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Exploring Techniques to Reduce Lamprey and Salmonid Entrainment into Canals

Final Progress Report
(from Yakama Nation)

Project Year 2016 - 2019
January 26, 2016 – June 30, 2019

Collaboration between
Yakama Nation,
Confederated Tribes of the Umatilla Indian Reservation,
National Oceanic and Atmospheric Administration Fisheries,
and Bureau of Reclamation

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Introduction

Background

Pacific Lamprey *Entosphenus tridentatus* are an important subsistence, ceremonial, and medicinal food source for Columbia River Basin (CRB) tribes. Pacific Lamprey abundance is at a fraction of historical numbers and distribution is increasingly limited to the lower portions of the CRB. To prevent further decline, local extirpations, and potential enlisting of the species under the Endangered Species Act, the CRB tribes and a consortium of partnering agencies, many of which signed the Pacific Lamprey Conservation Agreement in 2012, began work to protect and restore the local populations. The Bureau of Reclamation's (Reclamation) commitments in the Columbia Basin for lamprey are defined in memoranda of agreement known as the 2008 Columbia River Fish Accords. The Accords are related to the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion.

Reclamation's commitments are to assess Reclamation project effects to lamprey, and where appropriate, make recommendations for either further study or actions that may be taken to reduce effects on lamprey. Furthermore, Reclamation should develop a plan to address effects and seek to implement recommended actions from the plan. The Columbia/Snake Salmon Recovery Office in the PN Region has been funding this work since 2010.

This Project to investigate possible solutions to larval/juvenile lamprey entrainment not only enhances Reclamation's actions in the Columbia Basin but provide unique and innovative solutions to lamprey entrainment issues across the Pacific Northwest where lamprey are found. Pacific Lamprey are not currently listed, though there is likely a biological basis to do so. The Accords and current activities to address lamprey effects have provided a rationale for them not to be listed at this time. The objective was to find simple, cost-effective solutions to larval/juvenile lamprey entrainment. This is an issue common across where Reclamation projects and lamprey range coincide, and lamprey awareness is becoming ever more visible across Reclamation. Addressing these issues now could help prevent them being listed under the Endangered Species Act, and if they do become listed this research could provide cost-effective ways to address these issues. Additionally, the salmonid program has taken the opportunity to partner with this Project to assess possible techniques to better protect salmonid juveniles from entrainment, thus making this research valuable to an even broader audience of Reclamation.

Need and Benefit

Many Reclamation projects have fish screens in place designed to protect salmonids, but recent interest in understanding and reducing Reclamation project effects on lamprey have helped advance information regarding lamprey entrainment. Larval lampreys (also called ammocoetes; pre-outmigration stage with no eyes or teeth), juveniles (also called macrophthalmia; outmigration stage with eyes), and *Lampetra* resident adults (spawning stage) are physically and behaviorally very difficult to protect with conventional screening. According to Rose and Mesa (2012), entrainment and impingement rates were very high for many of the commonly used screen types (62-65% entrainment for 12- and 14-gauge wire cloth screens and 36-62% impingement for interlock screens). Research to date shows that larval and juvenile lampreys are vulnerable to entrainment in irrigation diversion. Not only young of the year fish, but many age classes of lampreys (even 3-5 year-old lampreys) are vulnerable to entrainment and impingement. Surveys conducted after dewatering in diversions within the Yakima Subbasin showed that thousands of lampreys are found entrained downstream of the fish screens each year (Lampman et al. 2014a and 2015). Of these, most are the more common Western Brook Lamprey *Lampetra richardsoni* (or other *Lampetra* species including Western River Lamprey *Lampetra ayresii*), but about 7% were Pacific Lamprey. Sunnyside and Wapato diversions have consistently carried the largest number of entrained lampreys by far within the Yakima Subbasin and the estimated number was 11,664 and 7,423, respectively, based on a mark-recapture study in 2014 (Beals & Lampman 2015a).

Sutphin and Hueth (2010) investigated lamprey entrainment in Reclamation projects on the Umatilla River in Oregon and found very few lampreys entrained, whereas juvenile lampreys have been observed in relatively large numbers in other canals in the same area. Interagency discussions have led us to hypothesize that the angle of canal and hydraulic properties of the intake may be contributing to the variation in lamprey entrainment rates. Replacing screens with smaller mesh screens to provide better protection for lampreys would be very expensive, may not even be feasible, and would be very difficult to maintain.

The tight knit relationship between lamprey entrainment and fine sediment accumulation was documented by the partners working on this Project (Lampman & Beals 2014b). The distribution of fine sediment within the diversion was effective in predicting where larval lampreys were found, potentially indicating that fine sediment and lampreys are traveling together in the rivers and streams. As a result, even if the movement of lampreys cannot be controlled directly and effectively, by focusing and controlling the fine sediment movement and transfer, entrainment of lampreys can likely be diminished or reduced. Solutions that targeted and controlled the movement of fine sediment was consequently pursued as a promising venue to reduce lamprey entrainment.

Additionally, accumulation of fine sediment in reservoirs as well as entrainment of fine sediment into associated diversions and canals cause operation and maintenance issues for the facilities managed by Reclamation. At many of the facilities that are part of this study, fine sediment is annually dredged, removed, and transported out of site, all of which are recurring operation and management costs to the projects (Lampman et al. 2014a). In addition, lampreys are often found in this dredged fine sediment, making the salvage efforts exceedingly difficult. As a result, pursuing effective ways to reduce fine sediment collection and accumulation in and near diversions will be a promising alternative to effectively reduce lamprey entrainment, serving two dual purposes.

Initial Research Questions

This Project used a set of sub-questions and sub-hypotheses initially to answer the overarching question: "Can alternative techniques be used to reduce juvenile lamprey / salmonid entrainment by reducing the proportion of migrating fish that enter the canal or interact with current fish screens?"

We developed three sub-questions and their correlated hypotheses based upon observations and through discussions with interested parties. Additional idea development could result in additional test treatments with research questions and hypotheses in out-years.

Q1. Does the angle of the headworks and fish screens at an irrigation diversion intake (in relationship to channel thalweg) significantly affect entrainment rates of larval/juvenile lampreys, juvenile salmon, and fine sediment within the diversion?

H1. A more acute headwork and fish screen angle (in relationship to channel thalweg) will result in less entrainment of larval/juvenile lampreys, juvenile salmon, and fine sediment within the diversion compared to those with a more shallow angle.

Q2. Could entrainment of larval/juvenile lampreys be reduced significantly by dredging or blowing out the fine sediment upstream of the headworks and/or within the diversion prior to or at the end of irrigation season?

H2. Removing fine sediment upstream of the headworks and/or within the diversion by either dredging or blowing out will reduce larval/juvenile lamprey entrainment and subsequent dewatering mortality significantly.

Q3. Could entrainment of larval/juvenile lampreys be reduced significantly by installing flow barrier structures (such as ecology blocks, concrete, metal, etc.) in a manner that reduces entrainment of fine sediment into the diversion and its deposition in front of fish screens?

H3. Installing flow barrier structures in a manner that reduces entrainment of fine sediment into the diversion and its deposition in front of fish screens will reduce larval/juvenile lamprey entrainment significantly.

Research Strategy

This Project first sought to establish a baseline proportional entrainment (the number entering the canal headworks compared to the number passing the diversion) of lamprey juveniles at four irrigation diversions in the Columbia River Basin. These include Sunnyside and Wapato diversions in the Yakima Sub-Basin, as well as Feed and West Extension Diversions in the Umatilla Sub-basin. In the Yakima Subbasin, the salmonid program (Yakima-Klickitat Fisheries Program, or YKFP) cost-shared with this Project to evaluate salmonid objectives as well. We used Passive Integrated Transponder (PIT) tag monitoring to determine the disposition of a known quantity of larval or juvenile lampreys released upstream of each diversion and to calculate a proportional rate of entrainment. Then we apply treatments of simple, inexpensive ideas to reduce entrainment and where feasible use tagged fish released upstream and monitored downstream to determine proportional entrainment with these methods employed.

Year 1 included installation of PIT detection infrastructure in each canal headworks and across the river just downstream of the diversion, and then release and monitoring of tagged test lamprey juveniles to get baseline entrainment and to compare proportional rates between diversions with different headworks angles. Sunnyside in the Yakima River and West Extension in the Umatilla River have relatively shallow angles to the river, whereas Wapato in the Yakima River and Feed Diversion in the Umatilla River have nearly perpendicular angle headworks. Due to some logistical issues on the ground and the scale of the PIT arrays, these tasks required extra time and continued into Year 2. In some sites where installation of a PIT tag array in the river channel was not feasible, monitoring focused on within diversion entrainment to determine the ratio of fish moving through the bypass vs. past the fish screens (PIT tag arrays in bypass channel and across fish screens).

Year 3 and 4 were used to test some unique, creative, and innovative ideas for simple and inexpensive solutions to keep more lampreys in the river and fewer lampreys entering the canal headworks and interacting with screens. Primary methods selected for treatment include 1) improving methods to prolong survival of entrained lampreys (see Task 4); 2) developing methods to improve the efficiency of lamprey rescue (see Task 5); and 3) modification of facility design and management (see Task 6). Additional treatment ideas, such as the use of Flow Velocity Enhancement System (Natural Solutions - A Dam Site-Better! LLC, Helena, MT; see Task 6.11) are currently being developed, proposed, and tested as part of new research and restoration projects through Bonneville Power Administration (BPA) Cost Savings Funds (a new funding developed through the Pacific Lamprey Conservation Initiative Team). An acoustic telemetry project was also initiated in 2018 (Liedtke et al. 2019b) as a result of partnership between Reclamation, Yakama Nation Fisheries Resource Management Project Pacific Lamprey Project (herein referred to as YN Fisheries), and other cost share funds (e.g. McNary Mitigation Funds, BPA Cost Savings Funds, and local irrigation districts). The acoustic telemetry project was initially a salmonid-focused project, but due to the various cost share, we were able to include juvenile lamprey in this 3-year study (2018-2020).

General objectives that were part of the Project scope of work include:
1) Enhance our understanding of the baseline information regarding the existing extent and mechanism of entrainment and/or mortality of larval and juvenile lamprey using PIT tag arrays and other available means,
2) Develop low-cost restoration projects that will help reduce and mitigate the rate of lamprey entrainment and mortality in these irrigation diversions,
3) Continue to evaluate the extent and mechanism of entrainment and mortality of larval and juvenile lampreys and where possible document the changes from the restoration projects.

Purpose

The purpose of this Final Progress Report (Project Year 2016-2019, January 26, 2016 – June 30, 2019) is to provide the Reclamation a summary of progress obtained for this project period.

The Goal of the Yakama Nation is to restore natural production of Pacific Lamprey to a level that will provide robust species abundance, significant ecological contributions and meaningful harvest throughout the Yakama Nations Ceded Lands and in the Usual and Accustomed areas.

This Project Final Report addresses seven key objectives listed below. Activities associated with these tasks were implemented by the YN Fisheries through the YN Fisheries Resource Management Program Pacific Lamprey Project and Yakima-Klickitat Fisheries Project. Each of the seven objectives is specific to the needs of the overarching original question, “can alternative techniques be used to reduce juvenile lampreys / salmonid entrainment?" Each of the seven objectives funded through this Project is briefly described below with more thorough details provided in Task 1 through 7 of this Progress Report.

Task 1: Installation of PIT and Acoustic Arrays for Monitoring
Both Passive Integrated Transponder (PIT) and acoustic tag arrays were installed at the diversions of interest. A summary of these efforts is provided in this section.

Task 2: Summary of Lamprey Entrainment Data (Post Dewatering)
Past lamprey rescue efforts going back to 2011 were summarized in this section. A review is provided for the overall rescue survey results across the Yakima Subbasin as well as for the two specific diversions of interest.

Task 3: Monitoring of Lamprey Movements into Irrigation Diversions

In addition to results from surveys that occurred after dewatering in the diversions, YN Fisheries employed several methods and strategies to help understand the magnitude of entrainment into irrigation diversions and their movements within these diversions. This section summarizes those various efforts and highlights.

Task 4: Methods to Improve the Efficiency of Lamprey Rescue

Various methods are used to rescue lampreys in irrigation diversions, including electrofishing, manual collection, "blind netting", "dry shocking," and sifting. We provided a concise summary for each methods and tips to help increase the efficiency in recovering lampreys. Selection of release locations and other species to consider (e.g., freshwater mussels) are also discussed.

Task 5: Methods to Prolong Survival of Entrained Lampreys

Despite the wide range methods available, larval/juvenile lampreys are very susceptible to desiccation, predation, and other mortality events during rescue operations in irrigation diverisons. In this section, we describe the various tools available to help prolong the survival of entrained lampreys in these diversions.

Task 6: Consideration for Facility Design and Management

Irrigation diversion facilities designed with salmonid species in mind do not always protect other alternative species, such as lampreys. In this section, we summarize what we have learned from both field and lab studies to date and also provide new insights that should help guide the short- and long-term efforts for improvement to irrigation diversions with lampreys in mind.

Task 7: Interagency Coordination and Communication

Lamprey rescue operations, like any other fish rescue operations, require considerable coordination and communication among the partner agencies. Even with the best intensions among working parties, miscommunication can still occur at any point of time and this in combination with occasional unforeseen events can severely disrupt the expected outcome of the rescue operation in the field. In this section, we provide examples of these events and share the lessons we have learnt in this process.

Between 2011 and 2018, YN Fisheries covered a range of key research topics and focused on addressing threats / limiting factors important to the Yakima Subbasin for the restoration of Pacific Lamprey (Luke and Rose 2012a; Lampman et al. 2013a; Lampman et al. 2014a; Lampman et al. 2015; Lampman et al. 2016; Lampman et al. 2017; Lampman et al. 2018; Lampman et al. 2019). A total of 83 appendix reports were completed over the years to address key research topics, including lamprey status (2% among all topics), limiting factor analysis (11%), biology and ecology (14%), juvenile passage (33%), adult passage (19%), and restoration activities (20%) (Table A and B and Figure A and B). The threats and limiting factors we addressed include lack of knowledge (12% among all threats), small effective population size (23%), dewatering and stream flow management (36%), passage barriers (20%), water quality (6%), and predation (2%)

(Figure C). YN Fisheries has made juvenile passage a key research topic and addressed dewatering and stream flow management threats more so than any other threats over the past several years. As part of the this new project “Exploring techniques to reduce lamprey and salmonid entrainment into canals,” which initiated in January 2016 and concluded in June 2019, YN Fisheries revamped its efforts to help address the issues surrounding irrigation diversion and lamprey entrainment. In this final progress report, we made an effort to highlight key findings during this period (including findings prior to 2016, going back to 2011) and to summarize the key take home conclusions that will be critical for reducing lamprey entrainment and mortality associated with the operations of irrigation diversions and canals within the Yakima Subbasin Pacific Lamprey Project and across their range at large.

Table A. Summary of annual progress reports submitted to the Reclamation by YN Fisheries (Pacific Lamprey Project) between 2011 and 2018, including the number of appendix reports.

#	Title	Work Year	Year Published	Contract #	Authors	Main Pages	# of Appendix Reports	Total Pages
1	2011 Annual Progress Report	2011	2012	R11AC10069	P. Luke and R. Rose	12	2	51
2	2012 Annual Progress Report	2012	2013	R11AC10069	Lampman, R., P. Luke, D. Lumley, and R. Rose	15	8	167
3	2013 Annual Progress Report	2013	2014	R11AC10069	Lampman, R., D. Lumley, T. Beals, P. Luke, and R. Rose	25	13	480
4	2014 Annual Progress Report	2014	2015	R11AC10069	Lampman, R., T. Beals, P. Luke, D. Lumley, E. Johnson, and R. Rose	33	15	572
5	2015 Annual Progress Report	2015	2016	R15AC00044	Lampman, R., T. Beals, and R. Rose	46	12	409
6	2016 Annual Progress Report	2016	2017	R15AC00044	Lampman, R., T. Beals, H. Arakawa, D. Lumley, and R. Rose	43	10	395
7	2017 Annual Progress Report	2017	2018	R15AC00044	Lampman, R., T. Beals, D. Lumley, and R. Rose	61	11	421
8	2018 Annual Progress Report	2018	2019	R15AC00044	Lampman, R., T. Beals, D. Lumley, S. Goudy, and R. Rose	45	12	260
-	**Total**	**-**	**-**	**-**	**-**	**280**	**83**	**2755**

Table B. Summary of the key "research topics" and "threats / limiting factors" covered in each of the appendix reports that are associated with each of the YN Fisheries (Pacific Lamprey Project) annual progress reports between 2011 and 2018.

		Research Topics						Threats / Limiting Factors					
#	Title	Lamprey Status	Limiting Factor Analysis	Biology & Ecology	Juvenile Passage	Adult Passage	Restoration Activities	Lack of Knowledge	Small Effective Population Size	Dewatering & Stream Flow Management	Passage Barriers	Water Quality	Predation
1	2011 Annual Progress Report	0	0	0	1	1	0	0	0	1	1	0	0
2	2012 Annual Progress Report	0	2	1	3	0	2	1	2	3	0	2	0
3	2013 Annual Progress Report	0	2	4	2	4	1	3	1	4	4	1	0
4	2014 Annual Progress Report	0	2	2	2	6	3	2	3	3	6	1	0
5	2015 Annual Progress Report	1	1	1	5	2	2	1	3	5	2	1	0
6	2016 Annual Progress Report	1	1	0	4	1	3	0	4	4	1	0	1
7	2017 Annual Progress Report	0	1	2	5	0	3	2	3	5	0	0	1
8	2018 Annual Progress Report	0	0	2	5	2	3	1	3	5	3	0	0
-	**Total**	**2**	**9**	**12**	**27**	**16**	**17**	**10**	**19**	**30**	**17**	**5**	**2**
-	**% within Categories**	**2%**	**11%**	**14%**	**33%**	**19%**	**20%**	**12%**	**23%**	**36%**	**20%**	**6%**	**2%**

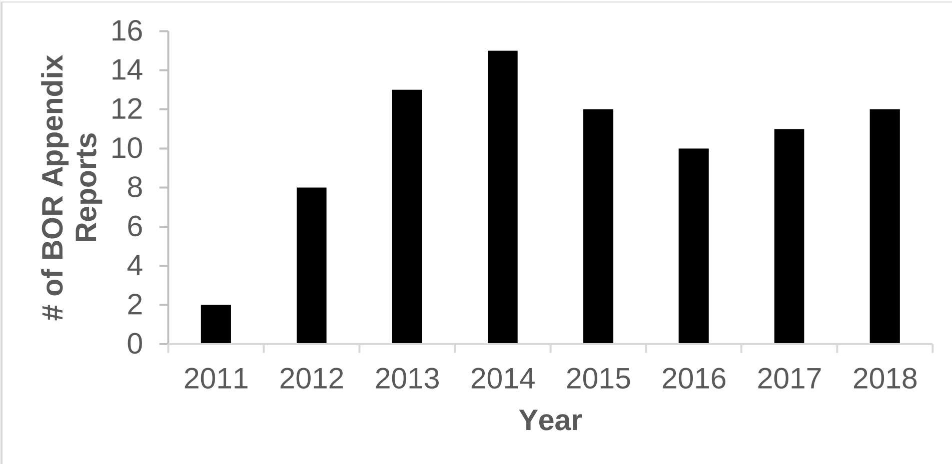


Figure A. Summary of the number of appendix reports associated with each of the YN Fisheries (Pacific Lamprey Project) annual progress reports between 2011 and 2018.

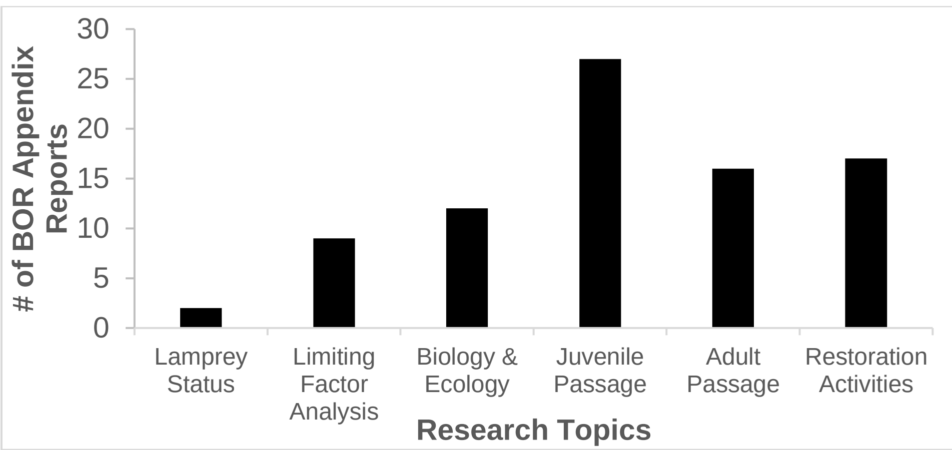


Figure B. Summary of the key research topics covered by each of the appendix reports associated with the YN Fisheries (Pacific Lamprey Project) annual progress reports between 2011 and 2018.

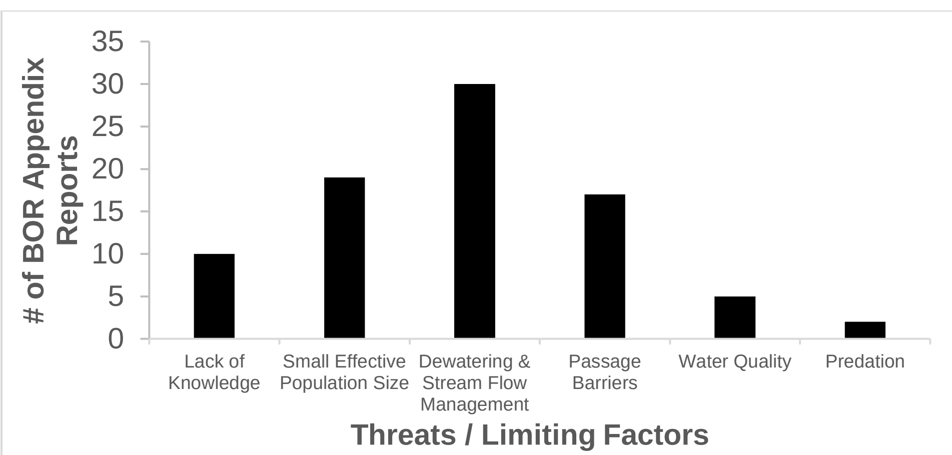


Figure C. Summary of the threats/limiting factors covered by each of the appendix reports associated with the YN Fisheries (Pacific Lamprey Project) annual progress reports between 2011 and 2018.

Progress Report by Tasks

Task 1: Installation of PIT and Acoustic Arrays for Monitoring

1.1 PIT Array Installation at Sunnyside Diversion

This section describes the PIT-tag detection array configuration and inventory of basic monitoring equipment that were purchased, fabricated, and installed by Yakima-Klickitat Fisheries Project personnel within the Sunnyside diversion channel infrastructure during the winter/spring of 2016. The equipment was used to monitor PIT-tagged lampreys and salmonids entrained into the canal from the mainstem Yakima River. Monitoring locations that were outfitted with PIT-Tag detection antennas include the canal trash rack structure, bypass inlets, and the bypasses outlet (Fig. 1.1). This equipment was scheduled to be operational for at least the project period (2016-2019), and YN Fisheries personnel monitored and maintained the installed equipment during this period.

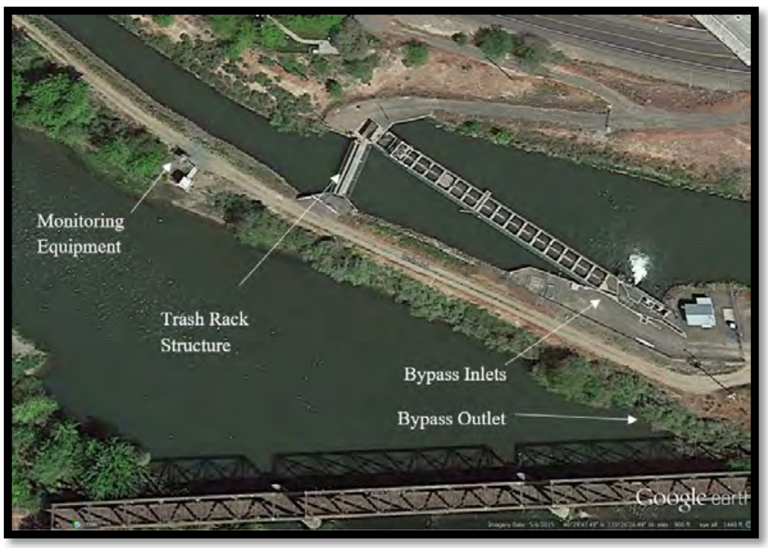


Figure 1.1. Illustration of Sunnyside Diversion channel and diversion infrastructure.

1.2 Sunnyside Diversion Trash Rack Structure

The Trash Rack Structure consist of 3 bays, each with a width of ~20 ft, and a height of ~12 ft (Fig. 1.2). The middle and right bays have horizontal flashboards installed in 3" vertical concrete slots that span the entire width. The flashboards sit 18" above the bottom of the channel, and continue vertically for 5-6 ft. Each of these 2 bays required antennas for the 18" opening at the bottom, and the 3-5 ft water column extending from the top of the flashboards to waters surface. The dimensions of the antennas needed to monitor the bottom openings were 20 ft in width, and 2.5 ft in height. The upper opening required a channel spanning antenna that was 6 ft in height (this unit weighed less than 25 lbs). Unlike the middle and right bays, the left bay has no horizontal flashboards installed in the vertical concrete slots. As a result, this bay required three antennas to monitor the entire opening and water column from top to bottom. From the testing that was performed after installation, the read range off the coil was 27 inches with no dead spots.

There were two potential options for anchoring the antennas in place including: 1) the use of existing concrete vertical slots and 2) anchoring the antennas to the exterior walls on the downstream side of the structure. The vertical slots present the easiest option, but they are lined with channel iron, so there exists the potential for interference problems which could hinder the detection capabilities of the antennas. Due to interference problems that compromised the antennas substantially, the antennas were placed on the downstream side of the concrete bays using ½" anchor bolts to keep them in place. In summary the trash rack structure required seven antennas total, each having an independent antenna control node (ACN), and wire extending to the Master control terminal. The master control terminal was located in a Job box close to an AC power source to the west of the trash rack structure (Fig. 1.1).

Figure 1.2. Sunnyside Diversion trash rack structure (looking upstream)

1.3 Sunnyside Diversion Bypass Inlets

There are two separate Bypass Inlets that required PIT-tag detection antennas (Fig. 1.3). Each of these are 2-3ft in width, and ~8ft in height. Like the trash rack structure, they have vertical concrete slots that can be used to slide the antennas in place. Due to the small width, a single antenna was used to monitor the entire water column for each of the bypass inlets. Thus, a total of 2 antennas and 2 ACNs were required for the Bypass Inlets. Wire extending from the antennas were placed in conduit, and buried beneath the surface substrate to avoid damage from foot and car traffic moving through the area.

Figure 1.3. Bypass #1 (orange arrow) and #2 (green arrow)

1.4 Sunnyside Diversion Bypass Outlet

The two bypass inlets meet at an underground junction point before entering the river, thus creating a single bypass outlet. The outlet is no larger than 4 ft in diameter, so a single pass-through antenna was placed on the exterior part of the outlet (Fig. 1.4). The antenna was installed on the downstream end of the outlet pipe using a PVC/wooden frame anchored securely into the bank. Wires were housed in conduit and ran to the same Master Control box used for the trash rack structure and Inlet antennas.

Figure 1.4. Sunnyside Bypass Outlet (yellow arrow) into the Yakima River

1.5 Inventory of Material and Monitoring Equipment

A total of 10 antennas were fabricated for monitoring the trash rack structure, bypass inlets, and bypass outlet. Antennas were configured in rectangle like shapes using 2”- 3” schedule 80 PVC. Each antenna has a total of 5 wraps of 10 AWG Litz wire internally, and was outfitted externally with waterproof locking connectors. Each antenna required an IS1001 Antenna Control Node (ACN) and IS1001 bridge board. There was one Master Control (QuBE controller) used to monitor all 10 antennas and store data temporarily. The Master Control was powered by two 12 V deep cycle batteries wired in series (24 volts required). Batteries were charged using an AC power source in near proximity and housed in a large Job box which was also used to house the Master controller and battery charge timer. Although issues with the array reading were detected in real-time remotely through the computer software system, YN Fisheries personnel monitored all the arrays periodically (weekly to semi-weekly) to ensure wood, sediment, and other debris are not accumulating in front of the arrays, cables, or equipment. The total cost of equipment and supplies is shown below.

Table 1.1. Summary of equipment and supplies needed for installation of PIT tag arrays by three locations (trashrack bays, bypass inlet, and bypass outlet) at Sunnyside Diversion.

Description	Units	Unit Price	#	TOTAL
Qube Controller for IS 1001	ea	$ 2,490	1	$ 2,490
IS1001 bridge boards	ea	$ 125	10	$ 1,250
IS 1001 Readers	ea	$ 1,285	10	$ 12,850
MC-BH3-F Standard wet - Con 3 female	ea	$ 20	10	$ 200
MC-BH3-M Standard wet - Con 3 male	ea	$ 23	10	$ 230
MC-DLS-M Standard wet - Con Locking sleeve M	ea	$ 7	10	$ 70
MC-DLS-F Standard wet - Con Locking sleeve F	ea	$ 7	10	$ 70
SOOW 1403 Cable 14 Ga 3 wire	ft	$ 0.67	2000	$ 1,340
10 AWG Litz wire for ACN antenna	ft	$ 1	2552	$ 2,807
Remaining material per antenna	ea	$ 650	10	$ 6,500
Total	-	-	-	**$ 27,807**

1.6 Operation and Maintenance of Sunnyside Diversion PIT Array

YN Fisheries and Yakima-Klickitat Fisheries Program have provided considerable cost-share to operate and maintain the installed PIT array for the project. Operation and maintenance included checking the physical conditions of the PIT array periodically (especially after high water events that transport large woody debris and sediment) to ensure the integrity of the array frames and associated cables and wires. Whenever damages occurred to the array, repair work was needed to fix the damages and get the system to run again. Finally, the electrical and computer components were also monitored, and repaired as needed, periodically to ensure that data input and output were executed as scheduled and programmed.

1.7 Collection, Tagging and Release of Juvenile Fish

The project goal was to first establish a baseline proportional entrainment (the number entering the canal headworks compared to the number passing the diversion dam) of juvenile fish at four irrigation diversions in the Columbia River Basin. These include Sunnyside and Wapato diversions in the Yakima Subbasin. The salmonid program (Yakima-Klickitat Fisheries Program) is cost-sharing with this project to evaluate salmonid objectives as well. PIT tag monitoring was used to determine the disposition of a known quantity of larval or juvenile lampreys released upstream of each diversion and to calculate a proportional rate of entrainment for baseline information. Additionally, we were interested in comparing entrainment rates of different canals with different angles of diversion from the river. In outyears of the study, we would then apply treatments of simple, inexpensive ideas to reduce entrainment and again use tagged fish released upstream and monitored downstream to determine proportional entrainment with these methods employed.

1.8 Acoustic Telemetry Array Installation in the Lower Yakima

In addition we were able to partner with a juvenile salmon acoustic telemetry study in the Lower Yakima River between the years 2018-2020. The YN Fisheries and USGS worked with BOR to secure project funding and to develop and refine the study plans. As the study planning for this effort progressed, it became apparent that significant investments were being made in the telemetry monitoring arrays for the study, and other projects could leverage those investments by purchasing transmitters to tag and release fish. The concurrent development and testing of the JSATS compatible lamprey tag by PNNL made an acoustic telemetry evaluation of juvenile lamprey feasible (see Fig. 1.5). The timing was well aligned to use a relatively small investment in transmitters and access to a large number of monitoring arrays (without further investment) to execute the first study of juvenile lamprey movements in the Yakima River and Mid Columbia River. The proposed project would not be have been feasible without the collaboration with PNNL to allow the use of the newly developed transmitter and without collaboration with the juvenile salmon study to allow the use of the monitoring arrays. Additional funding were acquired from McNary Mitigation Funds, The Reclamation Science and Technology Program Funds, and Bonneville Power Administration Cost Savings Funds for Pacific Lamprey Conservation Initiative for this acoustic telemetry project.

This acoustic telemetry study provided additional means for monitoring lampreys within diversions as well as Lower Yakima River at large. The project was conducted in the lower 111 river miles of the Yakima River, including associated irrigation diversions and bypasses such as Wapato and Sunnyside diversions (Fig. 1.6). The acoustic telemetry array was comprised of 48 receivers that were deployed to create 8 river reaches in the lower Yakima River and Columbia River, upstream of McNary Dam. In the Yakima River, 6-7 receivers were deployed at each of the four diversion dams (Wapato, Sunnyside, Prosser, and Horn Rapids) and 10 receivers were deployed at McNary Pool to monitor route-specific passage and survival. Through collaboration with PNNL who had JSATS monitoring arrays in place at McNary Dam, we were also able to detect tagged lamprey at and near McNary Dam. See USGS technical report for more information (Liedtke et al. 2019).

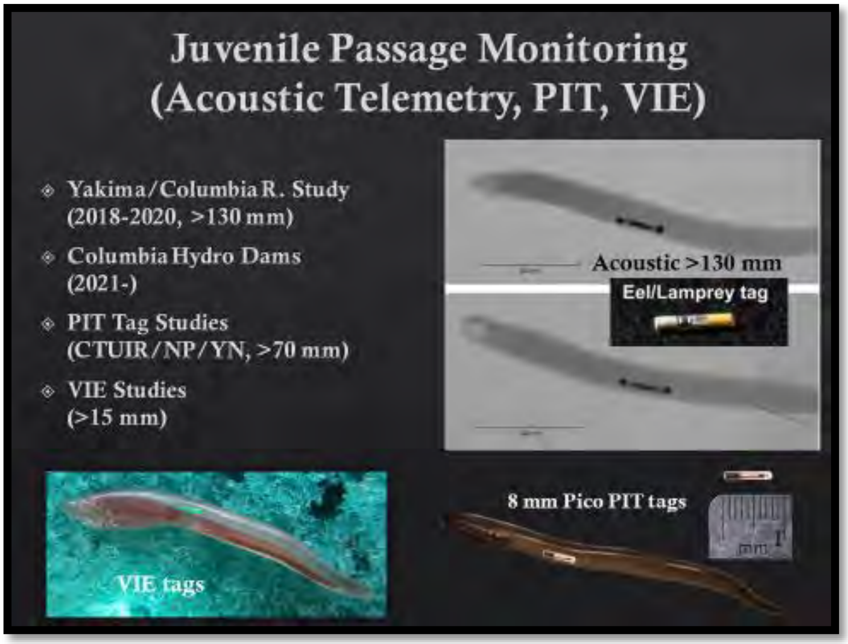


Figure 1.5. An overview of three types of tags currently available to monitor larval/juvenile lampreys. The minimum size thresholds as well as locations where these tags are being tested are listed as well.

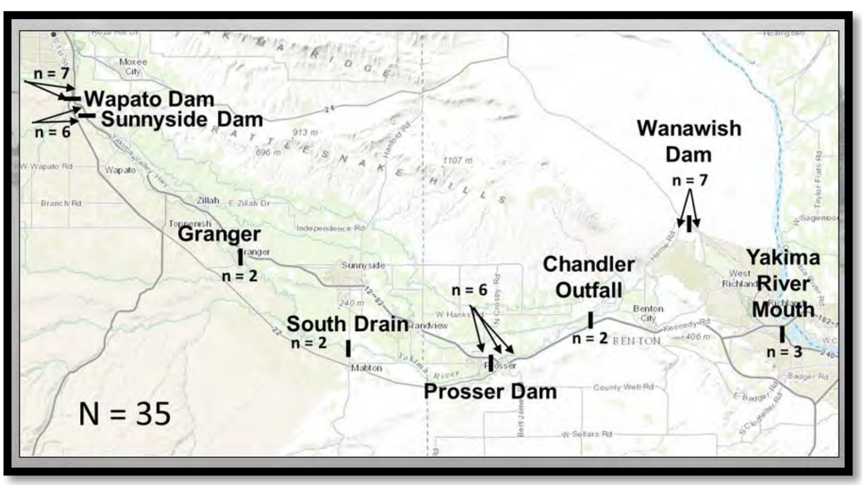


Figure 1.6. Locations where acoustic telemetry monitoring stations were deployed for the juvenile salmon / lamprey study. The figure shows the number (n) of receivers at each monitoring location, and the overall (N) number of receivers. Note that through additional funding, the overall number of receivers has increased from 35 to 48 total, with proposed additions at each dam and at the Yakima River Mouth and McNary Pool area.

Task 2: Summary of Lamprey Entrainment Data (Post Dewatering)

2.1 Entrainment in the Yakima Subbasin

One of the myriad of threats larval and juvenile life stages of lampreys face is entrainment within irrigation diversions; water is drained from these diversions typically in the fall in October/November (or summer in June/July for smaller tributaries), and lampreys that have burrowed in the fine sediment during the irrigation season are often left to perish in these locations unless rescue efforts take place to save them. Many hundreds of irrigation diversions are scattered throughout the Columbia Basin, so it is imperative that simple, adaptive, and innovative techniques to preserve the life of larval/juvenile life stage lampreys are developed, using our best understanding of the lamprey entrainment mechanisms.

Beginning in 2011, the YN Fisheries has performed lamprey rescue surveys in as many as 32 unique dewatered irrigation diversions within the Yakima Subbasin. Over the years, YN Fisheries rescue surveys have captured a total of 101,978 larval and juvenile lampreys (Table 2.1, Fig. 2.1). In total, 76,118 (75%) lampreys were captured upstream of the fish screens, whereas 25,860 (25%) were captured downstream, indicating that a substantial number is being entrained through the fish screens (Fig. 2.2). It is largely unknown how many lampreys may be moving further downstream of the fish screens past this immediate area downstream that we conduct our surveys in. Of the lampreys removed, 78,316 (77%) were captured from electrofising from wetted (and occasionally dry) fine sediment, and the remaining 23,662 (23%) were lampreys collected manually through other means, such as dry banks and dredged/discarded sediments (Fig. 2.3).

Starting in 2014, the electrofishing time (time the electrofisher's slow pulse was used and registered to shock lampreys in their burrows) was recorded during each of our lamprey rescue surveys (Table 2.2, Fig. 2.4). The Catch Per Unit Effort (CPUE, number of lampreys per min) has also increased in years when the electrofishing time was high indicating that our electrofishing time is strongly influenced by the CPUE (i.e. when the CPUE is high, more efforts were put in to capture the lampreys remaining). Over the past five year period, our electrofishing time totaled 5,689 min (94.8 hr), with an average of 1,138 hours per year. Our annual Catch Per Unit Effort (CPUE) has ranged from 2.3–21.7 lampreys min^{-1} (or 135-1,304 lampreys hour^{-1}), with an overall average of 12.9 lampreys min^{-1} (or 666 lampreys hour^{-1}). Based on 2017 data (a rescue survey in Dryden Diversion, Lower Wenatchee River), overall shock time was estimated to be 2.65 times longer than the slow pulse electrofishing time registered, so we used this correction factor to estimate the total time of electrofishing surveys, which amounted to 251.3 hr overall (annual average of 50.3 hr) (Table 2.2). Given this correction factor, the total time CPUE estimate is 252 lampreys hour^{-1} (range of 51-492 lampreys hour^{-1} annually).

Overall number of mortality (primarily from dry banks) ranged from 1,033 to 5,893 annually with an average of 3,215 (Table 2.2, Fig. 2.5). This was approximately 17% of the total number captured, but ranged from 9-37% annually. Finally, the percent mortality of the lampreys from the dry banks ranged from 34-94% annually with an average of 68%, showcasing that many of them do not survive the exposure and desiccation by the time we are able to capture them. However, this rate has been decreasing steadily since 2015, indicating that improvements in rescue efforts have reduced this rate substantially.

Table 2.1. Summary of all rescue surveys in irrigation diversion sites within the Yakima Subbasin between 2011 and 2018. "# Up" and "# Down" denotes the number of lampreys captured upstream and downstream of the fish screens, respectively. "# E-Fishing" denotes the number of lampreys captured using electrofishing (the remainder are collected on dry banks or other means).

Year	# Sites	# Lamprey Total	# Up	% Up	# Down	% Down	# E-Fishing	% E-Fishing
2011	7	903	535	59%	368	41%	903	100%
2012	16	2,450	1,818	74%	632	26%	2,450	100%
2013	18	1,631	808	50%	823	50%	1,631	100%
2014	14	2,945	2,403	82%	542	18%	1,783	61%
2015	12	18,317	15,696	86%	2,621	14%	15,292	83%
2016	20	46,775	36,041	77%	10,734	23%	39,114	84%
2017	14	17,251	11,069	64%	6,182	36%	8,515	49%
2018	15	11,706	7,748	66%	3,958	34%	8,628	74%
Total	**116**	**101,978**	**76,118**	-	**25,860**	-	**78,316**	-
Ave	**15**	**12,747**	**9,515**	**75%**	**3,233**	**25%**	**9,790**	**77%**
Min	**7**	**903**	**535**	**50%**	**368**	**14%**	**903**	**49%**
Max	**20**	**46,775**	**36,041**	**86%**	**10,734**	**50%**	**39,114**	**100%**

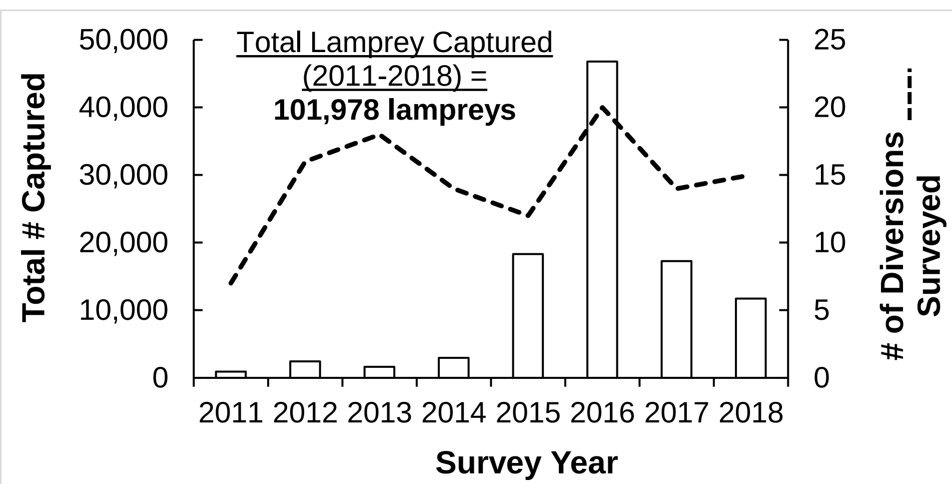


Figure 2.1. Summary of all lampreys captured from Yakima Subbasin irrigation diversions between 2011 and 2018. The number of diversions surveyed each year is also displayed (dotted line).

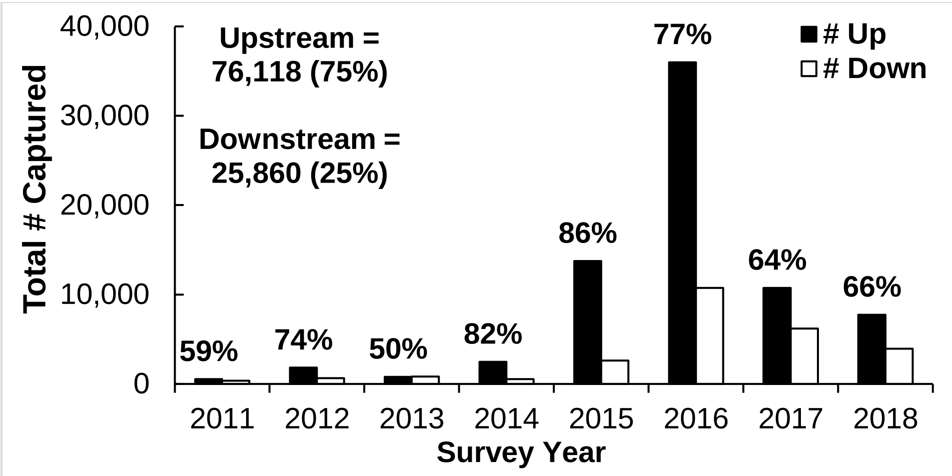


Figure 2.2. Summary of all lampreys captured upstream and downstream of the fish screens (percent of lampreys captured upstream is labeled in graph) from Yakima Subbasin irrigation diversions between 2011 and 2018.

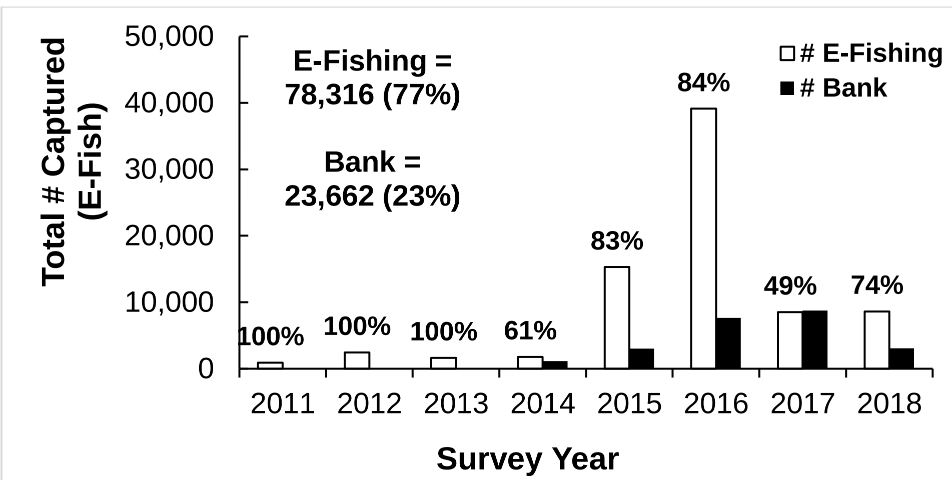


Figure 2.3. Summary of all lampreys captured via electrofishing (number labeled in graph) and from dry banks from Yakima Subbasin irrigation diversions between 2011 and 2018.

Table 2.2. Summary of additional data from the rescue surveys in irrigation diversions within the Yakima Subbasin between 2014 and 2018. "# on Bank" denotes the number of lampreys captured on dry banks. "E-Fish Time" is the time using the slow pulse on the electrofishing device whereas "Total E-Fish Time" denotes the estimated total time for the rescue from start to end of shocking (using a multiplication factor of 2.65 based on past averages).

Year	# Lamprey Total	# on Bank	% on Bank	# Morts	% Mort	% Mort (on Bank)	E-Fish Time (min)	E-Fish CPUE (#/min)	E-Fish Time (hr)	E-Fish CPUE (#/hr)	Total Time (hr) x2.65	Total Time CPUE (#/hr)
2014	3,019	1162	39%	1,087	37%	94%	790	2.3	13.2	135	34.9	51
2015	16,387	3025	17%	2,684	15%	89%	1,307	11.7	21.8	702	57.7	265
2016	46,411	7661	16%	5,380	12%	70%	1,800	21.7	30.0	1,304	79.5	492
2017	16,763	8736	51%	5,893	34%	67%	722	11.8	12.0	708	31.9	267
2018	11,703	3078	26%	1,033	9%	34%	1,070	8.1	17.8	484	47.3	182
Total	**94,283**	**23,662**	**-**	**16,077**	**-**	**-**	**5,689**	**-**	**94.8**	**-**	**251.3**	**-**
Ave	**18,857**	**4,732**	**25%**	**3,215**	**17%**	**68%**	**1,138**	**12.9**	**19.0**	**666**	**50.3**	**252**
Min	**3,019**	**1,162**	**16%**	**1,033**	**9%**	**34%**	**722**	**2.3**	**12.0**	**135**	**31.9**	**51**
Max	**46,411**	**8,736**	**51%**	**5,893**	**37%**	**94%**	**1,800**	**21.7**	**30.0**	**1,304**	**79.5**	**492**

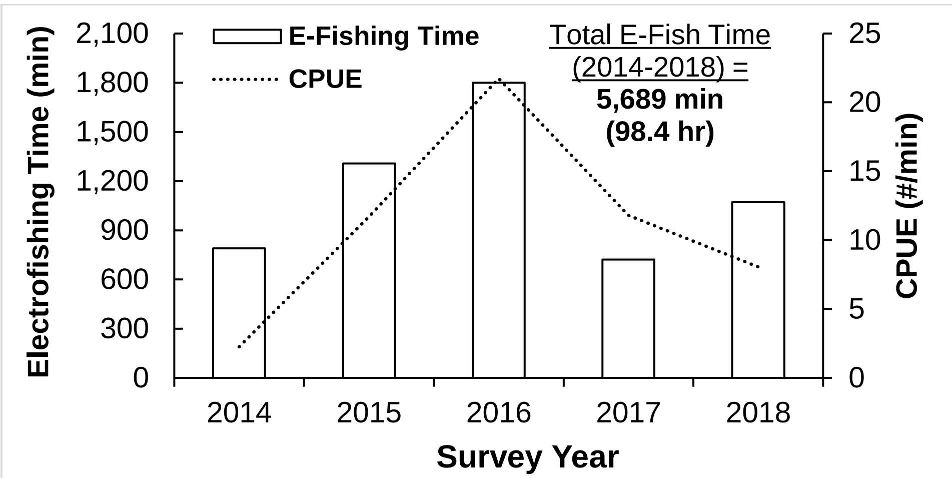


Figure 2.4. Summary of electrofishing time from lamprey rescue surveys and the associated capture per unit effort (CPUE) in Yakima Subbasin irrigation diversions between 2014 and 2018.

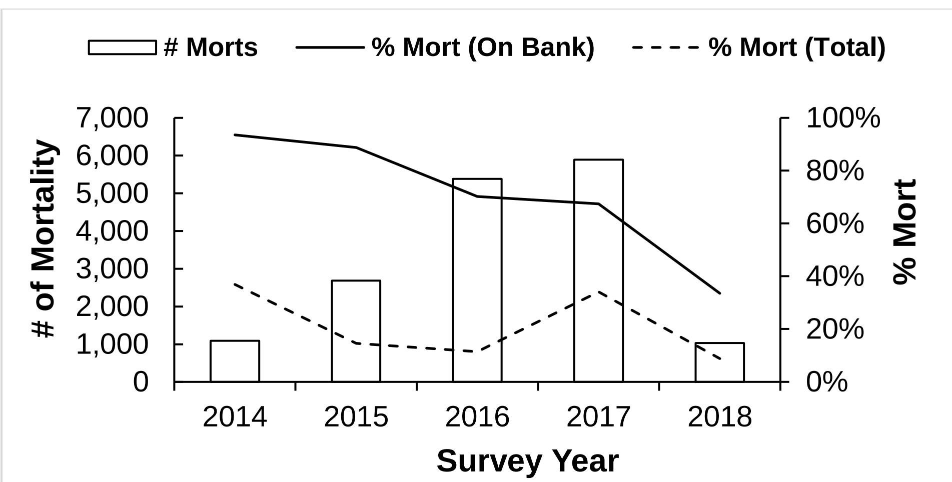


Figure 2.5. Summary of lamprey mortality numbers from lamprey rescue surveys and the associated percent mortality from the total number captured as well as from dry banks in Yakima Subbasin irrigation diversions between 2014 and 2018.

2.2 Adult Translocation Numbers in the Yakima Subbasin

Adult Pacific Lamprey have been translocated annually by the YN Fisheries to the YN Ceded Areas including the Yakima Subbasin since 2012 totaling 3,174 (Table 2.3). These release numbers were low initially (only 15 in 2012), but it has gradually increased and has been consistently higher than 400 adults per year since 2015 (2014-2015 broodstock year). Approximately 54% of the adults has been placed in Lower Yakima tributaries including Satus, Toppenish, and Ahtanum watersheds. The remaining (46%) has been placed in the mainstem Yakima River (38.7% downstream of the Naches River confluence and 7.2% upstream of the Naches River confluence). Of these release locations, those that are located upstream of Wapato and Sunnyside diversion dams include releases from Ahtanum Creek (575 adults, 18.1%) and Upper Yakima (76 adults, 7.2%). In addition, some of those released in the mainstem lower Yakima River (1229 adults, 38.7%) will potentially have a chance to migrate past these two diversion dams and spawn further upstream to contribute to the number of lampreys that may eventually be entrained at these two diversions.

As a result of these restoration actions, the ratio of Pacific Lamprey captured within these diversions (in comparison with Western Brook Lamprey) have steadily been increasing over the years (Fig. 2.6). Between 2012 and 2013, Pacific Lamprey were mostly absent in most of the Yakima Subbasin and the ratio was close to 0% in Wapato and Sunnyside diversions. Today, the average ratio is between 30-40% for these two diversions. In some of the tributary diversions (e.g., Bachelor Hatton and Upper WIP diversions), the ratio is close to 95% Pacific Lamprey.

Table 2.3. Summary of all adult Pacific Lamprey numbers (in broodstock years) translocated by the YN Fisheries into the Yakima Subbasin by watersheds between 2012 and 2019.

	Subbasin	Lower Yakima				Upper Yakima	Total
	Stream	**Satus**	**Toppenish**	**Ahtanum**	**Yakima**	**Yakima**	**-**
Year	2011-2012	15	-	-	-	-	15
	2012-2013	46	45	46	1	-	138
	2013-2014	92	78	85	9	-	264
	2014-2015	209	219	201	21	102	752
	2015-2016	117	128	130	72	-	447
	2016-2017	30	40	29	330	-	429
	2017-2018	23	35	20	384	68	530
	2018-2019	22	43	64	412	58	599
	Total	**554**	**588**	**575**	**1229**	**228**	**3174**
	%	**17.5%**	**18.5%**	**18.1%**	**38.7%**	**7.2%**	**100%**
	Ave	**69**	**84**	**82**	**176**	**76**	**397**
	Min	**15**	**35**	**20**	**1**	**58**	**15**
	Max	**209**	**219**	**201**	**412**	**102**	**752**

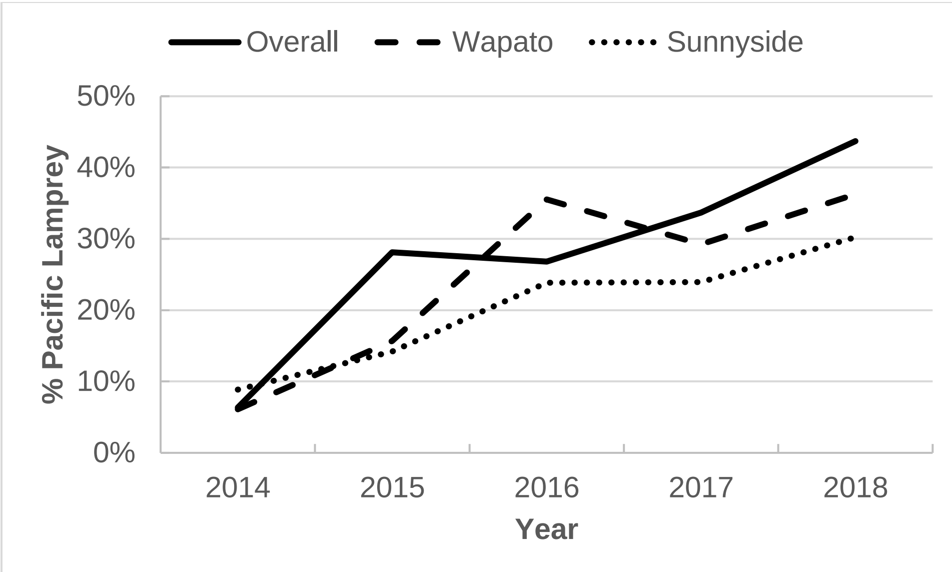


Figure 2.6. The ratio of Pacific Lamprey captured from Wapato and Sunnyside diversions as well as a combination of all sites annually between 2014 and 2018.

2.3 Entrainment in Sunnyside and Wapato Diversions

Among the 34 diversions that the YN Fisheries have surveyed, there are two diversions that consistently entrain a large number of lampreys annually: Sunnyside (River KM 173.4) and Wapato (River KM 176.3) diversions. The combined number of lampreys captured from these two diversions equates to 70.2% of the overall number of lampreys from all diversions (Fig. 2.6). In most years, the contribution from these two diversions have been over 78%, except for one year in 2015 when 10,706 lampreys were captured from a relatively small diversion in Ahtanum Creek (Bachelor-Hatton Diversion). On average, 46.9% and 23.4% of the total number of lampreys were found at Wapato and Sunnyside diversions, respectively. As a result, our annual lamprey rescue survey efforts have focused primarily on these two diversions over the years. Although both diversions are located in the middle reach of the Yakima River with similarly high diversion water intake rates, there are some contrasting characteristics that are worth mentioning here (see Task 6 for more information on this topic). At Sunnyside Diversion, both fine sediment and larval lampreys collect predominantly downstream of the fish screens (on average 95.8% of the lampreys were captured downstream), whereas the opposite is observed at Wapato Diversion where both fine sediment and larval lampreys collect predominantly upstream of the fish screens (on average only 1.5% of the lampreys were captured downstream) (Fig. 2.7). In addition, the percent of Pacific Lamprey (vs. Lampetra species) captured have increased steadily over the years in both diversions, starting from near 0% to approximately 40% in the most recent years. This gradual increase is likely a result of the adult translocation restoration work that has begun in 2012.

The total number of lampreys captured from dry banks (versus electrofishing) varied considerably from year to year at both diversions, but Sunnyside Diversion had a higher overall average compared to Wapato Diversion (50% and 14%, respectively; Fig. 2.8). The annual average rates were considerably similar (39% and 26%, respectively), but the years with higher number of captures corresponded to more dry bank captures for Sunnyside Diversion, whereas the opposite trend was observed at Wapato Diversion (less capture from dry banks in higher capture years). The annual average percent of dead lampreys was 27% at Sunnyside Diversion and 21% at Wapato Diversion. However, Sunnyside Diversion was considerably higher than Wapato Diversion for the weighted average percent of mortality values (39% and 10%, respectively). In general, the years with high mortality percent correspond to the years with higher ratios of captures from the dry banks (see Fig. 2.8).

In addition, the total numbers of lampreys residing at both diversions were estimated each year since 2014 by calculating the densities in representative subsample plots from backpack electrofishing (Table 2.4; see Task 2.4 for more details on estimation methods). If any were collected from dry banks prior to the subsampling surveys, those numbers were simply added to the calculated estimates to reconstruct the grand total number of lampreys that existed prior to any of the series of dewatering events. In both diversions, 2016 was the year with the highest number of estimates (70,391 and 19,138 lampreys for Wapato and Sunnyside diversions, respectively), followed by 2017 (33,499 and 12,687, respectively). We can estimate the percent of lampreys remaining that were not safely returned to the river by subtracting the total number of live lampreys captured and released back to the rivers from the estimated total number of lampreys.

The average annual percent remaining (estimated numbers of lampreys that were not captured each year) was 57% (at range of 41-81% annually) and 59% (range of 48-88% annually) at Wapato and Sunnyside diversions, respectively (Table 2.4 and Fig. 2.9). When you combine the dead lampreys captured with the estimated number remaining (i.e. all lampreys that were not released alive), the percent goes up even more: At Wapato and Sunnyside diversions, the average is 68% and 76%, respectively. This showcases that despite the large amount of efforts and collaboration to remove as many lampreys as possible each year, it is very difficult to capture and remove more than 50% of the overall estimated number of lampreys, and equally challenging to rescue alive 30-40% of the overall estimated numbers. In addition, the estimated total number of lampreys based on observed lampreys (i.e. a combination of captured and missed numbers of lampreys) from single pass electrofishing alone will likely produce a very conservative estimate in dewatered diversions with very high density of lampreys packed into very turbid water conditions. Based on our mark-recapture study in 2014, we concluded that our observation based estimates using capture and missed numbers comprised 45.0% or less of the estimated actual number of lampreys residing in the high density areas within the diversions. Capture efficiency from our single pass electrofishing was estimated to be only 22.3% of the estimated actual number of lampreys in this same area. Therefore, we recommend multiplying the estimates by a multiplication factor of approximately two (2.22 to be exact) or four (4.48 to be exact) when the corresponding estimates are based on observation or capture numbers, respectively. See the following Task 2.5 for more information on this mark-recapture study. The estimates we have produced for Sunnyside and Wapato diversions over the years (Table 2.4) do not make adjustment for this factor (see Task 2.4 for description of the estimation methods).

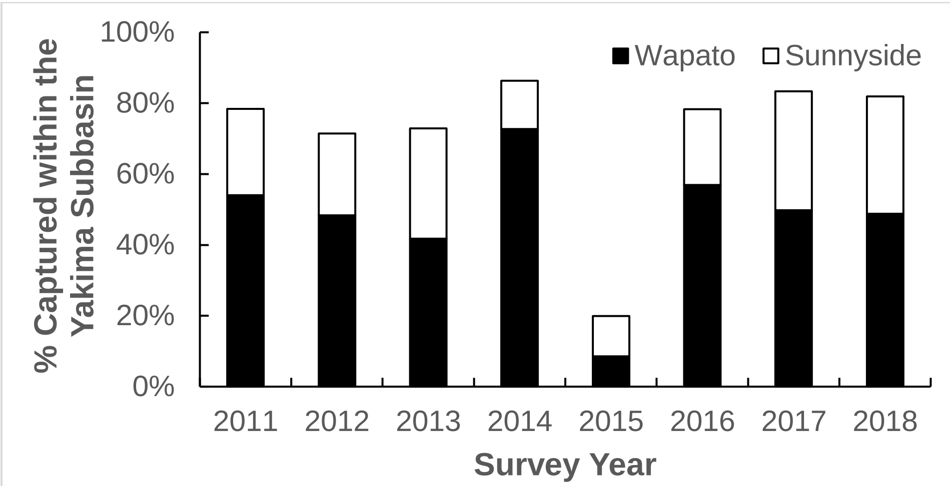


Figure 2.6. Percent captured from Wapato and Sunnyside diversions among all lampreys captured within the Yakima Subbasin between 2011 and 2018. Captured numbers include both live and dead lampreys.

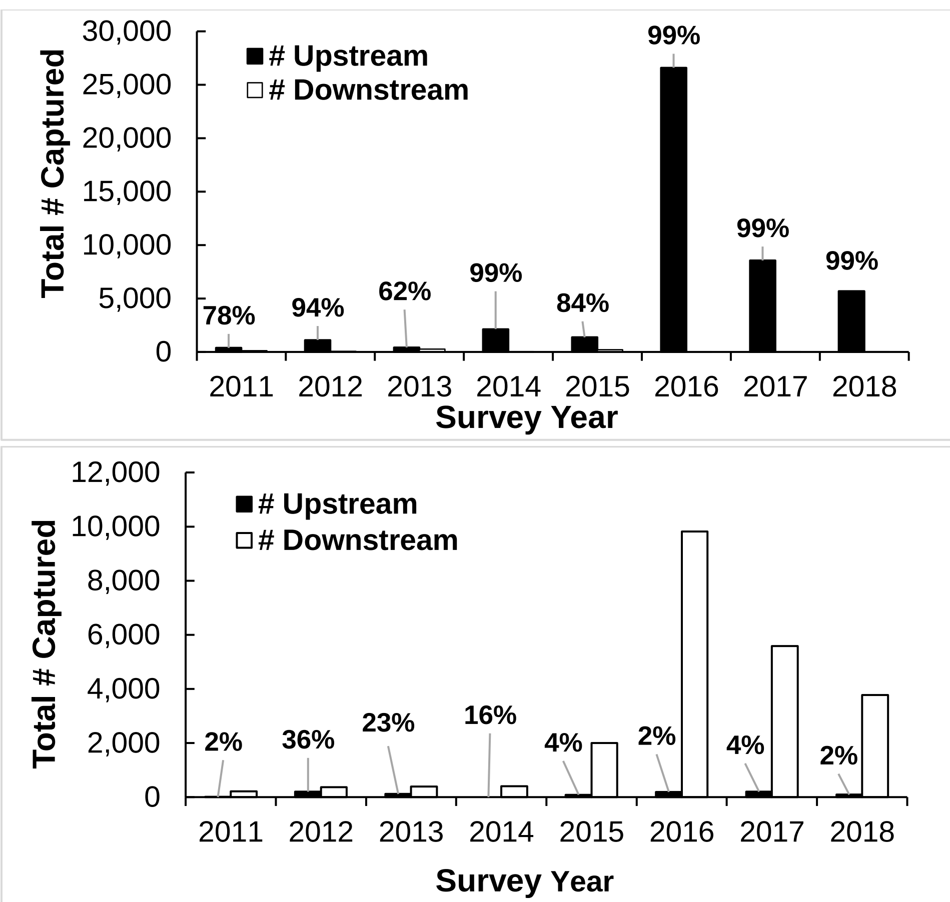


Figure 2.7. Annual lampreys captured from upstream and downstream of the fish screens at Wapato (top graph) and Sunnyside (bottom graph) diversions. Captured numbers include both live and dead lampreys.

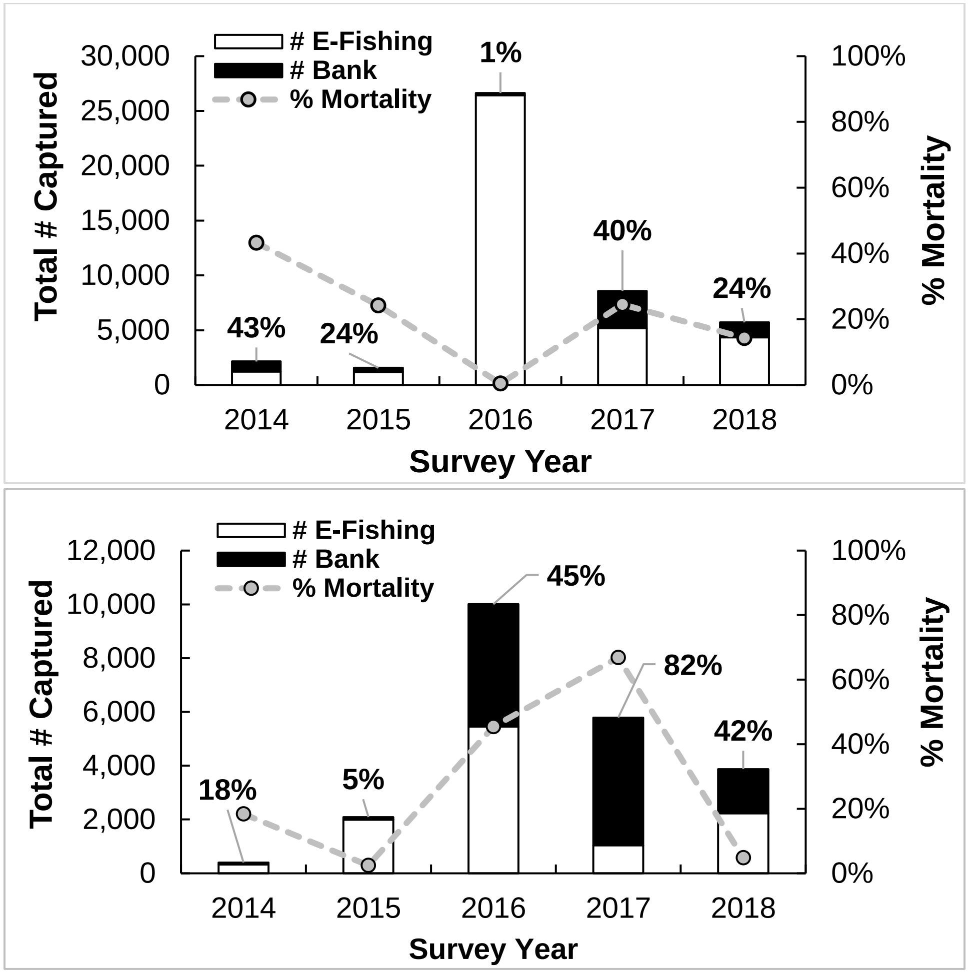
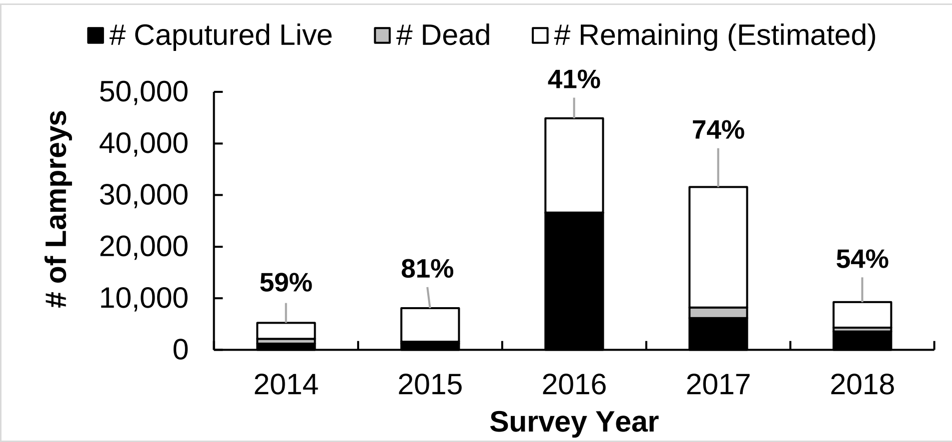


Figure 2.8. Number of lampreys captured from wetted habitat (i.e. electrofishing) and dewatered banks at Wapato (top graph) and Sunnyside (bottom graph) diversions between 2014 and 2018. Capture numbers are combined for upstream and downstream of the fish screens, and include both live and dead lampreys. The percentage of lampreys that were dead when captured is also shown for each site.

Table 2.4. A summary table for Wapato and Sunnyside diversions in the high density areas (upstream of the fish screens at Wapato Diversion and downstream of the fish screens at Sunnyside Diversion) between 2014 and 2018. The estimated numbers of lampreys, total numbers captured and those that were dead are also listed.

Diversion	Year	# Estimated	# Captured	% Captured	# Morts	% Captured Live
Wapato	2014	5,249	2,141	41%	926	23%
	2015	8,075	1,564	19%	378	15%
	2016	44,874	26,632	59%	116	59%
	2017	31,564	8,190	26%	2,062	19%
	2018	9,235	4,284	46%	706	39%
	Total	98,997	42,811	-	4,188	-
	Average	19,799	8,562	43%	838	39%
Sunnyside	2014	3,259	402	12%	74	10%
	2015	11,115	2,092	19%	49	18%
	2016	19,138	10,006	52%	4,512	29%
	2017	12,697	5,790	46%	3,777	16%
	2018	8,365	3,872	46%	186	44%
	Total	54,574	22,162	-	8,598	-
	Average	10,915	4,432	41%	1,720	25%



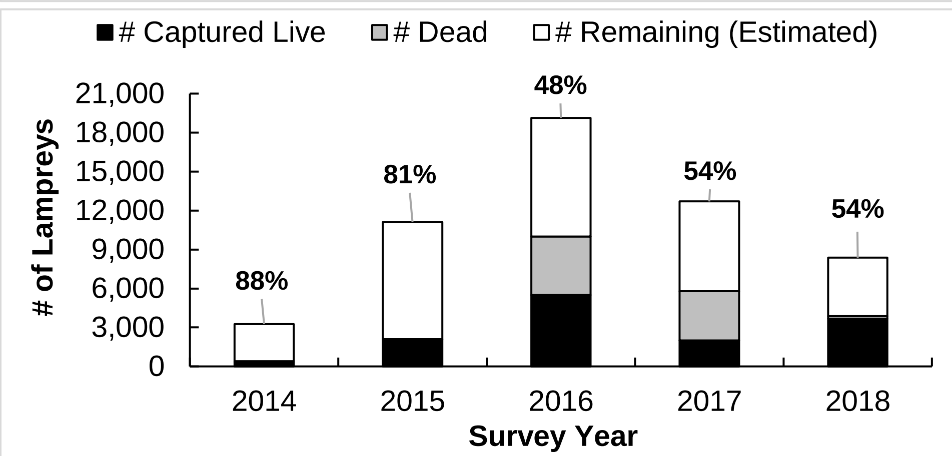


Figure 2.9. The number of lampreys estimated to be present at Wapato (top graph) and Sunnyside (bottom graph) diversions in the high density areas (upstream of the fish screens at Wapato Diversion and downstream of the fish screens at Sunnyside Diversion) between 2014 and 2018. The number of lampreys captured alive and dead are also displayed within the overall estimates. The percentage of the total number of lampreys that were not captured each year (i.e. the number estimated to be remaining, the white fill portion) is also labeled.

2.4 Description of Methods for Estimation

The following description provides an overview of methodology used to estimate lamprey numbers in Sunnyside and Wapato diversions between 2015 and 2018. Distribution of larval lampreys are typically very patchy and there are three types of habitat categories that help identify and qualify the quality of larval lamprey habitat (Fig. 2.10; Mullett & Bergstedt 2003; Slade et al. 2003; Moser et al. 2007). Type I habitat is preferred habitat which consists of a loosely compacted mixture of fine sediment (sand, silt, clay) and fine organic matter in depositional areas. Type II habitat is acceptable habitat which consists of shifting sand and/or a mix of fine and coarse substrates (typically with little fine organic matter). Type III habitat is unacceptable habitat which consists of all coarse substrate including gravel, cobble, boulder, and/or bedrock with no fine sediment. Our surveys focus primarily on Type I habitat where densities are typically much higher (~x10) than Type II habitat, but Type II habitat is also covered. See Task 6.5 for more information on habitat use.

This estimate methodology focuses primarily on Type I habitat where most lampreys are found and captured after irrigation shut down, but it can also incorporate data from Type II habitat (either separately or together). To estimate the number of entrained lampreys at large scale diversions (e.g. Wapato Diversion), the project area was first spatially divided into sections (prior to dewatering) to ensure our electrofishing efforts would cover representative density areas throughout the entire area (Fig. 2.11). The zone upstream of the fish screens at Wapato Diversion was divided into six sections, U1-U6 ("U" stands for "Upstream", numbered in order from downstream to upstream). The sections can be delineated also based on other notable features (e.g., sloped bank, isolated pool, Type II habitat) that influence the lamprey densities within the diversion facility if they are easy to partition geographically (see explanation for "habitat categories" below). Project area delineation is important because there can be considerably high variation in densities depending on the location within the diversion.

The polygon feature on Google Earth Pro was used to calculate the overall area (m^2) of each section within the overall project area such as the area upstream of the fish screens at Wapato Diversion. The areas outside this project area typically have a very low number of lampreys (from past surveys primarily due to habitat), so they were not included in the project area estimation. If various habitat categories existed within the section, the percentage of each was estimated. The percent of Type I habitat that is dry (as opposed to wet) is also estimated as an indicator for the degree of larval lamprey movement that have already occurred.

Single pass electrofishing surveys were performed in plots (2-5 m^2 in size), and covered representative larval lamprey habitat areas within each of the delineated sections. The overall size of the plots within each section depended on the total area of wetted habitat area within each section (an effort was made to cover at least 5% of the overall area whenever possible). Plot surveys are generally focused within the main water body, along the sloped edge of the main water body (the edge was defined as the area within 1-2 m from the fine sediment laden sloped water's edge), and within isolated pools (if present). These unique survey locations ("edge" of main water body, "main" water body and "isolated pool") were referred to as "habitat categories." Due to the generally high variance in survey density between each of these habitat categories, we estimated the number of lampreys separately within each category (within each section).

The number of captured and missed lampreys, electrofishing area and time, section number and habitat category were recorded from each plot. During each survey, the water visibility is recorded in 10% increments (100% being perfect water clarity with full visibility at all depths and 0% being no visibility at all in water due to factors stemming from turbidity, aquatic plants, and/or wind/rain). This measurement assessed the percent of water volume (from top of bottom substrate to water surface) that was visible to the surveyor within the shocked area. This visibility measure did not influence the capture numbers, but we used it to adjust the number of lampreys observed. For instance, if visibility was only 50%, and we missed 10 lampreys, the number of missed lampreys were divided by 0.5, resulting in an "estimated" 20 missed lampreys. The total number missed is then added to the captured number to attain the estimated number of observed lampreys. The total number of observed lampreys is divided by the plot area to get a plot density (# m^{-2}).

Resulting first pass lamprey densities covering representative areas of Type I habitat (within each habitat category and section) were then extrapolated over their respective wetted areas. The extrapolated totals were summed by habitat category to get the total number of estimated lampreys from electrofishing surveys for each section. The estimated number of lampreys for each section were then tallied together to get the total number of lampreys (for each diversion). In addition, the total number of lampreys removed from dry banks and electrofishing prior to the first pass estimation surveys in each section were added to the estimated total, to arrive at a final estimated number of lampreys at each diversion.

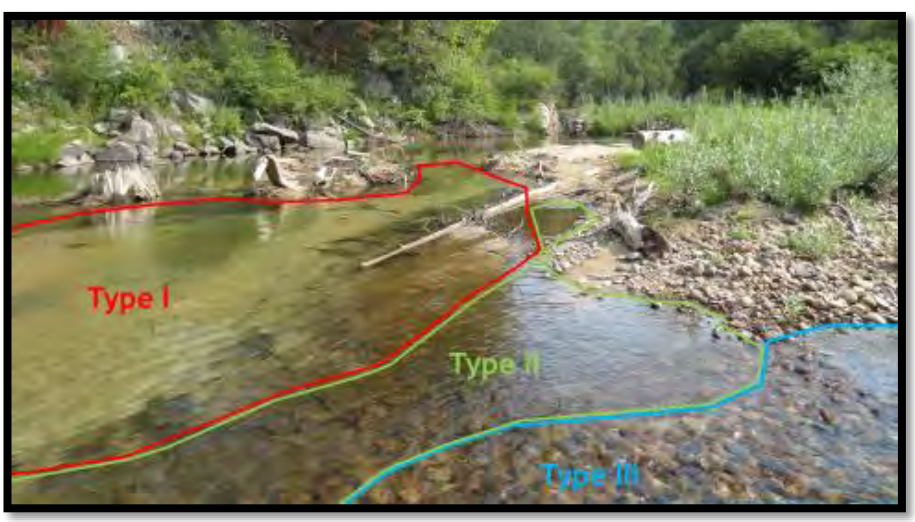


Figure 2.10. An example of Type I, II and III habitats used by larval/juvenile lampreys in a stream.

Figure 2.11. Delineated sections of the zone upstream of fish screens at Wapato Diversion (light grey polygons and blue arrows). Sections U1, U2, U3, and U4 divide the zone immediately upstream of fish screens. Section U5 surrounds the trashrack, and U6 is located in the upstream canal, reaching 50 m upstream of the trash racks (total project area length is 780 m).

2.5 Mark-Release-Recapture Study at Wapato Diversion

Since 2014, YN Fisheries has estimated the number of lampreys residing in high density areas at Wapato and Sunnyside diversions. Estimates were calculated by using single pass electrofishing densities (using an ABP-2 backpack electrofisher), and extrapolating those densities over the area of wetted sediments at the time of survey. If any lampreys were captured prior to these single pass surveys (such as from dry banks or electrofishing), those numbers were also tallied and added to the estimates. Mark-recapture methodology is much more time consuming, but allows for a better estimation given the large population size of lampreys that can be found within irrigation diversions. In 2014, we implanted larval and juvenile lampreys with Visual Implant Elastomer (VIE) tags (Fig. 2.12 and 2.13), and released them into a high density area of Wapato Diversion upstream of the fish screens (Beals & Lampman 2015a).

Lampreys were captured from Wapato Diversion, tagged with VIE tags and released at once back into the capture area. Electrofishing passes were made over the high density area where the tagged lampreys were released, and all tagged and untagged lampreys were numerated. For this study, we used the Chapman (modified Lincoln-Peterson) mark-recapture method to estimate the number of lampreys within the high density area on each recapture survey date.

The formula for the Chapman mark-recapture method is as follows:

$$\hat{N}_c = \frac{(M+1)(C+1)}{R+1} - 1$$

N̂c = Number of animals in the population
M = Number of animals marked marked on the first visit
C = Number of animals captured on the second visit
R = Number of recaptured animals that were marked

The Chapman method has three assumptions that need to be met:

1. No immigration, emigration, births or deaths between the release and recapture times.
2. The probabilities of being caught are equal for all individuals (including marked ones).
3. Marks (or tags) are not lost and are always recognizable.

Although assumption #1 is difficult to satisfy entirely, because the diversion was already dewatered, we can assume that immigration and emigration into and out of the study area was very limited. Larvae from dry banks were not emerging at this point of time and we assumed limited movement into the shallow water study area from the surrounding water after the rapid drop in water levels. Although lampreys can move out of the study area, larvae marked and released were observed burrowing directly in the area they were released, and habitat quality outside the study area was compromised with more Type II habitat, providing additional incentives for lampreys to remain within the given study area. It is safe to assume that the vast majority of lampreys stayed in this same area at least initially because the number captured and observed during the second survey was as high as the first survey during which mark and release occurred. It is, however, possible that some of these lampreys could have emigrated out over time, especially for the samplings that ensued later (third and fourth surveys). There were no births, and although deaths were possible, we assume that death is limited at least during the initial surveys for the reasons explained above. Assumptions #2 and #3 were met adequately. Tagged lampreys and non-tagged lampreys live in the same location, and are subjected equally to our survey method and we tagged representative size classes of lampreys captured during the initial electrofishing survey. Previous studies in 2012 at Prosser Hatchery with Western Brook Lamprey have confirmed that VIE tags remain visible for an extended period of time (at least longer than one year) (Lampman & Beals 2014c).

This study demonstrated that estimating the number of lampreys that reside within the Wapato Diversion (and potentially other irrigation diversions with similar overall conditions) based solely on single pass estimates may result in considerable underestimation of the actual number of lampreys. Our study suggested that 1) observed number of lampreys from a single pass survey equates to approximately 45.0% of the estimated actual number of lampreys, and 2) captured number of lampreys from a single pass survey equates to only about 22.3% of the estimated actual number of lampreys. Based on these results, it is prudent to use a multiplication factor of four (4.48 to be exact) or two (2.22 to be exact) to estimate the true population size of lampreys within irrigation diversions (with a combination of low visibility and high density conditions) when estimates are being made using single pass capture or observation numbers, respectively.

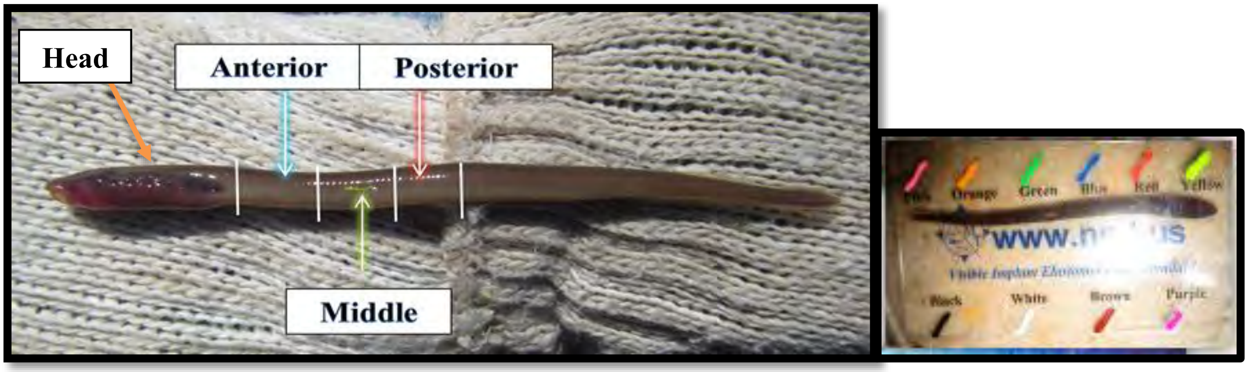


Figure 2.12. Available tagging regions (head, anterior, middle, and posterior) on larval lampreys greater than 50 mm (left photo). Shown is a Pacific Lamprey larva (~110 mm) captured and tagged (middle region) at Wapato Diversion on October 16, 2014. Tags can be inserted in these regions on both the left and right side of its body using various assortments of colors to increase the unique combinations of tags (right photo).

Figure 2.13. Available tagging regions on larval lampreys less than 50 mm (left photo). Shown is a larval lamprey (~ 38 mm) of an unknown species captured and tagged (middle region) at Wapato Diversion on October 16, 2014. For these smaller larvae, we recommend 1) making a light surface cut using a 3-mm microsurgical blade, 2) insert the needle through the surface cut at a high angle first to penetrate the skin, and 3) tilt the angle down to achieve a flat angle before sliding the needle in (right photo). Inserting the needle from the anterior end is recommended to avoid puncturing the heart and other critical organs just posterior to the last gill pore. A thinner needle is also recommended (30 or 31 instead of 29 gauge) for these smaller larvae.

2.6 Predation of Stranded Larval Lampreys

One threat that stranded and exposed lampreys face is predation when personnel are not present to remove them from the sediment surface. When predation occurs during dewatering, obtaining an accurate count of lampreys from dewatered banks becomes challenging, and these predation rates are important to consider when assessing the total numbers of entrained lampreys in the project area. Various avian and mammalian predator tracks typically show up immediately after the first dewatering in various diversion sites especially those that have a high percent of dried fine sediment. These predators likely smell the exposed and dying fishes (including lampreys) and congregate to these local areas. Sometimes their scat is also visible, indicating the long duration during which they stayed in the dewatered area. We made an attempt to document (photograph and film) these predators at various diversions since 2016. At Sunnyside Diversion in 2018, we documented both mammalian and avian predation of larval lampreys using a motion activated wildlife trail camera (Bushnell Trophy Trail Camera, Overland Park, KS). Desiccated small (<70 mm) larval lampreys collected from the banks were placed in front of a Bushnell Game Camera to monitor predators that visit the site to consume these lampreys. Killdeer birds showed up soon after placement during the dusk period and spent time feeding in the area (Fig. 2.14). Mink tracks were also observed in a different area. Great blue herons, ducks, geese, and raccoons are some additional species that have been observed at other diversion sites in the Yakima Subbasin shortly after dewatering (Fig. 2.15 and 2.16). At Dryden Diversion on Wenatchee River, a bobcat and a coyote were captured on the trail camera in 2016 and 2017, respectively, appearing to feed on larval lampreys, and have been observed by staff occasionally as well during day time (Fig. 2.17). Finally, a black bear tracks were also observed at Bachelor Hatton Diversion on Ahtanum Creek, although the bear was not picked up on the game camera. We suspect many other species will take advantage of the unique opportunity at these diversions to feed on dessicated lamrpeys.

Figure 2.14. The trail camera photo on the left shows several killdeer birds observed predating on larval lampreys on November 9, 2018. The yellow arrows in the photo shows the location of individual birds observed in the photo. The right photo shows many hundreds of killdeer bird tracks on a flat area of dewatered sediment where many larval lampreys were burrowing (explaining the high density of bird tracks).

Figure 2.15. Photos of avian predators at Sunnyside and Wapato diversions shortly after dewatering. The photo on the left shows a killdeer (November 11, 2018). The photo on the right shows a Great Blue Herron (October 19, 2016).

Figure 2.16. Overview of Raccoon tracks at Wapatox Diversion in the Naches River. The left photo shows one of many tracks that were found at the site. The photo on the right shows a raccoon potentially feeding on exposed lampreys. The raccoon was observed digging in the fine sediment, seemingly searching for more larval lampreys under the sediment.

Figure 2.17. Photos of a Bobcat at Dryden Diversion on Wenatchee River shortly after dewatering occurred. The photo on the left shows the Bobcat appearing to consume newly stranded lampreys. The photo on the right shows the Bobcat walking on top of newly dewatered fine sediment.

Task 3: Monitoring of Lamprey Movements into Irrigation Diversions

Over the years, several projects were developed and implemented by YN Fisheries to better understand the behavior of lampreys moving into and within the irrigation diversions. We will highlight some of these projects and studies in this section, including tagging studies using Passive Integrated Transponder (PIT), deep water electrofishing, and video monitoring using larval lampreys released.

Juvenile Pacific Lamprey tend to move downstream during the high flow events (Goodman et al. 2015), especially the rising curve of the high water events (Lampman et al. 2014b; Moser et al. 2015). One hypothesis is that the high turbidity conditions provide protections for lampreys from various predators as they migrate downstream. In rainfall runoff systems, these high flow events may occur primarily during the winter whereas in snowmelt runoff systems, they may occur primarily in the spring and early summer. For example, in the Lower Yakima River, which is fed by both rainfall and snowmelt runoffs, this results in bimodal peaks in both winter and spring/summer seasons (Fig. 3.1). This trend with more migration occurring during high flow events appears to be generally true for larval lampreys as well, but more research is certainly needed to understand their migration behavior near irrigation diversions and their use of both active and passive migration throughout the year.

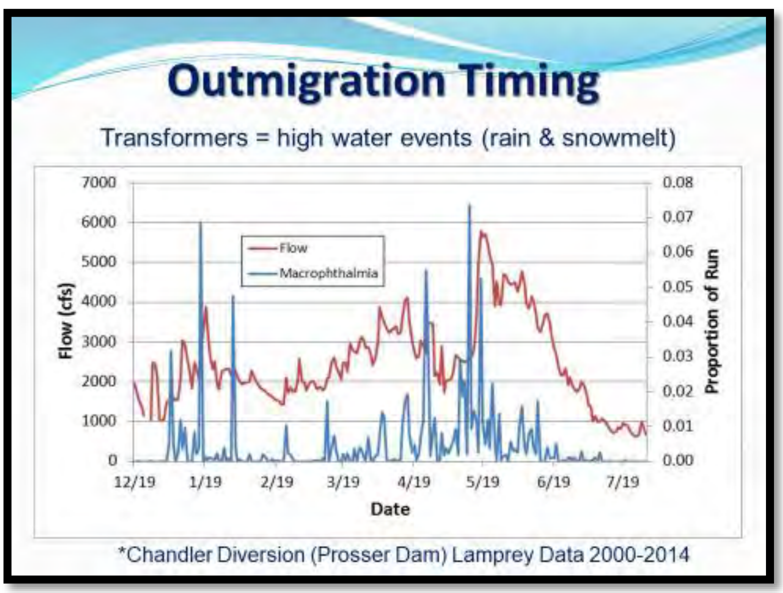


Figure 3.1. Average proportion of lamprey run (blue line) at Chandler Juvenile Fish Monitoring Facility (Chandler Diversion in Lower Yakima River, Prosser, WA) in relationship to average discharge data (red line) between 2000 and 2014. Most lampreys captured are juvenile Pacific Lamprey, but a small portion are Western Brook Lamprey, Western River Lamprey as well as larval Pacific Lamprey. The diversion is dewatered part of the time between late October and late December due to maintenance activities and may miss some of the fall / early winter high flow events.

3.1 PIT Tag Monitoring

Overview

Between 2014 and 2019, a total of 2040 lampreys (70 mm or larger in size) were PIT tagged using 8 mm full duplex tags and released within the Upper Columbia Basin to help understand their downstream migration behavior and interaction with hydroelectric dams and irrigation diversions (Table 3.1; Lampman & Beals 2015; Lampman 2016a; Lampman 2017a; Lampman 2017b). For information on tagging methods, see Moser et al. 2017 (Fig. 3.2). Of those, 1840 of them (90%) were released in the Yakima Subbasin; the remaining were released in the Methow Subbasin and mainstem Upper Columbia River near Yakima River mouth. The majority of tagged lampreys were juvenile Pacific Lamprey (68%), followed by larval Pacific Lamprey (23%), larval Western Brook Lamprey (8%), adult Western Brook Lamprey (1%), and juvenile Western River Lamprey (<0.1%, n=1) (Table 3.2).

Based on the past six years of monitoring, there are several key summary points to highlight: 1) entrainment rates of lampreys (both larvae and juvenile) into diversion headgates were estimated to be as high as 50-90% between April and October based on the Sunnyside Diversion study; 2) a very high percentage larval/juvenile lampreys (up to ~96% at Chandler Diversion and at least 74% at Sunnyside Diversion) are estimated to be lost when released in the upper part of diversions even after several years of monitoring; 3) detection efficiencies of instream PIT arrays placed on the bottom of the channel are substantially low (3~10% in Yakima River, and 6-15% in tributaries) in relation to discharge levels and season and some of the new diversion arrays have limited detection rates as well (~30% in Sunnyside bypass outlet); 4) detection rates at CJFMF (Prosser, WA) ranged between 1.0-8.5% annually; 5) detection rates at mainstem Columbia River Dam arrays ranged between 0.0-1.3% annually; 6) average migration speed was typically 10-20 km day^{-1}, but migration speed >40 km day^{-1} (up to -73.1 km day^{-1}) were also detected from several individual lampreys.

Table 3.1. Number of larval and juvenile lampreys PIT tagged and released between 2014 and 2019 in the Yakima and Methow subbasins and mainstem Columbia River.

Year	Start Date	End Date	# in Yakima	# in Methow	# in Columbia	# Total	Locations
2014	3/10/2014	4/4/2014	43	0	0	43	Yakima (Chandler Diversion)
2015	5/22/2015	5/22/2015	33	0	0	33	Yakima (Chandler Diversion)
2016	1/26/2016	10/7/2016	448	0	0	448	Yakima (Sunnyside, Chandler Diversions)
2017	4/25/2017	10/13/2017	250	44	0	294	Yakima (Sunnyside Diversion), Methow/Chewuch
2018	1/22/2018	9/15/2018	455	0	4	459	Ahtanum, Toppenish, Yakima, Columbia
2019	1/25/2019	7/9/2019	611	0	152	763	Ahtanum, Toppenish, Satus, Yakima, Columbia
Total	**-**	**-**	**1840**	**44**	**156**	**2040**	**-**

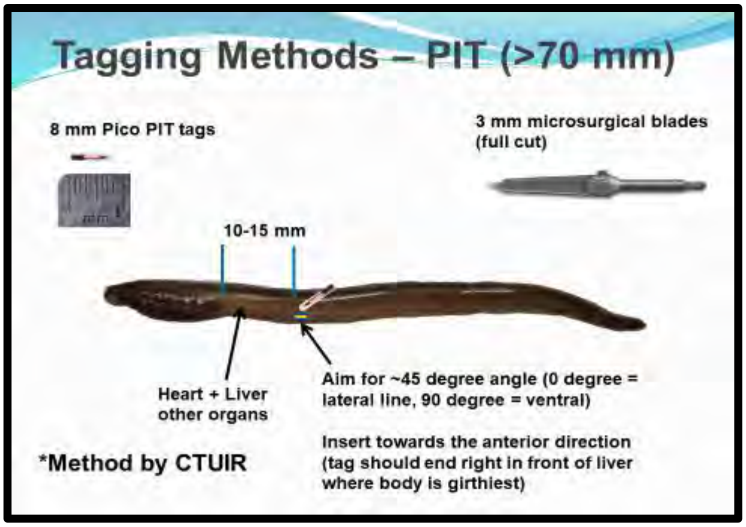


Figure 3.2. Overview of PIT tag methods for larval and juvenile lampreys. We use a 3 mm microsurgical blade to cut open an incision just large enough to insert the 8 mm PIT tag (see Moser et al. 2017).

Table 3.2. Number and proportion of PIT tagged Pacific Lamprey (PA), Western Brook Lamprey (WB), and Western River Lamprey (WR) by life stages (TR = eyed, metamorphosed juvenile lamprey, LA = larval lamprey) between 2014 and 2019 in the Yakima and Methow subbasins and mainstem Columbia River.

Year	# Total	# PA TR	# PA LA	# WB TR	# WB LA	# WR TR	% PA TR	% PA LA	% WB TR	% WB LA	% WR TR
2014	43	8	35	0	0	0	19%	81%	0%	0%	0%
2015	33	32	1	0	0	0	97%	3%	0%	0%	0%
2016	448	23	302	27	96	0	5%	67%	6%	21%	0%
2017	294	124	107	0	63	0	42%	36%	0%	21%	0%
2018	459	455	0	3	0	1	99%	0%	1%	0%	0.2%
2019	763	749	14	0	0	0	98%	2%	0%	0%	0%
Total	**2040**	**1391**	**459**	**30**	**159**	**1**	**68%**	**23%**	**1%**	**8%**	**0%**

2014 PIT Tag Releases

In 2014, 43 lamprey (8 juvenile and 35 larval Pacific Lamprey) were tagged and released near the upper end of the Chandler Diversion (Yakima River river km 75.4) between March 11 (n=7) and April 4 (n=36), 2014 (Fig. 3.3; Lampman & Beals 2015). These lamprey were all originally collected from Chandler Juvenile Fish Monitoring Facility (CJFMF). From these two releases, only two lamprey were detected; one juvenile Pacific Lamprey was detected 41 days later at CJFMF smolt bypass array whereas one larval Pacific Lamprey was detected 334 days later at CJFMF. This resulted in 12.5% and 2.9% detection rates for juvenile and larval Pacific Lamprey, respectively. All juvenile PIT tagged fishes returning from the canal back to the Yakima River would theoretically be detected when they pass through the smolt bypass array. As a result, we assume that only approximately 3% of the lamprey moving into Chandler Diversion are able to return back to the river system.

There are many factors that may have contributed to the limited percentage of lamprey detected in the bypass channel passage. Some could potentially be lost through predation, although for juvenile salmonids (*Oncorhynchus* spp.), predation rates are typically between 10-30% and usually lower in the spring when water temperature is still cold. Examples of predatory fish in Chandler Diversion besides salmonids include Smallmouth Bass (*Micropterus dolomieu*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Black Crappie (*Pomoxis nigromaculatus*), Bluegill (*Lepomis macrochirus*), Channel Catfish (*Ictalurus punctatus*), bullhead catfishes (*Ameiurus* species), and sculpins (*Cottoidea* species). It is known that Smallmouth Bass can feed heavily on larval/juvenile lampreys, and these other predatory species might be a threat to lampreys as well. In a laboratory feeding experiment, a Smallmouth Bass, 65 mm in length, collected from Chandler Diversion was able to eat four larval lamprey, between 34-49 mm in size, in only 40 minutes. Many Great Blue Herons also line the shores of the canal, and may consume larval/juvenile lampreys seeking out the slow water where herons (as well as other avian species) feed. River otters are also abundant in the area. There could also be additional areas upstream of the smolt separator, such as at the primary bypass flume, where lampreys may potentially be passing through or getting impinged (Fig. 3.4).

Figure 3.3. The two release sites into the canal upstream of the fish screens at Chandler Diversion (March 11, 2014 and April 4, 2014), relative to the diversion inlet, fish bypass, and the fish bypass outlet.

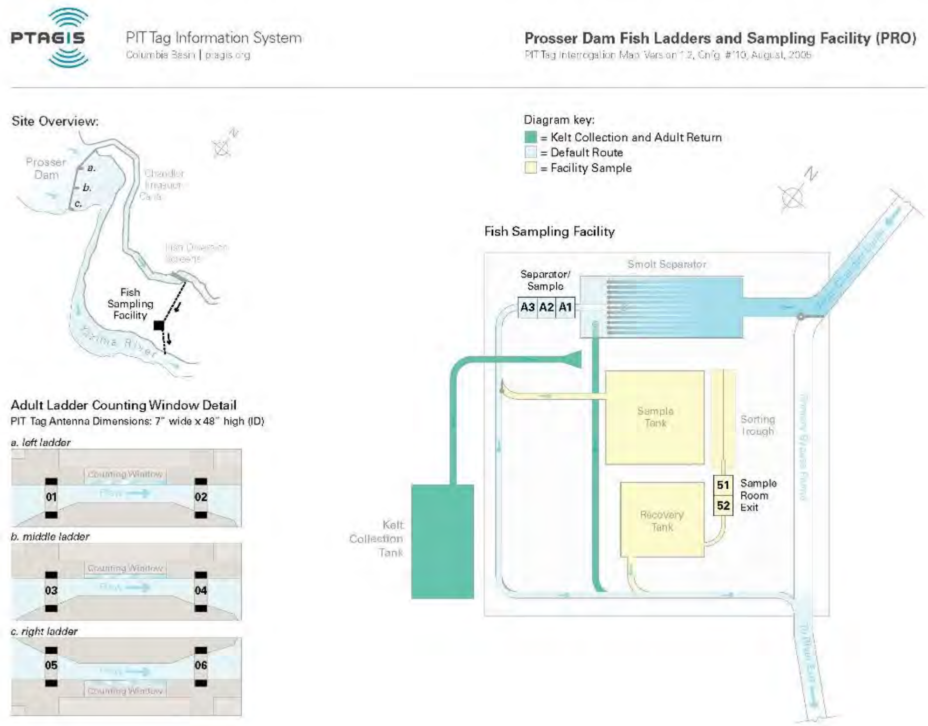


Figure 3.4. The PIT arrays located at Chandler Juvenile Fish Monitoring Facility (CJFMF).

2015 PIT Tag Release

In 2015, 33 lamprey (32 juvenile Pacific Lamprey and one larval Pacific Lamprey) were tagged and released near the upper end of the Chandler Diversion (Yakima River river km 75.4) on May 22, 2015 (Fig. 3.4; Lampman 2016a). All juvenile Pacific Lamprey were from John Day Dam Juvenile Bypass Facility and one larval Pacific Lamprey was from CJFMF. From this release, only one juvenile Pacific Lamprey was detected, and the detection time was six hours later at 23:18. This resulted in a 3.1% detection rate overall for juvenile Pacific Lamprey (in 2014, it was 12.5%, but was a much smaller sample size of only 8 fish). All juvenile PIT tagged fishes returning from the canal back to the Yakima River would theoretically be detected when they pass through the smolt bypass array. As a result, we assume that only approximately 3% of the lamprey (both larvae and juveniles) moving into Chandler Diversion are able to return back to the river system.

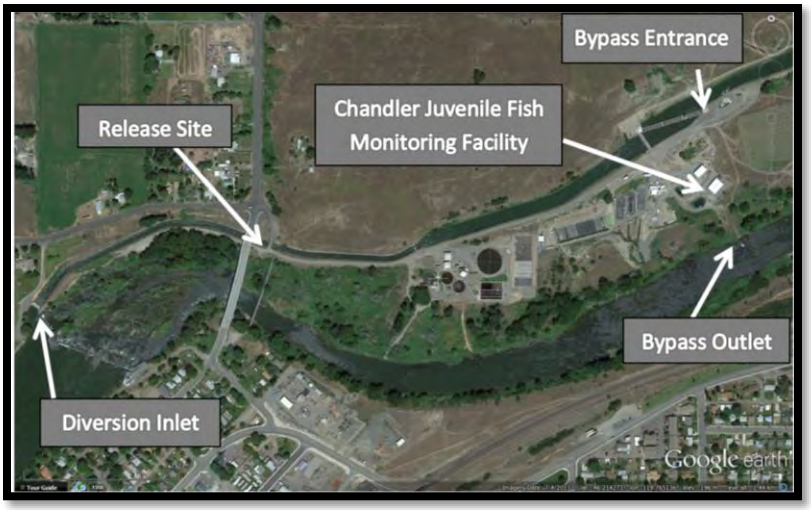


Figure 3.4. Overview map of Chandler Diversion and release site relative to the diversion inlet, fish bypass, and the fish bypass outlet.

2016 PIT Tag Releases

In 2016, a total of 448 lampreys were PIT tagged and released within the Yakima Subbasin. One group of release (n=73) was inside Chandler Diversion (Yakima River river km 75.4; Lampman 2017a). The rest of the releases were immediately upstream or downstream of Sunnyside Diversion Dam (Yakima River river km 171.2-171.5) during spring (n=98), summer (n=131), and fall (n=146) seasons (Lampman 2017b).

To investigate whether lampreys released closer to the bypass channel would be detected at a higher rate, 73 lampreys were tagged and released near the downstream end of the Chandler Diversion on January 26, 2016 (Fig. 3.5). The source of these lampreys were a mix of Pacific Lamprey and Western Brook Lamprey larvae and adult collected from Sunnyside/Wapato diversions (Yakima River) and Dryden Diversion (Wenatchee River – predominantly Pacific Lamprey). There were a total of four release sites, each with a group of 18-19 PIT tagged lampreys. The goal was to confirm whether the low detection rates observed in 2014 and 2015 would be repeated if the tagged lampreys were released closer to the PIT array antennas. The overall detection rate was much higher from these releases (71.2%). Those released at the trash rack had the lowest detection rate (36.8%), whereas those released near the bypass entrances had much higher detection rates (88.9%, 77.8%, and 83.3% from Bypass #1, #2, and #3, respectively, with an average rate of 83.3%). It is unknown whether the remaining 16.7% may be related to the compromised detection efficiency of the smaller 8 mm PIT tags or a small loss of fish in this final segment of the canal. This indicates that only about 44.2% (=0.368÷0.833) of the lampreys arriving at the trash racks are able to arrive at the entrance of the bypass channels. Furthermore, only about 8.2% (=0.03÷0.368) and 3.6% (=0.03÷0.833) of the lampreys from the upper canal are estimated to make it to the trash rack section and bypass channel, respectively, based on 2014-2016 data.

This indicates that the largest loss of lampreys may be occurring prior to arriving at the trash rack section and once lampreys arrive at the bypass, the chances of returning to the river is much higher.

There were some interspecific and life stage based differences in detections and sampling rates. For instance, of the 23 Pacific Lamprey juvenile released, 19 (82.6%) were detected. Of these 19 detected lamprey, 3 (15.8%) were captured at the CJFMF. Of the 25 Pacific Lamprey larvae released, 20 (80.0%) were detected. Of these 20 detected lamprey, 1 (5.0%) was captured at the CJFMF. Of the 25 Western Brook Lamprey transformers released, only 13 (52.0%) were detected. Of these 13 detected lamprey, only 1 (7.7%) was captured at the CJFMF. All of the lamprey that were detected seven days or later after the release date (past February 2, 2016) (n=6) were Western Brook Lamprey transformers, indicating they may be more likely to swim against the current or hold in the bypass channels. The CJFMF has a subsampling rate of 33.3% (sampling on for 5 min and off for 10 min), so the sampling rate observed for larval lampreys, adult Western Brook Lamprey, and juvenile Pacific Lamprey were considerably less (15.0, 23.1, and 47.4% of what is expected from the sampling rate, respectively). When extrapolating estimates of the numbers for lampreys, these sampling efficiency should be taken into consideration.

In addition, a total of 229 and 146 PIT tagged lampreys were released upstream and downstream of Sunnyside Diversion Dam to test the detection efficiency of the new PIT array installed on the mainstem Yakima River just downstream of the dam (Fig. 3.6). The lampreys used were a mix of larval Pacific Lamprey and larval and early adult Western Brook Lamprey collected from diversions on the Yakima/Naches River and Dryden Diversion on Wenatchee River (primarily Pacific Lamprey). The releases were split during three blocks of dates (April 15, July 28, and October 7) to help assess their detection rates at variable flow conditions. The goal was to confirm the detection efficiency of the new mainstem array as well as to assess the entrainment rate (if the sample size is adequately large to attain enough detections from both upstream and downstream releases). Both upstream and downstream releases were split into two groups for right and left bank releases (in case the release bank makes a difference in detection).

None of those released upstream of Sunnyside Dam were detected at the mainstem array located a few hundred meters downstream from the three release events in April, July, and October, 2016 (n=66, 66, and 97, respectively). This indicates that the chances of detection are less than 1.5% for the two early releases and less than 1.0% for the late release. Although none of these lampreys were detected at Sunnyside Dam, two tagged lamprey released in July, 2016, and one tagged lamprey released in October, 2016, were detected further downstream at McNary Dam (JCJ array) and John Day Dam (JDJ array) approximately 19 months later between May 11 and May 18, 2018, suggesting that they may have metamorphosed into a juvenile to migrate downstream.

For those that were released downstream of the dam, the detection rates were also very low; the detection rate was highest during the October 7 release (10.2%), followed by July 28

(6.2%), and April 15 (0%). None of the 32 lampreys released on April 15 were detected, so that is less than a 3.0% detection rate. The discharge level was highest during the April release (river 8019 cfs, diversion 627 cfs, 8% withdrawal), followed by the October release (river 472 cfs, diversion 671 cfs, 142% withdrawal) and the July release (river 386 cfs, diversion 1117 cfs, 289% withdrawal) (Fig. 3.7). Water temperature was 9.8, 22.6, and 14.5˚C during the April, July, and October releases. The detection rates were always slightly higher from the right bank releases (overall detection of 11.1% vs. 5.4% from left bank releases), indicating that the side of bank does matter for detection efficiency. There was one lamprey detected at an array further downstream from each of the three releases. From the April and July releases, one lamprey each was detected at CJFMF (Prosser, WA) (approximately 10 months later on 2/13/2017 and 5/6/2017, respectively). From the October release, one lamprey was detected at John Day Dam (JDJ array) approximately seven months later on 5/13/2018.

The cause of the low detection rates in the Yakima River array from the upstream release is likely a combination of the following: 1) low overall efficiency of the array for larval/juvenile lampreys with small 8 mm PIT tags, 2) some lampreys holding in places in between the release and array location and not moving downstream, or 3) some lampreys moving into the Sunnyside diversion. Given that the low efficiency of the array applies to both upstream and downstream releases, the unique causes that apply primarily to the upstream releases are #2 and #3. Although larval lampreys can stay put in place for several years without moving downstream (if conditions are conducive for rearing), more than three years have passed since their releases. We used large larvae (average size 115 mm) for this study and the smallest larvae was 68 mm. We estimate their ages to be predominantly 3-6 years and expect them to metamorphose in approximately 1-3 years for most of these cohorts; in fact, six lampreys (three from both upstream and downstream releases) were detected further downstream 1-2 years later in either Lower Yakima (CJFMF) or Lower Columbia River hydro dams (John Day and McNary dams). As a result, it is likely that these tagged lampreys have already moved past the PIT array site near Sunnyside Dam within the past three years. As a result, entrainment into the diversion may be the main culprit for the differences in the detection rates.

The detection rates for those released downstream of the dam were estimated to be at least 2.0, 4.1, and 10.2 times higher than the detection rates for those released upstream of the dam, suggesting that at least 50%, 76%, and 90% may be moving into the diversions during the April, July, and October, 2016, releases. Although discharge was the lowest and percent withdrawal was highest during the July release, more lampreys from the October release were detected at the PIT array and more were estimated to be entrained. One hypothesis is that larval lampreys may be migrating closer to the water surface to avoid predators during July, resulting in lower rates of detections from the PIT array on the river bottom surface and less entrainment into the headgate located on the river bottom compared to the October release. Obviously, more releases with larger sample sizes are desired to provide more accurate entrainment ratio estimates with higher confidence. Given that the same number of tagged lampreys were detected at array sites further downstream from both upstream and downstream release events (n=3 each, resulting in 1.3 and 2.1% detection rates for upstream and downstream releases, respectively), the high estimated entrainment ratio may not be resulting in a significantly lower survival rates overall at Sunnyside Diversion (estimated survival rates within the diversion is 62% based on this small limited sample size).

Figure 3.5. Overview map of Chandler Diversion and the four release sites on January 26, 2016. Release sample size and time of day are shown within the parenthesis next to the release location.

Figure 3.6. Overview map of Sunnyside Diversion and Dam as well as the four release sites from April, July, and October, 2016, located upstream [Above LB (left bank) and Above RB (right bank)] and downstream of the dam (Below LB and Below RB). The new channel spanning mainstem array is located downstream of all release sites and is displayed by the white line.

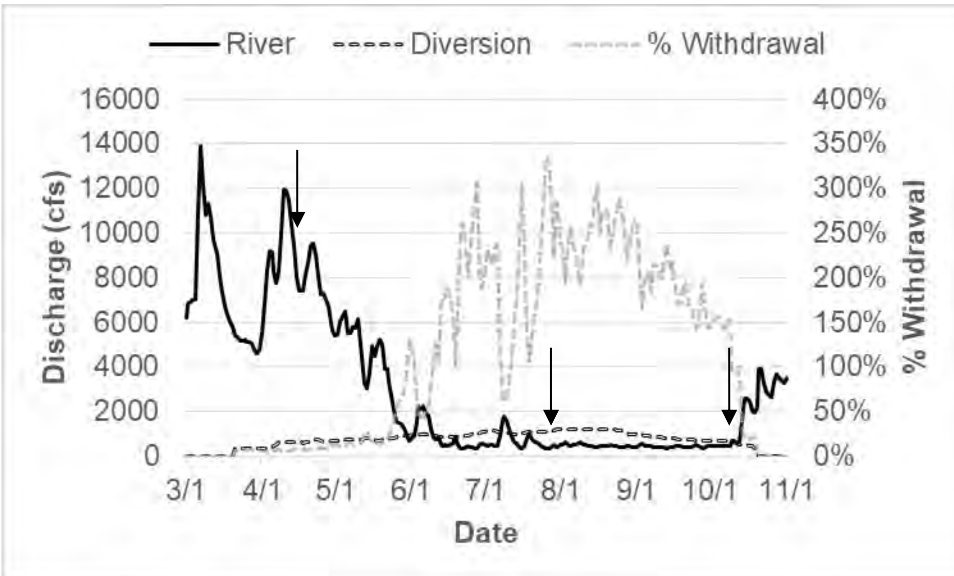


Figure 3.7. Discharge levels between March 1, 2016, and November 1, 2016 at Yakima River near Parker, WA (0.4 river km downstream of Sunnyside Diversion) compared to the withdrawal discharge at Sunnyside Diversion. The percent withdrawal is also shown on the secondary y-axis. Down facing arrows indicate the three release dates on April 15, July 28, and October 7, 2016.

2017 PIT Tag Releases

In 2017, a total of 294 lampreys were PIT tagged and released within the Yakima and Methow subbasins. One group (n=44) was released in early August in the Methow Subbasin (Methow and Chewuch rivers). Another group was released in the Yakima Subbasin near Sunnyside Diversion Dam (Yakima River river km 170.9-171.3 in April (n=126) and October (n=124).

A total of 44 lampreys (larval lampreys captured during larval surveys in the Methow Subbasin) were PIT tagged and released between August 8 and 10, 2017, where they were originally captured at river km 25.6 of Methow River (n=10) and river km 16.1 of Chewuch River (n=34). The goal of this tag and release effort was to learn more about the emigration rates of these larger size larvae and when they may show up in the lower parts of the Subbasin. Of these releases, only two lampreys have been detected to date: both of them were released at Chewuch River (river km 16.1) and they were detected 21 months later on May 21, 2019 (22:12 and 22:20, approximately 8 min apart) at CRW (Chewuch River above Winthrop near river km 1.6), approximately 14.5 km downstream. Their length was 108 and 116 mm, respectively, at the time of tagging and release, and they may have metamorphosed in approximately 2 years.

A total of 126 PIT tagged lampreys were released downstream of Sunnyside Diversion Dam on April 25, 2017, to test the detection efficiency of the PIT array on the mainstem Yakima River just downstream of the dam (see downstream release sites in Fig. 3.6). For this study we used primarily larval lampreys of both species (Pacific Lamprey and Western Brook Lamprey) from the same sources as the 2016 releases. The goal was to evaluate whether any lampreys could be detected with a higher number of sample size (n=126 compared to n=66 in 2016). No lampreys were detected at the array near Sunnyside Dam from the April 2016 release from the same locations. The release was again split into two groups for right and left bank releases to continue to evaluate whether the release bank makes a difference in detection. Similar to 2016 results, no lampreys were detected from the April 2017 release, suggesting that the detection rate may be less than 0.8% during this high flow condition (7633 cfs; discharge was similar in April, 2016, at 8019 cfs).

A total of 124 lampreys were also released inside the Sunnyside Diversion (Yakima River river km 171.3) in 2017 during the fall season just prior to irrigation shutdown in the Yakima River (Fig. 3.8 and 3.9). The releases were conducted on October 13, 2017, just prior to the irrigation shutdown. The goal was to test the detection efficiency of the new arrays installed within the irrigation diversion (by trash racks and bypass inlets and outlets). Lampreys were released in various parts of the irrigation canal to enhance our understanding of lamprey behavior within the diversion (n=41 near canal inlet, n=41 downstream of trash rack, n=22 at bypass inlet, n=10 at upper bypass outlet, and n=10 at lower bypass outlet). For this study we used primarily larval lampreys of both species (Pacific Lamprey and Western Brook Lamprey) from the same sources as the 2016 releases. At this point in time (2017), only two arrays were in operation (one by the upper bypass inlet and one by the lower bypass inlet), but no detections were made by the lower bypass inlet.

Of the five separate releases, the highest detection rates were observed for the upper bypass outlet (30.0%), followed by bypass inlet (9.1%), and downstream of trash rack (2.4%). No detections were observed for the releases at the upstream end of Sunnyside Diversion and at the lower bypass outlet, suggesting less than 2.4% and 9.1% detection rates, respectively. This group of releases showcased that the detection efficiency within the bypass section of Sunnyside Diversion (0-30.0%) is considerably lower than that from Chandler Diversion (77.8-88.9%), and consequently a much larger sample size is needed to assess diversion entrainment ratio and lamprey movement behavior, given the existing setup. Despite the lower bypass outlet not detecting any of our tags, the detection for the upper bypass outlet and bypass inlet were considerably higher (30.0 and 9.1%, respectively). If the lower bypass outlet was indeed detecting 0% at the time of the release, this indicates that about 30.3% (=0.091÷0.3) of the lampreys at the bypass inlet may have been moving into the upper bypass outlet whereas the remaining (~69.7%) may have been entering the lower bypass outlet. Furthermore, we estimate that 26.4% (=2.4÷9.1) of the lampreys approaching the trash rack area are estimated to reach the bypass channel area, which is slightly lower than the estimate provided for Chandler Diversion (44.2%). Two tagged lampreys were detected further downstream at a later date; one lamprey released at the lower bypass outlet was detected at Bonneville Dam (B2J array) approximately 19 months later on

5/7/2019; one lamprey released at the canal inlet was detected at John Day Dam (JDJ array) approximately 20 months later on 6/12/2019.

Figure 3.8. Overview map of Sunnyside Diversion including the release locations within the canal on October 13, 2017 (canal inlet, trashrack, and bypass areas; white arrows). See Fig. 3.8 for more details on the bypass area release, which consists of three separate releases.

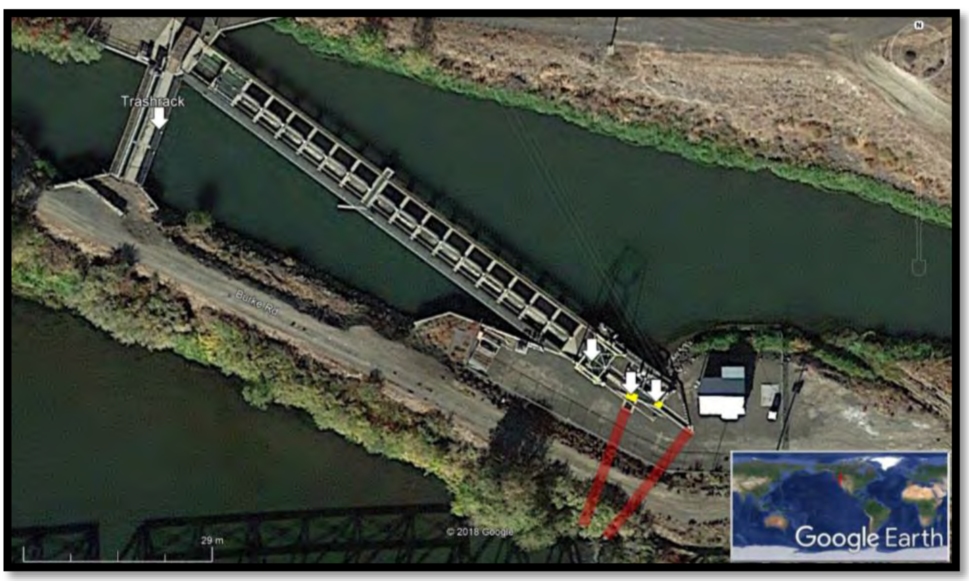


Figure 3.9. Overview map of Sunnyside Diversion fish screen area as well as the three release sites near the screens on October 13, 2017. One release was at the trashrack, another one was by the bypass inlet, and the third and fourth releases were directly in front of two bypass channels (red translucent polygons) that lead back to the mainsteam Yakima River (two new PIT arrays were installed just downstream of these two locations as depicted by the yellow lines).

2018 PIT Tag Releases

In 2018, a total of 459 lampreys were PIT tagged and released within the Yakima (n=455) and Columbia rivers (n=4). Within the Yakima River, there were five major groups of releases: Toppenish Cr. (n=383), Ahtanum Cr. (n=1), mid Yakima R. (n=23), mid-lower Yakima R. (n=19), and lower Yakima R. (n=29). Some of these releases were conducted in early spring (e.g. most of the Toppenish releases), whereas others were conducted in junction with the acoustic telemetry project, which started in May 2018. Table 3.3 summarizes all the detection data by release sites (in order of upstream to downstream and secondarily by date). No detections were made from Ahtanum Cr. and Columbia R. releases, which had very small sample sizes. Detections at Toppenish Creek lower PIT array (TOP; White Swan, WA) was 6.3% (based on all releases upstream). Detections at CJFMF in Lower Yakima River (PRO; Prosser, WA) was 1.0%. Detections from juvenile fish monitoring facility at McNary Dam (MCJ) and John Day Dam (JDJ) were 1.3% and 0.4%, respectively. Maximum swimming speed was 73.1 km day^{-1} [3.5 days from middle reach of Yakima River (river km 183.9) to McNary Dam], and two other lamprey had over 70 km day^{-1} migration rates (Table 3.4). Maximum number of detections per site per lamprey was 17 (from McNary Dam).

Table 3.3. Overview of all PIT tagged larval/juvenile lamprey releases and associated data in 2018. The release river km (RKM) as well as the Columbia and Yakima river RKM and overall RKM value (river km downstream to arrive at the mouth of Columbia River) are displayed for each release. The three letter abbreviation of the PIT array sites (see PTAGIS: https://www.ptagis.org/sites/map-of-interrogation-sites) from which detections were made are listed as a header with numbers of detection displayed. Using the overall number of PIT tagged lampreys that were released physically upstream of the PIT array sites, detection rates were calculated for each PIT array. If any of the PIT tagged larvae/juvenile were detected twice (# x2) or three times (# x3), the number of those lampreys are listed. Average number of days to detection, migration speed, and number of detections were calculated and listed as well. The overall total (for count values) and average values (for percent and average values) are also shown by rivers at the bottom of the table. Color coding is used for the percent and average values to help find the high (dark blue color) and low (dark red color) values.

Release River	Release RKM	Release Date	Release Time	Columbia RKM	Yakima RKM	Overall RKM Value	Total #	TOP	PRO	MCJ	JDJ	ALL	TOP -	PRO -	MCJ -	JDJ -	ALL	# x2	# x3	Days to Detection	Migration Speed (km/day)	# Reads
Ahtanum	4.3	4/16/2018	16:45	539	177	720	1	0	0	0	0	0	-	0%	0%	0%	0%	0	0	-	-	-
Toppenish	44.6	1/25/2018	16:15	539	130	714	63	4	0	0	0	4	6%	0%	0%	0%	6%	0	0	24.3	6.4	2.3
Toppenish	44.6	1/30/2018	18:00	539	130	714	52	2	0	0	0	2	4%	0%	0%	0%	4%	0	0	7.2	7.1	1.0
Toppenish	44.6	2/5/2018	15:25	539	130	714	27	3	0	0	1	4	11%	0%	0%	4%	15%	0	0	8.1	17.5	1.8
Toppenish	44.6	2/8/2018	17:20	539	130	714	40	1	1	0	0	2	3%	3%	0%	0%	5%	0	0	5.7	15.5	7.0
Toppenish	44.6	4/10/2018	16:24	539	130	714	3	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	-	-	-
Toppenish	7.3	1/22/2018	11:04	539	130	676	1	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	-	-	-
Toppenish	7.3	1/30/2018	13:30	539	130	676	6	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	-	-	-
Toppenish	7.3	7/6/2018	17:00	539	130	676	22	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	-	-	-
Toppenish	4.5	1/30/2018	16:30	539	130	674	27	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	-	-	-
Toppenish	4.5	2/8/2018	16:45	539	130	674	37	2	1	1	1	3	5%	3%	3%	3%	8%	0	1	38.6	19.8	4.6
Toppenish	2.8	1/30/2018	16:45	539	130	672	27	1	1	0	0	2	4%	4%	0%	0%	7%	0	0	3.1	11.1	4.0
Toppenish	2.8	2/8/2018	17:20	539	130	672	37	7	0	0	0	7	19%	0%	0%	0%	19%	0	0	0.1	10.3	1.1
Toppenish	2.8	4/12/2018	18:20	539	130	672	41	4	1	1	0	6	10%	2%	2%	0%	15%	0	0	4.6	14.5	2.7
Yakima	183.9	5/15/2018	10:17	539		723	20	0	0	3	0	3	-	0%	15%	0%	15%	0	0	-	-	-
Yakima	176.2	3/1/2018	13:30	539		715	3	0	0	0	0	0	-	0%	0%	0%	0%	0	0	-	-	-
Yakima	74.5	4/6/2018	12:00	539		614	3	0	0	0	0	0	-	-	0%	0%	0%	0	0	-	-	-
Yakima	74.5	4/16/2018	13:30	539		614	1	0	0	0	0	0	-	-	0%	0%	0%	0	0	-	-	-
Yakima	74.5	4/24/2018	18:45	539		614	2	0	0	0	0	0	-	-	0%	0%	0%	0	0	-	-	-
Yakima	74.5	5/24/2018	16:30	539		614	11	0	0	0	0	0	-	-	0%	0%	0%	0	0	-	-	-
Yakima	74.5	6/7/2018	15:00	539		614	1	0	0	0	0	0	-	-	0%	0%	0%	0	0	-	-	-
Yakima	74.5	9/15/2018	12:00	539		614	1	0	0	0	0	0	-	-	0%	0%	0%	0	0	-	-	-
Yakima	6.3	5/15/2018	13:28	539		545	29	0	0	1	0	1	-	-	3%	0%	3%	0	0	1.5	51.6	8.0
Columbia	535.1	7/24/2018	16:30			535	4	0	0	0	0	0	-	-	0%	0%	0%	0	0	-	-	-
Total	-	-	-	-	-	-	**459**	**24**	**4**	**6**	**2**	**34**	**6.3%**	**1.0%**	**1.3%**	**0.4%**	**7.4%**	**0**	**1**	**11.0**	**19.1**	**3.6**
Ahtanum	-	-	-	-	-	-	**1**	**0**	**0**	**0**	**0**	**0**	**0%**	**0%**	**0%**	**0%**	**0%**	-	-	-	-	-
Toppenish	-	-	-	-	-	-	**383**	**24**	**4**	**2**	**2**	**30**	**6%**	**1%**	**1%**	**1%**	**8%**	-	-	**12.0**	**13.2**	**2.7**
Yakima	-	-	-	-	-	-	**71**	**0**	**0**	**4**	**0**	**4**	**0%**	**0%**	**6%**	**0%**	**6%**	-	-	**3.0**	**66.6**	**10.3**
Columbia	-	-	-	-	-	-	**4**	**0**	**0**	**0**	**0**	**0**	**0%**	**0%**	**0%**	**0%**	**0%**	-	-	-	-	-

Table 3.4. 2019 Summary data for four PIT array sites (TOP=Lower Toppenish, PRO=Prosser Dam / CJFMF, MCJ=McNary Dam Juvenile Fish Monitoring Facility, and JDJ=John Day Dam Juvenile) (*ALL=all sites combined). See PTAGIS: https://www.ptagis.org/sites/map-of-interrogation-sites. Average, maximum, and minimum values for 1) number of days to detection, 2) migration speed, and 3) number of detections are displayed.

Variables	TOP	PRO	MCJ	JDJ	ALL
Ave Days to Detection	5.2	4.5	22.1	59.7	11.0
Max Days to Detection	0.0	9.3	94.3	97.3	97.3
Min Days to Detection	0.0	1.2	1.5	22.1	0.1
Ave Migration Speed	11.7	27.8	46.0	10.0	19.1
Max Migration Speed	27.3	48.8	73.1	16.6	73.1
Min Migration Speed	0.6	9.3	2.2	3.4	0.1
Ave # Reads	1.4	9.0	8.3	4.0	3.6
Max # Reads	6.0	13.0	17.0	4.0	17.0
Min # Reads	1.0	4.0	4.0	4.0	1.0

2019 PIT Tag Releases

In 2019, a total of 772 lampreys were PIT tagged and released within the Yakima (n=620) and Columbia rivers (n=152). Within the Yakima River, there were five major groups of releases: Ahtanum Cr. (n=4), Toppenish Cr. (n=128), Satus Cr. (n=87), mid Yakima R. (n=154), and mid-lower Yakima R. (n=247). Some of these releases were conducted in the winter (e.g., Satus releases), some in early spring (e.g. Ahtanum, Toppenish, and Yakima releases), whereas others were conducted in junction with the acoustic telemetry project, which started in May/June 2018. Table 3.5 summarizes all the detection data by release sites (in order of upstream to downstream and secondarily by date).

No detections were made from Ahtanum Cr. release, which had very small sample sizes. Detection at Satus Creek lower PIT array (SAT; Satus, WA) was 14.9%. Detections at Toppenish Creek lower PIT array (TOP; White Swan, WA) was 6.3% (exactly the same as the 2018 detection rate). Detections at CJFMF in Lower Yakima River (PRO; Prosser, WA) was 8.5%, a considerable increase from 1.0% detected in 2018. Detection at CJFMF was 12~13% from most Yakima tributary and lower Yakima mainstem releases, but was nearly 0% from the mid Yakima releases, suggesting that possibly something may be happening to these lamprey in that mid upper reach (diversions at Wapato/Sunnyside, predation, etc.). Most detections (89%) at CJFMF were from "Smolt Bypass Separator/Sample" arrays, but a small # were detected at the ladders (2.2, 4.4, 2.2% at left, center, right ladders, respectively), and 2.2% were detected last at "Smolt Bypass Sample Room Exit".

Detections from juvenile fish monitoring facility at McNary Dam (MCJ) and John Day Dam (JDJ) were 1.0% and 1.3%, respectively, which is slightly less than the detection rates from 2018 (1.3% and 0.4%, respectively). At John Day and McNary dams, 60% and 63% were last detected at "Full Flow Bypass" and 40% and 38% were last detected at "River Exit". In addition, for the first time we had a couple detections at the PH2 juvenile fish monitoring facility, resulting in 0.3% detection rates. Average migration speed was 11.1-18.2 km day^{-1} at the various PIT array sites (Table 3.6). Maximum swimming speed detected at various PIT array sites ranged from 20.1-44.6 km day^{-1} [1.3 days from lower Toppenish Creek to CJFMF for the highest rate], and five other lamprey had migration rates close to 40 km day^{-1}. Maximum number of detections per site per lamprey was 51 (from Bonneville Dam).

Table 3.5. Overview of all PIT tagged larval/juvenile lamprey releases and associated data in 2019. The release river km (RKM) as well as the Columbia and Yakima river RKM and overall RKM value (river km downstream to arrive at the mouth of Columbia River) are displayed for each release. The three letter abbreviation of the PIT array sites (see PTAGIS: https://www.ptagis.org/sites/map-of-interrogation-sites) from which detections were made are listed as a header with numbers of detection displayed. Using the overall number of PIT tagged lamprey that were released physically upstream of the PIT array sites, detection rates were calculated for each PIT array. If any of the PIT tagged larvae/juvenile were detected twice (# x2) or three times (# x3), the number of those lamprey are listed. Average number of days to detection, migration speed, and number of detections were calculated and listed as well. The overall total (for count values) and average values (for percent and average values) are also shown by rivers at the bottom of the table. Color coding is used for the percent and average values to help find the high (dark blue color) and low (dark red color) values.

Release River	Release RKM	Release Date	Release Time	Columbia	Yakima	Release RKM Value	Total #	TOP	SAT	PRO	MCJ	JDJ	B2J	ALL	TOP -	SAT -	PRO -	MCJ -	JDJ -	B2J -	ALL	# x2	# x3	Days to Detection	Migration Speed (km/day)	# Reads
Ahtanum	4.8	3/18/2019	13:55	539	177	721	4	0	0	0	0	0	0	0	-	-	0%	0%	0%	0%	0%	0	0	-	-	-
Toppenish	44.6	3/18/2019	17:00	539	130	714	60	3	0	3	1	3	1	9	5%	-	5%	2%	5%	2%	15%	2	0	10.8	19.7	16
Toppenish	44.5	3/19/2019	11:30	539	130	714	3	0	0	1	0	0	0	1	0%	-	33%	0%	0%	0%	33%	0	0	9.6	10.2	3
Toppenish	44.5	3/20/2019	11:30	539	130	714	1	0	0	0	0	0	0	0	0%	-	0%	0%	0%	0%	0%	0	0	-	-	-
Toppenish	2.8	3/21/2019	16:57	539	130	672	64	5	0	11	2	1	1	18	8%	-	17%	3%	2%	2%	28%	0	1	5.8	23.7	6
Satus	5.1	1/25/2019	12:52	539	112	656	3	0	1	0	0	0	0	1	-	33%	0%	0%	0%	0%	33%	0	0	0.3	0.3	1
Satus	5.1	2/8/2019	14:00	539	112	656	30	0	4	2	0	0	0	6	-	13%	7%	0%	0%	0%	20%	0	0	23.0	0.5	2
Satus	5.1	3/21/2019	16:40	539	112	656	54	0	8	9	1	5	0	20	-	15%	17%	2%	9%	0%	37%	3	0	8.3	15.4	9
Yakima	183.9	5/2/2019	17:25	539		723	78	0	0	1	0	0	0	1	-	-	1%	0%	0%	0%	1%	0	0	29.2	3.7	3
Yakima	183.9	6/6/2019	19:15	539		723	76	0	0	0	0	0	0	0	-	-	0%	0%	0%	0%	0%	0	0	-	-	-
Yakima	76.9	5/2/2019	16:00	539		616	79	0	0	13	0	0	0	13	-	-	16%	0%	0%	0%	16%	0	0	22.0	0.6	3
Yakima	76.9	6/6/2019	17:20	539		616	75	0	0	5	0	0	0	5	-	-	7%	0%	0%	0%	7%	0	0	4.2	3.3	3
Yakima	74.5	3/22/2019	13:04	539		614	11	0	0	0	0	0	0	0	-	-	-	0%	0%	0%	0%	0	0	-	-	-
Yakima	74.5	3/26/2019	16:15	539		614	39	0	0	0	0	1	0	1	-	-	-	0%	3%	0%	3%	0	0	54.3	4.9	26
Yakima	74.5	3/27/2019	15:30	539		614	43	0	0	0	0	0	0	0	-	-	-	0%	0%	0%	0%	0	0	-	-	-
Columbia	535.1	6/13/2019	12:00			535	75	0	0	0	2	0	0	2	-	-	-	3%	0%	0%	3%	0	0	8.0	8.1	30
Columbia	535.1	7/9/2019	14:30			535	77	0	0	0	2	0	0	2	-	-	-	3%	0%	0%	3%	0	0	25.1	8.2	33
Total	-	-	-	-	-	-	772	8	13	45	8	10	2	79	6.3%	14.9%	8.5%	1.0%	1.3%	0.3%	10.2%	5	1	12.0	13.1	8.3
Ahtanum	-	-	-	-	-	-	4	0	0	0	0	0	0	0	-	-	0%	0%	0%	0%	0.0%	-	-	-	-	-
Toppenish	-	-	-	-	-	-	128	8	0	15	3	4	2	28	6%	-	12%	2%	3%	2%	21.9%	-	-	7.6	21.9	9
Satus	-	-	-	-	-	-	87	0	13	11	1	5	0	27	-	15%	13%	1%	6%	0%	31.0%	-	-	11.0	11.9	7
Yakima	183.9	-	-	-	-	-	154	0	0	1	0	0	0	1	-	-	1%	0%	0%	0%	0.6%	-	-	29.2	3.7	3
Yakima	76.9	-	-	-	-	-	154	0	0	18	0	0	0	18	-	-	12%	0%	0%	0%	11.7%	-	-	17.1	1.3	3
Yakima	74.5	-	-	-	-	-	93	0	0	0	0	1	0	1	-	-	-	0%	1%	0%	1.1%	-	-	54.3	4.9	26
Columbia	-	-	-	-	-	-	152	0	0	0	4	0	0	4	-	-	-	3%	0%	0%	2.6%	-	-	16.6	8.2	31

Table 3.6. Summary data in 2019 for PIT tagged larval/juvenile lamprey for six PIT array sites (TOP=Lower Toppenish, SAT=Lower Satus, PRO=Prosser Dam / CJFMF, MCJ=McNary Dam Juvenile Fish Monitoring Facility, JDJ=John Day Dam Juvenile Fish Monitoring Facility, and B2J=Bonneville Dam PH2 Juvenile Fish Monitoring Facility) (*ALL=all sites combined). See PTAGIS: https://www.ptagis.org/sites/map-of-interrogation-sites. Average, maximum, and minimum values for 1) number of days to detection, 2) migration speed, and 3) number of detections are displayed.

Variables	TOP	SAT	PRO	MCJ	JDJ	B2J	ALL
Ave Days to Detection	0.9	1.4	11.4	24.5	24.4	25.8	12.0
Max Days to Detection	2.3	16.7	76.2	75.2	54.3	29.4	76.2
Min Days to Detection	0.1	0.1	0.2	4.3	14.2	22.2	0.1
Ave Migration Speed	11.4	0.7	16.6	11.1	15.1	18.2	12.0
Max Migration Speed	20.1	1.6	44.6	27.7	21.7	21.6	76.2
Min Migration Speed	6.3	0.0	0.0	1.4	4.9	14.9	0.1
Ave # Reads	1	1	3	24	29	41	8
Max # Reads	1	1	5	35	43	51	51
Min # Reads	1	1	1	13	18	31	1

3.2 Deep Water Electrofishing – Phase I

Because our estimation of lamprey abundance are based primarily on backpack electrofishing in shallow water and manual removal from dry sediment during and after dewatering, limited information is available regarding the abundance of lampreys during irrigation withdrawal period and how their numbers fluctuate in diversions within the irrigation season. Attaining this type of data allows us to learn considerably about the movement of lampreys into and within the diversions, which is a large knowledge gap. In collaboration with Pacific Northwest National Laboratory (PNNL), YN Fisheries has worked on estimating the number of lampreys during the irrigation season between 2015 and 2017.

Larval lamprey surveys were conducted using a deep-water electrofishing platform (DEP) deployed from a small floating platform at Wapato and Sunnyside diversion screens in October 2015 (Fig. 3.10 and Fig. 3.11; Mueller 2016a). PNNL developed the DEP to document larval lampreys that inhabit water at depths ranging from 1-9 m. The system was deployed from a portable boat which has the capability of surveying in small water bodies where motorboats cannot access. Lampreys are known to enter these regions as larvae and rear in the sediments deposited as water velocities slow near the fish screens. Currently no method exists to survey these regions and determine presence/absence, density, and size classes of larvae that are rearing near these facilities. The DEP has been laboratory and field tested, and shown to be an extremely effective tool at determining the presence/absence of larval lampreys as well as characterizing the physical habitat parameters encountered during the surveys.

Within the Sunnyside headgate forebay region (Fig. 3.12), suitable substrates were estimated to be 93.4 m^2 and lamprey density was estimated at 2.5 fish per m^2, which indicate ~232 lampreys occupying this region. The total survey area was 2,870 m^2 downstream of the screens and the total estimated survey area was 10.82 m^2 (Fig. 3.13). Seventy–five lampreys were observed across all size ranges. Within the suitable region (Type I and II substrates), 8.5 m^2 was surveyed with a density of 8.8 fish per m^2 and the total estimated lampreys inhabiting this region was 12,408.

At the Wapato headgate only a small region (3.3 m^2; Fig. 3.14) which was found in the upper portion adjacent to the log boom walkway was found to have suitable substrates. A total of 4 lampreys were observed in this region. Based on the surveyed area and a density of 4.2 fish per m^2, a total of 14 lampreys might be expected to occur. At the screens forebay region (Fig. 3.15), 50 lampreys were observed across all size ranges. The total survey area polygon was 2,220 m^2 and the total estimated survey area was 10.41 m^2. The suitable region encompassed 1,452 m^2 and an estimated 7.7 m^2 was surveyed with the DEP. The estimated density within the suitable region was 6.5 fish per m^2 and the total estimated lampreys that may be inhabiting this region was 9,404.

This was the first use of a portable electrofishing boat that was designed to be used in small hard to access water bodies. The system performed very well and enable us to surveys these regions effectively and determine relative larval lamprey densities. See Mueller (2016) for more information.

Figure 3.10. Bob Mueller (PNNL) operating the deepwater electrofishing platform at Sunnyside Diversion behind the fish screens.

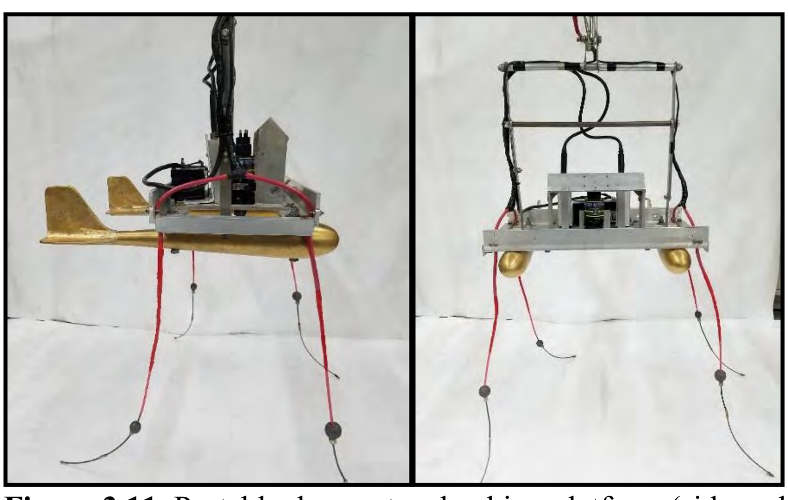


Figure 3.11. Portable deepwater shocking platform (side and front view).

Figure 3.12. Sunnyside headgate region illustrating total survey region (yellow and blue polygons) and suitable region (blue polygons) from surveys conducted on October 21, 2015.

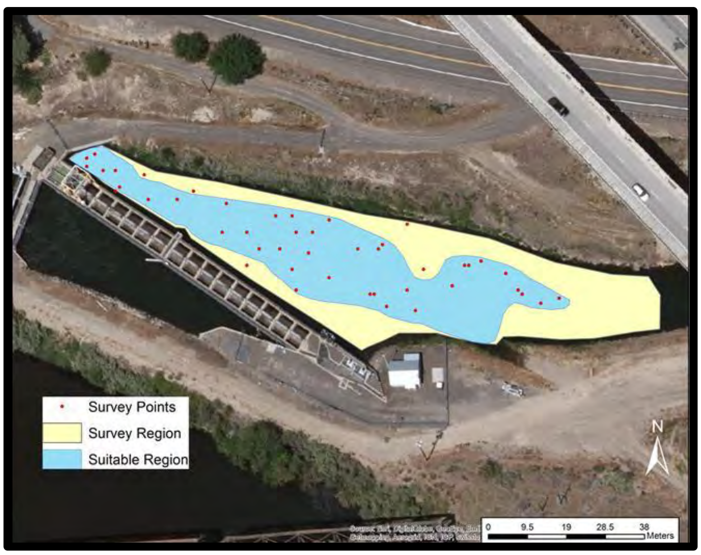


Figure 3.13. Sunnyside screen region illustrating sampling locations (red dots), total survey region (yellow and blue polygons) and suitable region (blue polygons) from surveys conducted on October 21, 2015.

Figure 3.14. Wapato headgate region illustrating total survey region (yellow and blue polygons) and suitable region (blue polygons) from surveys conducted on October 15, 2015.

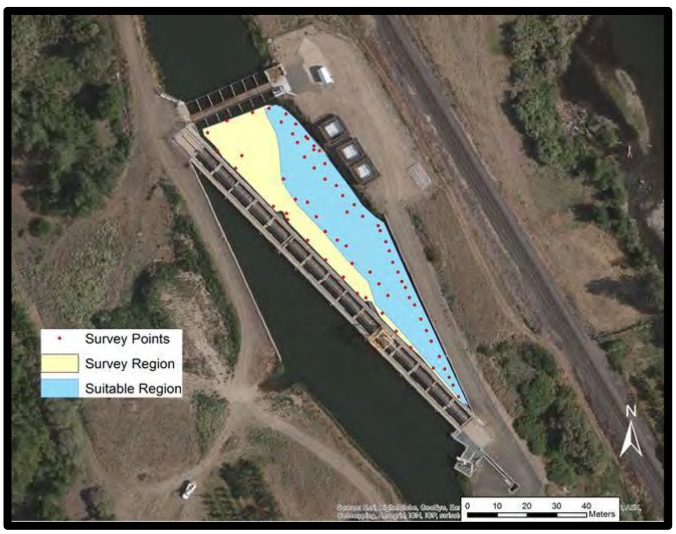


Figure 3.15. Wapato screen forebay region illustrating sampling locations (red dots), total survey region (yellow and blue polygons) and suitable region (blue polygons) from surveys conducted on October 15, 2015.

3.3 Deep Water Electrofishing – Phase II

In 2017, Pacific Northwest National Laboratory (PNNL), DC Consulting LLC and staff from the Yakama Nation conducted deep water larval lamprey surveys within Sunnyside Diversion Fish Screening Facility to determine lamprey relative abundance and temporal changes in abundance over time (Fig. 3.16; Mueller 2018). We used a deep-water electrofishing platform (DEP) designed and built by PNNL and deployed it from a survey boat (4 m V-hulled fishing boat).

The Sunnyside Diversion Dam is located at Rkm 165.7 of the Yakima River. Water is diverted from the river at flow rates up to 37 m^3 sec^{-1} during the irrigation season which starts in mid-March. The canal is normally dewatered mid to late October. The facility consists of a headgate, 15 drum screens, trash rack, and fish return bypass systems. The survey location included the region immediately downstream of the drum screens in the canal. Two surveys were conducted on August 16 and September 25, 2017 (Fig. 3.4.1). On the first survey, a total of 70 locations were electroshocked within the region of interest in water depths ranging from 1.4 to 4 m. Water clarity was conducive to electrofishing with ~1 m visibility. The majority of the substrates were Type I or Type II. Hard and rocky bottom was observed along the immediate downstream portions of the screens and along the north canal bank. A total of 18 larval lampreys were observed across all size ranges. The total area surveyed using a 0.33 m^2 average was 23.1 m^2 and the overall density was estimated to be 0.74 fish per m^2.

The second survey was conducted on September 25, 2017 and a total of 60 locations were surveyed. A total of 47 larval lampreys were observed across all size ranges. The total area surveyed using a 0.33 m^2 average, was 19.8 m^2 and the overall density was estimated to be 2.4 fish per m^2. Based on our survey in 2017, larval lamprey densities increased from less than 1 lamprey per m^2 (estimated 1,128 lampreys) in August, 2017, to 2.4 m^2 (estimated 3,066 lampreys) over a 40-day period (Table 3.18). YN Fisheries also made an estimate of lamprey numbers after dewatering 37 days later on November 1, 2017, using shallow water electrofishing. This estimate (6,582) was considerably larger than the September estimate (3,066). It is apparent that large fluctuations do occur from year to year as lamprey entraining rates may be impacted by population fluctuations, annual fluctuations in discharge, local changes in channel hydrology and river bottom configurations, and mortalities associated with dewatering operations.

See Mueller (2018) for more information. A manuscript is also in its final stages for submission to North American Journal of Fisheries Management, summarizing the 2015 and 2017 data from Sunnyside and Wapato diversions. In summary, the estimates for the total lamprey numbers at each of the region using a portable deepwater electrofishing platform (PDEP) was very similar to those estimates using backpack electrofishing post-dewatering; the PDEP method was 12− 36% higher where comparisons were available from similar survey dates. From the continuous monitoring that occurred in 2017 in August, September, and early November at Sunnyside Diversion, we documented a 200% and 95% increase in total larval lamprey estimates, respectively, indicating that larval lamprey numbers may be increasing rapidly during this late summer months (Fig. 3.18). Although larval/juvenile lampreys are known to move considerably during the high flow season, during those periods, the percent withdrawal from the irrigation diversion is considerably small due to the large portion of water that flow over the dams (see Fig. 3.7). As a result, entrainment into irrigation diversions may be considerably higher during the summer and fall months when the percent withdrawal are substantially higher, forcing more lampreys to interact with the diversion headgate. Part of this increase in estimated lamprey numbers could also be influenced by the visibility of young-of-the-year age 0+ larvae (increasing chances for these small larvae to be observed and detected over time). More research is needed to verify these results related to the temporal dynamics of larval and juvenile lamprey movement into these diversions. Our results indicate that the use of the deepwater shocking system was very safe and effective at determining larval lamprey densities at hard to sample regions which are present near irrigation facilities.

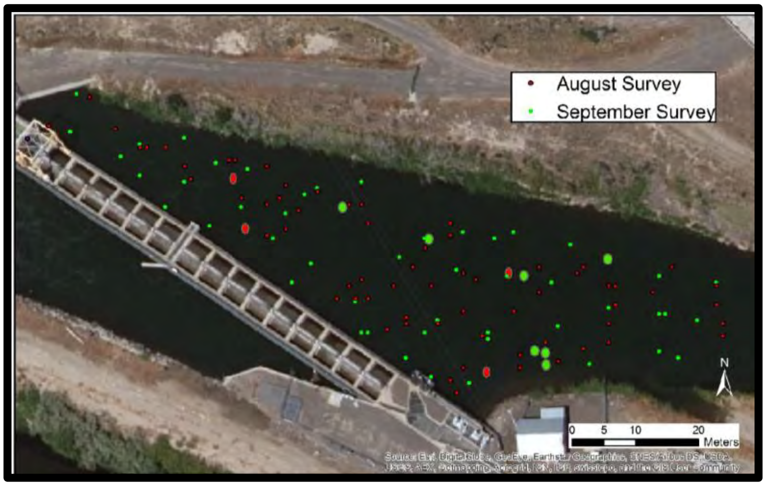


Figure 3.16. Location where more than one lamprey was observed indicated by the larger circles for the August and September surveys.

Table 3.7. Sampling parameters and lamprey densities observed downstream of Sunnyside Screening Facility on August 16 and September 25, 2017.

	Survey 1	Survey 2
Overall Size (m^2)	2,870	2,870
Suitable Region (m^2)[1]	1,410	1,410
Number of Lampreys Observed	18	47
Density (average)	0.8	2.4
Estimated Number	1,128	3,384

[1] Includes Type I and Type II substrate types

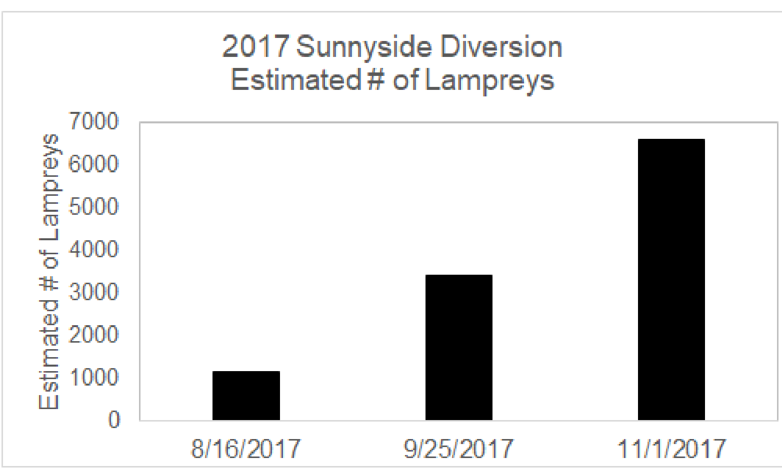


Fig. 3.18. Estimated numbers of lampreys in 2017 in late summer (mid August and late September) using deep water electrofishing methods and in early November using backpack electrofishing in shallow water in post dewatering conditions.

3.4 Deep Water Electrofishing - Roza Dam and Yakima River Delta

In 2015, PNNL and YN Fisheries staff also conducted deep water larval lamprey surveys near the Roza Dam Diversion Fish Screening Facility (Fig. 3.19) and at the Yakima River delta region (Fig. 3.20) to determine lamprey occurrence and provide a general assessment of substrate composition (Mueller 2017). Results from surveys indicated that very few larval lampreys are inhabiting deep water regions in Roza Dam forebay although suitable substrates are present and abundant; a total of four larval lampreys were observed in Type I and II substrates. Three of the four lampreys were found near the trash racks upstream from Screening Bay 5 at a water depth of 5.3 m, and the other was found ~515 m upstream from the facility at a water depth of 2.9 m. At the Yakima River delta, larval lamprey searches were conducted at three general areas consisting of the main river channel and delta regions to the north of the mouth. Most of the substrates in this region had significant macrophyte growth over soft sand/silt sediments reducing visibility. A total of three larval lampreys were observed in a relatively small region along the north section of the delta region in water depths of approximately 6 m in Type I and II substrates.

Figure 3.19. Roza Project area. Red line delineates the overall project area, light blue region delineates the zone that was surveyed and remains wetted year round, and blue line delineates the area that dries up during dewatering.

Figure 3.20. General survey regions near the Yakima River Delta.

3.5 Video and VIE Monitoring

In 2014, a video monitoring and VIE tag study was conducted to improve our understanding of larval lamprey behavior within the diversion and in front of fish screens (Lampman & Beals 2014a). At Congdon Diversion (Naches, WA; Fig. 3.21 and 3.22), which has a rotating drum screen (woven wire mesh size of 3/32"; Fig. 3.23), we conducted a mark-release-recapture study on larval/juvenile lampreys, using a total of 190 Western Brook Lamprey (31-171 mm) and 1,256 Pacific Lamprey (7-25 mm). We conducted three types of test releases 1) trap efficiency release, 2) screen release for video monitoring, and 3) upstream release, in addition to the dewatered canal sampling. The main objective of this study was to understand the mechanism through which larval lampreys can pass the fish screens. The second research question we pursued was the "fate" of juvenile/larval lampreys that enter a diversion.

The trap efficiency tests indicated that larvae can be effectively recaptured within various areas of the diversion (such as bypass and canal outlet channels) using plankton and custom-made nets (Fig. 3.24; Fig. 3.25). When 0+ age larvae were released in the canal, capture efficiency from the plankton nets was correlated with the flow rates (Fig. 3.26). With the respective increase in flow rates, plankon nets set in the upper water columns captured more lamprey while those in the lower water column only increased capture efficiency slightly with the respective increase in flow rates. At this size, lampreys in swift water may be migrating closer to the surface rather than the stream bottom in or near the thalweg channel.

Through the screen tests using video monitoring, we observed and documented a wide variety of behavior in front of the fish screens, which we categorized into six general modes, including "escaped", "averted", "rolled", "impinged", and "passed" (Fig. 3.27). These various modes of behavior were strongly related to the size classes of the larvae; for example, 85.7% of the large larvae (>85 mm) were able to "avert" the screens whereas 94.1% of the 0+ age larvae "passed" directly through the screens (Fig. 3.28). As a result of the upstream release tests, we discovered that the vast majority of larvae remained inside the diversion and very few larvae actually moved out into the bypass (<3%) or canal outlet channels (<2.4%) immediately after release. The distribution and abundance of fine sediment within the diversion may play a large role in where larval lampreys will disperse. However, over time these larvae appear to be moving out of the diversion; through dewatered canal sampling using VIE tags, we found that only a small portion of larvae (<7%) remained in the diversion project area after dewatering. Furthermore, many of the VIE tagged larvae were found below the fish screens, regardless of size classes, indicating that even large lampreys (>124 mm) can be vulnerable to entrainment.

Although the results from this study inevitably only portray the outcome from one single site, it seems to encapsulate the conundrum of lamprey entrainment. Our screen test release, similar to the study conducted by Rose and Mesa (2012), demonstrated that many of the small and medium size larvae (<85 mm) can pass through the fish screens, either by passing directly, slithering through, or rolling over. Our upstream test release suggests that the majority of lampreys (whether large or small) remained within the diversion and entered neither the bypass nor the canal outflow at least in the short term. Even 0+ age Pacific Lamprey larvae, which appeared to be at the mercy of stronger currents based on trap recapture tests, showed that they can effectively find a place to borrow when fine sediment was available within the project area.

Because Congdon Diversion collects voluminous fine sediment upstream and downstream of the screens, lots of habitat exists for larval lampreys to burrow in. However, only a small portion of these larvae were later detected in the diversion after dewatering occurred, which indicates that the majority of larvae moved out of the fine sediment sometime between the release (in late September) and the dewatering canal sampling (in late October). Although our study depicts clearly what happens immediately after the release, whether larvae will move out of the diversion through bypass or canal outflow at night time when they are more active and/or days and weeks after the release requires further investigation. The emigration rate immediately after and during the dewatering period merits further research. A release study in spring when fine sediment deposition is minimal (due to facility maintenance involving dredging during the winter) may provide useful insights for their dispersal behavior. Fine sediment in irrigation diversions provides a noteworthy predicament. In a sense, fine sediment in diversions can be both a blessing and a curse for larval lampreys; blessing because we found very few that ventured down the canal outflow (despite the fact that the majority can move through the drum screens) and a curse because larvae will not use the bypass route, either, and will remain within the diversion for extended periods.

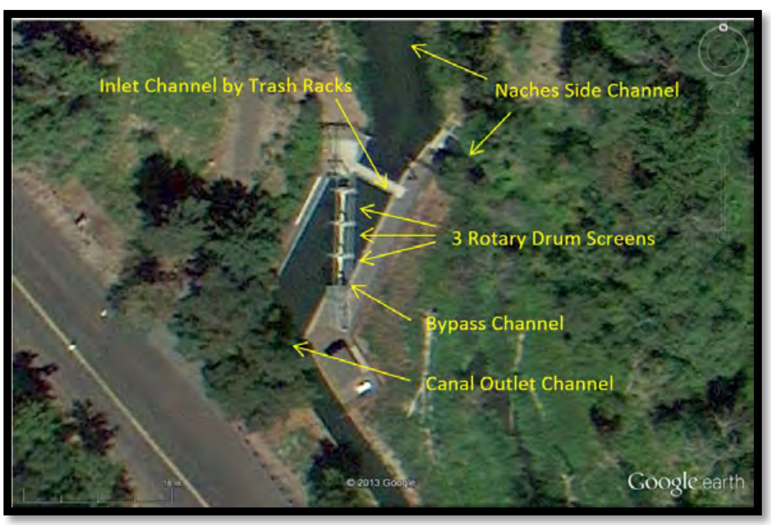


Figure 3.21. An aerial map of Congdon Diversion with labels for key components.

Figure 3.22. Looking upstream towards the three rotary drum fish screens at Condon Diversion.

Figure 3.23. Woven wire mesh with a 3/32" (2.84 mm) opening at Congdon Diversion.

Figure 3.24. Inserting a custom made net for the trap efficiency test in the bypass channel.

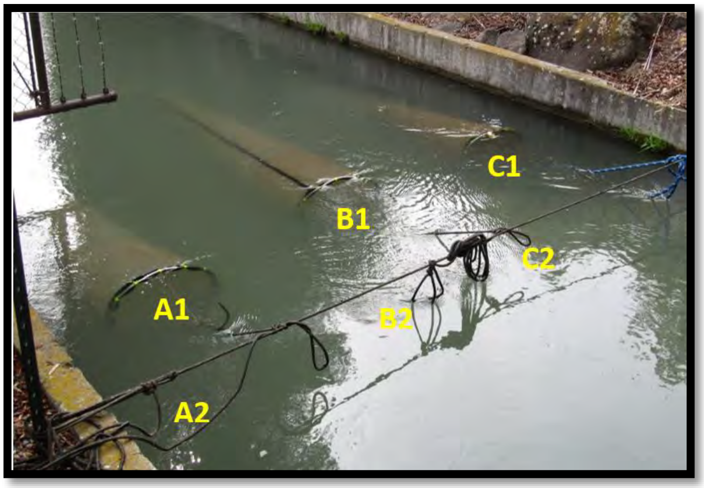


Figure 3.25. Three 0.5 m plankton nets placed in the upper water column inside the canal outlet channel to test the trap efficiency. "A1", "B1", and "C1" refer to the position of the net in the upper water column. When nets were placed on the bottom of the water, they were referred to as "A2", "B2", "C2."

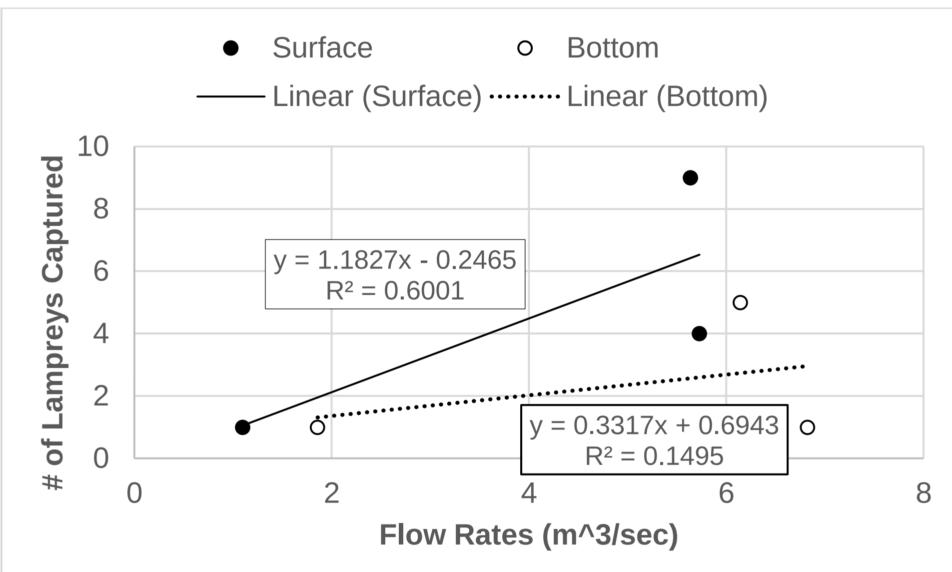


Figure 3.26. Number of recaptured Pacific Lamprey 0+ age larvae and the mean discharge rate in each of the three plankton nets placed in the upper and bottom water columns.

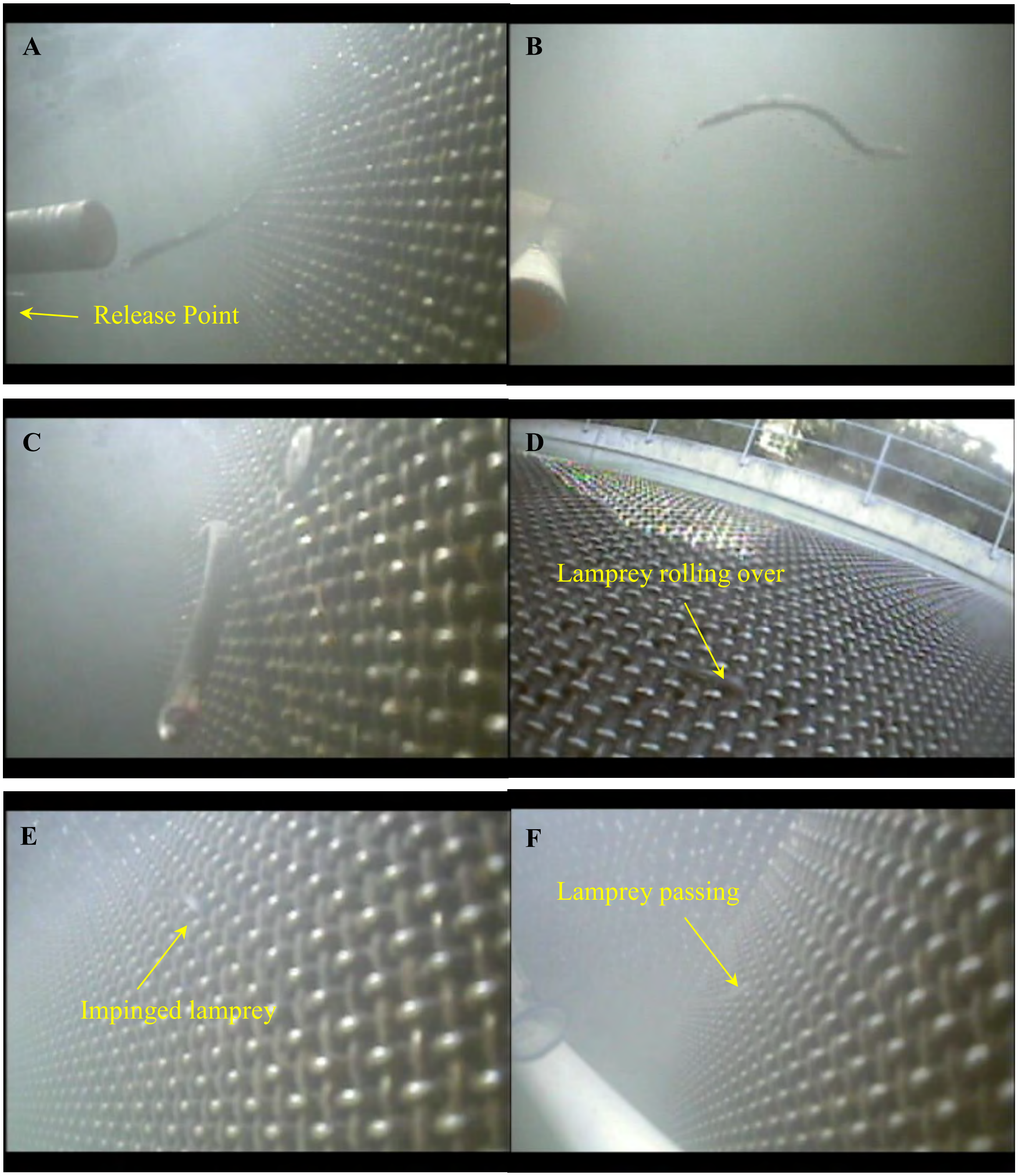


Figure 3.27. Still images from the underwater filming of screen release test, depicting various modes of behavior: typical release through the suction hose (A); "escaped" (B); "averted" (C); "rolled" (D); "impinged" (E); and "passed" (F).

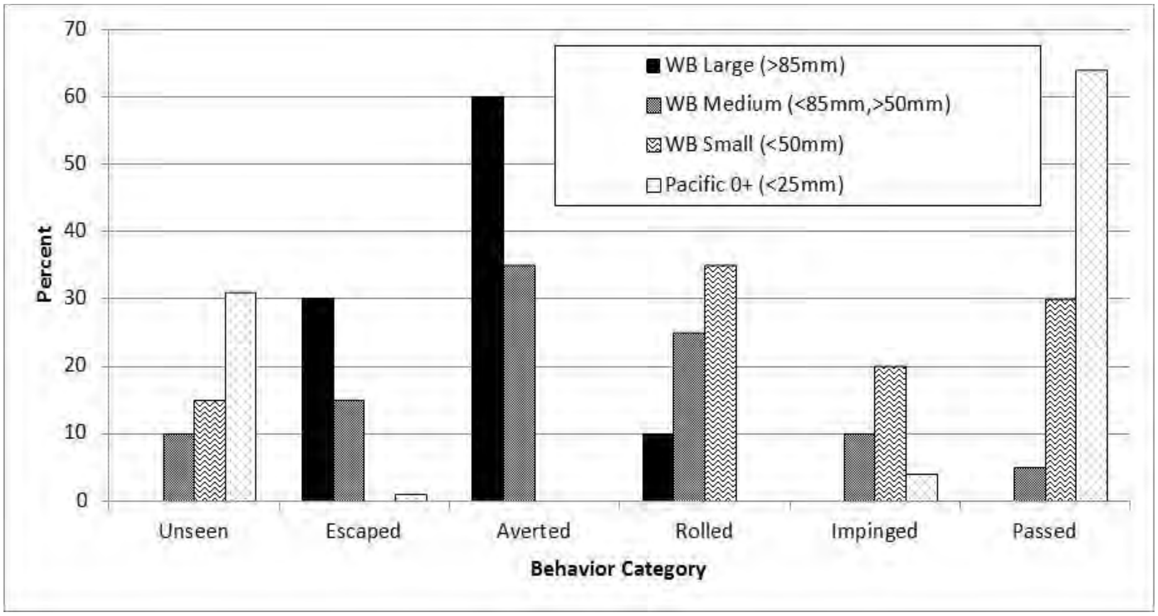


Figure 3.28. Percent histogram of the six modes of behavior displayed by four size classes of juvenile/larval lampreys at Congdon Diversion after releasing them in front of the rotary drum screens. See Fig. 3.27 for a photo of the modes of behavior.

Task 4: Methods to Improve the Efficiency of Lamprey Rescue

Our efforts focus on three core objectives during and after irrigation shut down; 1) check dried banks closely for the salvage of desiccated or desiccating lampreys, 2) efficiently rescue as many larval/juvenile lampreys in water as possible; and 3) return them to their respective stream downstream of the diversion. Having a good understanding of the lamprey distribution and densities upstream and downstream of the fish screens will help ensure the operation stays efficient. Freshwater mussel species can also occupy habitat that are being used by larval lampreys in irrigation diversions (typically more mussels are found in Type II habitat than Type I); these species should also be rescued during this operation (see Task 4.9).

To effectively rescue the highest percentage of larval and juvenile lampreys during and after a dewatering event (and ensure their best chances of survival), we perform operations in the following order. However, every site is unique and may require rescue/salvage efforts to occur in slightly different order than what is listed below:

1. Rescue stranded lampreys from dry banks
2. Perform the "dry shocking" technique on dry banks to reveal concealed lampreys
3. Rescue lampreys from isolated pools
4. Rescue lampreys from the main water body
5. Perform "blind netting" technique if water turbidity is high
6. Deploy a sprinkler system to keep dry banks moist (at end of day / overnight)
7. Return live lampreys back to the river downstream of the project headgate.

If more detailed understanding of entrained lamprey numbers is an important objective, see Task 2.4. We provide a general overview of how our program has estimated the number of lampreys in diversions, using Wapato Diversion as an example.

4.1 Backpack Electrofishing

During lamprey rescue operations, lampreys are often removed from wetted areas using a backpack electrofisher (Fig. 4.1). Electrofishing settings can greatly vary depending on the target species. Electrofishing for salmonid and most other fish species typically require much higher voltages and frequencies than what is needed for lamprey capture and often results in immobilization or worse yet electronarcosis of larval lampreys within the fine sediment they reside in. Some lampreys may emerge with the high voltage settings used for other species, but a large portion of the burrowing larval lampreys may remain within the fine sediment, preventing surveyors from ever seeing the majority of lampreys residing within the area of interest. Larval lampreys are best sampled using a two-stage settings including a "tickle" slow pulse setting that coaxes them from the substrate and a "stun" fast pulse setting that is used to immobilize them once they emerge from the substrate. Examples of electrofishers that have this capacity include ABP-2 backpack electrofishers from ETS Electrofishing Systems (Madison, WI) as well as LR-24 and

Apex backpack electrofishers from Smith-Root (Vancouver, WA). We use ABP-2 electrofisher and the standard larval lamprey electrofishing setting is: slow tickle pulse of 3 pulses/sec and fast stunning pulse of 30 pulses sec^{-1}, 25% duty cycle, 3:1 burst pulse train, 125 volts. As water temperatures drop in the fall (<10°C), the voltage is increased to 150-200 volts in order to compensate for the reduced conductivity.

In general, high densities of lampreys are typically found along the edge of the dewatered sediment and at the base of steep slopes (see Fig. 4.2). We recommend that rescue surveys focus primarily on wetted Type I habitat, which is preferred by larval lampreys and consists of fine sediment (sand, silt and clay) and/or detritus (fine and coarse organic matter). Type II habitat consists of a mix of fine and coarse sediment and can be surveyed as well, but densities tend to be lower (typically 10% of Type I). To preserve water clarity and reduce long-term exposure to electricity, we recommend the use of single passes at a steady pace (~1 min per m^2 of habitat covered). This is important especially in high density areas. The shock time, shocked area, and number of lampreys removed is recorded for each pass to provide density and catch per unit effort (CPUE), which helps guide the areas to prioritize. It is important to assess all potential locations so removal efforts can focus on the highest densities of lampreys first. All captured lampreys are immediately placed into flow through mesh baskets until counting, identification, and release takes place (or until density is too high within mesh baskets).

Although electrofishing is considered one of the most effective methods to sample and capture larval lampreys, its efficiency is typically estimated to be only about 50% (often ranging between 20-80%) (Harvey & Cowx 2003; Steeves et al. 2003; Lasne et al. 2010). The efficiency decreases considerably in high density and high turbidity conditions and for smaller larvae (especially young-of-the-year larvae) (see Task 2.4). In irrigation diversions where dewatering has already begun, water is often very turbid and densities are often very high (from lampreys being forced to move into smaller and smaller available wet habitat), greatly reducing the visibility and capture efficiency extensively. Larval lampreys that emerge but escape capture often burrow right back into the nearest fine sediment; these lampreys that already came out once are usually very difficult to capture as they tend to remain in the fine sediment persistently despite extra electrofishing efforts to coax them out. The YN Fisheries annual average CPUE from electrofishing ranged from 2.3-21.7 lampreys min^{-1} (slow pulse time) between 2014 and 2018, which equates to approximately 51-492 lampreys $hour^{-1}$ (Total Time CPUE; see Task 2.1). Conversely, given that 25,000 or more lampreys could reside in some of these large scale diversions, it will take 50-500 hours for a crew of 2 people to remove all the lampreys from one facility. As a result, rescuing thousands of lampreys within diversions can be quite time consuming, often resulting in several days or more of electrofishing within these large diversions.

Figure 4.1. YN Fisheries crew conducting backpack electrofishing in Wapato Diversion upstream of the fish screens in winter of 2018. Dave'y Lumley (left) electrofishing while Shekinah Saluskin (right) assists with the fine mesh net and lamprey containers.

Figure 4.2. An example of open water areas that can be electrofished after stranded lampreys are recovered. In the left photo (Sunnyside Diversion), larval lamprey densities tend to be highest along the banks, especially towards the base of the taller mounds. In the right photo (Wapato Diversion), lamprey densities tend to be high along the bank, especially along the steeper banks.

4.2 Blind Netting in High Turbidity Conditions

"Blind netting" is a useful technique that could be used in high turbidity and low visibility water conditions whereby the netter(s) scoops through the electrofished water to capture anything that may be in the turbid water even without any direct observation of lampreys (Fig. 4.3). In many cases, the water clarity during a diversion salvage will become turbid, and it will become very difficult to see larval lampreys during electrofishing (Fig. 4.4). Blind netting consists of a second person (netter) waving a fine mesh net through the water (near the bottom) during the electrofishing survey to capture escaping lampreys that are not seen. This method is particularly effective in shallow water (or isolated pools). This method can capture all size classes of larval/juvenile lampreys, although it appears to be most effective in capturing small lampreys (< 50 mm) as they swim much slower when they escape the sediment, and are easily captured in the net. Perform the blind netting technique throughout the survey area, but focus in areas where larvae densities are expected to be high (such as edges of wetted habitat, base of steep slopes, or along concrete walls where lampreys seem to congregate). In high density and high turbidity water conditions and at appropriate water depth (typically 16" or less), this method can be quite effective, allowing surveyors to continue to electrofish and rescue lampreys despite the high turbid and low visibility conditions. However, many lampreys can still be left behind with this method and care is needed to ensure you do not electrofish lampreys in one area over and over (best to maintain a 1 m^2 min^{-1} electrofishing pace to stay on the move).

Figure 4.3. Example of conditions (high turbidity and high density of lampreys) in which "blind netting" can be effective in rescuing lampreys. Netters with large size nets can scoop the area surrounding the electrofishing probes back and forth to capture any invisible larvae that emerge from the fine sediment.

Figure 4.4. Highly turbid water encountered during a lamprey salvage operation at Upper WIP Diversion on Ahtanum Creek in July, 2019. Blind netting was used to capture larval lampreys during this salvage operation.

4.3 Manual Collection

As water recedes in irrigation diversions or streams/rivers, a portion of the larval lampreys will remain burrowed in the fine sediment and emerge from the substrate at various timing after the substrate gets dewatered (often depending on the rate of dewatering and sediment conditions as discussed under Task 3; Fig. 4.5). Manually picking these larval and juvenile lampreys as they emerge is another useful method available to rescue numerous lampreys without the aid of any specialized equipment. In areas where lampreys appear to be concentrated, the substrate could also be dug by hand or using hand tools to locate the ones that are still in the burrow to increase efficiency. In naturally deposited fine sediment, the majority of larval lampreys are found within the top 6 inches (Liedtke et al. 2015), so there is no need to excavate very deep. However, in mechanically laden sediment piles that are part of sediment dredging and/or excavation, for instance, it is possible for larval lampreys to get buried inside much deeper layers of substrate.

Manually picking up lampreys from dry or drying banks is an important rescue strategy during dewatering activities as many will not be able to return volitionally to standing water, especially when the dewatering rates are fast (>20 cm hour^{-1}). At the same time, a large portion of lampreys tend to remain inside the substrate despite the bank losing water (estimated as ~50% according to Liedtke et al. 2015), and it is difficult to predict when exactly they will all emerge. A large portion of those that do emerge will do so relatively quickly after the dewatering, but others may emerge much later and a considerable portion will stay put in the substrate till the sediment dries out further (or till they reach their death from desiccation within the substrate). CPUE for bank collection varies considerably, but can be as high as 500-1,000 lampreys hour^{-1} (such as at Wapato and Sunnyside diversions). Often, though, when the densities are at such high levels, a considerable portion will also become desiccated and turn into mortality. When dewatering is forcing many lampreys to emerge, it makes sense to focus on collecting those lampreys on the dry banks as they need the utmost care to ensure survival and recovery; missing the chance to get them in time will lead to a high portion of mortalities.

It is important to check the entire dewatered surface (do not get caught up picking up lampreys in one location). It is important to assess all potential locations so removal efforts can focus on the highest densities of live lampreys first, then move to areas with more desiccated lampreys. Once the area is assessed for bank lampreys, focus your collection on live lampreys, then move onto dead lampreys. Get a tally of live and dead lampreys for the entire dewatered area (or estimate the total number of each group if time is limited). Highest densities of larval lampreys are likely to collect at the base of steep banks, flat surfaces or within concave surfaces (Fig. 4.6). Repeat daily as lampreys tend to emerge from the sediment even several days after the sediment surface has become dewatered.

Figure 4.5. Examples of desiccated larval lampreys on drying banks. Many larval lampreys will remain in the fine sediment for some time after the dewatering.

Figure 4.6. Desiccated larval lampreys on top of dewatered sediment at the base of a slope at Sunnyside Diversion shortly after dewatering in 2017. The left photo shows the sediment contour (overview of the steep slopes). The right photo shows about 100 dead larval lampreys accumulated at the low gradient area (zoomed in view of the left photo). A higher number of lampreys are often found in these types of depositional areas with debris (branches, rocks, etc.); lampreys are often found underneath the debris.

4.4 Dry Shocking

Due to the numerous limitations found in the two primary means of capturing lampreys, a few other approaches were invented to enhance the efficiency in capturing and rescuing lampreys during this Project period. A combination of the two primary methods, electrofishing in wet habitat and manual collection from dry banks, are termed "dry shocking" whereby lampreys are electrofished in dry or drying banks where they are stranded beneath the drying sediment. The drying banks often contain enough water and/or moisture underneath the sediment to still transfer electricity within the substrate and the lamprey-specific setting for the electrofishers are quite effective in coaxing lampreys to emerge out of the dry banks (Fig. 4.7 and 4.8). Larvae will emerge from the drying sediment and they can be manually picked up by hand or small dip nets as they wiggle their way out and try to slide down the sloped banks towards water. In some instances, such as when the density is high, the efficiency can be improved further by pouring some water (one to several 5-gallon buckets) over the drying banks immediately prior to electrofishing. For instance, lamprey containing substrate that dried up substantially (thwarting emergence of larval lampreys likely due to excessive weight of the substrate) or depositional shallow areas with convex banks (often inducing isolated pools) can benefit considerably by applying water prior to the electrofishing. See directions below for specific description of the guidelines.

Dry Shocking Recommendations

a. Look for dry sediment surfaces where lampreys are most likely to become stranded (large and small concave dips in the sediment, base of steep edges, flat low gradient areas, or other similar contours). It makes sense to focus on areas where some lampreys have emerged.
b. Pour several 5-gallon buckets of water over the sediment surface until the surface is visibly moist (or has a trace of standing water on top).
c. Place probes roughly shoulder distance apart and hold probes on the surface of the sediment and press the slow tickle pulse button.
d. Shock for 1-2 minutes, scooping out any lampreys that emerge.
e. Repeat this process in various 1-2 m^2 plots over representative areas where you suspect that there could be lamprey stranded under the sediment. Perform this technique until CPUE decrease substantially (less than 1-3 lampreys m^{-2}).

Figure 4.7. Examples of visibly dry areas where larval lampreys were still concealed under the surface at Wapato Diversion (October 23, 2017). Water was poured over these areas, electrofished, and densities of 20-30 live larvae m^{-2} were observed in many areas (even though no lampreys were emerging on the surface of the sediment). In the back of the right photo, you can see the moist sediment (shiny/reflective areas in the photo) where 70-80 lampreys m^{-2} were observed.

Figure 4.8. Examples of visibly dry areas where larval lampreys could still be concealed under the surface of the sediment where dry shocking is effective at Sunnyside Diversion (November 1, 2017). In the left photo, water could be poured on the outside edges of the visibly wetted surface as larval lampreys likely have congregated at the bottom of the slopes. In the right photo, pouring water on the flat surface (with small mounds) or over the cracked sediment at the bottom of the hill would be great places to perform the dry shocking method.

4.5 Rescuing Lampreys from Isolated Pools

Some isolated pools (small pools of water isolated by dry habitat) provide temporary refuge to large numbers of lampreys (Fig. 4.9). Isolated pools located in prime habitat tend to have very high densities of lampreys, and should be the initial focus of electrofishing efforts. Similar to the bank salvage methods, each isolated pool should be assessed for lamprey numbers before focus is placed on one pool (to make sure efforts are focused on the highest densities of lampreys to be rescued). Remove lampreys from isolated pools before they dry up (focusing on pools with higher densities of lampreys). The size of the isolated pool is another factor to consider when prioritizing (i.e. small pools tend to dry up first). Water could be poured over these isolated pools to help increase the electrofishing efficiency as well as to prolong their survival. Whenever possible, electrofishing should occur in single passes (at a rate of 1m^2 per minute) to limit long-term exposure to electricity potentially leading to electronarcosis.

Figure 4.9. An example of isolated pools that held high densities of larval lampreys at Sunnyside Diversion in 2016 (~100 lampreys m^{-2}). The left photo is an example of a small, shallow isolated pool (high priority). The right photo is an example of a large isolated pool (that would be second in priority to the smaller pool).

4.6 Rescuing Lampreys from Dredged Material

To protect rearing larval lampreys during instream dredging operations, use of simple, adaptive, and efficient methods to rescue and salvage entrapped lampreys from dredged materials is needed. Dredging of sediment occurred in the forebay of Dryden Diversion on the Wenatchee River (Dryden, WA; Fig. 4.10) in March, 2016, and reoccurs every few to several years as part of a maintenance operation by Chelan County PUD (CCPUD). The slow water and fine sediment in the forebay area provides refuge to many thousands of larval and juvenile Pacific Lamprey. The YN Fisheries along with other partners aided CCPUD in lamprey rescue operations at Dryden Diversion to help rescue as many lamprey as possible and experience and observe the rescue process. Some recommendations were made on methods to improve rescue efficiency and minimize mortality.

On March 4, 2016, YN Fisheries aided CCPUD on the first day of rescue operations. The forebay area was dredged using a 150-ft tall crane and a grab dredger (Fig. 4.11). At a time, 6-8 cubic yards of dredged material from the grab dredger was placed directly into a custom-built dump truck (Wilsonville Concrete Products, Wilsonville, OR; Fig. 4.12). The truck's water-proof design significantly limited loss of lamprey when transferring the fine sediment. Each truck load of sediment was transferred to a nearby dirt parking lot and spread out using rakes and a backhoe. Larvae were primarily gathered by hand from the sediment surface (Fig. 4.13). Intermittently, canal water was sprayed over sediment using a generator run pump and fire hose (pin stream spray) to spread out sediment and uncover burrowed larvae. A total of 3,614 larvae and 5 eyed juvenile lamprey (tallied using mechanical counters) were rescued from four truckloads of sediment by a dozen staff from CCPUD and YN Fisheries (about 1.5 - 3 hours were spent on each truckload for lamprey rescue). At the end of the day, rescued lamprey were released a few km downstream of Dryden Diversion into the Wenatchee River (river km 24.1) where 50-60 m^2 of larval lamprey habitat (Type I/II) was available within an inside meander. Over the whole rescue operation (7 days), 18,746 larvae and 21 eyed juvenile lamprey were rescued from ~244.5 cubic yards of sediment (~30 truckloads). Accordingly, the density upstream of the headgate before the rescue operation was estimated to be 33 lamprey m^{-2}. Initially, YN Fisheries inquired if just the upper sediment layer (~1 ft) could be dredged to focus the rescue on the sediment depth where the most lamprey would likely be encountered. However, moving the large crane around twice within the project area was too time consuming for the operator and this was logistically challenging. As a result, all sediment (primarily silt) transferred from various depths were monitored by the crew. Although some differences in densities were noted per each truckload, none of the loads had zero or near zero lamprey.

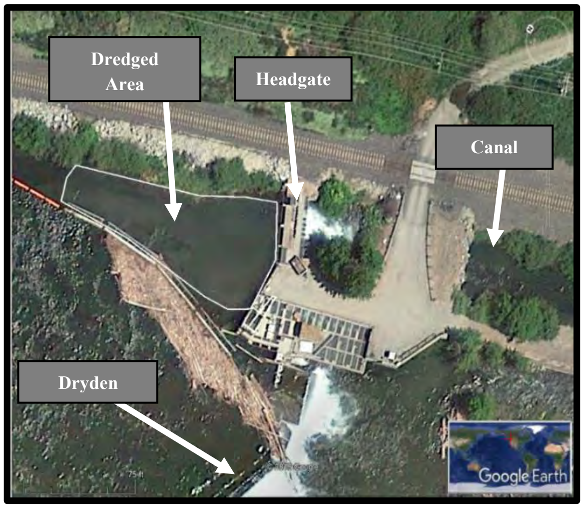


Figure 4.10. Area dredged in the forebay of Dryden Diversion on the Wenatchee River (RKM 27.8, Dryden, WA).

Figure 4.11. The 150-ft tall crane (top photo) and the dredge grabber (bottom photo) used for the dredging operation at Dryden Diversion forebay.

Figure 4.12. Custom-made waterproof dump truck owned by Wilsonville Concrete Products (Wilsonville, OR). Overview (left photo) and the inside (right photo).

Figure 4.13. Efforts to rescue larval lamprey from discarded material included searching the sediment surface by hand (top photo), and use of a fire hose to disturb and spread sediment to expose burrowed lamprey (bottom photo).

Dredging Operation Recommendations

a. If the dredged fine sediment (as well as lampreys inside) could be moved to a different area within the river/stream rather than a transfer outside of the water, always pursue those options.

b. Place a large tarp or pond liner (preferably non-black color for best visibility) under the dredged sediment to prevent lamprey from burrowing into the dirt (when spraying water, this tends to occur). Placing the tarp on a slant, with the dredged sediment at a slightly higher elevation, will potentially allow water and lamprey to flow downhill, enabling netters to collect them more easily (see Fig. 4.11 in Task 4.7).

c. Use of electrofishers with lamprey settings (e.g., ETS ABP-2 Backpack) are highly recommended during rescue operations in wetted areas. This can aid in improving capture efficiency in isolated pools (e.g., 500-700 lamprey were rescued in one isolated pool). Repeated attempts are often necessary.

d. Many lamprey (especially YOY) are small and hard to find and are therefore easily overlooked within the fine sediment. It is important to spend ample time to search and scan through the sediment.

e. Regularly monitor temperature in all static water buckets/holding containers and use aerators whenever possible. Maintain all containers at least half full with water to provide more dissolved oxygen and minimize temperature fluctuations. Add fresh water periodically and keep within 2-3°C of the river temperature. Should temperatures be different, temper slowly prior to release (goal of <1.5°C change per half hour), and preferably start this process prior to traveling to the release site.

f. Release larvae at dispersed locations across entire release area, releasing more upstream to allow them to drift downstream and spread out. Monitor lamprey recovery at site before and after release and note any injuries/mortalities (i.e. bruised lamprey were often observed during this process).

g. Additional lamprey sifter designs that could potentially improve the efficiency of the rescue operations are discussed in Task 4.7 (see Fig. 4.17, 4.18, and 4.19).

4.7 Development of New Rescue Methods

Sluice Box Lamprey Sifter Using a Venturi Pump

Although both "dry shocking" and "blind netting" can aid substantially in removing larval lampreys within the irrigation diversion environment during dewatering activities, there are clearly limits in efficiency even with these new alternative methods as well. Efficiency never approaches 100% and these methods still take considerable time to implement especially in large scale diversions. In an effort to explore other potential alternative methods, a pilot study was conducted during the 2017-2018 irrigation off season at Wapatox Diversion on the Naches River (Beals & Lampman 2018c). We worked closely with Natural Solutions, Inc. (Helena, Montana) to operate an educator pump suction dredge to remove lampreys and sediment from the canal bottom and sift them using an attached sluice box. Gordon Burns (with Natural Solutions, Inc.) has designed an educator pump system (venturi pump design) proven to pass fish through the pump system safely. This venturi-style pump was attached to a modified sluice box (originally designed for gold mining and other in-stream dredging operations). The goal of this pilot project was to provide proof of concept with the lamprey sifter design, test larval lamprey passage through the system, and identify any potential issues. We also brainstormed on ways to improve efficiency and potential new designs to enhance the initial design.

The sluice box was operated on November 16, 2017, and 17, 2017 (day 1 and 2). Wapatox Diversion, a diversion of the Naches River at river km 29.0, was chosen as the best test site for the modified sluice box. Initially, we had plans to implement this project at Sunnyside and Wapato diversions, but impromptu lowering of water levels at both facilities (to <18 inches) during the project period rendered this impossible at both locations. The water depth at Wapatox Diversion was approximately 24-48 inches (well over the minimum water depth of 18 inches). The depth that was dredged was approximately 12 inches. The sluice box was operated for a total of 80 minutes on day 1 and 122 lampreys were captured, with a CPUE of 1.5 lamprey min^{-1} (or 90 lampreys hour^{-1}). On day 2, the sluice box was operated for 60 minutes and 130 lampreys were captured, with a CPUE of 2.2 lampreys min^{-1} (or 132 lampreys hour^{-1}). Overall, the injury rate of captured lampreys was 4.1% and 3.1% on day 1 and 2, respectively. The injuries varied from severed heads (causing mortality) to a slight scrape on the side of the body. A backpack electrofisher (designed for the capture of larval lampreys) was used on the outside edges of the dredged areas after dredging operations ended on day two. The electrofisher was ran for 3.3 minutes on site as well and a total of 94 lampreys were captured, with a CPUE of 28.9 lampreys min^{-1} (or 1,734 lampreys hour^{-1}).

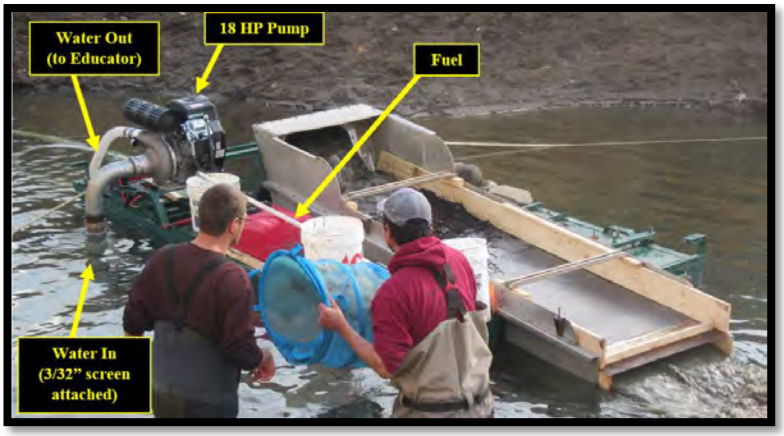


Figure 4.14. Side angle view of the sluice box system with labels for pump and associated parts.

Figure 4.15. The sluice box in operation. "T"-handle used to maneuver the 4-inch suction hose for fine sediment and larval lampreys. With the heavy pump on side side, the sluice box tended to sink down on that side when a crew personnel also stood on that side.

Table 4.1. Summary of the dimensions and operation specifics of the sluice box designed and operated by Natural Solutions, Inc. (Helena, Montana).

System Components	Specification
Pump Horse Power (HP)	18
Pump Discharge (gpm)	100 to 400
Flow to the Educator (gpm)	Between 50 - 150
Suction Flow through Nozzle (gpm)	300 - 400
Hose from Pump to Educator	15 ft (2" hose)
Hose from Nozzle to Flair	30 ft (4" hose)
Sediment Collection Rate (yards/hr)	1 - 4 (varies by sediment type)
Sluice Box Length	9' 4" (112")
Sluice Box Width	2' 5" (29")
Perforated Plate Mesh Size	3/32 " (2.38 mm)
Minimum Water Depth For Operation (inches)	18

Potential Improvements to Lamprey Sifters

There are a few issues that will need to be resolved to make this lamprey sifter more effective: 1) too much coarse organic matter was mixed in with the fine sediment and lampreys, making the separation of lampreys very difficult and time consuming; 2) dredging a large area of fine sediment was very time consuming; and 3) it is difficult to know where to focus the dredging effort (the person maneuvering the nozzle end does not see the lampreys being syphoned into the sluice box directly). We discussed a few potential solutions to these issues and also made alternative potential designs that could be built in the future, with the hopes that they will be much more efficient in rescuing and capturing more lampreys.

Issue #1

A large volume of organic debris (leaves, sticks, pine cones, pine needles, etc.) was mixed with the fine sediments at Wapatox Diversion (Fig. 5.8). Organic debris does not pass through the perforated mesh plate; hence, it was very difficult to separate larval lampreys trapped in the large volumes of organic debris. In general, larval lampreys tend to congregate in areas where the organic debris is highest (their preferred habitat), so this problem is enviable if high amounts of organic debris is present in the area of interest.

Potential Solutions for Issue #1

- Collect all organic debris along with the lampreys trapped within it and return them altogether to the river (minus the fine sediment that was sifted and sieved). This will limit the time needed to separate and sort out the lampreys. However, we would miss the chance to count the lampreys, measure them, and/or identify them to species.
- Create a pool of water on top of the perforated plate, where organic debris can spread out, and swimming lampreys can easily be observed and captured; rather than encounter a pile of organic debris. We experimented by placing various shapes of wooden stop logs underneath the perforated screen plate inside the sluice box to achieve this – this worked best when the stop logs had limited opening (allowing water to effectively rise above the perforated screen plate).
- Install two separate sifting plates (a coarse mesh that all larval/juvenile lampreys can pass and a fine mesh that essentially all larval/juvenile lampreys cannot pass) so that large debris can be first removed from the sediment mix with lampreys (see Fig. 5.9).

Issue #2

It is time consuming to cover a small area with the sluice box dredging (operation as well as equipment transfer). If there is a large area of Type I habitat, it is difficult to be efficient.

Potential Solutions for Issue #2

- Limit the depth of the dredging effort. The depth of the dredging effort was generally greater than 12” (30 cm). Larval lampreys reside primarily in the top 6” (15 cm) of habitat. If we focus only on the top 6” of sediment, more area can be covered, as well as potentially less organic debris (which tended to be deeper in the fine sediment layer).

- Build the sluice box large enough so that the fine sediment can be collected using heavy equipment (backhoe, cat, etc.) (see Fig. 5.9).
- Build the sieve into a dump truck so that the sifting can take place while the dump truck is in transport (as a result of transport vibrations) (see Fig. 5.10). This will remove one step from the sorting of fine sediment and/or organic debris. The transported lampreys/sediment mix could then be spread out on the ground for lamprey salvage (see Fig. 5.11).

Issue #3

It is difficult to know where the high density of lampreys are and where to focus the efforts when using sluice box dredging (i.e. lots of time could be spent unknowingly in areas with low densities).

Potential Solutions for Issue #3

- Electrofish the area first (when the water level is wadeable). Use the sluice box in areas with the highest observed density of lampreys to greatly improve efficiency.
- Combine the sluice box dredging with an electrofishing operation – by operating the two pieces together, the dredging can focus on the larvae that emerges from the fine sediment, greatly limiting the amount of sifting and sieving needed to capture the lampreys (see Fig. 5.12 and 5.13). The sluice box may not need to be as large if it is operated together; a small surface area of screen may be sufficient to capture the lampreys efficiently.

Figure 4.16. Tyler Beals (left) and Ralph Lampman (right) collecting lampreys from the sluice box during salvage operation on November 17, 2017. The organic debris built up quickly, and sifting through the large amounts of organic debris to find lampreys proved to be time consuming and difficult.

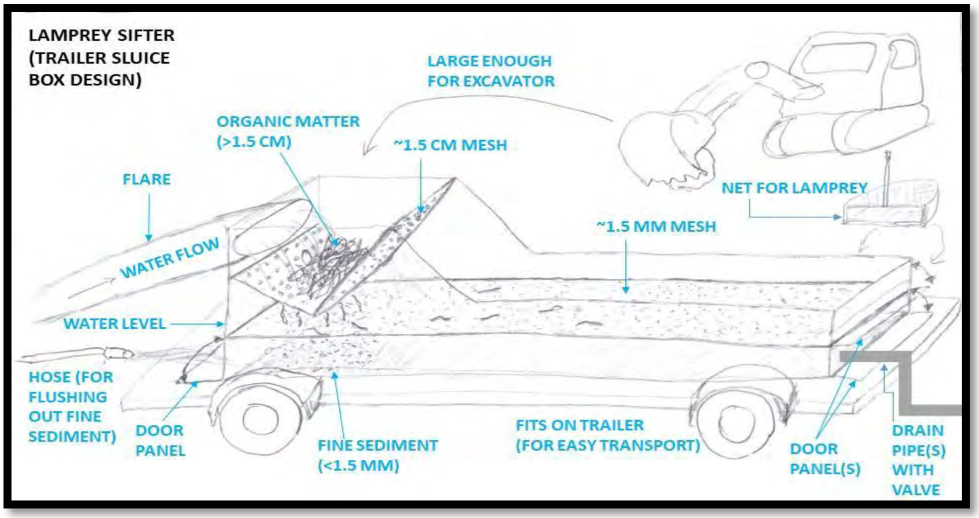


Figure 4.17. A lamprey sifter that will fit on a trailer. It has a sluice box with two built in mesh sizes: a coarse mesh (~1.5 cm) that will hold coarse organic material while larval/juvenile lampreys pass through and a fine mesh (~1.5 mm) that will hold the majority of larval/juvenile lampreys while fine sediment will pass through.

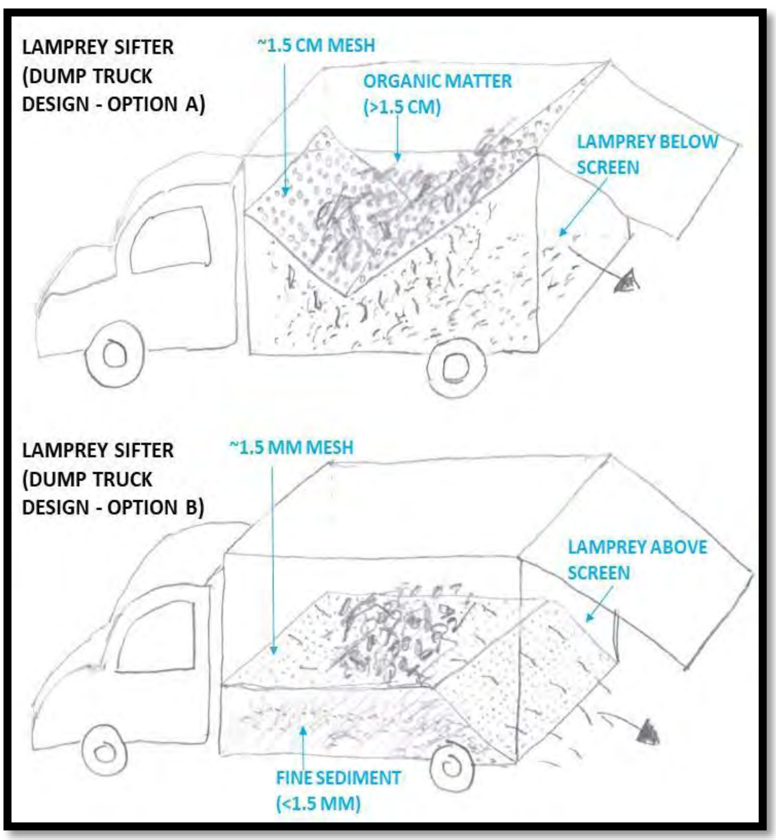


Figure 4.18. A couple options for a lamprey sifter built into a dump truck. Option A uses a coarse mesh screen that will separate coarse organic matter from mixing with larval/juvenile lampreys using the vibrational sifting force from driving the truck. Option B uses a fine mesh screen that separates fine sediment from larval/juvenile lampreys using the vibrational sifting force. As the dump truck opens the gate, lamprey mixed water will come out. Potentially, these two screen options could be combined as well.

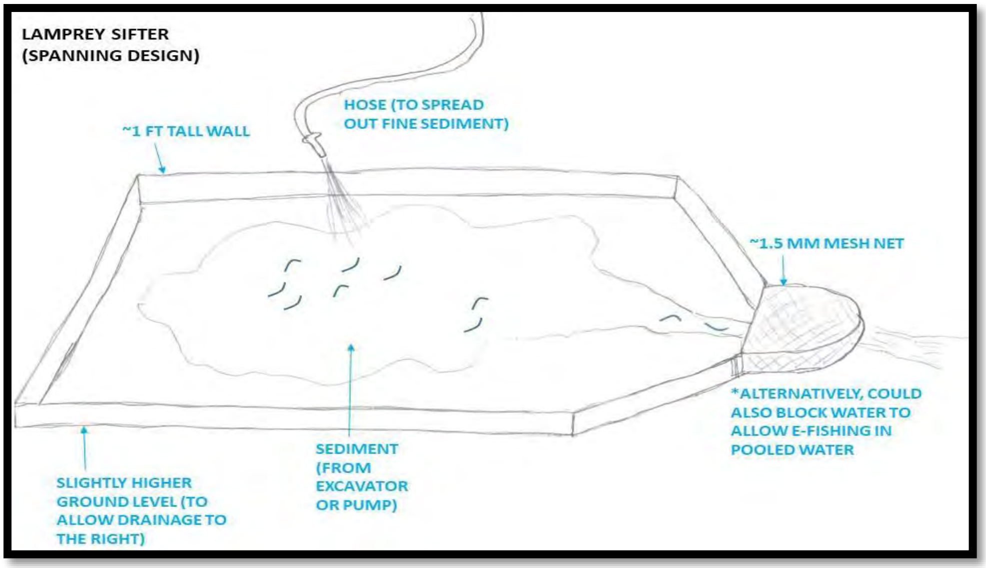


Figure 4.19. A device that allows dredged sediment (from excavator, dump truck, etc.) to be fanned out to find and salvage larval/juvenile lampreys effectively. It can be made from tarp (non-brown / non-black color, such as blue). Lampreys can be salvaged or netted in the open area or collected at the large net (right end) as a result of flowing water moving to that direction. The right end could also be prevented from draining, allowing electrofishing in the water puddle formed. The left end and edges should be slightly higher in elevation so that water effectively drains into the large net area.

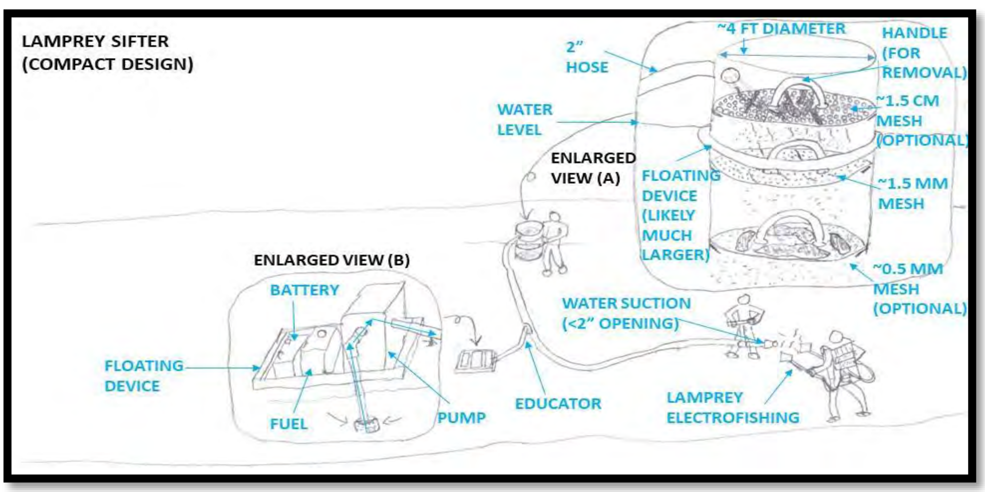


Figure. 4.20. A compact venturi pump sluice container design that floats on water. This design could be used in combination with lamprey electrofishing to minimize the amount of fine sediment to be sifted. Instead of having a sluice box, this design has a rounded sifter that could be carried and operated by one person. Another person will be needed to operate the nozzle end (along with an electrofisher). Another person may be needed to carry and watch the pump, fuel tank, and battery component. This design will be useful in streams/canals that have a high density of larval/juvenile lampreys with turbid water, making electrofishing inefficient. This design could also be used without the electrofishing component; however, the optional 1.5 cm mesh screen on the top is likely needed to separate the coarse organic matter that will also be syphoned from the stream/canal bottom. The optional 0.5 mm mesh screen on the bottom is only needed if a lot of YOY larvae are known to be in the area.

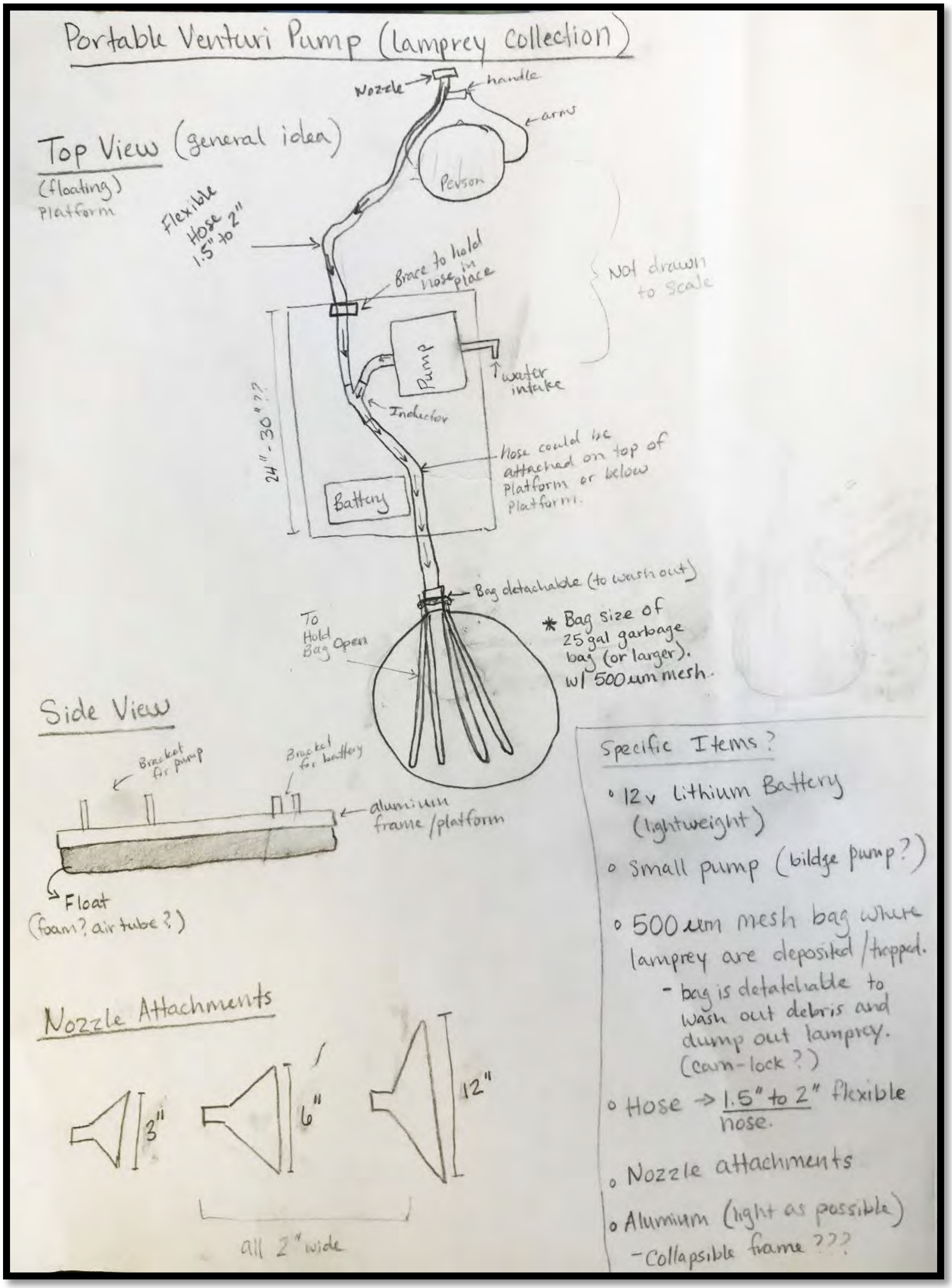


Figure 4.21. Another conceptual design for a portable lamprey sifter that uses a small scale venturi pump in combination with an electrofisher. After the electrofishing forces larval lampreys to emerge, the lamprey sifter will siphon lampreys into an expandable mesh bag (500-750 micron), which can be sifted in water if any fine sediment is also collected. A few nozzle attachments will be available to allow for the most efficient lamprey collection based on canal water height.

4.8 Selection of Release Location

In general, rescued lampreys should be released back to the river downstream of the irrigation diversion headgate. However, there may be extenuating circumstances that warrant other options and alternatives. For example, if there are multiple diversions further downstream, it may make sense to release them past those series of diversions (so released lampreys do not have to encounter yet another diversion soon after release). As for the physical attributes of the release location, ideal locations would contain Type I (or secondarily Type II) habitat - a slow water area with fine sediment - so that released lampreys can find cover relatively quickly (Fig. 4.22). To minimize stress from transport, the shorter and easier the walk-in is to the release site, the better. A temperature difference of 2˚C or less between the holding container water and release stream is ideal; otherwise lampreys should be tempered and acclimated to the appropriate temperature at a rate of approximately 1.5˚C every 30 minutes. We recommend checking the holding containers for immobile and/or discolored lampreys to evaluate whether any lampreys are succumbing to stress or body injuries. If water clarity is conducive, dead lampreys can also be visible on top of the fine substrate (due to their inability to burrow). Electrofishing settings, or any other suspected pertinent protocols, can be subsequently modified accordingly to help minimize these mortalities.

Figure 4.22. An example of a release location with Type I/II habitat selected for lamprey rescued from Dryden Diversion.

4.9 Other Species to Consider (Freshwater Mussels)

Fisheries has encountered high densities of freshwater mussels (up to 6” at their longest length) upstream and downstream of the fish screens at Sunnyside Diversion on the Yakima River (primarily Western Pearlshell species) (Beals & Lampman 2018d; Beals 2019). Freshwater mussels have also been encountered in other diversions, such as Wapato and Ellensburg Mill diversions, albeit lower numbers. The mussels found downstream of fish screens were likely entrained during the larvae/glochidia stages and subsequently reared in the irrigation diversion water as subadults/adults (Fig. 4.23). There is some evidence that a portion of these mussels can overwinter within the dewatered canal, surviving potentially multiple years of watering and dewatering cycles as a result of the subsurface flow. This phenomenon was evident due to the continued appearance of many large adult freshwater mussels (100-170 mm) each year downstream of the fish screens despite our intensive and thorough efforts each year to remove the mussels after dewatering. The mussels found were too large to be capable of passing through the fish screens and their growth rates are too slow to attain their lengths within a year (or even after several years). Because mussels are able to hide well under rocks or stay burrowed under fine sediment, we are likely finding only a portion of the overall populations each year; the ones we find each year are suspected to be the ones that were well concealed the previous year. Based on accounts of old timers that used to work for YN Fisheries (Robert L. Tuck, pers. comm., 2014), Sunnyside Diversion has been known to produce many mussels for decades.

Although the diversion may provide favorable refuge habitat to these mussels, similar to larval lampreys, each year a large portion of the population is susceptible to risk of desiccation and once they are downstream of the fish screens, no path back to the river is available. Out of the few hundred mussels we discover each year at Sunnyside Diversion, a large portion of the mussels tend to be dead ones (typically >50%), which is a considerable die off considering their longevity (of over 100 years). To provide them the best chances of survival, we rescue as many as possible and release them downstream of the irrigation headgate in slow water habitat (same release site used for larval lampreys). While conducting lamprey rescue operations, we recommend staff to keep an eye out for freshwater mussels in all project area, especially in areas with rocky/sandy bottoms where their density seems to be higher, to help restore this important group of filter feeders. We recommend this search to occur in the early part of the dewatering operation while survival rates tend to be higher.

Figure 4.23. Western Pearlshell mussels collected from the canal downstream of the fish screens at Sunnyside Diversion in 2017. The left shows many live and dead mussels collected from the canal (up to 6” long). The right photo shows the canal where the mussels were collected after dewatering.

Task 5: Methods to Prolong Survival of Entrained Lampreys

5.1 USGS Study on the Impacts of Dewatering

A USGS study conducted in 2014 and 2015 (Liedtke et al. 2015) at the Columbia River Research Laboratory summarized complex larval lamprey behavior and responses related to dewatering activities. This information is important because larval lampreys are known to be present in tributary delta areas vulnerable to drawdowns (Mueller et al. 2014). Jolley et al. (2012 and 2013) indicated that larvae were present in a broad range of sizes, indicating multiple age classes and long-term rearing. This information has relevance to many other activities, including sediment dewatering for culvert / bridge installation, stream restoration, and irrigation diversions.

Some of the key findings include:

- Larval lampreys did not burrow deeper than 15.2 cm.
- Larval lampreys did not respond to the changing head pressure (reacted only after burrowing habitat was exposed).
- Behavioral responses to dewatering varied widely and across time; about one-half of the fish emerged from the sand following dewatering and about one-half stayed burrowed.
- Larval lampreys were able to survive short exposure to dewatering, but mortality increased steadily when exposure time exceeded 24 hours. By 48 h, mortality was greater than 60-90 percent.
- Delayed mortality was observed (29% of lethargic lampreys died within 24 hours).
- Larger lampreys had higher rates of survival (larger lampreys tended to stay burrowed and those that emerged made the transit more readily to reach water compared to smaller lampreys).
- The fast dewatering rate (51 cm/hr) stranded more lampreys than the slow rate (7.6 cm/hr)

These findings are mostly in agreement with what YN Fisheries has been observing during dewatering events in irrigation diversions. Most of the mortalities from dry banks are smaller larvae and those that are found alive on dry banks tend to be larger larvae (see Task 2.3). Slower rates of dewatering (<10 cm/hr) has resulted in much lower rates of stranding on the dry banks from surveys in Sunnyside and Wapato diversions (see Task 5.2). The recovery rates of lethargic lampreys are generally high (i.e. most that show breathing when placed in water will eventually recover fully), yet a portion of them will die in the field. However, one major difference was the rate of mortality observed after dewatering. Although there are many cases where larval lampreys maintain high survival rates long after dewatering, there are also plenty of instances in which large numbers of larval lampreys die soon after dewatering in the field potentially due to various environmental conditions (e.g., sediment type and moisture, air temperature, etc.). Even after just 1-2 hours of dewatering, larval lampreys can perish quickly if sediment becomes completely exposed and conditions are not conducive; therefore, it is strongly recommended that larval lampreys are always rescued as soon as feasible, minimizing their time out of water.

5.2 Reduce Dewatering Rate during Irrigation Shutdown

At the end of the irrigation season, larval and juvenile lampreys are susceptible to stranding on and within dry sediment banks when irrigation headgates close and water levels recede. A study by USGS showed that burrowed lampreys do not respond to changes in head pressure, and lampreys do not move to sediment surface until after the surface becomes dry (Liedtke et al. 2015). Based on this behavior, dewatering rates do not matter much until the water level reaches the fine sediment containing larval lampreys. Ongoing research and field observations have shown that a slow dewatering rate is important to allow burrowed lampreys to "self-rescue," (i.e. escape their burrows and wiggle into the nearby water) (Beals & Lampman 2018a). If the dewatering rate is too fast, lampreys may not be able to reach the water's edge on their own, even if they are able to emerge from their burrows. Once the fine sediment starts to become exposed, the dewatering rates should be lowered to the slowest possible rate (<10 cm hour^{-1}) to protect burrowed lampreys and allow them to self-rescue (see discussion below).

The sediment surface contour can also affect lampreys' ability to reach the water's edge (Fig. 5.1). For example, it is often difficult for lampreys to reach the water's edge from a concave surface where they slide downhill into a "dip." On convex surfaces, it is much easier for lampreys to slide downhill into the new water's edge at the base of the hill. Lampreys that reach the wetted habitat have a much higher chance of survival even in irrigation diversions; it allows them to escape desiccation and predation, enter the bypass back to the river, or be rescued by humans.

At Wapato and Sunnyside diversions, large areas of fine sediment (holding high densities of larval lampreys) become exposed during dewatering operations after the irrigation season in the fall. In an attempt to limit lampreys stranding on dry banks and associated mortalities, we work closely with stakeholder agencies to coordinate various strategies to reduce the dewatering rate to the slowest possible rate at these diversion sites. In the area upstream of the fish screens at Wapato Diversion, and downstream of the screens at Sunnyside Diversion (where lamprey densities are highest), we estimated dewatering rates during the irrigation shutdown between 2014 and 2018 using gauge measurements and manually placed measuring tapes. In addition, we calculated the ratio of lampreys captured on the bank in comparison to the overall number of lampreys captured at the diversion. This ratio was used to evaluate the effectiveness of the associated dewatering rate (considered "effective" if a lower ratio of lampreys were stranded on dry banks).

Prior to 2016, dewatering rates at Wapato Diversion were designed around salmonid regulations with no adjustments for burrowed lampreys. In 2014 and 2015, the dewatering rates were estimated to be approximately 28.5 cm hour^{-1} (Fig. 5.2). During this two year period, we noticed a considerably high ratio of lampreys stranded on dry banks after dewatering (45% and 53% of all captured lampreys stranded on dry banks in 2014 and 2015, respectively). Through close coordination with Wapato Irrigation Project (WIP) and the Reclamation, we developed a plan so that the headgate would be closed in stages, and water loss would be controlled and slowed down using a weir located 1.5 miles downstream (called "Drop 1"). This process was very successful in reducing lamprey stranding in 2016 (~1% stranded on dry banks). In 2017, we attempted a similar strategy, but a tree got stuck under the headgate and its sudden removal resulted in a dewatering rate similar to 2014 and 2015 (22.6 cm hour^{-1}) and a higher ratio of associated stranded lampreys (35%). In 2018, despite proper staged closing of the headgate, water drained quickly through the fish bypass as well as the downstream weir resulting in a faster than expected dewatering rate (24.4 cm/hr) and bank stranding ratio (24%).

At Sunnyside Diversion, the dewatering process is a little different than other diversion sites. After the headgate is closed, there is seeping water that keeps the screening area watered up (a combination of subsurface flow and headgate leak). In order to dewater the site, the Reclamation must operate two industrial water pumps (12 and 8 inch pumps) to drop the water level further for fish rescue. The large 12 inch pump drops the water level only initially and shuts off automatically, whereas the smaller 8 inch pump is on continuously to drop the water level the remaining distance (including the zones with critical fine sediment habitat). In 2014 and 2015, the hose to the small 8 inch pump had a substantial leak, which dumped water back into the screening area, effectively slowing the overall dewatering rate. The leak was largest in 2015, resulting in a dewatering rate of 18.3 cm/hr and a stranding percentage of only 2% (Fig. 5.3). However, in 2016, the Reclamation replaced the hose, and a much faster dewatering rate (54.8 cm hour^{-1}) and a much higher stranded percentage (43%) was observed. In 2017, the water drained out much faster than anticipated potentially due to a couple factors; the leak through the headgate was substantially less and both pumps were being operated simultaneously at parts of the critical water levels (exposing fine sediment and larvae). In addition, the critical dewatering occurred at both evening hours and over the weekend, preventing lamprey rescue (see Task 7 for more discussion on this issue). In both 2017 and 2018, we coordinated closely with the Reclamation and the Sunnyside Valley Irrigation District regarding the dewatering operations in an attempt to reduce the dewatering rate and associated bank stranding. In 2018, the Reclamation was able to provide us with more control over the dewatering process, namely with the small pump running only during the day time and week days and the option to turn off the small and large pump as needed.

The strong relationship between the dewatering rates and the associated stranded lamprey percentages that has been observed at Wapato and Sunnyside Diversion between 2014 and 2018 (Fig. 5.4) suggests that dewatering rate does influence lamprey stranding. Our results indicate that a dewatering rate of 10 cm hour^{-1} or less is quite effective in reducing larval entrapment on dewatered surfaces. USGS concluded that a dewatering rate as high as 7.6 cm hour^{-1} occurs in the Fraser River as an example of a natural mainstem river free of flow management (Liedtke et al. 2015). We conjecture that larval lampreys are adapted to the natural fluctuations in hydrography and so long as the dewatering rates are within those confines, they will likely respond to those changes favorably. In Sunnyside Diversion, even 20 cm hour^{-1} was shown to be effective in most cases. However, in 2018, an outlier was observed where a relatively high ratio of stranding (42%) occurred despite the low dewatering rate (20.8 cm hour^{-1}). One potential cause for this discrepancy is that in 2018 the water level lowered to its lowest level and most of the critical larval lamprey habitat was dewatered by the time YN Fisheries crew arrived on site, limiting the area for electrofishing and rescue. Over the years of lamprey rescue, we have found that so long as a salvage crew is available to rescue lampreys as they show up, lamprey mortality can be minimized even when the dewatering rate is around 20 cm $hour^{-1}$. However, if no salvage crew is available (such as during night time or weekend), we recommend that slower dewatering rates (as close to ~7 cm/hr) are applied to maximize their ability to "self-rescue."

In 2018, YN Fisheries compared the size class distributions of lampreys collected from the main water body using electrofishing and those collected from the dry banks manually by hand at Sunnyside Diversion downstream of the fish screens (Fig. 5.5; Beals et al. 2019c). Lampreys were collected in water and on the surface of the dry banks within the first two days of the area becoming dewatered. Lampreys collected from the dry banks were separated into two groups; live and dead. Our results suggested that lampreys stranded on dry banks tend to be smaller than those found in wetted habitat. In addition, when trapped on dewatered banks, smaller lampreys (< 50 mm) are more likely to perish compared to the larger lampreys. This trend with smaller larval lampreys showing up in dry banks and also at higher mortality rates have been observed repeatedly each year at Sunnyside Diversion as well as many other diversions and was also reported in a laboratory study conducted by USGS (see Task 5.1; Liedtke et al. 2015).

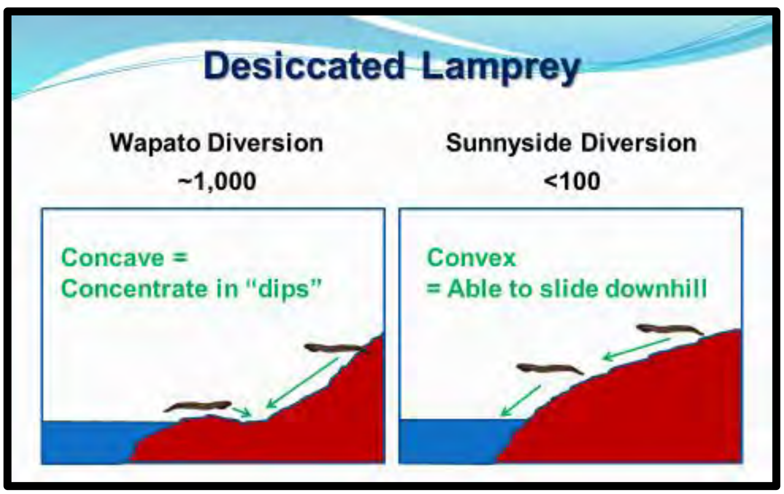


Figure 5.1. Examples of different sediment surface contours that lampreys can encounter after they escape their burrows.

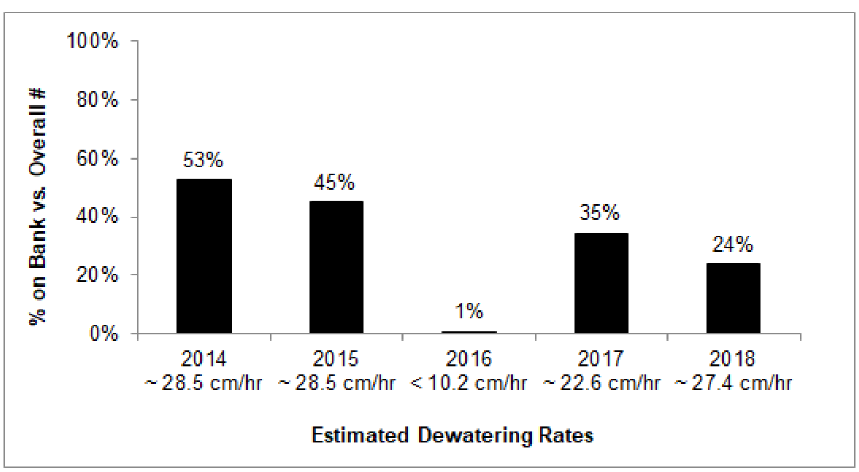


Figure 5.2. Percentages of lampreys found on dewatered banks of the total number of lampreys captured from all rescue efforts (including electrofishing in wetted habitat and salvage on dry

banks) between 2014 and 2018 at Wapato Diversion in the area upstream of the fish screens with respective estimated maximum dewatering rates shown below the years.

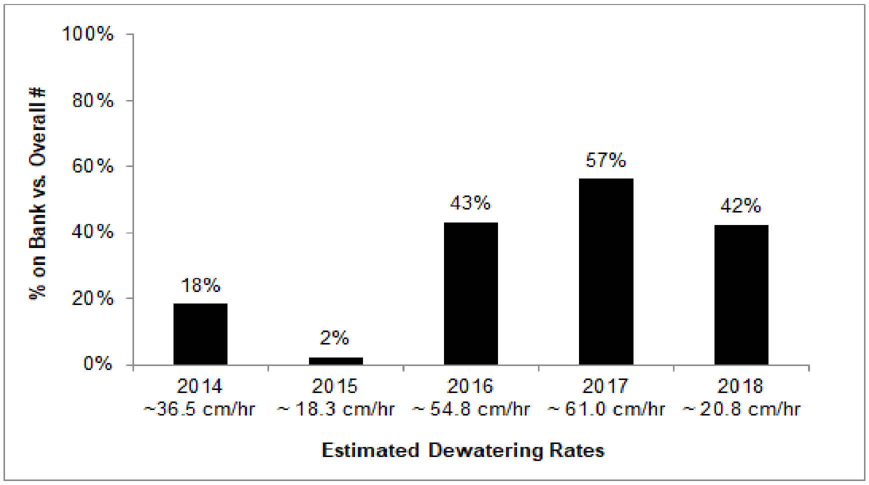


Figure 5.3. Percentages of lampreys found on dewatered banks of the total number of lampreys captured from all rescue efforts (including electrofishing in wetted habitat and salvage on dry banks) between 2014 and 2018 at Sunnyside Diversion in the area downstream of the fish screens with respective estimated maximum dewatering rates shown below the years.

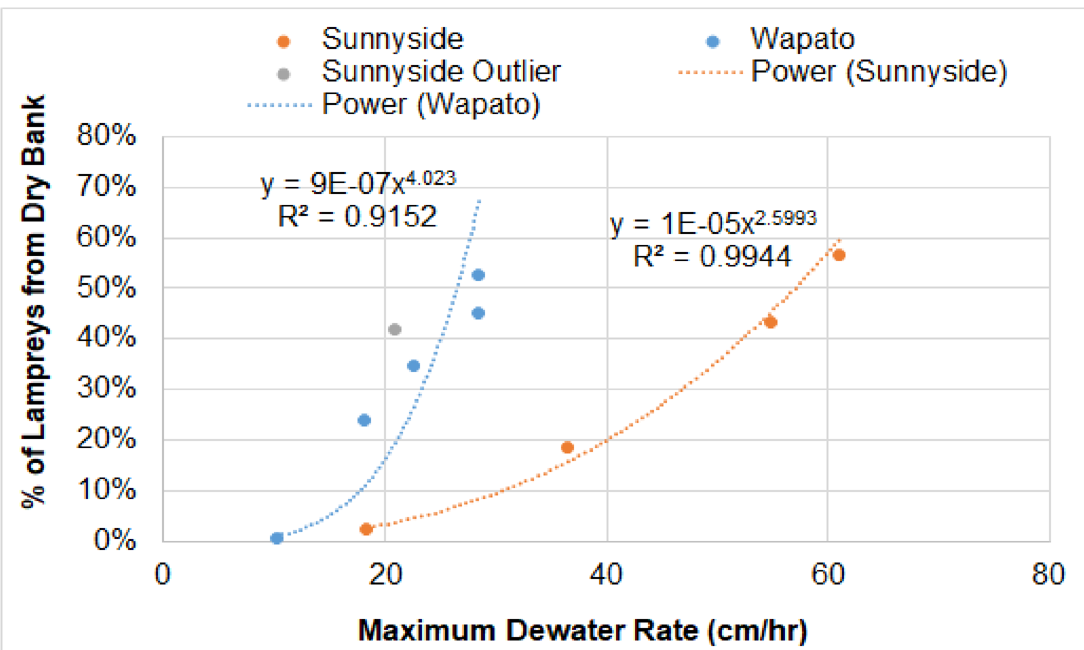


Figure 5.4. X-Y scatter plot of maximum dewatering rates (from a minimum of 2 hour period during the key period) and percent of lampreys captured from dry banks annually between 2014 and 2018 at Sunnyside and Wapato diversions. The trend line (power function), associated equation, and r-square values are also shown.

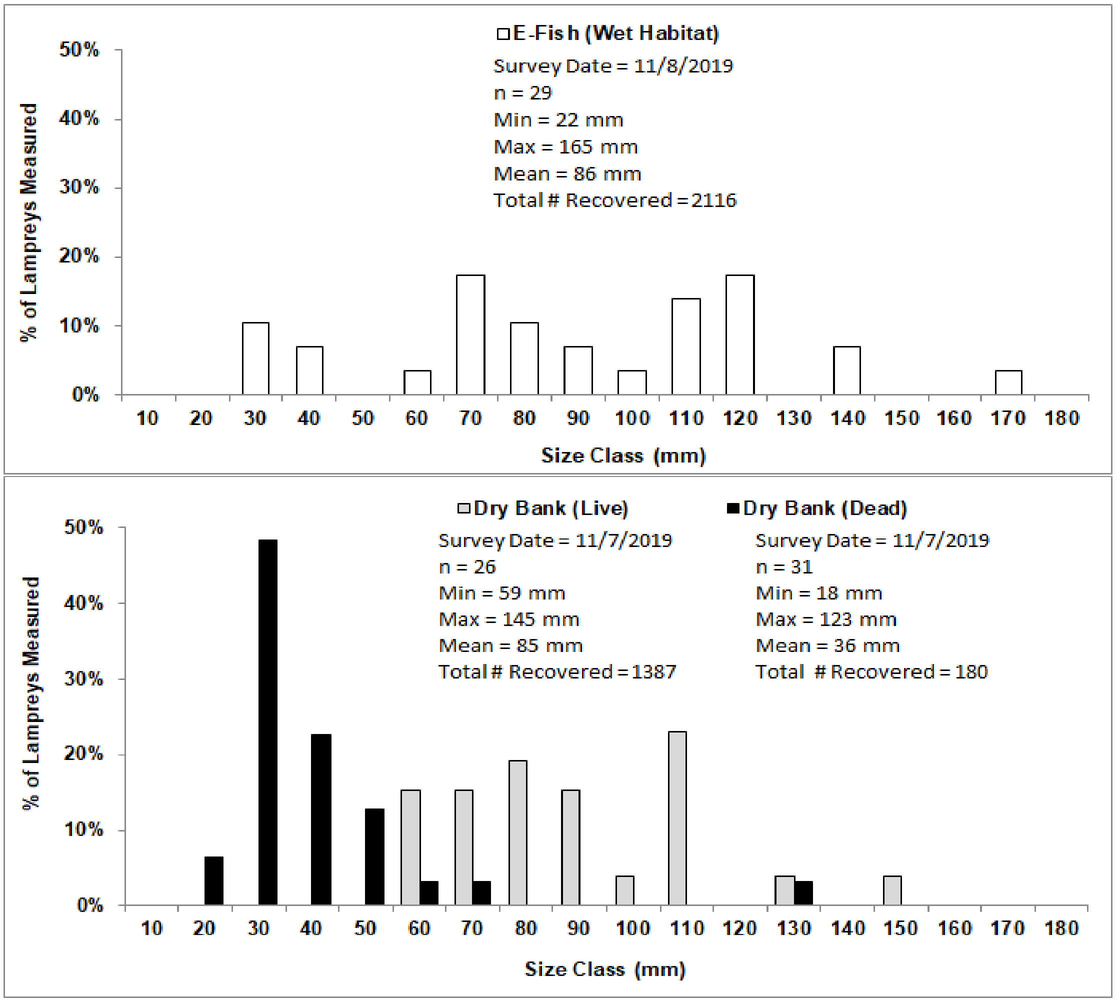


Figure 5.5. Size class distributions (in percent of total) of lampreys captured from wetted habitat (top figure) and lampreys captured by hand from dewatered banks (bottom figure) in November, 2019, at Sunnyside Diversion downstream of the fish screens. Those collected manually from dry banks are displayed separately by live and dead lampreys.

5.3 Use of Post-Irrigation Water

The time available to rescue lampreys from irrigation diversions after shutdown can be limited as lampreys can quickly perish due to predation, exposure on dewatered banks, high densities and lack of flow. At Bachelor-Hatton Diversion (a small 58 cfs irrigation diversion on Ahtanum Creek), we discussed potential options with the Reclamation and the Ahtanum Irrigation District to increase survival of lampreys in this small diversion. One solution that we were able to implement successfully was the opening of the headgate after the end of the irrigation season to re-wet dewatered sediments, providing flow to the high densities of lampreys in the screen area (Fig. 5.6;). The downstream gates were completely closed so no water goes down the canal, and the bypass was fully open to allow all flow to return directly to the river. This operation was implemented for 1-2 weeks during the dewatering season to protect lampreys overnight (or during daytime when we are not available to rescue lampreys). During the day time when we were available to rescue lamprey, the water was drained by partially closing the headgate and allowing water to drain out through the bypass. Access to the headgate allowed us to set the water height to the desired depth and adjust the flow rates to minimize turbidity levels during salvage activities. This process is most likely not available for large scale irrigation diversions. However, for small stream diversions this is often a very viable option given close coordination with the appropriate management and partnership agencies. However, the headgate flow may change over time due to debris getting stuck on the headgate and/or potentially by uninformed partners (with the best intentions) and it is always advisable to rescue and return as many lampreys to the rivers/streams when practical rather than relying on these temporary solutions to last all winter. In some diversions, the solutions can be implemented more reliably for extended periods (see Task 6.10 for discussion on Wapatox Diversion).

Figure 5.6. The left photo shows the area between the headgate (upper left-center) and the fish screens at Bachelor-Hatton Diversion with a small amount of water flowing in through the headgate. The photo on the right shows ~150 gallons min^{-1} entering the screening area (to provide flow to entrained lampreys).

5.4 Sprinkler Water System

In 2018, we developed an experimental sprinkler system that was designed to provide a supply of water to larval lampreys trapped and stranded on (and within) dewatered dry banks (Beals et al. 2019a). The sprinkler system was constructed with various sizes of PVC pipes (ranging from 0.5-2 inch diameter), and deployed on dewatered banks at Sunnyside and Wapato diversions on the first day of dewatering in the larval lamprey habitat area. At both facilities, the sprinkler system was ran for 3-4 days during the most critical period after dewatering to provide water to stranded lampreys. The diameter of each sprinkler head watered area is approximately 30 ft. The sprinkler system was turned off primarily during regular work hours when staff was available to rescue lampreys on site and was turned on at the end of day to minimize the desiccation and stranding of lampreys overnight. An overview of the system at Sunnyside and Wapato diversions are shown in Fig. 5.7 and 5.8.

Place sprinkler on the sediment surface soon after the sediment surface becomes dewatered. It might be difficult to collect lampreys from the sediment surface with the sprinkler system running, so the system can be set up at the end of the day after stranded lampreys have been removed for the day. Focus the sprinkler spray on flat and concave sediment contours where larval lampreys will have a hard time escaping on their own. The sprinkler spray can also be directed to enter isolated pools of water on the sediment surface that might otherwise dry up in a short period of time. Search the sprinkler area each morning after overnight operation (or periodically during operation if running throughout the day) to check the sediment for emerging lampreys. Repeat the dry shocking technique in wetted areas after the sprinkler has been running for a period of time (when the sediment surface is visibly moist).

Although this system could certainly be improved further, it is an inexpensive and adaptable way to provide life support to lampreys that have a low chance of reaching the water's edge due to dewatering. The total estimated cost for one sprinkler system (approximately 30 m in length with 4-6 sprinkler heads) is approximately $1600; $600 for the water supply pump and hose, and $1000 for the PVC sprinkler system itself. This cost can likely be brought down considerably once a design is finalized with a minimal list of supplies/equipment (our estimate includes component purchases stemming from trial and error). This sprinkler system can be extended or scaled down to fit any dewatering scenario.

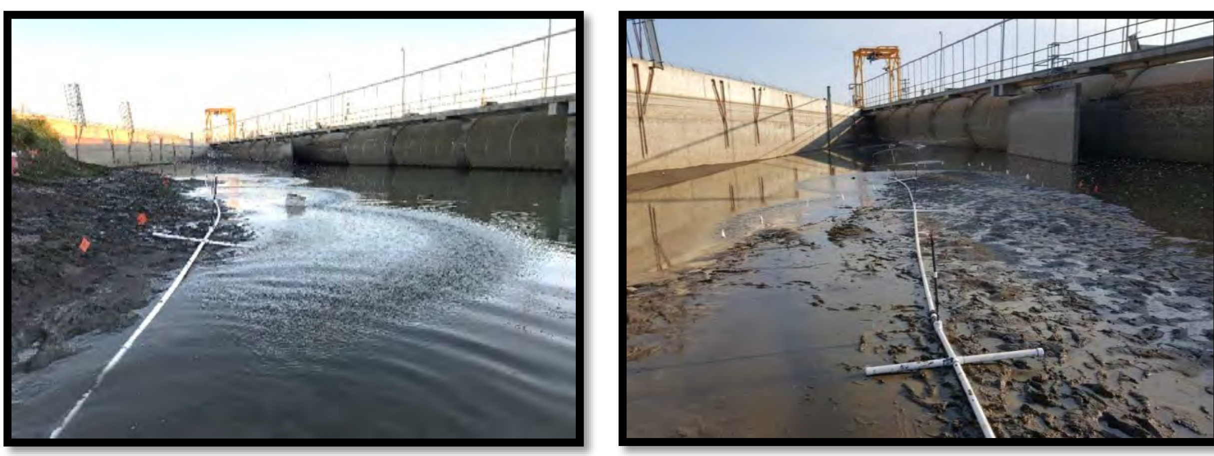


Figure 5.7. Overview of the sprinkler water system operation upstream of the fish screens at Wapato Diversion immediately after dewatering of key larval lamprey habitat occurred (left photo). In the right photo, the sprinkler water system is laid down on the flat surface where many larvae remain after dewatering.

Figure 5.8. Overview of the sprinkler system operation downstream of the fish screens at Sunnyside Diversion immediately after dewatering of the key larval lamprey habitat occurred. Part of the sprinkler system was able to cover the high density isolated pools.

<u>*Overview of the Sprinkler System Set-up and Cost*</u>

Water Supply (~$600)

- The sprinkler system consists of a ½ Horsepower Pump (capable of ~60 gallons min^{-1} with 15 ft. of head) with a modified fish screen (~$300).
- The pump was hooked to a 100 ft long flexible Helix Flex Hose. The flex hose allows for easy maneuvering and positioning of the pump and sprinkler system (~$300).
- The Helix Hose then connected to the main sprinkler system (via a cam-lock fitting).

Main Sprinkler System (~$1000)

- The main line of the sprinkler system was constructed out of different sizes of PVC pipes (2”, 1.5”, 1.25”, 1”, ¾”, and ½”).
- The first series (~30 ft.) of PVC pipes were 2” diameter (connected to the flexible hose). Connected to the end of the 2” PVC was smaller diameter PVC pipes (~30 ft. each of 1.5” and then smaller diameter pipes). The gradual decrease in pipe sizes was designed to compensate for the reduced pressure experienced towards the opposite end of the pump.
- A total of 4 to 6 sprinkler heads (rated for ~5,000 ft^2 of water coverage each) were attached to the PVC via a Tee sockets and various adapters/fittings needed to attach the sprinkler heads. Approximately one sprinkler head was attached to the PVC pipes every ~30 ft.
- At the very end of the system was a “blow-out” valve. The purpose of the blow-out valve was to remove any sediment that accumulated in the main pipe line before or during the operation.

<u>*Important Lessons Learned During Our Sprinkler System Operation*</u>

Focus Sprinkler Spray On Low Gradient Dewatered Sediment

We recommend the placement of the sprinkler system on dewatered low gradient fine sediment where lampreys tend to collect in high numbers during the dewatering process. Lampreys tend to have difficulty reaching the water's edge in these locations as the water level drops. On sloped banks, lampreys have a higher chance of "rolling" or "sliding" down the sloped bank to reach the water's edge, so it is more important to keep the sprinkler system spray focused on these low gradient areas that instigate the most amount of stranding.

Sprinkler Spray Provides Water to Isolated Pools
Isolated pools (pools of water surrounded by dry sediments) can hold large densities of larval lampreys (such as at Sunnyside and Wapato diversions). These pools can dry up quickly over time. The sprinkler system, if set up in proximity with these pools, will keep water in the pool and extend the life of trapped lampreys, thereby allowing future rescue efforts to rescue them safely.

Small PVC Is Easy To Maneuver
The gradual decrease in PVC sizes within our system not only appeared to increase pressure throughout the system, but also made for easy maneuvering and flexibility around large humps and other obstacles.

Keep Electrical Connections Dry
Our pump shut off during night operations on several occasions. One probable cause of the system malfunction was moisture reaching the electrical supply (mostly from rain or morning dew). It is imperative that the electrical connection stays dry during this operation and heavy duty outdoor grade extension cords are used.

Importance of a "Blow-Out Valve"
During the set-up process, sediment became lodged in many of the pipes. The system was first turned on with all sprinkler heads closed and the blow-out valve opened, effectively pushing out all debris/sediment lodged in the pipes (which would otherwise clog the sprinkler heads).

5.5 Netting Material on Dry Banks

One proposed method to help protect exposed larval lampreys from predation after dewatering (when personnel are not available, and throughout the evening hours) is to place a 1/8" or smaller mesh net over the high density dry banks to prevent predation. This may be most effective if used in conjunction with the water sprinkler setup, which will help them traverse to the water's edge. By coupling this with the sprinkler system, it will not only limit predators' ability to pick up exposed lampreys but also allow water to seep through the holes and keep lampreys moist/wet. The netting material does not have to cover the entire dry sediment area, but can be used in high density critical areas. It can be placed at the base of concave surfaces, bottom of steep slopes, or placed over isolated pools (that may dry up), and other areas where larval lamprey densities were observed (or predicted) to be the highest on (or within) the dry bank. One potential option for netting material is grass seed netting, which comes in a variety of sizes, can absorb water to stay moist, and is biodegradable. Reusable options include poly mesh tarps (such as 70% shade; Fig. 5.9).

Figure 5.9. An example of a polymesh tarp material that could be used for covering dry banks with a high chance of predation.

5.6 Close Coordination for Facility Maintenance Activities

After the irrigation season, diversion facilities typically undergo annual maintenance activities that can be harmful to entrained lampreys. Annual maintenance activities include screen raising and washing, operating pumps to drop the water level, and sediment removal. To improve lamprey survival during dewatering, a rigorous and effective salvage plan needs to be in place before dewatering occurs. In order to develop this plan, it is important to coordinate closely with the appropriate agency to understand both the timing and protocol of each relevant maintenance activity, including dewatering, fish (non-lamprey) rescue, and maintenance activities.

If possible, it is generally important to schedule lamprey salvage operations before maintenance operations occur. Activities such as screen raising and washing activities can create turbid water conditions which make lamprey electrofishing efforts difficult and inefficient (Fig. 5.10). If possible, it would be best to avoid the time when the screens are being washed. Small industrial pumps are occasionally used to drop the water level for fish salvage or to dredge the area (Fig. 5.11). Larval lampreys can be sucked through the pumps (Fig. 5.12). For instance, two pumps (50 gallon min^{-1} and 300 gallon min^{-1} pumps) were used during a dredging operation on October 16 and 17, 2015, at Bachelor-Hatton Diversion (Ahtanum Creek, Ahtanum, WA). The pumps were placed immediately upstream of the fish screens and used to draw down the water level. Based on the subsampling, we estimated that approximately 1,188 larval lampreys passed through these two pumps during approximately 500 minutes of run time (average of 142 lampreys hour^{-1}), resulting in approximately 16-25% mortality (~321 lampreys). When lampreys are still relatively abundant, it is important to place a fish friendly screen on the pumps (3/32” mesh or smaller is preferred) and point the outflow back into the river to ensure the greatest chance of survival for lampreys that may pass through the pumps alive.

Dredging operations typically deposit lampreys on dry banks. A high portion of lampreys trapped in dredged material can be bruised or mutilated (Fig. 5.13). On October 16-17, 2015, over 700 larval lampreys were recovered from dredged material at Bachelor-Hatton Diversion. This accounts only for lampreys on the surface of the material; the number of lampreys within the discarded material could have been much higher. Salvage operations should be completed before dredging occurs, as lampreys trapped in discarded material are nearly impossible to remove or in bad condition (compared to those removed by electrofishing). Knowing if and when dredging operations will occur is an essential step to any lamprey rescue operation.

Figure 5.10. Screen washing activity at Sunnyside Diversion in November, 2018. Water turned very turbid, which made observing lampreys during electrofishing extremely difficult.

Figure 5.11. The left photo shows small (50-300 gallon min^{-1}) industrial pumps removing water from Bachelor-Hatton Diversion in October, 2016. The right photo shows the intake screening system on one of the pumps which is designed to prevent entry of large debris, but not lampreys.

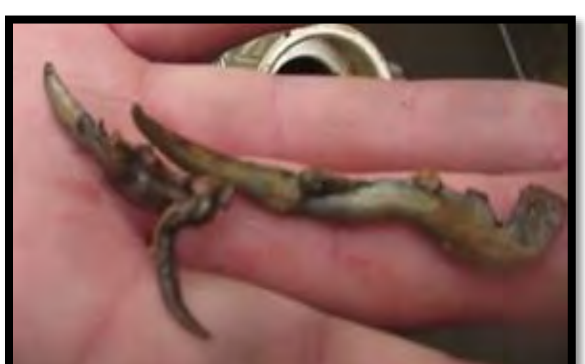


Figure 5.12. Mutilated lampreys found within the camlock that connects pump to the discharge hose at Bachelor-Hatton Diversion on October 16, 2015. C

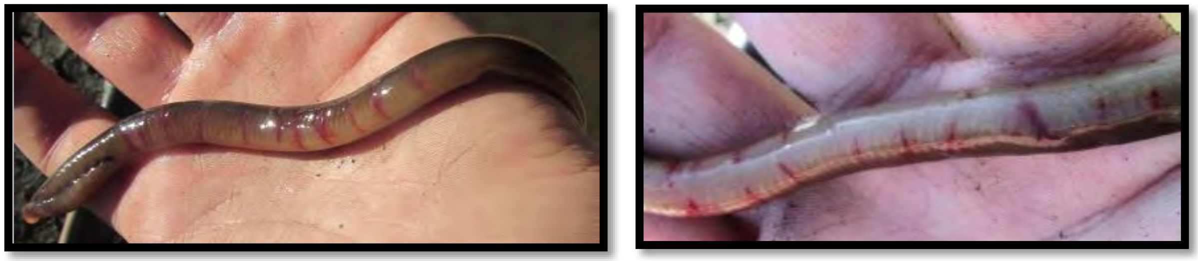


Figure 5.13. Injured larval lampreys found at Sunnyside Diversion in previous years, which are suspected to be caused by either unscreened pumps or dredging.

Task 6: Consideration for Facility Design and Management

6.1 Overview of Fish Screen and Lamprey Sizes

Many of the irrigation diversions in the Yakima Subbasin are known to entrain larval lampreys downstream of the fish screens based on past annual sampling by the YN Fisheries during the canal dewatering season. This is understandable as none of the fish screens currently in use are small enough to prevent young-of-the-year 0+ age larvae (see Fig. 6.1) from getting entrained (i.e. to move through the screens). Existing fish screens in habitat with salmonids have a mesh size that is typically between 1.75 mm and 3.2 mm. For any new screens that need to be installed, the current NOAA Fisheries criteria for salmonid species is 1.75 mm to 2.4 mm (3/32 inch) depending on specific screen type (with a minimum opening of 27%). If fry-sized salmonids are never present at a site, 6.35 mm (1/4 inch) mesh screen are allowed to be used (with a minimum opening of 40%). However, even the fish screens approved for salmonids fry are passable not only for young-of-the-year lampreys but also 2-3 year old lampreys that are 50-70 mm in size (see Rose & Mesa 2012). To prevent 0+ age larvae, which can be as small as 7 mm but generally 10-35 mm, from being entrained, a screen mesh size would need to be 0.5-1 mm in size (Fig. 6.2). Achieving 27% opening on fish screens become increasingly difficult as the mesh size decreases further, and if screens with smaller percent opening are used, this will lead to less water being available for the irrigation districts; the only way around this is to increase the surface area of the screen, which involves new channel construction within the canal, which can be both financially and logistically challenging for irrigators.

The YN has surveyed numerous diversions within the Yakima Subbasin and as a result we have had a chance to see firsthand diversions that entrain many lampreys vs. those with limited number of lampreys behind the screens. A variety of screen types are used in these diversions, including woven wire cloth, perforated, profile bar, and interlock screens (Fig. 6.3). Woven wire cloth screens (2.4 mm – *existing requirement for salmonid screens mesh opening) are typically used on rotating drum screens. Profile bar (1.75 mm) and Intralox (1.7 mm) screens are typically used on flat vertical screens (interlock are also used for traveling screens). Perforated screens (2.4 mm) can be used on both drum and vertical screens.

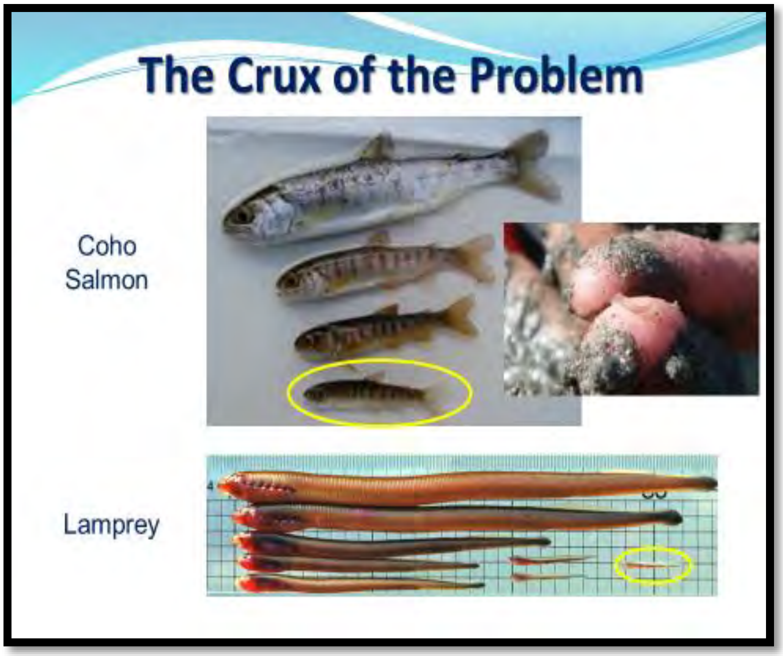


Figure 6.1. Examples of juvenile salmonids (coho salmon) and larval lampreys and their relative sizes as they grow larger. Young-of-the-year larvae (circled in yellow) are so small they can fit through a 500 micron mesh whereas the smallest coho fry can be adequately protected by a 3/32 inch screen. Lamprey photo credit: Yuji Seo (Hokkaido, Japan, EcoTech, Inc.).

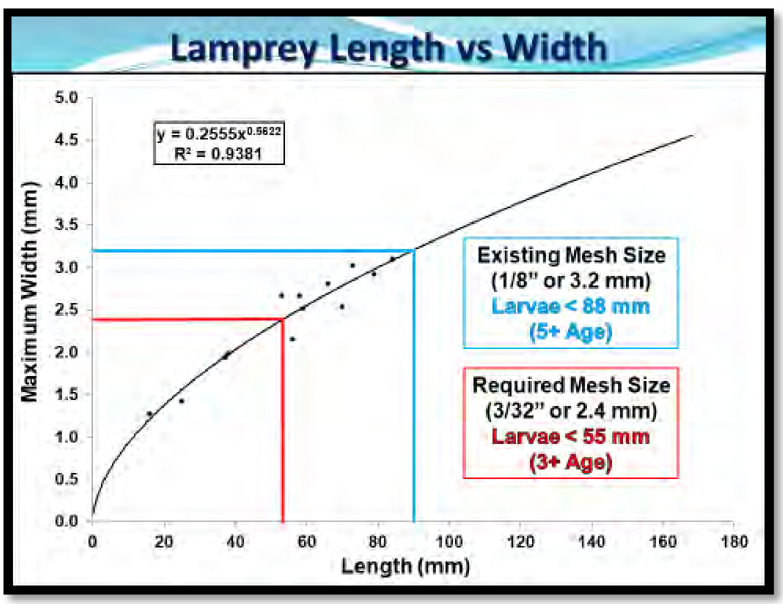


Figure 6.2. Measurements of larval lampreys length and maximum width (by the head region anterior to the first gill pore). Both adult and larval lampreys are known to be capable of slithering through areas that are slightly smaller than their widest region width; hence 60 mm larvae may still be able to slip through a 2.4 mm mesh. As a result, it is important to be extra conservative in selecting the appropriate mesh size to prevent entrainment / passage.

Figure 6.3. Photos displaying the four main types of screens and examples of facilities that use these screens. The NOAA Fisheries salmonid criteria for the mesh opening size are also displayed for each screen type.

6.2 Field Studies on Fish Screens and Lamprey Interactions

One of the primary YN Fisheries goals in 2014 water year was to evaluate the influence that existing fish screens have on lamprey dispersal within the irrigation diversion facilities. For this study, we separated the diversions surveyed into four general areas (see Table 6.1 and Fig. 6.4). By monitoring the distribution of lampreys above and below fish screens in light of the fish screen types and mesh sizes, we attempted to evaluate whether certain types of fish screens can effectively reduce (if not prevent) lamprey passage into the canal systems compared to others. The Yakima River Subbasin contains many dozens of irrigation diversions within the system with a wide variety of fish screen types and sizes and can therefore serve as a "natural laboratory" to better understand larval/juvenile lampreys interaction with irrigation diversions.

Of the 30 diversions surveyed, we examined the size classes of larvae from 19 diversions that contained larvae both upstream and downstream of the fish screens (Lampman & Beals 2014b). Fish screen types examined in this study included drum screen 3/32 inch (2.4 mm) woven wire (n=8), drum screen 1/8 inch (3.2 mm) woven wire (n=4), vertical screen 1.75 mm profile bar (n=3), and vertical screen 3/32 inch (2.4 mm) perforated (n=3). Although some lampreys were found in the canal further away from the fish screens, the highest densities and as a result the largest numbers of lampreys were found immediately upstream and downstream of the fish screens (Fig. 6.5). Lampreys captured immediately downstream of the fish screens were smaller in size compared to those captured immediately upstream of the screens (average size of 62 and 86 mm, respectively). This indicates that the fish screens are preventing at least some of the larger larvae from being entrained. However, the trend was reversed in the canal, where those captured further downstream from the fish screens were larger compared to those captured further upstream from the screens (94 and 63 mm, respectively). This seems to indicate the presence of some larvae that are capable of spending multiple years in the canal below the fish screens, overwintering and surviving in the low base flow conditions.

When the proportion of size classes for those captured immediately upstream and downstream of the fish screens are compared side by side, it is evident that larvae smaller than 60 mm are more commonly found downstream of the fish screens (Fig. 6.6). Those that are 70-80 mm are slightly more abundant upstream of the screens, and those that are 90 mm or larger are much more abundant upstream proportionally. An entrainment ratio analysis was conducted using the overall length data to determine the likelihood of entrainment by specific size classes (in 10 mm increments). The percent found immediately downstream of screens was divided by the percent found immediately upstream of screens for each size class to attain a ratio, and if this ratio is larger than one it indicates that a higher proportion of larvae are found downstream of the screens for that particular size class. This analysis helps display the sizes for which entrainment occurs as well as its magnitude of entrainment (Fig. 6.7). Most larvae larger than 100 mm had a much smaller entrainment ratio (<0.3), but there were exceptions and outliers. Although it is evident that the fish screens are preventing entrainment for some of the larvae (especially sizes above 90 mm), a considerable number of even larger larvae appear to be susceptible to entrainment (all the way up to 170 mm size).

When entrainment ratio analysis was conducted separately by the type of fish screens encountered (vertical bar, perforated plate, woven wire mesh in two sizes), the size at which the entrainment ratio dropped considerably below 1.0 was the smallest for the vertical bar screen (>50 mm), followed by perforated plate (>60 mm), followed by 2.4 mm woven wire mesh (>70 mm), and finally 3.2 mm woven wire mesh (>100 mm) (Fig. 6.8). These results are in line with those reported by the USGS study (Rose & Mesa 2012; also see Task 6.3). However, outliers (large larvae entrained) were observed in facilities with all four types of fish screens, indicating that either lampreys are finding larger gaps to pass through or are simply residing downstream of the screens for multiple years to attain those sizes.

Table 6.1. Definition and description for the four locations identified within each diversion surveyed.

Locations	Definition/Description
Above Screens Canal	[Upstream of fish screens] The location starts at the head gate, downstream to the trash racks, if present, or the initial change in canal configuration (widening or narrowing) where it transitions into the “Above Screen” area.
Above Screens	[Upstream of fish screens] The location starts at the end of the “Above Screens Canal” area (see above), downstream to the fish bypass inlet.
Below Screens	[Downstream of fish screens] The location starts at the fish screens, downstream to the initial change in canal configuration (narrowing or widening) where it transitions into the “Below Screens Canal” area.
Below Screens Canal	[Downstream of fish screens] The location starts at the end of the “Below Screens” area (see above), downstream.

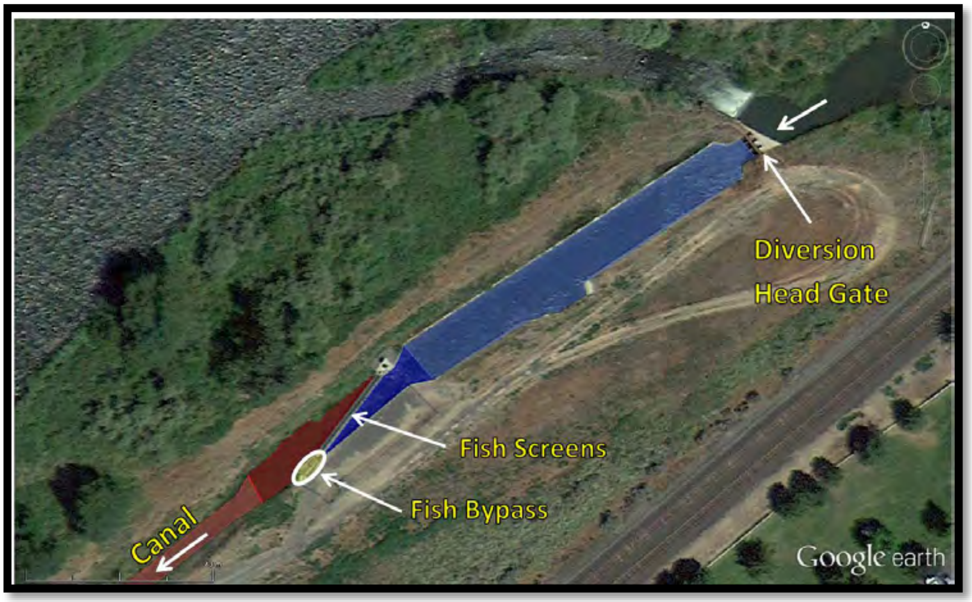


Figure 6.4. Overview of Selah-Moxee Diversion (Yakima River) displaying the four key areas: Above screens canal (light blue), above screens (dark blue), below screens (dark red), below screens canal (light red) (see Table 1 for more information). Key structures in the photo are also labeled.

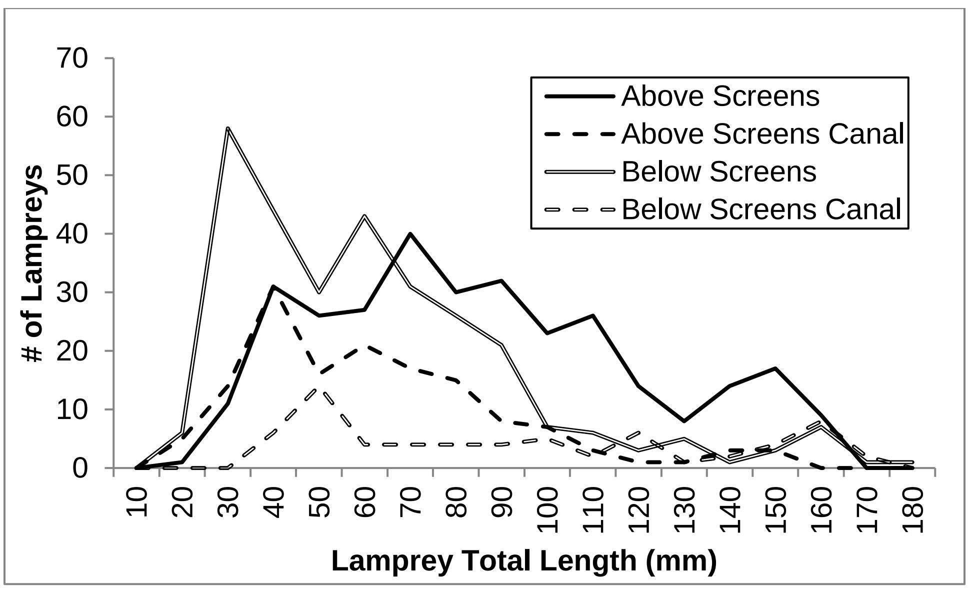


Figure 6.5. Density estimate curves for the sizes of lampreys captured upstream and downstream of the screens as well as in canals away from the fish screens (upstream and downstream).

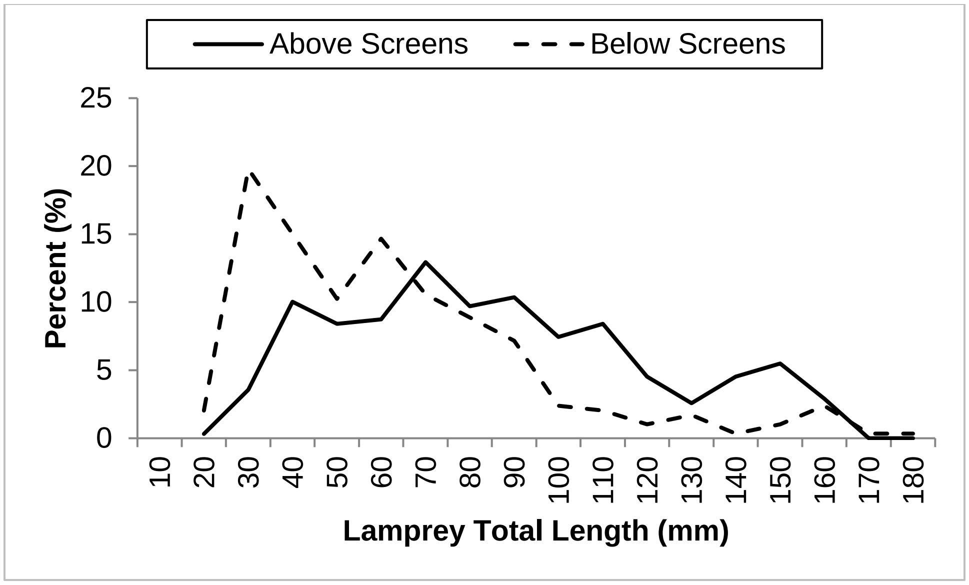


Figure 6.6. Proportion of lamprey sizes captured upstream and downstream of the screens in 2013-2014 shown as density estimate curves. Entrainment was observed for all sizes of larvae, but those under 70 mm were the most vulnerable (a larger proportion of those that are 70 mm or smaller were found downstream of the fish screens).

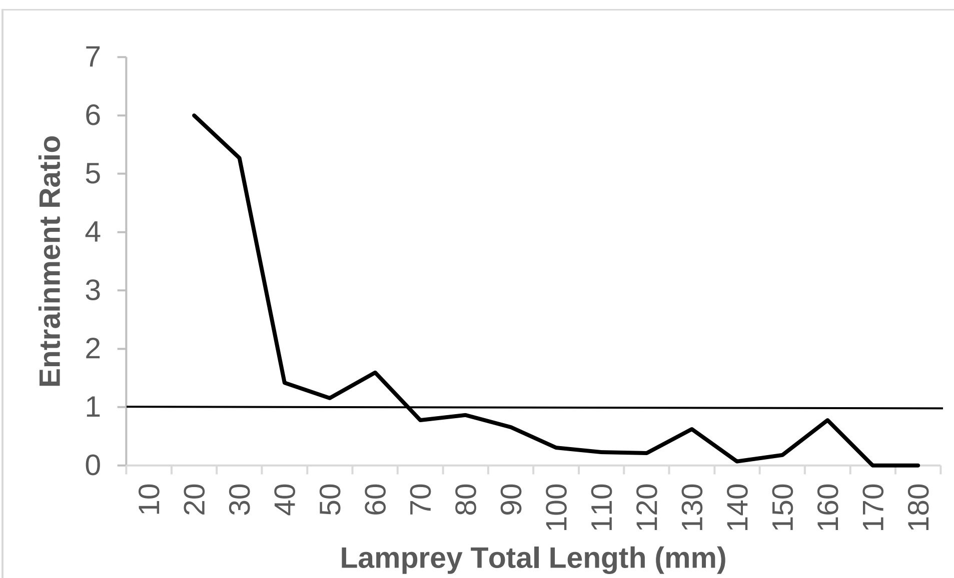


Figure 6.7. Entrainment ratio analysis (percent found downstream of screens divided by percent found upstream of screens) by 10 mm increment size classes, displaying the sizes for which entrainment occurs as well as its magnitude. If the entrainment ratio is larger than one (black line), that means a higher proportion of larvae at that size are found downstream of the screens. Most larvae >90 mm had an entrainment ratio of <0.3 (with some exceptions / outliers – see 130 and 160 mm).

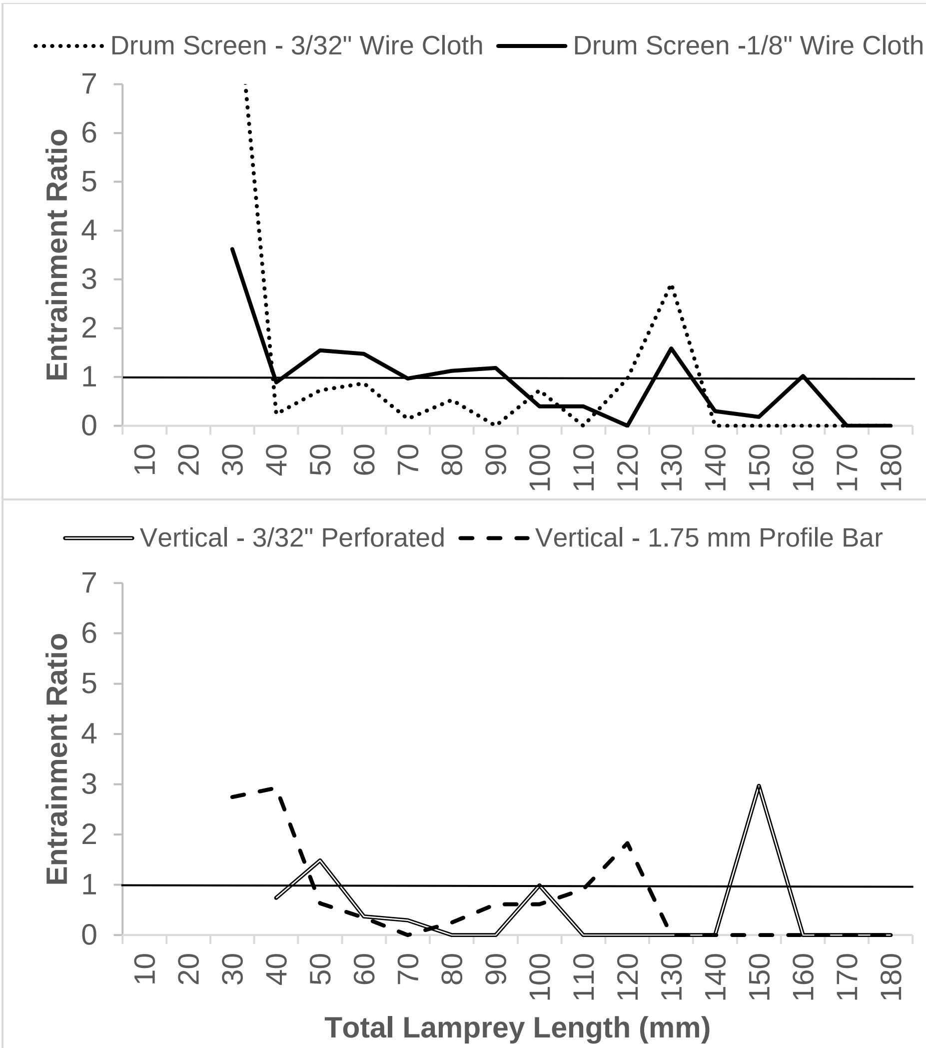


Figure 6.8. Entrainment ratio analysis (percent found downstream of screens divided by percent found upstream of screens) displaying the sizes for which entrainment occurs as well as its degree of magnitude for four types of screens (top: drum screen 3/32 and 1/8 inches; bottom: vertical perforated and profile bar). See text and Figure 6.6 for description of entrainment ratio calculation.

6.3 USGS Study on Fish Screens and Lamprey Interactions

A study conducted in an experimental flume by USGS with vertically oriented screens demonstrated that perforated screens performed slightly better than Intralox and profile bar screens for minimizing entrainment under the 12 cm/sec approach velocity (AV) and 35 cm/sec sweeping velocity (SV) conditions (*NOAA Fisheries maximum AV is 12.2 cm/sec) (Fig. 6.9 and 6.10; Rose & Mesa 2012). On the other hand, when the flow velocity rate was adjusted lower (6 cm/sec AV; 18 cm/sec SV), profile bar and Intralox screens appeared to performed better than perforated screens. Under both flow rate conditions, however, woven wire cloth screens (2.4 - 3.2 mm opening) performed the worst and entrained the most number of lampreys (including medium size larvae that are 80~90 mm). The poor performance of the woven wire is likely driven by a combination of two factors: 1) the larger mesh size; and 2) the configuration of the mesh. From the video monitoring at Congdon Diversion, we observed medium sized larvae frequently sliding in their tail through the woven wire mesh, getting themselves stuck and subsequently impinged (Photo E in Fig. 3.7). Another USGS test compared the performance of screens at 12 and 20 degree angles and showed that although there was no discernable difference in the entrainment or impingement rates between the two types of screens, the time it took to reach the bypass was approximately two times longer for the 20 degree angle screen type (Liedtke et al. 2019). In addition, based on field observations, the screen angle appears to influence the sediment transport mechanism; the shallower the angle, less sediment appears to move through the fish screens (see Task 6.8). This should help minimize not only larval lamprey interaction with fish screens (especially in an environment with sediment present) but also the canal maintenance work (i.e. dredging) required downstream of the screens.

In general, based on both USGS lab studies as well as field studies conducted in the field, we recommend the following when considering fish screen types:

1) Use the smallest mesh opening as possible (the smaller the better).
2) Use perforated, Intralox, or profile bar screens rather than woven wire mesh screens.
3) Minimize the approach velocity while maximizing the sweeping velocity.
4) Design the fish screens with the shallowest angle practical (i.e. the closer the screen angle is parallel to the direction of the flow rather than perpendicular, the better).

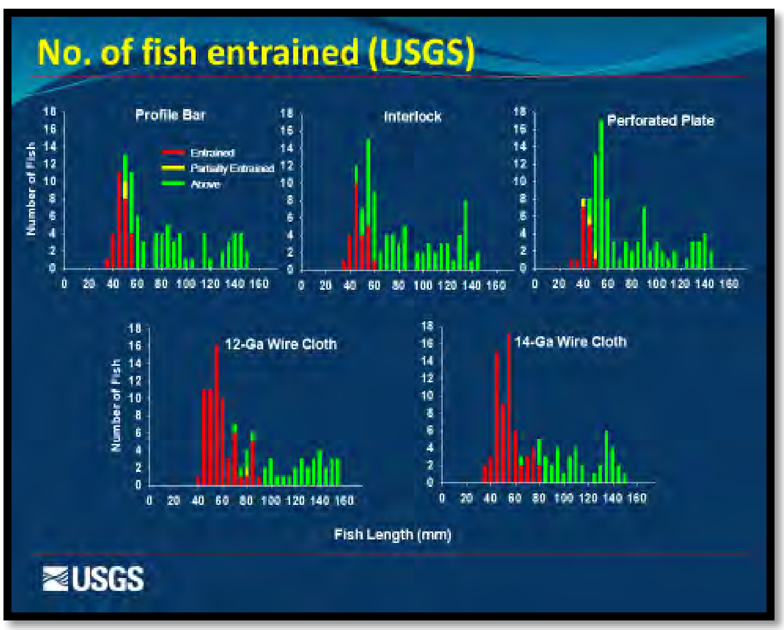


Fig. 6.9. Histogram of larval lamprey lengths used for a USGS fish screen study with color coding displaying the resulting behavior (entrainment, impingement, or staying above the screen) for each of the five screen types using a 12 cm/sec approach velocity (Rose & Mesa 2012).

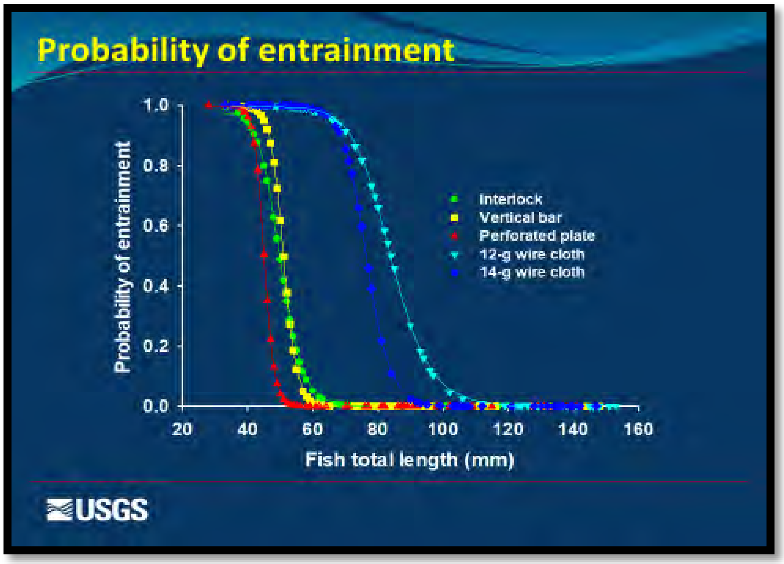


Figure 6.10. Probability curve of larval lamprey entrainment in relationship to their total length and screen types using a 12 cm/sec approach velocity (Rose & Mesa 2012).

6.4 Gaps/Tears in Fish Screens

The passage of larval lampreys into the area downstream of fish screens in any diversion is dependent on the mesh size and type of the fish screens. Regardless of fish screen types and mesh opening size, large larval lampreys (>100 mm) were frequently found downstream of fish screens in many diversions, alluding to the possibility that there may be gaps in the fish screens that allow these larger lampreys to pass through. The raised drum screens at Sunnyside Diversion that we examined in winter 2013 provided some insight on how larger lampreys may be maneuvering past this screen type. We observed gaps and tears in the rubber seal on the edges of the drum screens that ranged from 5-14 mm (Fig. 6.11). With a 3.2 mm (1/8 inch) mesh opening screen size at Sunnyside Diversion, only larvae 90 mm or larger is generally susceptible to entrainment (see Fig. 6.8, 6.9, and 6.10). Even though a 5 mm gap is only 1.6 times larger than the 3.2 mm mesh opening, based on our body width measurement this will allow lampreys ~200 mm and larger to be entrained (see Fig. 6.2). Given that the largest larvae/juvenile are ~200 mm typically, this essentially provides volitional passage to all lampreys (with the exception of adult Pacific Lamprey). As a result, even a modest increase in gaps can result in a substantial increase in entrainment threshold sizes (a mere 1.8-mm increase resulting in a two fold increase in passage in this case). In addition to allowing the passage of larger larvae, these loose and damaged rubber seals may also allow passage of many more small larvae. There may be other potential passage routes, such as through the bottom seals, which we were unable to monitor closely during our inspection. In slow water habitat, larvae tend to orient themselves to the bottom, and this is another likely location where we expect to see larvae approach the screens. To help minimize lamprey entrainment each coming year, we recommend a thorough inspection and repair of these gaps in fish screens by the operators on an annual basis.

Figure 6.11. Examples of gaps/tears observed at Sunnyside Diversion during winter of 2013. The size of gaps ranged from 5-14 mm. The left photo shows a gap with a 14-mm opening. The right photo displays a damaged rubber seal, resulting in a larger opening.

6.5 Habitats Used by Lampreys within Diversions

The total amount of observed larval habitat area (wetted and dry) from the 18 surveyed sites in 2013-2014 was estimated to be 13,729 m^2 above fish screens and 18,372 m^2 below fish screens, totaling 32,102 m^2, which is equivalent to approximately six football fields. This included both Type I and II habitat (see Task 2 for a definition of these habitat types). A total of 14,615 lampreys were estimated to reside in this habitat (an average of 0.46 lampreys m^{-2}). Diversions along the mainstem Yakima River contained considerably larger quantities of larval habitat compared to Naches and other tributaries of the Yakima River (Fig. 6.13). The amount of habitat area within diversions tended to increase as you move downriver, with Chandler Diversion (second lowermost diversion in the river) having the largest amount of larval habitat. The distribution of habitat area above and below fish screens varied considerably, however. In some sites the majority of larval habitat were found upstream of the fish screens (such as in Westside, Packwood, Selah-Moxee, and Union Gap diversions) whereas in other sites a larger portion was found downstream of the fish screens (such as Roza and Sunnyside).

High density areas for larvae were primarily found in small puddles of water over Type I habitat, wetted edges of fine sediment piles, or areas with a large amount of accumulated fine organic matter mixed with fine sediment (Fig. 6.14). Above screens, these areas were generally located against the concrete wall along the banks directly above the fish screens, but varied considerably depending on site conditions. Below screens, high density areas again varied, but were most frequently found along the wall directly downstream of the screen or in isolated pools further downstream. In general, areas with a higher amount of Type I habitat yielded a greater number of lampreys. Occasionally, the highest densities of larval lampreys can be found in Type II habitat, and this is typically due to the dewatering operation forcing lampreys to shift their habitat as they escape the drying banks, relocating to habitat still under water and available.

In 2013-2014, of all the captured lampreys, 2.5% (N=44) were transformers, and this ratio has been relatively consistent each year. During these early years, all the transformers were Western Brook Lamprey (with darkly pigmented caudal ridge and a translucent tail); however, in recent years, the percent of Pacific Lamprey have increased considerably, similar to the increase observed in the ratios of Pacific Lamprey larvae. The majority of these transformers are found upstream of fish screens except for Wapato, Sunnyside, and a few other diversions. Wapato and Sunnyside diversions had the highest number of transformed lampreys overall. Transformers are commonly found in high densities in areas among coarse organic matter, such as wood, that collect at the base of the drum screens and can also be found in coarse substrate (we find them in both fine and coarse substrates in October and November, depending on their metamorphosis development stages). Transformers are also found in high densities among other larvae, primarily in areas against or near the base of drum screens above and below screen areas.

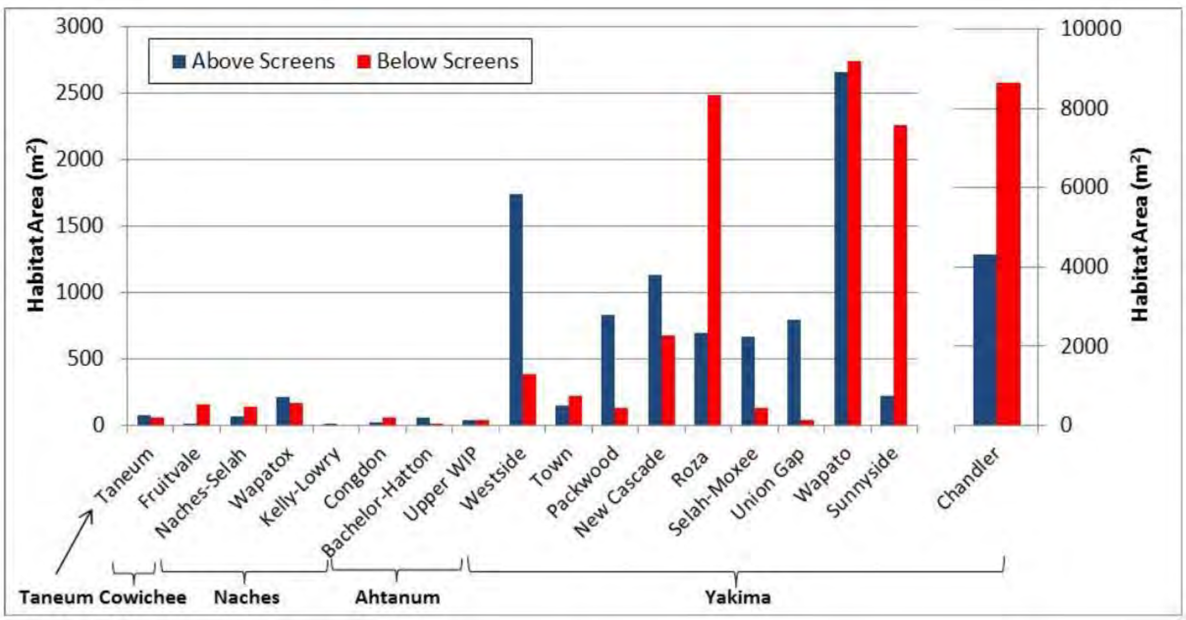


Figure 6.13. The total amount of observed larval lamprey habitat area above and below fish screens for each diversion surveyed in the Yakima Subbasin. The diversions are ordered from upstream to downstream (left to right) within their respective watersheds; bar graphs for Chandler diversion, however, was placed on the secondary y-axis due to their substantially higher values.

Figure 6.14. A representative photo showing observed dry Type I and II habitat area (grey color polygon), wetted habitat area surveyed (green color polygon), and a typical high density habitat area for larvae (pink color polygon) and transformers (yellow color polygon) from Taneum Diversion.

6.6 Relationship between Fine Sediment and Larval Lamprey Distribution

Because there are numerous variables that can influence the number of lampreys found at each diversion site (such as types of fish screens, headgate / fish screens orientation, proximity to natural rearing habitat, etc.), we conducted a matched-pair analysis in 2013-2014 to compare two variables both above and below fish screens at each site: 1) estimated number of lampreys and 2) habitat availability (see Fig. 6.15). We used ratios to compare the two values from each area and excluded the canal habitat further away from the fish screens to focus on the direct influence from the screens. For this analysis, we only compared sites that were surveyed both above and below the fish screens area that had at least one fish captured in both locations. The relationship between estimated habitat area and number of estimated lampreys was very strong (r^2 = 0.92; Fig. 6.16). The intercept for the above screens area was 0.31 higher than that for the below screens area, suggesting that the ratio of estimated lamprey numbers were on average 31% higher in above screens area compared to below screens area given an equal ratio of habitat area.

We also compared the ratio of the estimated number of lampreys and that of the estimated fine sediment volume (Fig. 6.17). The volume was estimated based on the maximum depth and was calculated based on a polyhedron shape (area x maximum depth x 33%). The relationship was equally strong (r^2 = 0.83) compared to the habitat area comparison, but the difference in intercept was smaller (0.11), suggesting that the ratio of estimated lamprey numbers were on average only higher by 11% in the above screens area compared to below screens area given an equal ratio of fine sediment volume. Although the amount of available habitat area was on average 2.0 times higher downstream than upstream of the fish screens, the amount of available habitat volume was only 1.4 times higher downstream than upstream of the fish screens, suggesting that sediment depth was generally deeper upstream of the screens. A couple outliers included Taneum and Wapatox diversions. Taneum Diversion had a low ratio of observed lamprey numbers below the screens, whereas Wapatox Diversion had a high ratio of observed lamprey numbers below the screens considering the volume of fine sediment available at these sites. This was most likely influenced by the amount of wetted habitat available during the survey; Taneum Diversion had only 4.7% of the overall habitat available for survey below screens (compared to 29.3% above screens) whereas Wapatox Diversion had 39.8% of the overall habitat available for survey below screens (compared to 18.4% above screens).

In conclusion, our analysis demonstrates that the amount of fine sediment habitat can effectively predict where the larvae will be distributed, regardless of the presence and type of fish screens. In other words, larvae may simply be moving with the fine sediment and if more fine sediment habitat is distributed above the screens, a proportionate amount of larvae will be found there. If more fine sediment habitat is distributed below the screens, on the other hand, a proportionate amount of larvae will be found there instead (see Fig. 6.16 and 6.17). As a result, although the screens are found to be effective in reducing the proportion of larger size class larvae (>85 mm) to some degree, they do not appear to influence the overall number of larvae substantially upstream and downstream of the fish screens. In addition, the number and/or magnitude of larvae moving further downstream into the canal during irrigation season is completely unknown.

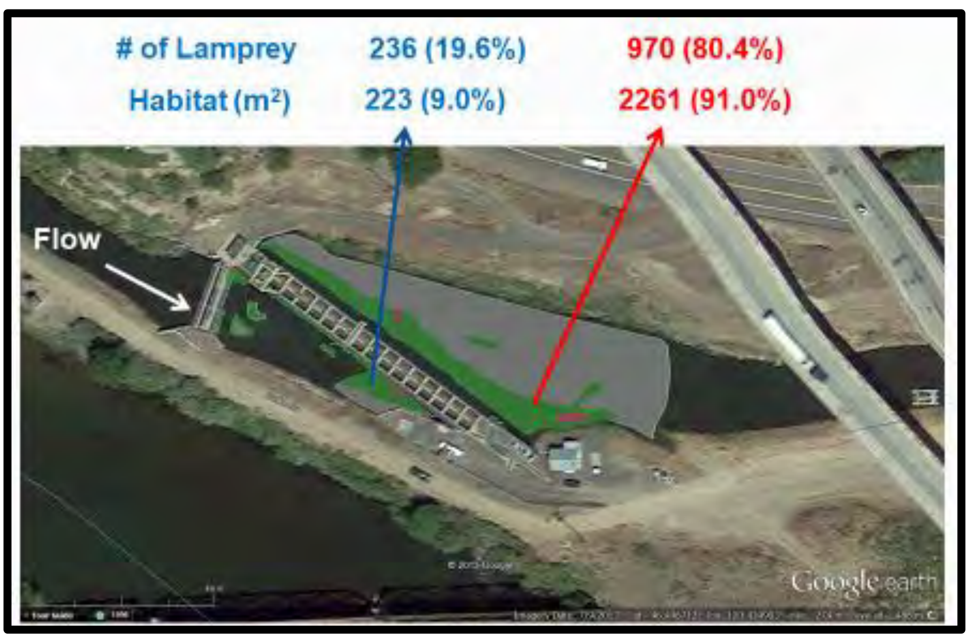


Figure 6.15. Overview of Sunnyside Diversion larval lamprey habitat from 2013-2014. The grey polygon displays the overall larval lamprey habitat area, the green polygon displays the wetted remaining larval lamprey habitat after dewatering, and the pink polygon displays the high density habitat. The values and ratios of the overall habitat area in comparison with the estimated numbers

of lampreys upstream (blue font) and downstream (red font) of the fish screens are displayed above.

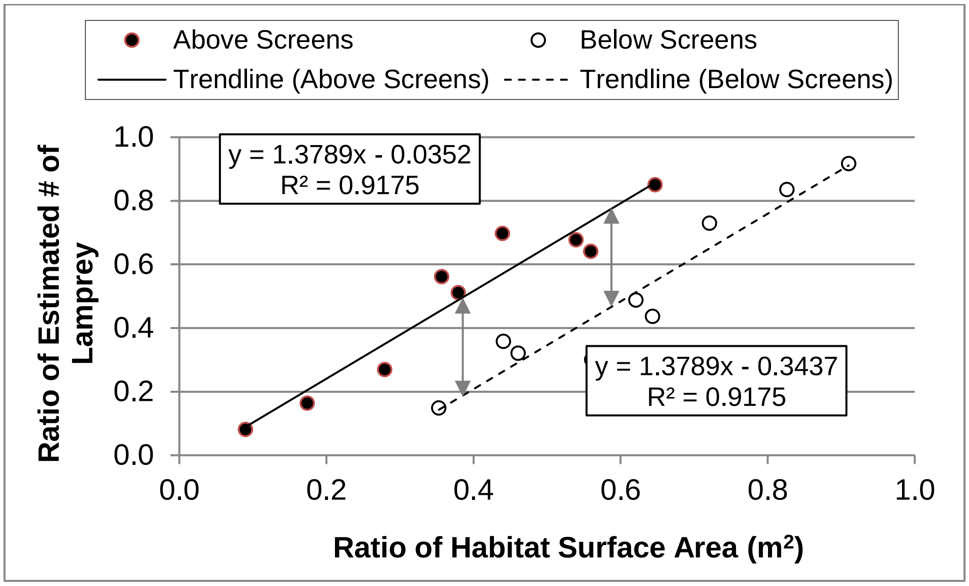


Figure 6.16. Matched pair analysis of the ratios for fine sediment habitat surface area (x-axis) and estimated number of lampreys (y-axis) between above and below screens areas. The trend line equation and r square values are also shown. The trend line slopes for above screens area and below screens area are identical to each other because they are paired ratios. The two arrow lines indicate the difference observed in lamprey number ratios between above and below screens (i.e. the potential magnitude of density reduction due to fish screens).

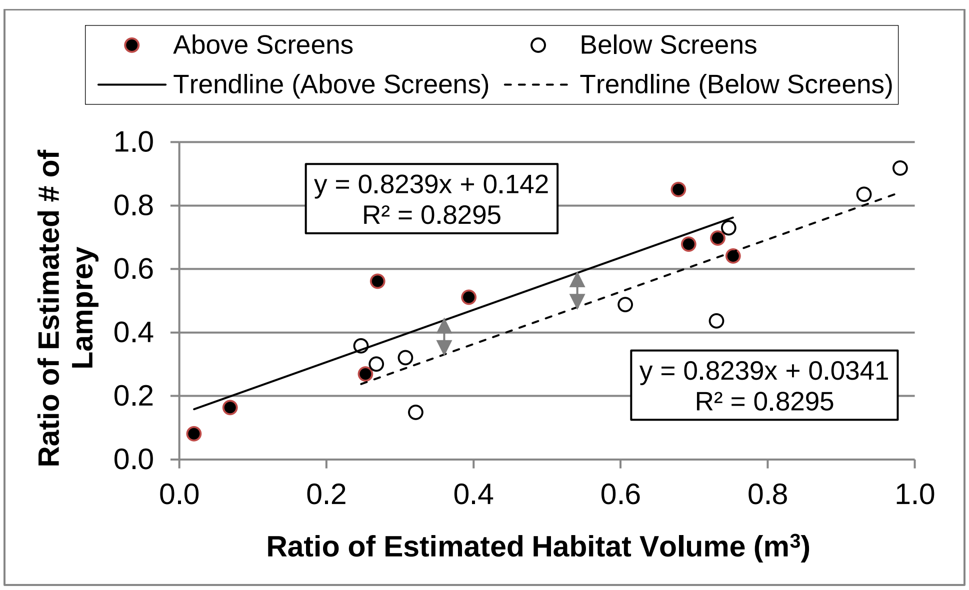


Figure 6.17. Matched pair analysis of the ratios for fine sediment habitat volume (x-axis) and estimated number of lampreys (y-axis) between above and below screens areas. The trend line equation and r square values are also shown. The trend line slopes for above screens area and below screens area are identical to each other because they are paired ratios. The two arrow lines indicate the difference observed in lamprey number ratios between above and below screens (i.e. the potential magnitude of density reduction due to fish screens).

6.7 Intrinsic Potential Scoring System for Headgate Entrainment

There are considerable differences in the abundance of entrained lampreys among diversions, with some diversions entraining thousands of larvae each year while others retain almost no lamprey. What factors are possibly influencing the risk of entrainment for lampreys? Based on our many years of monitoring within the Yakima Subbasin diversions, we have identified that both the size of the diversion (in terms of water discharge) and the orientation of the diversion inlet (by the headgate area in relation to the direction of the thalweg flow) appear to play critical roles in determining the amount of fine sediment delivered to the canal each year by the fish screens area. Based on the relationship we observed between the fine sediment and lamprey numbers (see Task 6.5), we suspect that an increase in fine sediment loading will also lead to an increase in entrained lampreys.

The type of fish screens being used and their angle/orientation is an important factor in determining the degree of lamprey entrainment moving past the fish screens once they are in the diversion as explained in the previous sections (see Task 6.2 and 6.3). However, arguably the disposition of the headgate may play an even more important role in determining the potential risk of larval/juvenile lampreys entering these diversions and therefore hold the key to the overall risk of entrainment. In 2013, 72 diversions within the Yakima subbasin were each rated by two criteria 1) canal width and 2) diversion inlet angle, to provide a scoring system for the lamprey entrainment intrinsic potential (Lampman 2014c). Canal width was used as a surrogate of water discharge (Fig. 6.18) and was measured in Google Earth using 2013 summer aerial photos at a representative section immediately below fish screens. The angle of the diversion inlet in relationship to the thalweg flow was also measured in Google Earth using 2013 summer aerial photos. Fig. 6.19 through 6.21 illustrate how the angle was determined for some of the diversions in the Yakima River (Columbia, Richland, Chandler, and Roza diversions) using Google Earth.

The overall score was calculated by the equation below:
Overall Score = (100 – (diversion inlet angle)) * ((canal width) / (maximum canal width from all select diversions))

As a result, the maximum score is 100 * 1 = 100.

Table 6.2 displays the two measurements as well as the overall scores for diversions of interest within the Yakima Subbasin. The fact that Sunnyside (Yakima R.), Chandler (Yakima R.), and Unit 2 Feeder (Toppenish Ck.) were the three diversions with the highest scores illustrate well how the overall score can be used as an effective surrogate value for the amount of fine sediment that accumulate in these systems (Fig. 6.22). However, very few larval lampreys have been found in Chandler and Unit 2 Feeder diversions during the fall dewatering period to date, most likely due to warm water temperature (>24 C°) these sites experience during the summer. Although some diversions with high scores may not always have a large number of larval and/or juvenile lampreys due to these other factors (water temperature, sediment availability, etc.), the majority of sites with high scores (>20) correspond very well with the sites we have succeeded in capturing many larval lampreys – including, Taneum, Selah-Moxee, Wapato, Westside, Fruitvale, Moxee (Union Gap), and Wapatox. Conversely, no larval lampreys have been found in diversions with low overall scores, such as Hoptowit, Hatton, and WIP Simcoe Narrows.

In conclusion, diversions can be prioritized for larval lamprey entrainment risk by using an overall score based on canal discharge and diversion inlet orientation (angle). Furthermore, in future years as diversion headgates reach the end of their life span, we recommend the installation of headgates that are positioned as close to parallel to the thalweg flow, which will not only help diminish the potential for lamprey entrainment, but also minimize fine sediment entrainment in general, significantly reducing the annual site maintenance required for these diversion sites.

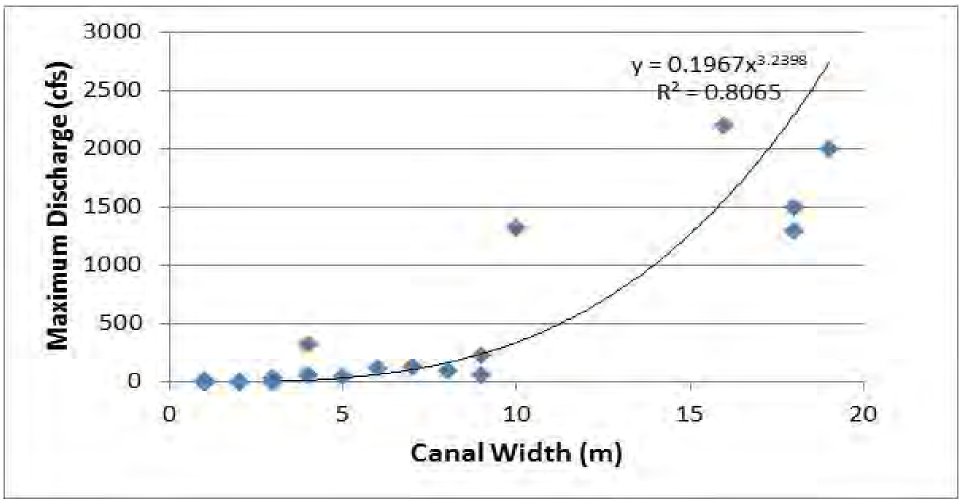


Figure 6.18. The x-y scatterplot of irrigation canal width and maximum discharge, showing a strong correlation using a power regression trend line.

Figure 6.19. Columbia Diversion (left) (inlet angle = 90 degrees, canal width = 8 m) and Richland Diversion (right) (inlet angle = 90 degrees, canal width = 9 m) on the Yakima River. The blue arrow displays the thalweg flow direction and the yellow lines display the general orientation/angle of the headgate structures.

Figure 6.20. Chandler (Prosser) Diversion on the Yakima River (inlet angle = 45 degrees, canal width = 11 m). The blue arrow displays the thalweg flow direction and the yellow line displays the general orientation/angle of the headgate structure.

Figure 6.21. Roza Diversion on the Yakima River (inlet angle = 80 degrees, canal width = 6 m). The blue arrow displays the thalweg flow direction and the yellow line displays the general orientation/angle of the headgate structure.

Table 6.2. Larval/juvenile lamprey entrainment intrinsic potential scores based on irrigation canal width and inlet angle in relationship to thalweg flow (in order of combined score). Red and blue colors indicate high and low scores, respectively.

Diversion Name	River/Stream	Inlet river km	Canal Width (m)	Inlet Angle (°)	Combined Score (100)
Sunnyside	Yakima	171.4	18	0	94.7
Chandler	Yakima	75.7	18	45	52.1
Unit 2 Feeder	Toppenish	44.7	12	45	34.7
Naches-Selah	Naches	30.7	6	0	31.6
Taneum	Taneum	3.9	6	0	31.6
Selah-Moxee	Yakima	203.7	6	0	31.6
Wapato	Yakima	176.3	19	70	30.0
Packwood-McAusland	Yakima	263.4	7	20	29.5
Kittitas (Easton)	Yakima	329.7	10	45	28.9
West Side	Yakima	272.4	8	45	23.2
Fruitvale	Cowiche	4.4	4	0	21.1
Moxee (Union Gap)	Yakima	189.8	4	0	21.1
Taylor	Yakima	201.2	4	0	21.1
Wapatox	Naches	28.9	7	45	20.3
Upper (Main) WIP	Ahtanum	32.8	5	30	18.4
Roza	Yakima	210.7	16	80	16.8
Kelley-Lowry	Naches	23.0	3	0	15.8
Snipes-Allen	Yakima	159.8	3	0	15.8
Town	Yakima	264.7	9	70	14.2
Bachelor-Hatton	Ahtanum	31.8	4	45	11.6
Olney	Toppenish	73.0	4	45	11.6
Herke North Side (Lower)	Ahtanum	34.3	3	30	11.1
John Cox	NF Ahtanum	4.1	3	30	11.1
Lafortune-Powell	Naches	22.0	2	0	10.5
Scott Ditch	Naches	22.9	2	0	10.5
New Cascade	Yakima	262.8	10	80	10.5
Herke South Side	Ahtanum	37.3	3	45	8.7
Old Union	Naches	4.3	3	45	8.7
Congdon	Naches	14.6	3	45	8.7
Wilson/Bull	Wilson	11.1	3	45	8.7
Forgarty-Dyer	Yakima	251.6	3	45	8.7
Herke North Side (Upper)	Ahtanum	34.9	2	30	7.4
Ellensburg Mill	Dry	0.3	2	30	7.4
Yakima-Tieton	Tieton	23.6	4	65	7.4
Lower WIP	Ahtanum	16.5	3	60	6.3
Gleed	Naches	15.6	3	60	6.3
Toppenish-Satus	Toppenish	7.7	12	90	6.3
Barnes Road	Manastash	2.3	2	45	5.8
Unknown	SF Ahtanum	2.5	2	45	5.8
Lindsey	Naches	50.8	1	0	5.3
Richland	Yakima	28.7	9	90	4.7
Columbia	Yakima	28.7	8	90	4.2
Yakima City	Naches	16.1	3	80	3.2
Clark	Naches	25.5	2	70	3.2
Diversion 31	NF Ahtanum	1.0	2	70	3.2
Hubbard-Smartlowit	Simcoe	27.3	1	45	2.9
South Fork Simcoe	Simcoe	29.3	1	45	2.9
Knudson	Taneum	5.7	1	45	2.9
3-Way	Toppenish	69.7	1	45	2.9
Hatfield	Manastash	8.8	4	90	2.1
NF Ahtanum Gage	NF Ahtanum	7.4	2	80	2.1
Royal Gun Club	Toppenish	39.6	2	80	2.1
Younger	Yakima	298.8	4	90	2.1
Manastash	Manastash	9.2	3	90	1.6
City of Yakima (Naches-Cowiche)	Naches	6.0	3	90	1.6
Hoptowit	Simcoe	30.2	1	70	1.6
Hatton	Ahtanum	30.5	2	90	1.1
Anderson	Manastash	5.7	1	80	1.1
AID/Billy Smith	Ahtanum	11.9	1	90	0.5
AID/Anna Marie Morton Pump	Ahtanum	14.4	1	90	0.5
AID/Janet Clark Pump	Ahtanum	21.2	1	90	0.5
AID/Leo Richardson Pump	Ahtanum	22.7	1	90	0.5
Diversion 14	Ahtanum	24.7	1	90	0.5
Lesh	Ahtanum	38.2	1	90	0.5
Reed	Manastash	8.5	1	90	0.5
Keachs-Jensen	Manastash	9.0	1	90	0.5
Chapman Nelson	Naches	9.7	1	90	0.5
Shaw-Knox	NF Ahtanum	3.2	1	90	0.5
Satus Orchard	Satus	49.6	1	90	0.5
AID/Marc Martin Pump	SF Ahtanum	1.6	1	90	0.5
Unknown	SF Ahtanum	3.7	1	90	0.5
WIP Simcoe Narrows	Simcoe	21.3	1	90	0.5

Figure 6.22. Examples of diversions with a high accumulation of fine sediment accumulation. Left photo shows the sediment accumulation at Sunnyside Diversion (Yakima River, Union Gap, WA) downstream of the fish screens after dewatering. The right photo shows the built-up of sediment at Chandler Diversion (Lower Yakima River, Prosser, WA) immediately upstream of the fish screens after dewatering.

6.8 Orientation of Headgate and Fish Screens at Wapato and Sunnyside Diversions

Intensive monitoring of larval/juvenile entrainment is ongoing and long term solutions need to be addressed to reduce the number of lampreys that enter these diversions. It has been documented in previous survey years that the orientation of the headgate (relative to the direction of the main channel thalweg flow) may have a considerable impact on the amount of fine sediment entering diversions; headgates perpendicular to the flow may increase incoming fine sediment and those that are parallel to the flow may reduce fine sediment (see Task 6.7).

Sunnyside and Wapato diversions present two unique headgate orientations. The headgate of Wapato Diversion is parallel with the main channel flow (Fig. 6.23) and the headgate of Sunnyside Diversion is perpendicular (Fig. 6.24). Based on the data we collected, and observations at various sites throughout the Yakima Subbasin, a headgate that is perpendicular to the main channel flow may entrain more fine sediment into the diversion. On the other hand, a headgate that is perpendicular to the flow may allow more fine sediment (to move into the diversion). Indeed, a larger quantity of fine sediment was observed near the fish screens at Sunnyside Diversion compared to Wapato Diversion in 2014-2015 (926 and 500 m^3, respectively), supporting this hypothesis. These two diversions are both located in the mid-reaches of the Yakima River (171.0 and 175.5 river km, respectfully) and availability of fine sediment should be comparable to each other. Because Wapato Diversion is located upstream of Sunnyside Diversion (intercepting sediment first) and diverts more water than Sunnyside Diversion (maximum flow rates of 2000 and 1300 cfs, respectfully), Wapato Diversion would be naturally inclined to collect more fine sediment than Sunnyside Diversion.

The channel flow configuration between the headgate and fish screens may also have an impact on fine sediment transport in these two diversions. At Wapato Diversion, the channel curves and the main current (thalweg) is directed towards the bypass rather than the fish screens, allowing flow to dissipate and fine sediment to deposit (Fig. 6.25). On the other hand, at Sunnyside Diversion, the channel is relatively straight and the thalweg is more or less directed towards the fish screens, allowing more fine sediment to be forced through the screens (Fig. 6.26). This explains perfectly what has been observed at Sunnyside and Wapato diversions; the vast majority of the fine sediment (larval habitat) is collected upstream of the fish screens at Wapato Diversion, whereas fine sediment is mostly collected only downstream of the fish screens at Sunnyside Diversion.

The allocation of fine sediment appears to directly impact where larval lampreys are found based on previous diversion surveys. The highest number of larval lampreys are found where fine sediment collects, suggesting that the allocation and deposition of fine sediment may play a large role in where lampreys end up in diversions. Consequently, by reducing the amount of fine sediment that moves into the diversions through the headgate and through fish screens, we may be able to also reduce the number of lampreys that interact with fish screens and become entrained. These conclusions are preliminary, but provide a viable outlook into potential long term solutions to reduce larval/juvenile lamprey entrainment. New irrigation diversion designs that incorporate these factors (low headgate and fish screen angles, shallow and curved canal channel configuration, etc.) is recommended to help minimize the entrainment potential of lampreys.

Finally, we hypothesized that a large percentage of entrained larvae may enter the canal when diversion head gates first open in the spring (typically in mid-March). To evaluate this, we conducted a pilot study to assess the amount of Type I habitat and larval lamprey density, and estimated the number of larval lampreys occupying the area of interest above the headgate at Sunnyside Diversion (Fig. 6.27). On March 3, 2013, we confirmed the presence of larval lampreys (Fig. 6.28) and mapped available habitat within the area of interest. Although we were unable to assess habitat directly upstream of the head gate (due to the water depth and lack of water clarity), we estimated conservatively that at least 725 larval lampreys reside within the observed habitat. On August, 20, 2013, three months after the irrigation season began, no larvae were detected in the same general area, suggesting they either moved around locally within the area of interest, migrated down river, or became entrained in the diversion.

Figure 6.23. A) Overview of the inlet to Sunnyside Diversion displaying the orientation of the headgate (yellow) relative to the direction of the main channel flow. B) Overview of the flow direction between the headgate and the fish screens.

Figure 6.24. A) Overview of the inlet to Sunnyside Diversion displaying the orientation of the headgate (yellow) relative to the direction of the main channel flow. B) Overview of the flow direction between the headgate and the fish screens.

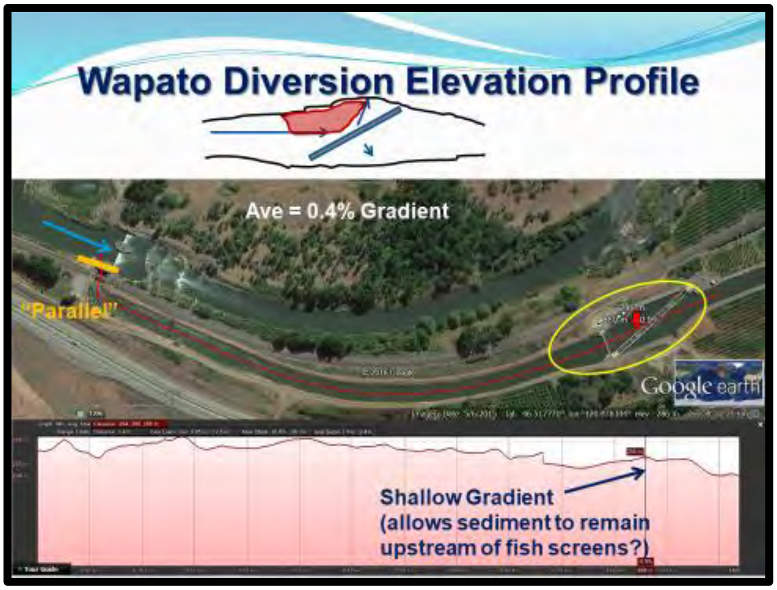


Figure 6.25. Wapato Diversion canal configuration between headgate and fish screens. The channel is not as straight as Sunnyside Diversion (curves to the left) and the average gradient is shallower (0.4%) with the shallowest gradient found in front of the screens.

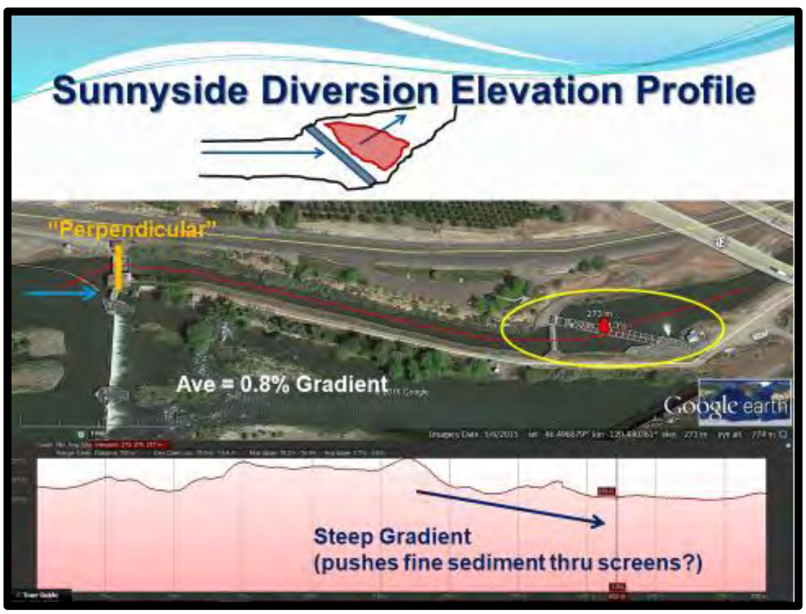


Figure 6.26. Sunnyside Diversion canal configuration between headgate and fish screens. The channel is straighter compared to Wapato Diversion and the average gradient is steeper (0.8%) with the steepest section right in front of the fish screens.

Figure 6.27. The area upstream of the Sunnyside Diversion headgate displaying confirmed Type I habitat (light blue polygon), coarse substrate (dark blue polygon), unknown habitat (grey polygon), and dip net survey locations A, B, and C [sites where larvae present (pink) and sites where larvae absent (orange)] on March 3, 2013.

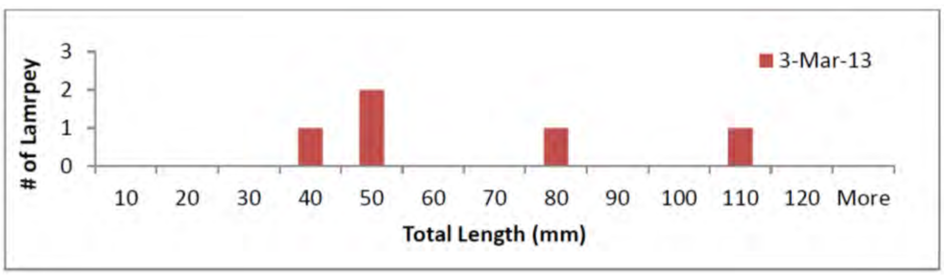


Figure 6.28. Frequency histogram displaying size class distribution of larvae captured within the area of interest on March 3, 2013, form the dip net survey.

6.10 Solutions #1: Simulated Perennial Side Channel Flow Regime

Many of the irrigation diversions have a long canal segment between the headgates and the fish screens. Large volumes of fine sediment (and large numbers of associated lampreys) can accumulate in this section of the canal. Due to this expansive area, it is very labor intensive and time consuming to rescue lampreys in this section after dewatering, and it is simply impossible to rescue all of the lampreys (typically less than 50% is captured with single pass electrofishing, and much less when lamprey densities are high and water clarity low). One potential solution to help lampreys rearing in this section of the canals is to turn the upper canal area into a simulated perennial side channel, where water is let in through the headgates (at a reduced amount) and allowed to flow through the flow return channel during the irrigation off season (Beals & Lampman 2019). This design works very well when there is some type of a water holding structure (weir, regulating gate, etc.) and a flow return channel available. At Wapatox Diversion (Naches River), an opportunity was available to implement a simulated perennial side channel flow regime during the 2018-2019 irrigation off season, providing year-round rearing habitat for larval lampreys upstream of the fish screens.

Wapatox Diversion is located in the lower reach of Naches River (headgates at river km 29.0; Fig. 6.29). Wapatox Diversion has a long canal (350 m) between the fish screens and the headgates. There are a set of regulating gates 210 m downstream of the headgates, which during the irrigation season regulate the flow further downstream (Fig. 6.30). Immediately upstream of these regulating gates is a flow return channel, which returns excess flow (and trapped fishes) back to the river (Fig. 6.31). Further downstream (56 m) of the regulating gates are the fish screens and the main fish bypass channel. Annually after dewatering, a high density of lampreys (up to ~50 lampreys/m^2) and a large area of dewatered larval lamprey habitat (up to ~550 m^2) are found between the headgates and regulating gates (Fig. 6.32). Past surveys have shown that the majority of lampreys at Wapatox Diversion reside between the headgates and regulating gates with a significantly lesser number found downstream of the regulating gates.

In November 2018, the YN Fisheries and the Reclamation coordinated and managed to maintain sufficient flow year-round in the section upstream of the regulating gates. The availability of regulating gates and the flow return channel at Wapatox Diversion provides the option for water and fishes to return immediately to the river (prior to approaching the fish screens). The canal section downstream of the regulating gates is left dry, and no water infiltrates the area immediately upstream of the fish screens, preventing damage to the fish screens related to freezing and icing. The operations at Wapatox Diversion to create a perennial side channel has the potential to provide a safe year-round rearing habitat as long as the initial extended dewatering period could be shortened. After a period of dewatering lasting a few hours, water was restored into the canal and lampreys that were initially stranded in the dried fine sediment regained access to water (Fig. 6.33). However, lampreys can still desiccate in even 1-2 hours and either a shorter dewatering period or a break in between the dewatering to allow staff to rescue stranded lampreys was recommended to reduce the risk of desiccation. The following year in 2019, the Reclamation staff was able to maintain the water levels above the primary fine sediment habitat during the initial dewatering, significantly minimizing risks of larval lamprey desiccation. Finally, accumulated sediment in the canal area downstream of the headgates will need to be dredged using heavy equipment ever few years. During those special operation years, more extensive dewatering and associated intensive lamprey rescue efforts will be required.

Figure 6.29. An overview of Wapatox Diversion, Naches River (water flow from left to right). The area with high densities of larval lampreys is outlined in red. Larval lampreys are found downstream of the regulating gates (green outlined area) near the fish screens, but in significantly lower densities. On November 1, 2018, immediately after irrigation shutdown, the headgates were left open slightly, and flow was provided between the headgates and regulating gates; in previous years this area was left mostly dewatered during the winter months. All winter flow re-entered the river via the return flow channel.

Figure 6.30. The regulating gates after dewatering looking downstream (left photo). The regulating gates after dewatering looking upstream (right photo). In 2018, the gates were fully shut after the reopening of the headgates for the winter months. Water level is generally low after irrigation shutdown, limiting potential damages caused by freezing water coming into contact with the gates.

Figure 6.31. An overview of the canal between the headgates and the regulating gate looking upstream on November 1, 2018 at 12:05 p.m. (left photo). The area upstream of the regulating gates looking downstream (right photo). The blue arrow in both photos show the location of the return flow channel.

Figure 6.32. An overview of the canal between the headgates and the regulating gates on November 1, 2018, immediately after the headgates were reopened, looking downstream from the headgates (left photo) and approximately two hours after the headgate was reopened; all exposed larval lamprey habitat was covered again (right photo). High densities of larval lampreys have been observed annually in this area after fall season dewatering.

Figure 6.33. Larval lampreys collected from dewatered banks at Wapato Diversion in 2015, showing stranded larval lampreys on dry banks shortly after dewatering (left photo) and a collection of many hundreds of larval lampreys from the canal section between the headgates and the regulating gates during electrofishing and bank collection (right photo).

6.11 Solutions #2: Flow Velocity Enhancement System

<u>Background on Study Site</u>

Bachelor-Hatton Diversion on Ahtanum Creek (near Yakima, WA) is a small irrigation diversion (Fig. 6.34) that has an irrigation season lasting from April 15 through early July each year. The diversion diverts approximately 58 cfs with an average water use of 12,500 acre feet per year. The fish screens consist of rotating drum screens with 1/8" woven wire mesh, which do not meet the current NOAA standards for new fish screens (3/32") to protect entrainment of salmonid species. The screens did meet the screening criteria during the time of installation. Adult Pacific Lamprey have been released into Ahtanum Creek since 2013 in an effort to restore Pacific Lamprey numbers in the watershed where they were once historically abundant. Both Pacific Lamprey and Western Brook Lamprey (resident species) are present in Ahtanum Creek.

With an increase in Pacific Lamprey larvae in the Yakima Subbasin, there is an increased risk of lampreys entering irrigation diversions. Between 2015 and 2018, we have removed 14,259 larval lampreys from Bachelor-Hatton Diversion, Ahtanum Creek (Ahtanum, WA). Before adult translocation began in 2013, the ratio of larvae (> 50 mm) that were Pacific Lamprey was 0% in this diversion. However, in 2015 through 2018, the ratio of Pacific Lamprey is near 95-99% each year, showing an increase in abundance of Pacific Lamprey larvae in the system.

More larval lampreys were recovered from upstream of the fish screens (87.4%, or 13,130) than below the screens (12.6%, or 1,129). Although these data show that a larger portion has been captured upstream of the fish screens, it is unknown how many lampreys move through the fish screens and travel down the canal and leave the system completely. In addition to the uncertainty related to the number of lampreys moving down the canal, we do not know what percentage of lampreys find their way into the diversion through the headgate from Ahtanum Creek. Recent research by USGS suggests that increasing the sweeping velocity in front of the fish screens will reduce lamprey interactions with the fish screens and encourage more lampreys to return to the river through the bypass (Liedtke et al. 2019). Similarly, if we create a sweeping velocity in front of the headgate (diversion inlet) we may be able to reduce (or prevent) lamprey entrainment all together.

Figure 6.34. Overview of Bachelor-Hatton Diversion on Ahtanum Creek. The left photo shows the diversion with water flowing during the irrigation season (flow from left to right). The right photo shows the area upstream of the fish screens after dewatering in July, 2018 (photo taken from the headgate facing downstream).

Flow Velocity Enhancement System

In November, 2018, the Northwest Power and Conservation Council approved funding ($51,539) for a pilot project using a Flow Velocity Enhancement System (FVES) at Bachelor-Hatton Diversion on Ahtanum Creek (near Yakima, WA). The FVES system is designed and operated by "Natural Solutions-A Dam Site Better!" out of Helena, MT. The system utilizes fish-friendly venturi pumps, which can be used to manipulate sweeping velocities and thalweg flows (Fig. 6.35). The goal of this project is to understand how the FVES unit influences 1) larval lamprey movements into the fish bypass system by increasing the sweeping velocity in front of the fish screens and 2) larval entrainment into the diversion by changing the stream thalweg flow upstream of the headgate to angle away from the diversion inlet (Fig. 6.36). This project will not only allow us to understand the effects that the FVES unit will have on larval entrainment, but also what our released lamprey numbers mean in relation to overall abundance within the stream.

Figure 6.35. A Flow Velocity Enhancement System venturi pump similar to the one that will be installed at Bachelor-Hatton Diversion during the 2020 irrigation season, as part of a project funded by the Northwest Power and Conservation Council. Photo provided by Natural Solutions, Helena, MT.

Figure 6.36. Overview of the planned placement locations for the FVES units at Bachelor-Hatton Diversion. The left photo shows the thalweg flow (yellow arrow) immediately upstream of the fish screens, and planned directed flow by the FVES unit at this location. The right photo shows the thalweg flow (yellow arrow) immediately upstream of the headgate, and the planned flow direction by the FVES unit at this location.

<u>*Monitoring Strategy*</u>

During the irrigation shutdown period (prior to April 15, 2020), PIT tag arrays will be installed in three locations at the diversion site: 1) within the fish bypass, 2) downstream of the fish screen in the canal, and 3) within Ahtanum Creek during the irrigation shut down period (prior to March 15, 2020). Pacific Lamprey larvae collected from Bachelor-Hatton Diversion in July, 2019, will be PIT tagged prior to the start of this study (during fall 2019 and winter 2020). Pacific Lamprey larvae too small for pit tagging (< 70 mm) will be tagged with VIE Tags prior to the start of the study as well.

Both FVES units will be in service for approximately 10 weeks and will be turned on and off using a systematic block design (one week block periods). There will be three control periods during which the FVES units will be turned off. Tagged lampreys will be strategically released between April 15 and June 1, 2020, both upstream and downstream of the headgate (Table 1). Movements of Pacific Lamprey larvae will be monitored in the fish bypass (i.e. successful return to the river), movements downstream of the fish screens (i.e. non-successful return to the river), and within the stream (diversion avoidance as well as successful bypass passage). VIE tags are detected visually, so no instream equipment is needed (however, they will need to be handled manually to be detected). Different colors of VIE tags can be used for each release. Additionally, the flow at Bachelor-Hatton Diversion will be monitored once a week (in the stream, screening area, and fish bypass) to ensure that the operation from the FVES unit is not negatively affecting the irrigation canal water intake.

Table 6.3. Overview of a draft weekly operation schedule for the FVES units and corresponding fish releases. Under "Pump Operation" column, "Testing/Efficiency" stands for a period of time when the FVES units will be tested for proper operation and PIT arrays will be tested for detection efficiency, "Control" stands for no FVES operation, and "Both" stands for both the headgate and screen area FVES units running at the same time.

				Release Location		
Week	**Date**	**Pump Operation**	**Fish Release?**	**Headgate (PIT))**	**Screens (PIT)**	**Screen (VIE)**
1	4/15/2020	Testing/Efficiency	Yes	25	25	-
2	4/19/2020	Control	Yes	25	25	25
3	4/26/2020	Both	Yes	25	25	25
4	5/3/2020	Both	No	-	-	-
5	5/10/2020	Control	Yes	25	25	25
6	5/17/2020	Both	Yes	25	25	25
7	5/24/2020	Both	Yes	25	25	25
8	5/31/2020	control	Yes	25	25	25
-	-	-	-	175	175	150
				Total	**500**	

Task 7: Interagency Coordination and Communication

7.1 Background

The YN Fisheries work closely with various federal, state and tribal agencies to develop and implement unique strategies to improve the survival of entrained lampreys during irrigation shut down and maintenance operations. We work closely with the Reclamation, WDFW, and several irrigation districts (e.g., Wapato Irrigation Project) annually to develop dewatering and maintenance plans to reduce lamprey mortalities in irrigation diversions throughout the Yakima Subbasin. The order of our sampling is based on the scheduled dewatering dates, and we coordinate closely with the partnering agencies to schedule the larval lamprey surveys. We appreciate all the partners' active involvement and engagement in this process and valuable discussion over the years to implement the best practical solutions for lampreys.

Volunteers have been a huge help to our program as well. We have solicited volunteers and interns from the general public as well as through the Washington Conservation Corps (WCC), USFWS, and local colleges (such as Heritage University, Central Washington University, and Oregon State University). This help not only provides direct benefit in terms of increased number of lampreys rescued, but also promotes a great opportunity to educate a wide range of individuals with various background and interest levels about the troubles lampreys currently face; we hope these experiences will inspire all those involved in lending a helping hand for lamprey restoration in future years.

The number of days it takes from the beginning of dewatering till the site is shallow enough (<1 m) for fish survey varies from site to site. For small facilities, the site is typically ready for fish salvage in less than a day. In large facilities, this may take several days or more as additional measures (such as extra water pumps) are needed to dewater adequately for fish surveys. Diversions are surveyed as close as possible to the time period when the site first become ready for larval/juvenile lamprey surveys, as any delay in the survey could easily lead to more loss of lampreys from desiccation and/or predation. Larval lampreys typically rear in the channel margins in fine sediment, so it is important to survey for them promptly as the fine sediment continues to dry up (even if the diversion itself is still deep and full of water). Hence, the degree to which fine substrate heaps are drying up is another important criterion to keep in mind when planning for larval lamprey surveys. When multiple diversions were dewatered at the same time, they were prioritized by their entrainment potential; in general, small diversions with less fine sediment deposition were placed at a lower priority than large diversions with more fine sediment deposition.

Through our extensive coordination with various agencies over the years, we have created many strong interagency relationships. However, even with effective and smooth communication between all participating agencies, there are often unforeseen events that can occur. Communication efforts are never perfect, and we have faced many preventable (and nonpreventable) challenges that have hindered the success of various projects. The lessons we have learned from these mistakes in communication have substantially strengthened the probability of success for future entrainment projects. In the sections below, we describe two examples in which projects did not go according to “the plan” due to communication errors and unforeseen events. The lessons from these events ultimately led to better collaboration and project planning among the partners in future years.

7.2 Stuck Headgate Incident (Wapato Diversion)

At Wapato Diversion, we have been communicating closely with WIP to control the dewatering rate in the screening area in an effort to reduce lamprey mortality. The goal in 2017 was to close the headgate in stages (dropping by 100-200 CFS daily). The headgate would be closed during the early morning hours, and we would have the morning and afternoon to rescue any lampreys that showed up on the dewatered banks. This staged dewatering worked well in 2016, and the resulting slow dewatering rate resulted in very few lamprey mortalities. When WIP went to seal the headgate on October 23, 2017 at 12:00 PM, the headgate became stuck open due to the presence of a lodged tree. The resulting water level was perfect, and the sediment and lampreys were protected. However, when WIP removed the tree and sealed the headgate the water level dropped very quickly (in the late afternoon) and many thousands of lampreys perished. No one informed us that the headgate was sealed, and the lampreys simply became too numerous for our crew of two people to pick up as they emerged rapidly. By the time we got more staff to provide assistance on the ground, it was already getting dark and became very challenging to see the exposed lampreys. On that evening (October 23, 2017), we found 485 live lampreys, but 915 of them were already dead. The following day, we encountered 480 live lampreys, but 420 of them were dead, totalling 1,335 mortalities altogether.

This incident increased our awareness of unexpected circumstances and the importance of continued close communication. We immediately set up a meeting with WIP and worked together on plans to prevent these types of mishaps and large mortalities. Specifically, we saw the need to find ways to hold up water at the project area upstream of the fish screens so that water will not drain immediately after the headgate was shut, and we have since found two alternative locations to help hold the water we need (using stop logs within the bypass channel and at a weir 1.5 miles down the canal). We also discussed the importance of having periodic check-ins for coordination (yearly, daily, and even hourly on the event day) to ensure the goals and objectives are clear for everyone on the crew for all parties involved. This helps ensure that an open channel is available to relay and discuss all changes and issues as they arise. This level of close communication allows everyone on the ground to be aware of the needs for the project and is critical for project success.

7.3 Pump Operation Incident (Sunnyside Diversion)

At Sunnyside Diversion, in addition to some amounts of subsurface water seepage, there has typically been a slow leak in the headgate area even after the headgate is closed in the past. To circumnavigate this issue, there are large 12” and 8” pumps that are used to drop the water level by the fish screens. Prior to 2017, the diversion area took about three days to dewater, which from our observations, created a nice slow dewatering rate for lampreys. The pump was turned on on Friday in expectation that the larval lamprey habitat would be getting dewatered close to Monday morning.

What we did not realize was that the Reclamation replaced the pump hose on the 8” pump. This hose previously have had a large leak in it during operations prior to 2017, which substantially slowed down the dewatering rate. The larger pump turns off automatically after the water levels reach a threshold level, so once the water level gets to this level, the smaller pump is the only one that operates during this period. With this new hose installed, the water level dropped rather quickly at this critical level, and most of the sediment became exposed by 7:00 PM on Friday (the day that the pump was turned on), exposing hundreds and thousands of larval lampreys starting that evening. In an emergency measure, some of our staff worked early morning the following day along with the help of dedicated volunteers in an effort to rescue as many emerging lampreys, but unfortunately most were already dead on the dry sediment, totaling 3,736 dead lampreys. Only 875 lampreys (~19%) were found alive.

This incident led to stronger communication between YN Fisheries and the Reclamation. In 2018, we worked together to develop a plan that ensured that the pump would be started earlier in the week (avoiding Fridays), and dewatering would be halted at the end of the day so that the sediment does not become dewatered overnight. The Reclamation was also willing to shut down the small pump as needed to slow down the overall dewatering rate. This resulted in a considerably slower dewatering rate and our crew was able to pick up lampreys as they popped up, resulting in a much higher survival rate compared to 2017 for the lampreys removed from dry banks (only 6.8% mortality among the 1,231 lampreys collected).

Conclusion

Based on data and information shared in this document, we can make the following general conclusions regarding irrigation diversions and larval/juvenile lampreys:

1. Irrigation diversions are serving as “refuge habitats” for larval/juvenile lampreys, providing ample slow water habitat with fine sediment, which is their preferred habitat. The amount of Type I/II habitat available within the diversion system is enormous (~15,000 m^2 directly above and below the fish screens, and a substantially larger sum is likely available in the canal further upstream and downstream from the fish screens; see Task 6.5 and Fig. 6.13). Diversions typically provide steady constant flow with an abundance of organic matter and fine sediment deposition, serving as ideal habitat for larval lampreys. Although this in itself is beneficial for larval/juvenile lampreys, the problem is the dewatering operation, which forces the majority of larval/juvenile lampreys to not only lose their existing preferred habitat but also face high risks of mortality.

2. The amount of habitat available is strongly linked to the number of larval/juvenile lampreys present. If there is a large amount of fine sediment habitat available above the fish screens (as in Union Gap Diversion), more larval lampreys will be found there (see Task 6.6). On the other hand, if there is a large amount of habitat available below the fish screens (as in Sunnyside Diversion), more larval lampreys will distribute themselves there. Hypothetically, larval lampreys may be drifting downstream along with the fine sediment, and while in transit, they could be constantly seeking fine sediment depository areas to burrow into. If the majority of fine sediment is moving through the fish screens, it is likely that larvae are also moving in the same direction. Furthermore, in addition to the surface area, the volume of fine sediment within the available habitat may be effective in predicting the abundance of larval/juvenile lampreys, which takes into account the three dimensional quality of the habitat (see Fig. 6.16 and 6.17).

3. Mesh size does matter. Although the smallest mesh size (such as 1.75 mm) cannot effectively prevent small larval lampreys from passing through the screens, the diversion sites with finer mesh screens appeared to be more effective in reducing at least some of the medium sized larvae from moving downstream (Fig. 6.8). No existing screens can completely prevent lamprey passage as the smallest sized larval lampreys are as small as 6 mm x 0.6 mm; a 0.5 mm (500 micron) mesh, roughly 1/50” in size, or smaller, would be needed, which is neither practical nor feasible in the near future. However, by using the smallest required mesh size (such as 3/32” and 1.75 mm), we found that many of the medium and large larval lampreys can be effectively deterred from moving past the fish screens. For larger juvenile, such as eyed transformers, the majority were found upstream of the fish screens. In some instances, transformers were found downstream of fish screens, but these were most likely due to large gaps or larvae spending multiple years downstream of the fish screens rather than passage.

4. Density of observed lampreys were higher above the screens than below the screens in all four types of fish screen sites we surveyed, suggesting that the screens are preventing some larval/juvenile lampreys from moving downstream. The density levels were reduced by 23.5% in 1/8" mesh drum screen sites, 35.5% in 1.75 mm mesh vertical screen sites, 58.8% in 3/32" mesh drum screen sites, and 70.8% (albeit based on a very small sample) in 3/32" mesh vertical screen sites. The density levels of lampreys may be an indicator for general abundance, although it may also be a product of the higher amount of habitat that is available below the screens. For example, the highest levels of density were found further downstream in the canal area, most likely due to the patchily distributed limited available habitat.

As for fish screen recommendations, based on both USGS lab studies (Liedtke et al. 2015 & 2019) and field studies conducted by the YN Fisheries (Lampman & Beals 2014b), we would like to reiterate the following when considering fish screen types:

1) Use the smallest mesh opening as possible (the smaller the better).
2) Use perforated, Intralox, or profile bar screens rather than woven wire mesh screens.
3) Minimize the approach velocity while maximizing the sweeping velocity.
4) Design the fish screens with the shallowest angle practical (i.e. the closer the screen angle is parallel to the direction of the flow rather than perpendicular, the better).

There are other types of fish screens on the market as well. Although we have not conducted a mark-recapture release study to date, "Farmers Screen" (Farmers Conservation Alliance; Hood River, OR; https://farmerscreen.org/) can potentially be an effective alternative design for screening larval lampreys. Water traverses through the bottom oriented screens very rapidly with this screen design, significantly reducing the chance for fine sediment (and larval lampreys) to move through the screens or deposit within the system (Fig. 7.1). This fish screen design was installed in 2013 at Scott Ditch Diversion (maximum of 23 cfs flow) on the Naches River (Yakima River tributary), and in addition to the very low operation and maintenance costs, it has demonstrated to transfer minimal quantity of fine sediment downstream of the fish screens due to its swift flow rate through the screens (Fig. 7.2). Other similar modified designs are also available (Paul Tappel, Fisheries Engineers, 2018, pers. comm.). Although these fish screen designs are currently used for small and medium size diversions (50-500 cfs), with design modification, these designs may one day be applicable for large diversions (>1,000 cfs). A release study using mark-recapture methods will be informative in understanding how well they may work for lamprey species.

Other alternative solutions not mentioned in this document but considered include the use of electricity on fish screens or immediately upstream to deter fish interaction with the screens and increase their bypass use, such as through the use of Graduated-Field Electric Barrier systems (Fig. 7.3). Initially, this was considered a viable approach to supplement the use of FVES in Bachelor-Hatton Diversion (see Task 6.11). However, the use of electricity made it more challenging to receive environmental compliance in areas used by listed species during the limited time window available to implement the project and was subsequently dropped from this project.

Vibration of fish screens was another alternative idea considered to potentially help deter lamprey screen interaction while increasing bypass use. Although rotating drum screens are examples of active screens that move (i.e. not static), those screens currently being used in the field have not demonstrated any notable reduction in entrainment based on existing data. Traveling Intralox screens is another example of active screens that will likely perform better than rotating drum screens in the field, but no direct testing on lampreys has occurred to date except for those reported by Goodman et al. (2016) which focused on metamorphosed juveniles. Activating a vibrational back and forth movement of the screens may potentially elicit a completely different response from lampreys than the active screens currently being used whose movement are only unidirectional and constant.

Chemical cues and pheromones in Sea Lamprey (*Petromyzon marinus*) have been studied extensively in the Great Lakes region (Buchinger et al. 2015) and there may be some potential applications in mitigating larval lamprey entrainment in the future. In recent years, lamprey alarm chemicals have been developed and explored by researchers in that region and they have been demonstrated to effectively influence adult lamprey behavior at least in the laboratory environment (Hume and Wagner 2018). Its application and effectiveness to larval lamprey life stage is still unknown, but as more research advancement is made in this field, this could potentially be used in combination with other solutions.

If there are ideal release locations for both lampreys and the fine sediment they burrow in where they can be transferred from diversions (or dredging project areas), both lampreys and sediment could be dredged and transported to those release locations using waterproof dump trucks (Fig. 7.4; see Task 4.6 and 4.7). If perennial side channels or acclimation ponds are used, this will give a chance for the fine sediment (as well as lampreys) to settle out before they move back to the river/stream (reducing impacts to turbidity). Furthermore, if lampreys could be left in the diversions without any risk of desiccation or the need to be transferred, those options should be pursued. Short- and long-term examples of this was shared in Task 5.3 and 6.10, respectively. If there are ways to allow lampreys to continue to use the refuge habitat provided by the irrigation diversions year around, this is obviously the best solution available (Fig. 7.5).

However, in the absence of these options available, one of the best practical solutions for lamprey entrainment today may be to focus on the fine sediment transport within diversions. Effectively managing and controlling the transport of fine sediment may lead the way for reducing lamprey entrainment. For example, reducing fine sediment input at the headgate area may be a potential "long-term" solution (see Task 6.7), whereas creating effective structures upstream of the fish screens to divert sediment towards the bypass and away from the screens are "short-term" solutions that could be implemented relatively quickly (see Task 6.8).

Diversions with headgate orientation that are more parallel to the river/stream thalweg flow appear to be generally successful in reducing fine sediment input into the canal compared to those that are more perpendicular. As the lifespan of the older diversion facilities near their end, we recommend that lamprey species are also taken into considration for the configuration of the headgate structures and practical improvements are made to minimize lamprey entrainment. In addition to the angle/orientation, if there is a way to modify the headgate structure so that they open in the mid-water column (rather than from the river/stream bottom), this can also minimize the input of fine sediment and lampreys considerably (Fig. 7.6). In addition, many diversions dams have a sluice gate structure that are located close by the headgate. If the sluice gate could be opened for extended periods prior to the start of the irrigation season (focusing especially on high flow events), this could help guide more lampreys rearing immediately upstream of the headgate structure to move downstream away from the risk of diversion entrainment. To help push even more lampreys downstream prior to the start of the irrigation season, heavy equipment (which are often present or available at most diversions) could also be mobilized to physically scoop them downstream.

Additionally, artificial structures can be used to create fine sediment habitat for larval lampreys to burrow into. Based on survey observations, larval/juvenile lampreys were frequently found in fine sediment created around various types of physical structures ranging from bypass walls, ecology blocks, woody debris, to used tires. In Town and Naches-Selah diversions, high densities of larvae were found directly upstream of "ecology blocks" (Fig. 7.7). Flow barrier structures placed above the fish screens can be beneficial in preventing lampreys from rearing directly in front of the fish screens, reducing lamprey-screen interaction and potentially the consequential entrainment. Alternatively, structures placed below the fish screens can be beneficial in that they can capture fine sediment that would have otherwise traveled further down the canal, providing a last opportunity for lampreys to remain in the project area (to be rescued). Many diversions also use stop logs immediately downstream of the fish screens to reduce the amount of sediment that collects near the screens. However, if these stop logs simply push more fine sediment downstream (by increasing water velocity), it is probably not helping deter lamprey entrainment; they may aid lampreys in passing through the screens.

In conclusion, there are several short- and long-term solutions that are currently available for the reduction of larval lamprey entrainment. More alternative solutions may become available in the near future. Given the dire situation with high rates of entrainment observed in larval lampreys, we recommend that irrigation diversion operators and managers continue to pursue as many of these alternatives based on the specific facility and site conditions and share the valuable lessons learned from these experimental trials.

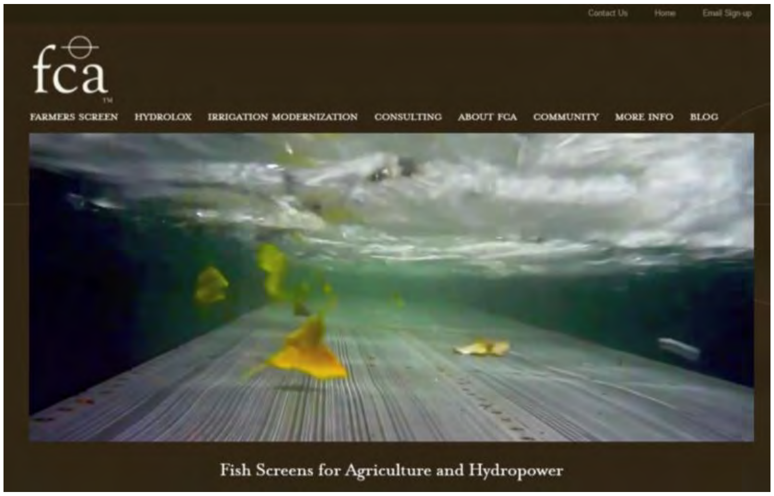


Figure 7.1. Underwater view of Farmers Screen, which is a horizontal, passive fish screen design that uses hydraulics to manage debris and protect fish. It has no moving parts and does not require power to operate. The Farmers Screen is a patented technology licensed solely to FCA (https://farmerscreen.org/).

Figure 7.2. Overview of Scott Ditch Diversion (Naches River, Naches, WA). Water flow is swift preventing the deposition of fine sediment within the canal. Left photo shows the segment upstream of the bypass area (looking downstream). The right photo shows the downstream end of the screen (the slow water on the right side holds water that moved under the bottom oriented screen.

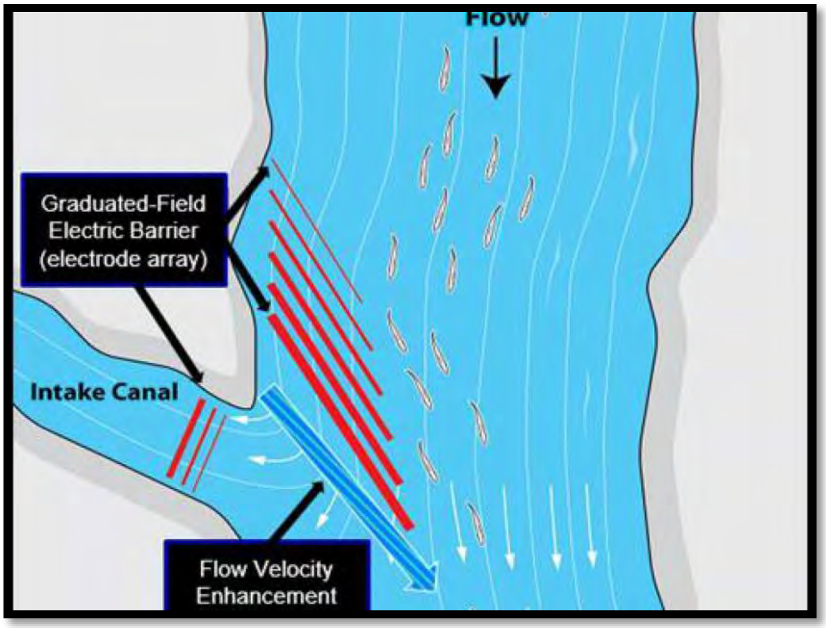


Figure 7.3. A conceptual design for combining the Graduated-Field Electric Barrier system and the Flow Velocity Enhancement system to exclude migrating fish from water intake structure and guide them safely downstream.

Figure 7.4. Lampreys, fine sediment, and accompanying water could be transported in a waterproof dump truck to a nearby refuge release location where they have a chance to settle out (such as side channels, acclimation ponds, etc.) before they move or transferred back to the river/stream.

Figure 7.5. A conceptual model of using an irrigation diversion upstream of the fish screens as a "perennial side channel" with water returning through the bypass channel (yellow line tracing the flow direction with the arrow pointing to the bypass return flow). Water would have to be blocked at or near the fish screens (yellow polygon) so that no water can permeate downstream of the screens into the canal.

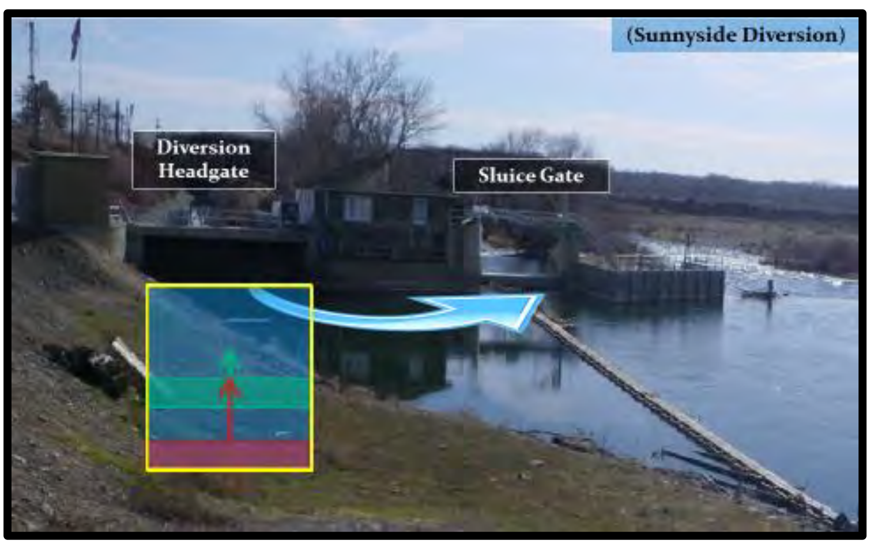


Figure 7.6. Diversion headgates that open from mid-water column (green area) rather than the bottom (red area) will likely help reduce entrainment for lampreys that congregate in the forebay upstream of the headgate, such as at Sunnyside Diversion shown here. Opening sluice gates prior to the start of the irrigation season during high flow events should also help move the larvae congregating in the forebay and minimize their entrainment into diversions.

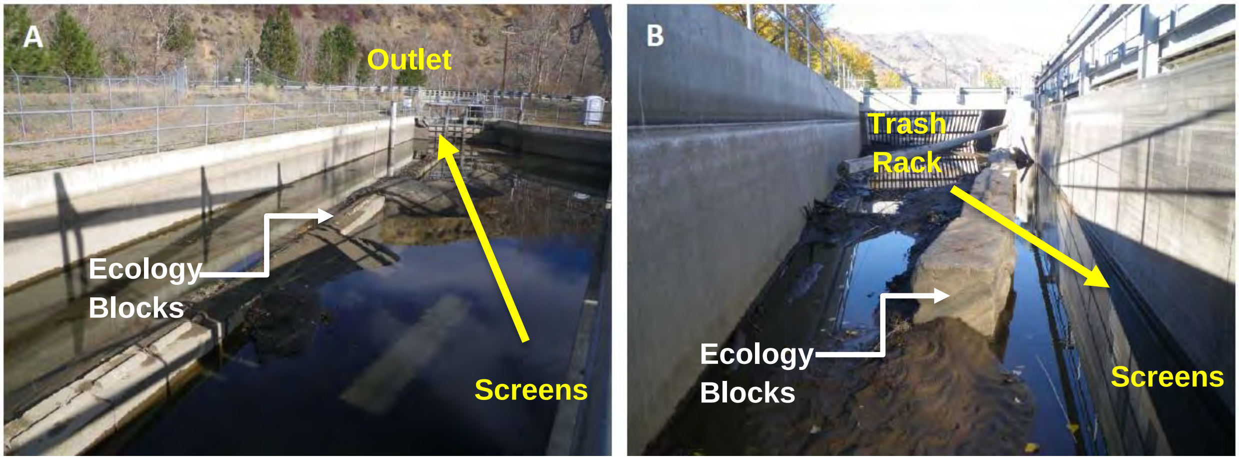


Figure 7.7. (A) Ecology blocks laced downstream of the drum screens at Town Diversion, effectively capturing fine sediment that would have otherwise traveled down the canal. (B) Ecology blocks placed upstream of the vertical screens at Naches-Selah Diversion, preventing fine sediment to collect in front of the fish screens. Yellow arrow shows the direction of water flow.

Yakama Nation / Bureau of Reclamation Report References

Listed below are a complete list of references for all the irrigation diversion related Reclamation funded annual progress and appendix reports produced by the YN Fisheries Pacific Lamprey Project between 2012 and 2019. The main report is followed by the appendix reports for each year. Some additional reports that were originally not submitted to the Reclamation are also added to the list below if they have some relevance to the irrigation diversion goals and objectives. All titles are in bold font.

2011-2012 Main Report:

Luke, P., & Rose, R. 2012a. **Yakama Nation Pacific Lamprey Project 2011 Annual Progress Report** (Cooperative Agreement No. R11AC10069). Prepared for the U.S. Department of Interior, Bureau of Reclamation, Boise, ID. 12 pp.

2011-2012 Appendix Reports:

Luke, P., & Rose R. 2012b. **Assessment of lamprey presence in irrigation diversions and canals in the Yakima Basin.** Appendix 1.1 / A in Yakama Nation Pacific Lamprey Project 2011 Annual Progress Report (Cooperative Agreement No. R11AC10069 / Project No. 2008-470-00). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID, and U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 12 pp.

2012-2013 Main Report:

Lampman, R., Luke, P., Lumley, D., & Rose, R. 2013a. **Yakama Nation Pacific Lamprey Project 2012 Annual Progress Report** (Cooperative Agreement No. R11AC10069). Prepared for the U.S. Department of Interior, Bureau of Reclamation, Boise, ID. 15 pp.

2012-2013 Appendix Reports:

Lampman, R., Luke, P., & Rose, R. 2013b. **Monitoring strategies for the entrainment of juvenile and larval lamprey in irrigation diversions.** Appendix 4 in Yakama Nation Pacific Lamprey Project 2012 Annual Progress Report (Cooperative Agreement No. R11AC10069). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID. 5 pp.

Lumley, D., & Lampman, R. 2013a. **Assessment of lamprey entrainment in irrigation diversions and canals in the Yakima Basin, 2012-2013.** Appendix 3.1 / G2 in Yakama Nation Pacific Lamprey Project 2012 Annual Progress Report (Cooperative Agreement No. R11AC10069 / Project No. 2008-470-00). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID, and U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 40 pp.

Lumley, D., & Lampman, R. 2013b. **Repeat sampling of juvenile lamprey in New Rez Diversion (rkm 175.5) within Yakima Basin.** Appendix 3.2 / G3 in Yakama Nation Pacific Lamprey Project 2012 Annual Progress Repor (Cooperative Agreement No.

R11AC10069 / Project No. 2008-470-00). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID, and U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 16 pp.

2012-2013 Non-BOR Report:

Lampman, R., & Beals, T. 2013. **Evaluation of the potential impacts of "Flip Flop" on larval lamprey in the Upper Yakima River using photo documentation and habitat assessment: Summer 2012.** Appendix D4 in Yakama Nation Pacific Lamprey Project 2012 Annual Progress Report (Project No. 2008-470-00). Prepared for the U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 21 pp.

2013-2014 Main Report:

Lampman, R., Lumley, D., Beals, T., Luke, P., & Rose, R. 2014a. **Yakama Nation Pacific Lamprey Project 2013 Annual Progress Report** (Cooperative Agreement No. R11AC10069). Prepared for the U.S. Department of Interior, Bureau of Reclamation, Boise, ID. 25 pp.

2013-2014 Appendix Reports:

Beals, T., & Lampman, R. 2014. **Pilot assessment of larval lamprey habitat and occupancy at the inlet of Sunnyside Diversion prior to the beginning of irrigation season.** Appendix 2.2 / F2 in Yakama Nation Pacific Lamprey Project 2013 Annual Progress Report (Cooperative Agreement No. R11AC10069 / Project No. 2008-470-00). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID, and U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 10 pp.

Lampman, R. 2014a. **Collection of larval lamprey close-up photos of various size classes to compare and contrast Pacific Lamprey and resident Lampetra species.** Appendix 3.3 / K2 in Yakama Nation Pacific Lamprey Project 2013 Annual Progress Report (Cooperative Agreement No. R11AC10069 / Project No. 2008-470-00). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID, and U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 13 pp.

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Lampman, R., & Beals, T. 2014c. **Evaluating persistence of visibility with Visible Implant Elastomer Tags on assorted sizes of larval and transformer Western Brook Lamprey over a five month period: Preliminary report.** Appendix 3.2 / K1 in Yakama Nation Pacific Lamprey Project 2013 Annual Progress Report (Cooperative Agreement No. R11AC10069 / Project No. 2008-470-00). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID, and U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 9 pp.

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2013-2014 Non-BOR Report:

Lampman, R., Lumley, D., & Beals, T. 2014b. **Yakama Nation Pacific Lamprey Project 2013 Annual Progress Report (Project No. 2008-470-00).** Prepared for the U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 21 pp.

2014-2015 Main Report:

Lampman, R., Beals, T., Luke, P., Lumley, D., Johnson, E., & Rose, R. 2015. **Yakama Nation Pacific Lamprey Project 2014 Annual Progress Report** (Cooperative Agreement No. R11AC10069). Prepared for the U.S. Department of Interior, Bureau of Reclamation, Boise, ID. 33 pp.

2014-2015 Appendix Reports:

Beals, T., & Lampman, R. 2015a. **Intensive monitoring of larval/juvenile lamprey entrainment within Yakima Basin irrigation diversions, 2014.** Appendix 2.2 / G8 in Yakama Nation Pacific Lamprey Project 2014 Annual Progress Report (Cooperative Agreement No.

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2015-2016 Main Report:

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Beals, T., & Lampman, R. 2016a. **Intensive monitoring of larval-juvenile lamprey entrainment in the Yakima River Subbasin, 2015.** Appendix 3.2 / G2 in Yakama Nation Pacific

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Beals, T., & Lampman, R. 2017b. **Summary assessment of larval/juvenile lamprey entrainment in irrigation diversions within the Yakima Subbasin, 2016.** Appendix 3.1 / D1 in Yakama Nation Pacific Lamprey Project 2016 Annual Progress Report (Cooperative Agreement No. R15AC00044 / Project No. 2008-470-00). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID, and U.S. Dept. of Energy, Bonneville Power Administration, Portland, OR. 8 pp.

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