at Sunnyside Dam, and 57% at Wapato Dam. When separated by release dates the fall group decreased in success from 50% at Prosser to 40% at Wapato while the spring group increased greatly from 30% to 100%. The numbers of lampreys passing these dams however was small. A total of five (7%) lampreys succeeded in passing two dams from all releases combined. Only two lampreys made it through three dams, one from each release group. Of the 30 lampreys released downstream of Wanawish, only two (7%) successfully passed all four diversion dams; one from each release group (Table 11).

Table 11. Release site, period, and number of radio-tagged Pacific lampreys that passed the lower four diversion dams on the Yakima River during fall 2011 and spring 2012.

Release Site And Period	n	Number of Passage Events							
		WAN Fall	**WAN Spring**	**PRO Fall**	**PRO Spring**	**SUN Fall**	**SUN Spring**	**WAP Fall**	**WAP Spring**
WAN Fall Up	5			1	2		1		
WAN Fall Dn	16	3	5	0	4		1		1
WAN Spr Up	4				1				
WAN Spr Dn	14		10		3		1		1
PRO Fall Up	4					1			
PRO Fall Dn	16			4	3		2		1
PRO Spr Up	4								
PRO Spr Dn	13				5		1		1
Totals	***76***	***3***	***15***	***5***	***18***	***1***	***6***	***0***	***4***

Dropouts between Dams

Not all lampreys that passed a dam continued their migrations upstream to the next dam. These “dropouts” consisted of both lampreys that passed a dam and never arrived at the next and also those that were unsuccessful at passing a dam and ultimately moved back downstream. Last known locations between dams were obtained for thirty of these individuals. Eight lampreys were present between the mouth of the Yakima River and Wanawish Dam (Figure 39). Eight lampreys were between Wanawish and Prosser dams (Figure 40), including six that approached Prosser Dam and then moved downstream and two that moved upstream from Wanawish but never reached Prosser Dam. In the reach between Prosser Dam and Sunnyside Dam a total of fourteen last known locations were recorded (Figure 41). Six were lampreys that had moved downstream from Sunnyside Dam. Eight ceased their upstream migrations and never reached Sunnyside Dam. No lampreys were in between Sunnyside and Wapato dams at the end of the study period. In addition to these known locations, another twenty-six lampreys dropped out in the reaches between the lower four dams (Table 12). Lampreys released in the spring upstream of Prosser Dam had the highest rate of dropouts with 100%. Percentages for all other releases were between 69% and 80%.

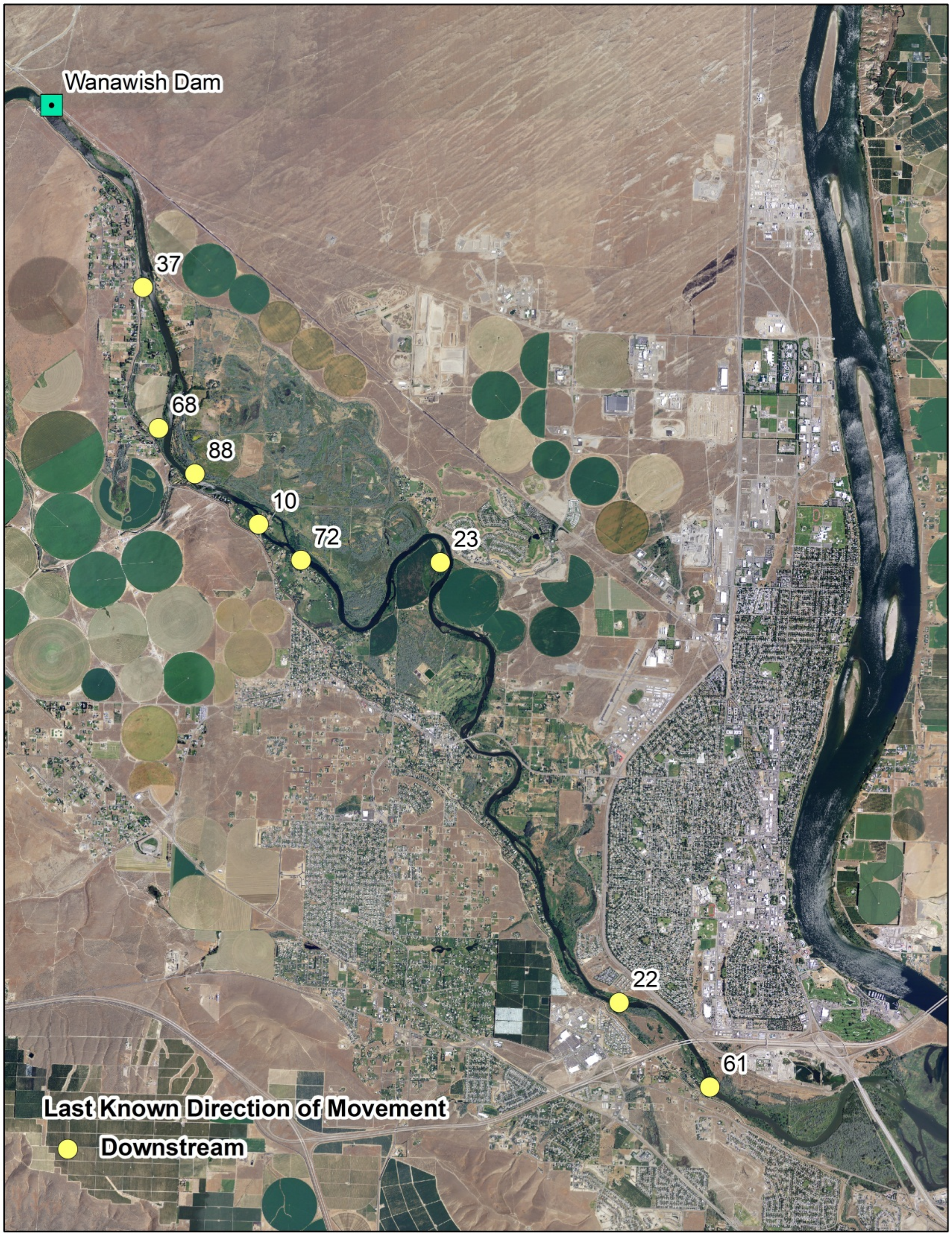

Figure 39. The last known locations of radio-tagged Pacific lampreys downstream of Wanawish Dam on the Yakima River, 2011-2012. The number represents the code of each radio tag.

Figure 40. The last known locations of radio-tagged Pacific lampreys between Wanawish Dam and Prosser Dam on the Yakima River, 2011-2012. The number represents the code of each radio tag.

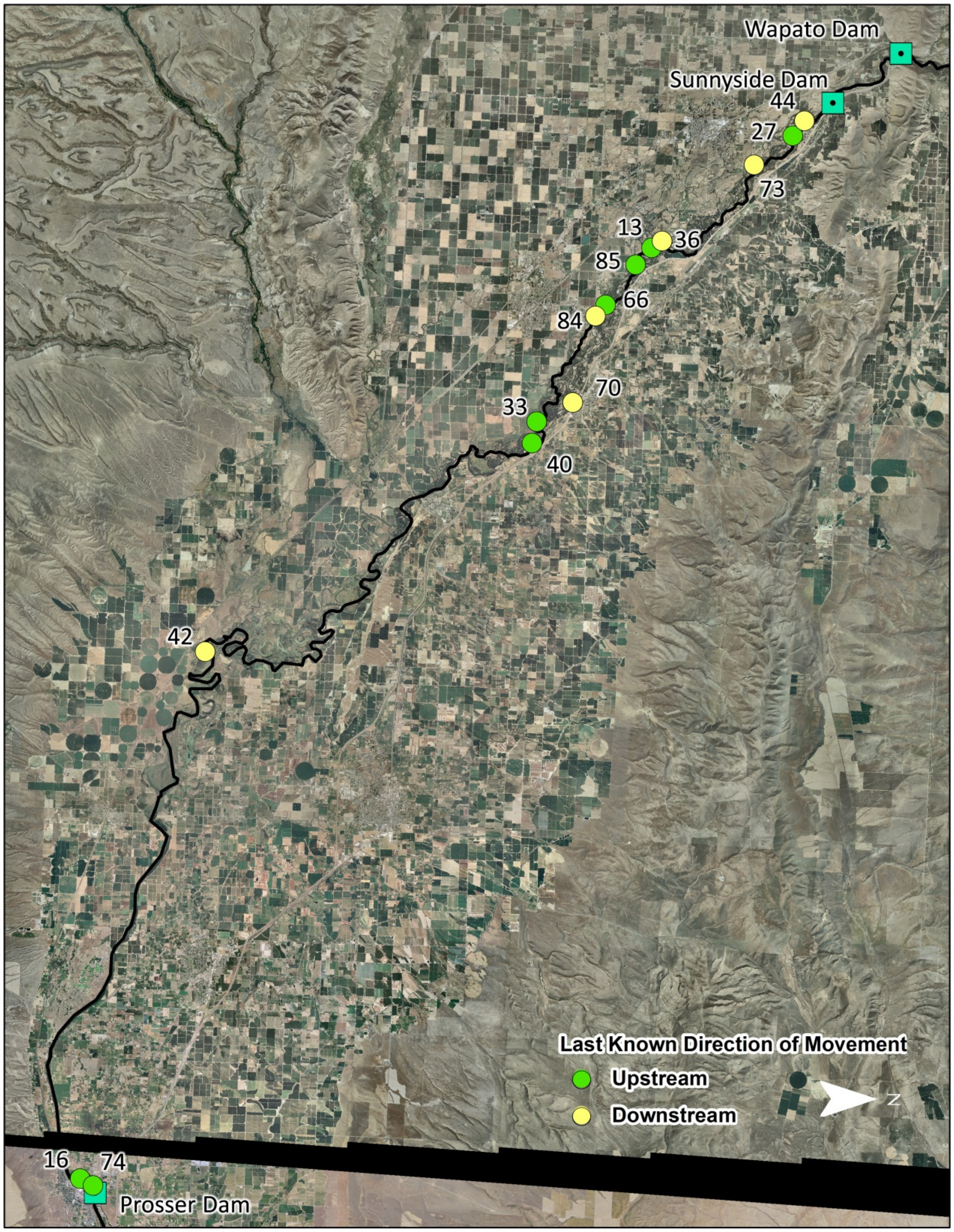

Figure 41. The last known locations of radio-tagged Pacific lampreys between Prosser Dam and Sunnyside Dam on the Yakima River, 2011-2012. The number represents the code of each radio tag.

Table 12. The number of radio-tagged Pacific lampreys that remained in between the lower dams on the Yakima River, 2011-2012.

Release Site/Period	D/S WAN n Dropouts/ n in Reach	WAN to PRO n Dropouts/ n in Reach	PRO to SUN n Dropouts/ n in Reach	Total (%)
WAN Fall Up		2/5 (40%)	2/3 (67%)	4/5 (80%)
WAN Fall dn	7/16 (44%)	3/8 (38%)	2/4 (50%)	12/16 (80%)
WAN Spr up		2/4 (50%)	1/1 (100%)	3/4 (75%)
WAN Spr dn	3/14 (21%)	6/10 (60%)	2/3 (67%)	11/14 (79%)
PRO Fall up			3/4 (75%)	3/4 (75%)
PRO Fall dn		6/16(38%)	4/7 (57%)	10/16 (63%)
PRO Spr up			4/4 (100%)	4/4 (100%)
PRO Spr dn		5/13 (38%)	4/5 (80%)	9/13 (69%)

Gate Stations

No Pacific lampreys were detected entering Satus or Toppenish creeks. Lampreys were not detected on the gate stations at the Roza Canal Wasteway outfall, Cowiche Dam on the Naches River, or at Roza Dam. No lamprey were detected on the station near the mouth, however, one lamprey was detected via truck tracking upstream of the station just out of its range.

Discussion

A total of 76 Pacific lampreys were radio-tagged, released, and tracked in the Yakima River during the 2011 migration season. Nearly all the tagged lampreys actively moved upstream and attempted to pass the diversion dams. Overall, about 50% of each release group failed to pass a dam and 25 to 40% of the lamprey that successfully passed each dam subsequently dropped out from the migration before reaching the next dam. Thus, during the 2011 migration season, only about 5% of the tagged lampreys were able to pass above Wapato Dam, the fourth diversion they encounter on the lower Yakima River.

Less than 50% of radio-tagged Pacific lampreys successfully pass each hydroelectric dam on the lower Columbia River (Moser et al. 2005; Keefer et al. 2009) and at Willamette Falls Dam on the Willamette River (Clemens et al. 2011). During our study to date, success rates for each of the lower Yakima River dams varied between 39% and 62%. Thus, although main stem Columbia River dams and the Willamette Falls Dam are much larger and more complex, our results indicate that small diversion dams on the lower Yakima River are similarly impeding and obstructing the migration of Pacific lampreys.

Dams with low passage rates and localized lamprey holding areas are prime candidates for lamprey passage structures (LPS) (Moser et al. 2006). Installed at Bonneville Dam on the lower Columbia River, LPS provide a series of ramps and pools which a lamprey can utilize to bypass the fishways and pass the dam (Moser et al. 2011, Reinhardt et al. 2008). At Prosser Dam tagged lampreys had a strong preference for residing in the pool at the corner along the left bank, which is essentially a dead end with no direct access to a fishway. Lampreys were detected residing in this pool during daylight hours and attempting to find passage across the width of the dam during night hours. Night observations showed tagged lampreys in this corner attempted to pass the dam via the exposed bedrock at the face of the dam. Velocities over the face appear to have been too swift as lampreys were unable to make the transition from bedrock to face without being swept downstream. Even if velocities were low, the overhanging lip at the crest of the dam is probably an insurmountable obstacle. Thus, this area appears to be an ideal place to install a LPS at Prosser Dam (see Appendix A for our conceptual design).

Wanawish Dam had the highest rate of passage (62%) but the average delay at the dam during the spring was 32.4 days. If there were no dams on the Yakima River, and lamprey were able to freely and naturally migrate at the overall mean speed of 7.7 km/d exhibited by our tagged lampreys between dams, after 32.4 days they would be 250 km upriver and into presumably suitable spawning areas above Roza Dam in the upper Yakima or Cowiche Dam in the Naches. Thus it is imperative that measures are developed to simultaneously reduce delays and increase passage rates at all of the dams. Any potential measures need to incorporate lamprey behavior and physiology while also considering the requirements for salmonid passage and the human factors of operation and maintenance.

At Wanawish Dam, for example, very few lampreys actually used one of the fishways. Instead, use of a concrete ledge along the right side of the dam appeared to account for the majority of passage events. This ledge extends approximately 6.5 m downstream from the face of the dam and is covered in water when flows are approximately 6,000 ft^3/s or higher. It is likely that the lampreys climbed over this ledge like a waterfall, although no passage events were witnessed. Only three lampreys passed Wanawish Dam at flows less than 6,000 ft^3/s. None of these were detected as moving through a fishway and it is possible that at lower flows lampreys are capable of climbing over the face of the dam. The left bank fishway was also closed for much of the spring season as attraction water was not flowing due to a broken gate. Miscommunications between maintenance staffs caused disruption in the routine cleaning of the trash rack at the exit of the fishway. These factors significantly reduced the amount of flow exiting the fishway. This may have inhibited the lampreys from finding the entrance and using the fishway despite the fact that more than half the lampreys first approached the dam on river left. Operating procedures however are to close both entrance gates when discharge is expected to exceed 4,000 ft^3/s for a week or longer (NMFS 1987). Discharge at Wanawish Dam exceeded this from February 23 to July 6, thereby encompassing the entire spring migration. Had the fishway been operated as normal it would still have been inaccessible to lampreys. Opening the left fishway during higher flows may increase lamprey passage so long as velocities do not significantly increase. One modification that may reduce delay and increase passage is adding rounded steps to the ledge which would allow for shorter climbing distances over a wider range of flows. Note that any modifications done to the ledge should be minor and not interfere with a lamprey’s ability to use it. Any large scale modifications such as a metal ramp LPS should be done on the left bank, which receives the greatest number of first approaches.

Yakima River diversion dam fishways are much smaller and simpler than those of the main stem Columbia River. Tagged lamprey spent on average of 4.2 hours in the ladders at Yakima River dams compared to McNary Dam where tagged lampreys took an average of 67.2 hours to pass through a fishway (Boggs et al. 2008). Residence time downstream of the Yakima dams, however, was longer than for Columbia River dams (Boggs et al. 2008; Keefer et al. 2009). This suggests that finding or entering a fishway at the Yakima diversions may be more of an obstacle than the fishway itself. The fishways were designed for salmonids that swim higher in the water column. Pacific lampreys tend to be bottom oriented and the elevation of the fishway entrance may affect their ability to find and enter the ladder. This warrants additional attention and if it is an issue, we suggest the construction of “mounds” connecting the river bottom to the elevated fishway entrance to guide the lamprey to the opening (see Appendix A).

Water velocity is known to affect lamprey entry and passage in the ladders. Given the variation in the recorded velocities, particularly at Prosser Dam, we cannot be certain what the exact entrance velocities were when a lamprey entered, but most probably passed in the range of 2 to 7 ft/s. Johnson et al. (2009) found that reducing entrance velocities below 4 ft/s increased the number of Pacific lamprey entering a fishway. Moser et al. (2002) however, saw no increase in entry when velocities were reduced from 8 ft/s to 4 ft/s. Provided that adequate surfaces are available to attach for resting, it is possible for Pacific lampreys to pass through velocity barriers up to a maximum of 9 ft/s using burst swimming, though few are able to so (Moser et al. 2002; Keefer et al. 2010). Velocities at Prosser Dam’s right bank lower entrance exceeded this maximum on several occasions and use of this entry did not occur until velocities dropped below approximately 3 ft/s. A reduction in velocities may encourage more entries by lampreys, particularly in the spring months when most passage occurs. Techniques to reduce velocities and still provide passage for salmonids should be investigated. If reduction of velocities is not possible, other techniques such as rounding the corners of the cement walls at the entrances and in the vertical slots have proven effective in increasing passage (Moser et al. 2002).

A wide range of velocities were recorded at the fishway entrances. Some entrances such as the center island in the east channel at Wapato Dam and the center island at Sunnyside Dam had nearly constant velocities throughout the study period. Others such as those at Prosser Dam were very inconsistent and often had negative values. High discharge and water levels made it difficult to standardize the measurement methods as the entrances were not visible. This often prevented accurate determination of where in the water column the probe was in relation to the entrance as well as keeping the probe in a constant location within the flow exiting the fishway. Large eddies formed near the entrances at high discharge and appeared to interfere with the velocity readings. Very low discharge also interfered as the water level was too low to reach and adequately submerge the probe. Daily operation of the fishways directly influenced the flow and velocity at the entrances. Fishways were closed during high discharge events to protect equipment. Attraction water was also closed at Wapato Dam’s east channel center island and Wanawish Dam’s left bank. The cleaning schedules of the fishway trash racks also impact the velocities. Velocity measurements were taken during weekly downloading of the telemetry stations, therefore the recorded entrance velocity was often two or three days prior to or after a passage event. Installing a more sophisticated velocity meter with a standard depth and recording schedule at the entrances is needed to precisely determine the velocity when a lamprey enters the fishway. This system would provide feedback and assist in the development of modifications of the operations to reduce velocity to increase passage of lamprey.

Fish counts at Prosser Dam are done with video recording equipment in each fishway. These data indicate that Pacific lampreys pass upstream primarily during the spring period of the migration, mostly in April and May but a few pass earlier in the migration during the previous late summer and fall period. Our results are consistent with these observations, with over half of the passage events occurring in April and May and a smaller number passing the previous October. Fifty-five percent of our tagged lampreys successfully passed through a fishway when the video cameras were operational but were not recorded. This indicates that a significant portion of lampreys are passing in the fishways at the dam without being counted. Alterations of the video procedure or the counting area may be needed if more accurate counts of Pacific lampreys are desired. Picketed leads are used to direct salmon past the counting window to increase detection and species identification. It is likely that adult Pacific lamprey pass through the 22 mm space between the bars in the leads so reducing that gap may force the lamprey to pass in front of the counting wall and increase the video detections. However, care should be taken that any changes do not make it more difficult for them to pass this area. For example, lampreys move in the ladders at night and may be passing through the leads behind the counting wall to avoid the bright electric lights used to illuminate the counting area. Decreasing the space between the bars may inadvertently delay or prevent many from passing the counting area.

Pacific lamprey telemetry studies on Columbia River tributaries (Baker et al. 2012, Courter et al. 2012) have shown that movement around dams also occurs almost exclusively at night. Pacific lampreys in the Columbia River are more likely to move during the day in areas of low gradient or low risk (reservoirs) than in high gradient or high risk areas such as fishway entrances (Keefer et al. 2012). Our results are consistent with these in that almost all entrances into a fishway occurred at night and half of the downstream movements during daylight hours. A similar proportion of daylight downstream movements occurred during the pilot year of this study (Johnsen et al. 2011).

Spawning areas of Pacific lamprey in the Yakima River basin have not yet been definitively identified. Only one lamprey was detected above Wapato Dam during mobile tracking. It was found under a logjam in a reach with potential spawning substrate but no indications of spawning were observed in the immediate area. Lampreys were also detected during aerial, truck, and boat tracking throughout the reaches between the lower four dams. Most of these reaches do not appear to hold much suitable spawning habitat, but we were unable to make in-river observations of these individuals and do not know if they were attempting to spawn. No entries into Satus, Toppenish, or Ahtanum creeks were detected despite the presence of larval Pacific lamprey and western brook lamprey *Lampetra richardsoni* (Reid 2012; Patrick Luke, Yakama Nation, pers. comm.) and the availability of likely spawning areas. The next phase of our study will include releasing lampreys at Sunnyside and Wapato dams, resulting in a greater number of individuals gaining access to potential spawning areas farther up in the basin. We will continue to monitor lamprey movements within these reaches and attempt to document reproductive behavior.

Insights from the pilot study (Johnsen et al. 2011) were incorporated into our study design. Solar power backup was added to all stations at the dams and kept the telemetry receivers operating when AC power at the dams was turned off during high flow events. Based on data from the pilot study, hanging antennas were added this year and resulted in additional information on finer scale movements and holding areas at the dams. Cowiche Dam and Roza Dam were not originally part of this year's study plan; however manpower and resources were available to equip them with telemetry stations, which reduced the amount of effort required to monitor migrations upstream of Wapato Dam. Future phases of our study will include additional antennas at these dams to better understand their impacts on Pacific lamprey passage.

Aerial tracking of our tagged lamprey was conducted on one occasion by Yakama Nation Fisheries personnel during their steelhead telemetry study. The flight detected lampreys between the dams, including many that never arrived at the next dam, and provided information we likely would not have otherwise collected. Aerial tracking will be used if possible for next year's study.

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Appendix A: Conceptual designs for improving Pacific lamprey passage at Prosser Dam

To date, our telemetry study has identified several methods that may improve passage efficiency for adult Pacific lamprey at Prosser Dam. Four concepts are developed and discussed in this appendix.

Lamprey Passage Structure

A lamprey passage structure (LPS) pumps water through a series of metal ramps and holding tanks to allow lampreys to pass over dams (Moser et al. 2006). These systems are used effectively at other dams including Bonneville Dam on the Columbia River (Moser et al. 2011) and Three Mile Falls Dam on the Umatilla River (Jackson and Moser 2012).

Justification

Telemetry data show that lampreys gather and hold in the pool area at the left bank of the dam. Adults have been observed attempting to move upstream by climbing the bedrock there (Figure A-1).

Figure A-1. Pacific lamprey (circled in red) climbing bedrock on left bank at base of Prosser Dam.

Placement and Construction

The area on the river-left side of the dam would be the best place to build a LPS for adult lamprey passage. The ramp would start at the bedrock on the downstream side of the dam between the canal and the river (A-2). The ramp would then angle up and over the dam in the space between the gatehouse wall at the head of the canal and a wall at the end of the dam (Figure A-3).

Figure A-2. Proposed site of LPS on the left bank of Prosser Dam at low flow.

Figure A-3. Prosser dam and the head of the Chandler Canal. The ramp would be placed in the space (circled in red) between the gate house and the slanted wall at the left bank of the dam.

The entire system would consist of a covered ramp, a pump, and either a collection box at the top end of the ramp or an outlet into the river above the dam (Figure A-4). Water would be pumped from the river on the upstream side of the dam to the highest section of the ramp and then flow down the ramp, out the entrance, and over the bedrock. At base flows, this pumped water would be the only attraction water in the area.

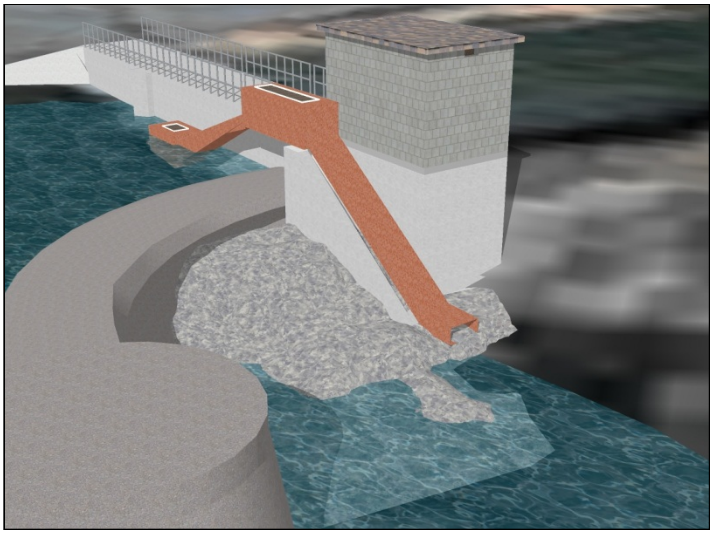

Figure A-4. Concept of proposed LPS on the left bank at Prosser Dam. The existing structures of the dam are shown in grey with the proposed lamprey ramp in red.

Advantages

The LPS at this site has several advantages. The system would be protected from floating logs and debris as the proposed site is sheltered between two concrete walls. AC power is available in the gate house at the location and water for the ramp would be pumped and regulated, allowing for constant velocities and operation regardless of river flow. The system could also be used as an adult trapping facility to aid in collection of lampreys for propagation or future studies. Finally, building the ramp here would not require any modifications to the dam structures or river channel.

Disadvantages

The ramp system relies on water being pumped from the river to the higher elevation of the ramp. Thus, the system requires electricity and potentially more maintenance than passive systems. The outfall ramp of the LPS needs to be carefully positioned in order to avoid entrainment of lampreys back over the dam or down the canal.

Underground Lamprey Passage Structure

Telemetry identified another possible location for a LPS on the right bank of the river. One radio tagged lamprey entered and traveled up the existing drain pipe into the fish trapping facility, suggesting that lampreys looking for passage would find a LPS ramp entrance in the area.

Placement and Construction

The ramp would begin on the downstream side of the dam near the drain outflow pipe and then proceed underground to exit upstream of the dam (Figure A-5). By placing the LPS in a concrete trough under ground-level, the structure would not interfere with access to the right bank facilities or with operations of the trap and the fish ladder.

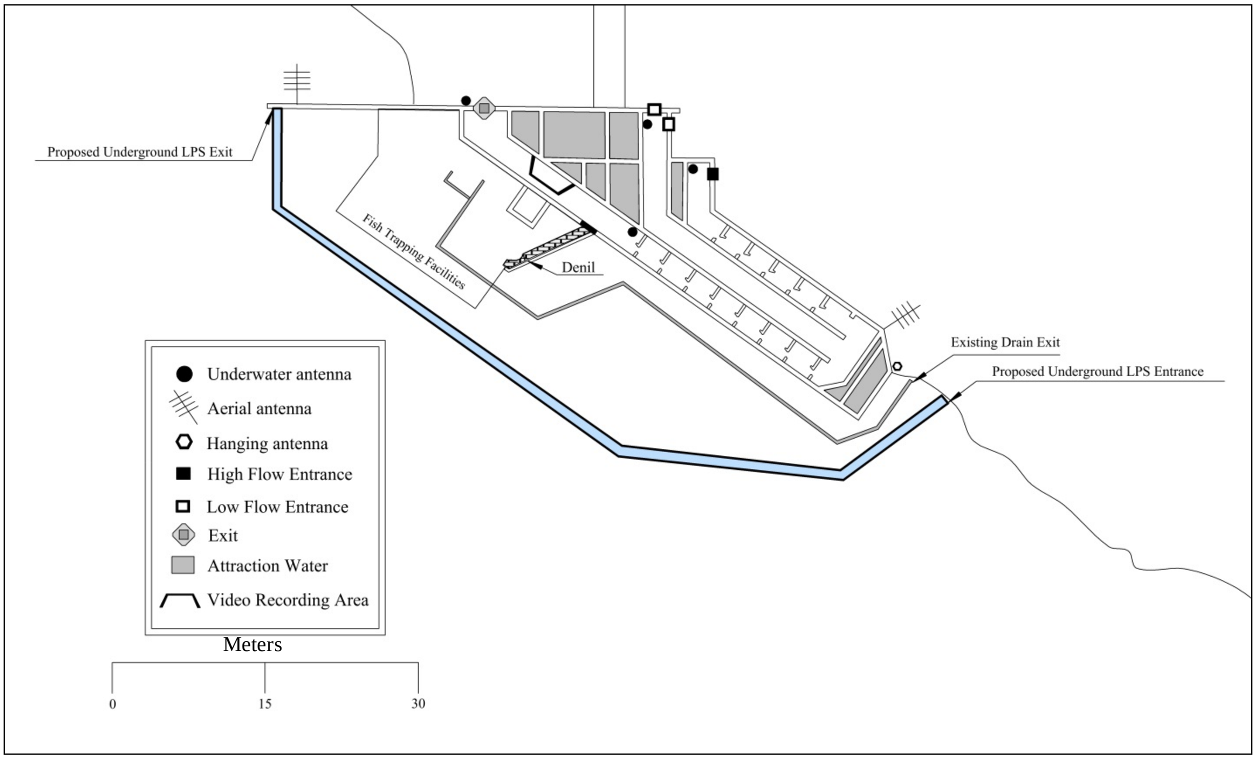

Figure A-5. Proposed site and concept for an underground LPS on the right bank of Prosser Dam.

Rock Ladder

A "natural" pile of rocks extending from the crest of the dam to the river bed on the downstream face of the dam could provide passage for up-migrating adult Pacific lamprey.

Justification

Provided suitable surfaces to hold onto, Pacific lampreys have the ability to climb over steep and turbulent sections of river. For example, Pacific lampreys are known to climb Willamette Falls (Clemens et al. 2011). We observed lampreys at Prosser Dam attempting to move upstream by climbing natural bedrock but the rock does not extend up to the dam crest (Figure A-6).

Figure A-6. Pacific lamprey climbing bedrock at the base of Prosser Dam.

Placement and construction

The bedrock on the left bank of Prosser Dam is the best location for the rock ladder (A-7). Lampreys have been observed climbing bedrock in the area and telemetry data show that lampreys congregate there. Additionally, a log boom just upstream of the dam in the area reduces debris going over the dam face at that location.

The construction of a rock ladder would require placing large rocks and boulders at the base of the dam and building them up to the crest. This construction would use the bedrock as a base with the added rocks cemented or otherwise secured to ensure that they stay in place during high flow events. The rock ladder needs to be designed so that there are areas of varying velocities and that water is flowing over the rocks at a wide range of discharges. This would provide a variety of paths for the lampreys to take over the dam as conditions change.

Figure A-7. Proposed site at Prosser Dam of rock ladder showing bedrock at low flow. The head of the Chandler Canal is just right of the edge of the frame.

Advantages

The rock ladder holds several advantages over other potential systems. First, the rock ladder is passive and does not require water to be pumped, eliminating the need for personnel to monitor and maintain a pump. Second, the base of the ladder could be quite large to make it easier for lampreys to find a place to start climbing. This may increase passage compared to a single ramp with a small entrance. Finally, as lampreys recover and are once again plentiful in the future, a rock ladder would better serve as a tribal fishery location where lampreys could be captured using traditional methods.

Disadvantages

A rock ladder may be prone to catching tree trunks, branches, or other debris and it may be necessary to clear the area at times. Construction would likely be a regulatory challenge requiring permits to do work in the river and on the dam. The proposed site of the rock ladder is dry at base flows, so the dam crest may need to be modified to keep water flowing over the rocks. Finally, lampreys using an open and uncovered system such as this may be more susceptible to predation or illegal harvest before a fishery is established.

Fish Ladder Modification: Entrance Mounds

Mounds could be built at the base of the entrances to the existing fish ladders (Figure A-8). These structures would slope down on all three sides from the lower edge of the entrance to the river bed.

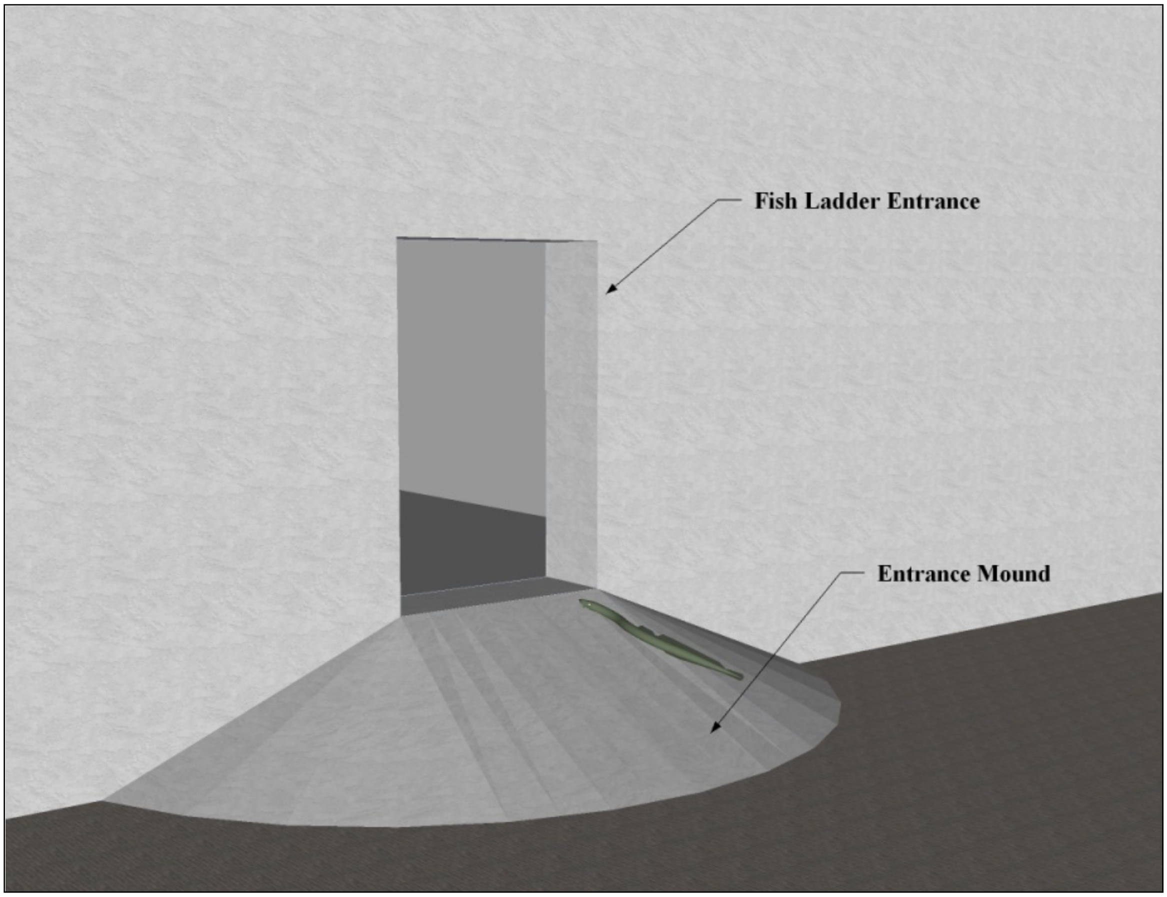

Figure A-8. Concept of proposed fish ladder entrance mound.

Justification

One factor contributing to the difficulty faced by lampreys in using the existing fishways may be an inability to find the ladder entrances. The ladders were designed for salmonids that swim in the water column, but Pacific lampreys move close to the river bed, often anchoring themselves to rocks. Thus, lampreys may not be swimming high enough in the water column to discover those ladder entrances that may be located above the river bed. Entrance mounds could guide lampreys to the entrances and provide an attachment surface to negotiate higher velocities (Figure A-8).

Placement and construction

Modifications would be made to the existing fish ladder entrances. Initially, a single ladder could be modified in order to test the effectiveness of mounds and then other ladders could be modified later if the changes increase passage. The river left ladder could be changed first as telemetry data suggest lampreys congregate in the area. Passage through the ladder is monitored by video, so effectiveness of modifications could be quantified.

The construction of concrete mounds would require coffer dams and diverting water from the base of the ladder. Concrete would be used to form mounds sloping to the river bed from the bottom of the ladder entrances. This new concrete would need to be secured in place, possibly using rebar or by excavating in front of the entrances so that it is sufficiently buried. Permits would be needed for working in the river and on the dam.

Advantages

Adding mounds to the fish ladder entrances would be a relatively simple modification to an existing fish passage system. Constructing the mounds may be cheaper than constructing an entirely new system for lamprey passage. The system is passive and it should not require any maintenance beyond what is currently required to keep fishways clear. Finally, the modifications could be undertaken as a trial, and if proven effective could be implemented at other dams that have similar fishway entrances.

Disadvantages

Constructing mounds at fish ladder entrances would require working in the river and modifying the dam structures. Permits and various agency approvals would be needed. Also, it is currently unknown by us how many entrances are elevated and whether it makes it more difficult for lampreys to find the ladder or if other factors are preventing them from entering (e.g. high water velocities or squared edges at fishway entrances).

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Appendix B: Water velocities at the entrances of fish ladders at Yakima River diversion dams during 2102.

The following tables contain the velocities of water flowing out of fish ladder entrances at Wanawish Dam (Table B-1), Prosser Dam (Table B-2), Sunnyside Dam (Table B-3), and Wapato Dam (Table B-4). Velocities at open gates were measured with a portable flow meter (Marsh McBirney Flo-Mate™ 2000). Gate labels for each entrance (NMFS and BOR 1992a-e) are shown in Figures B-1 through B-5.

Table B-1. Water velocities (ft/s) measured at fish ladder entrances on Wanawish Dam during 2012.

Date	Left Bank G1*	Right Bank G2
4/5/2012	5.77	3.34
4/18/2012	5.4	3.7
4/25/2012	6.75	2.8
4/30/2012	4.61	3.08
5/10/2012	5.41	2.89
5/16/2012	6.85	
5/23/2012	6.56	2.61
5/31/2012		0.6
6/7/2012	5.06	3.16
6/13/2012	0.76	2.4
6/20/2012	-0.325	-0.81
6/27/2012	5.66	1.96
7/2/2012	-1.42	-1.17
7/12/2012	4.22	-0.7
7/18/2012	3.18	4.92
7/25/2012	2.03	6.92
8/7/2012	3.7	5.84
9/12/2012	3.5	3.63

*The fishway entrances appeared to be closed during the study and the measured velocities represent the speed of the river current moving across the ladder opening.

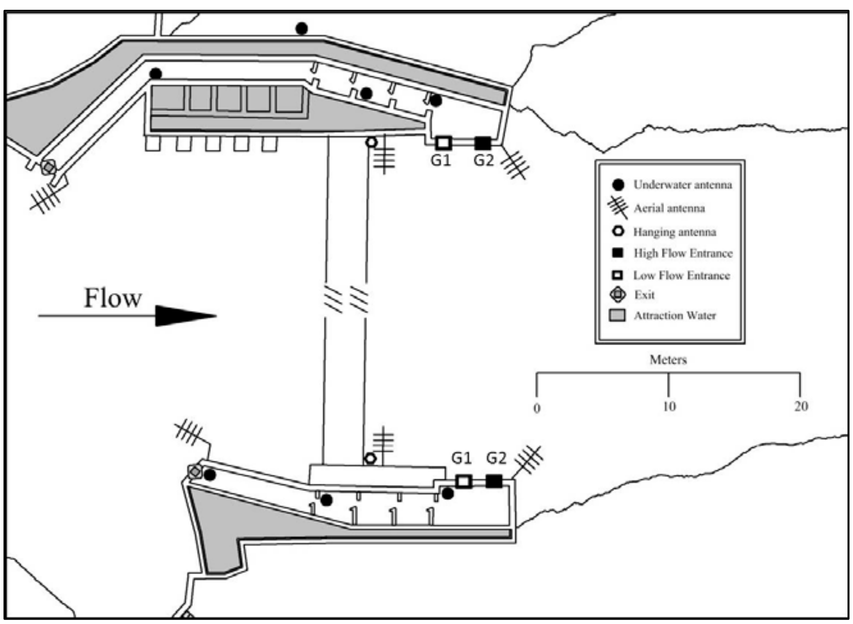

Figure B-1. Wanawish Dam fishway gate labels.

Table B-2. Water velocities (ft/s) measured at fish ladder entrances on Prosser Dam during 2012.

	Left Island				Center Island				Right Bank		
Date	**G1**	**G2**	**G3**	**G4**	**G1**	**G2**	**G3**	**G4**	**G1**	**G2**	**G3**
4/5/2012			4.7	4.7		6.4		3.9	3.6		9.6
4/19/2012			6.39	5.14		7.23		6.57	2.05		9.2
4/25/2012			-0.9	-0.9		7.65					2.6
4/30/2012			0.93	0.99		1.76		-0.33			1.45
5/10/2012			7.05	6.53		6.89		5.9	-0.48		6.94
5/16/2012						8.18		7.9			6.5
5/23/2012						4.68		6.23			6.87
5/31/2012			3.79	4.22		6.27		6.25			6.13
6/7/2012						4.58		3.64			2.99
6/13/2012			6.67	6.12		8.24		6.73			8.3
6/20/2012		-0.74	1.1	0.47		4.19		3.78			2.99
6/27/2012		-0.63	0.14	0.83		4.63		4.28			2.53
7/2/2012		4.83	9.86	7.62	2.34		4.91			5.31	7.48
7/12/2012		4.32	7.32	5.53			8.48			6.24	6.86
7/18/2012			6.36	6.82						4.56	3.77
7/25/2012					4.23		7.18		6.27	5.74	
8/7/2012	5.77				5.03		6.02			5.01	5.51
9/6/2012					6.32		6.52			6.51	4.88
9/12/2012					7.67		6.46		0.4		6.7

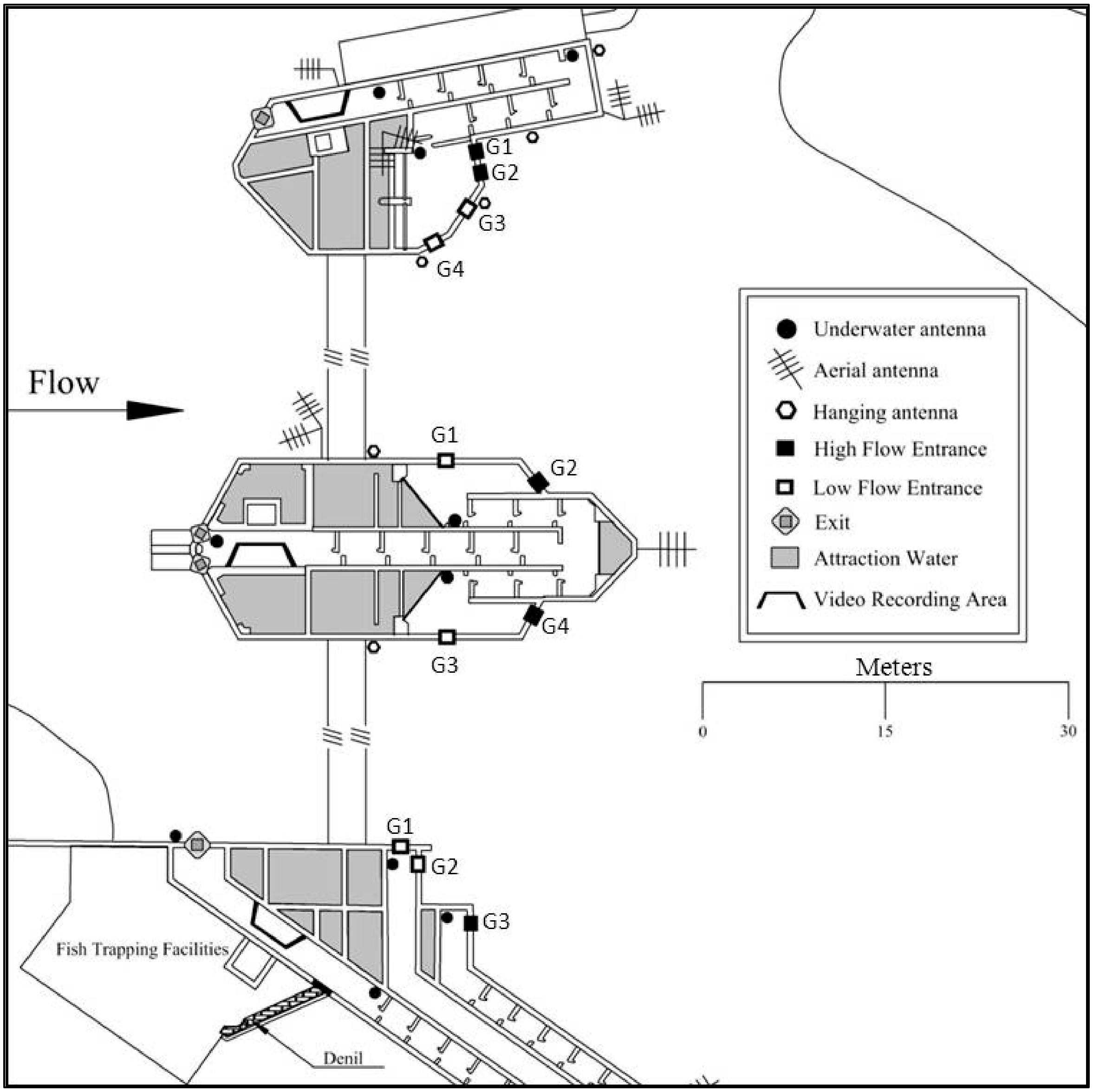

Figure B-2. Prosser Dam fishway entrance gate labels.

Table B-3. Water velocities (ft/s) measured at fish ladder entrances on Sunnyside Dam during 2012.

	Left Island		Center Island				Right Bank	
Date	G17	G18	G11	G12	G13	G14	G3	G4
4/5/2012								6.6
4/6/2012		6.33						
4/19/2012		8.6		7.81		8.23		6.71
4/25/2012								-0.1
4/30/2012		3.05		-0.52		-0.53		0.13
5/11/2012		8.26		7.22		9.67		4.89
5/16/2012		8.1		6		5.2		4.4
5/24/2012		8.82		6.17		6.41		5.3
5/31/2012		7.9		9.67		9.28		5
6/7/2012		3.18						1.13
6/13/2012		8.55		8.99		8.62		7.41
6/21/2012		6.46		6.71		6.44		4.58
6/28/2012		10.09		8.39		8.93		7.51
7/3/2012		8.63		5.2		6.54		4.68
7/13/2012		6.79	6.63		6.95		1.62	
7/19/2012		6.89	6.17		6.1		4.2	
7/26/2012		6.78	7.31		7.02		5.28	
8/7/2012		8.49	7.57		7.22		5.35	
9/5/2012	7.81		6.93		7.97		8.02	
9/13/2012	7.95		4.35		6.58		4.92	

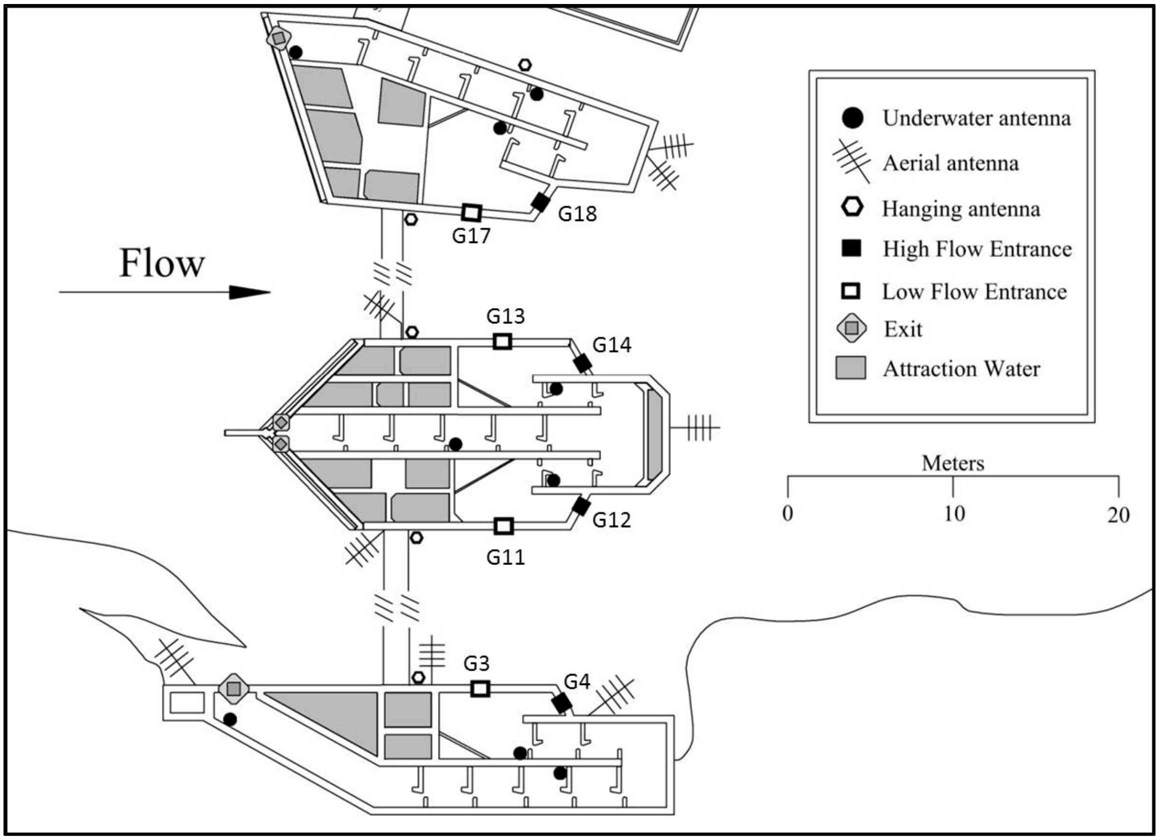

Figure B-3. Sunnyside Dam fishway entrance gate labels.

Table B-4. Water velocities (ft/s) measured at the entrances to fish ladders at Wapato Dam during 2012.

	East Branch Center Island		East Branch Right Bank	West Branch Center Island			
Date	**G8**	**G10**	**G4**	**G7**	**G8**	**G9**	**G10**
4/5/2012	4.21	4.21	4.1				
4/6/2012					7.4		4.8
4/19/2012	2.13	2.3	2.8		2.45		2.26
4/25/2012	2.2	2.1	3.6		3.9		3.2
4/30/2012	2.19	2	4.6				
5/1/2012					3.29		2.18
5/11/2012	1.83	1.59					
5/16/2012	2.3	2	1.6		6.2		5.6
5/24/2012	2.41	2.18	2.88		2.66		1.99
5/31/2012	1.81	1.65	4.1		6.76		5.04
6/7/2012	2.34	1.32	3.95				
6/8/2012					2.12		2.53
6/13/2012	2.36	2.15	5.5				
6/14/2012					2.91		3.37
6/20/2012	1.37	0.84	5.32				
6/21/2012					3.33		3.35
6/28/2012	1.96	1.8			4.76		3.62
7/3/2012	1.6	1.71	5.56	0.71		0.87	
7/13/2012	1.96	1.98	4.85		0.94		0.95
7/19/2012	1.9	1.7	6.69	3.28		3.41	
7/26/2012	1.54	1.98	1.28		4.69		4.55
8/7/2012	1.92	1.98	5.89				
8/8/2012					4.4		6.35
9/5/2012	1.98	2.03	5.7		5.71		5.39
9/13/2012	3.07	3.36	4.76		3.75		3.83

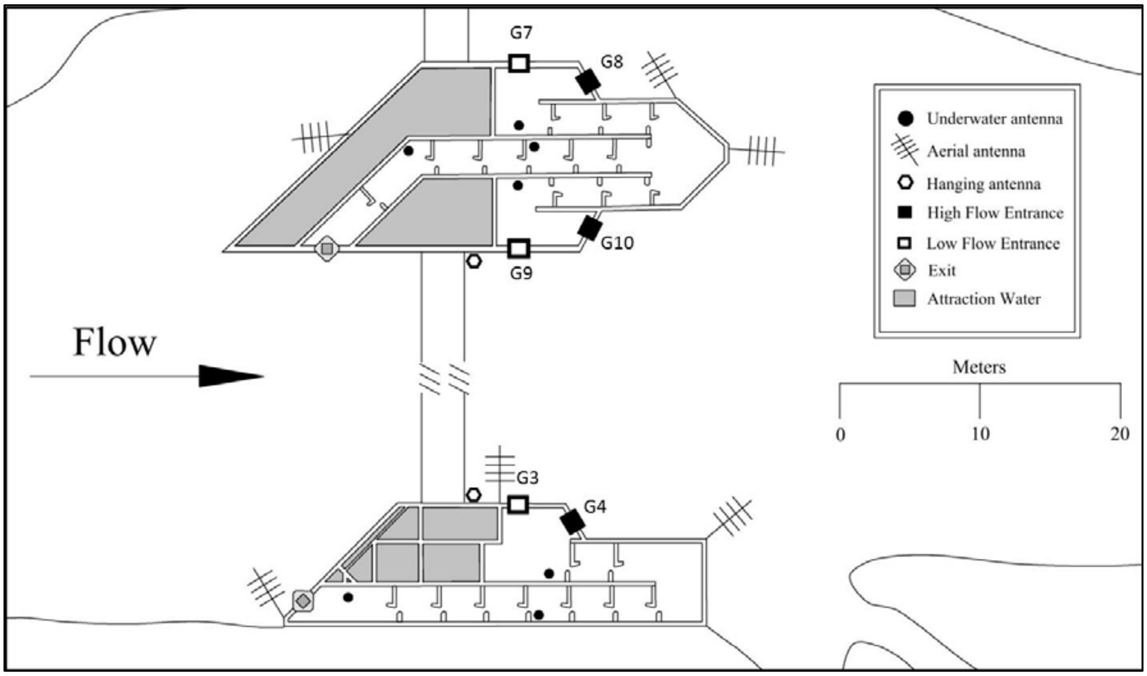

Figure B-4. Wapato Dam east branch fishway entrance gate labels.

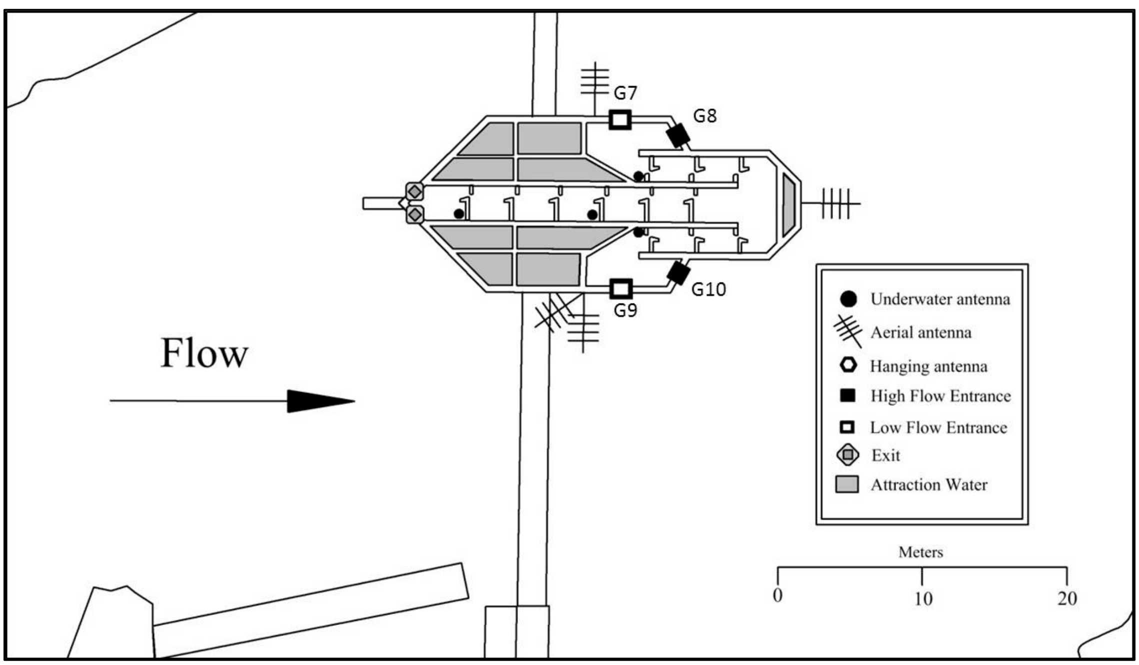

Figure B-5. Wapato Dam west branch fishway entrance gate labels.

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