Run Characteristics, Current Distribution, and Efforts to Improve Passage of Adult Pacific Lamprey in the Columbia River Basin, 2011

Prepared for Consideration in Developing Recommendations

for Passage Objectives in the Columbia River Basin

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# Introduction

The Lamprey Technical Workgroup (LTWG) was tasked with developing lamprey passage objectives and related performance standards and measures in 2007. The Passage Standards Subgroup was formed to address the inherent challenges with establishing such metrics. At the April 15th, 2009 meeting, the LTWG determined that the current goal of passage – that metrics must be equal to or superior than those established elsewhere in the region – was inadequate for current and future management objectives. The Passage Standards Subgroup subsequently reconvened on June 22nd, 2009, and decided on a three-phase approach to make progress on the assignment. The steps are as follows:

* Phase One: Identify potential research metrics that quantify indirect or direct effects on survival and fitness of juvenile and adult Pacific lamprey related to up- or downstream passage.
* Phase Two: Determine which of the above-listed metrics are measurable with scientific rigor and quantify effects of biological relevance.
* Phase Three: Develop and recommend basin-wide passage standards or objectives for metrics deemed as measurable and biologically relevant in Phase Two.

Initial drafts of Phase One and Phase Two were completed and submitted to the LTWG during 2010, leaving the final task of using this information to develop recommendations regarding basin-wide passage objectives. The Passage Standards Subgroup reconvened in January, 2011, and determined that more information would be required to supplement the metrics assessed during the above-mentioned process of identifying appropriate metrics. Specifically, the Subgroup decided that an up-to-date assessment of (1) Columbia River geography, (2) migratory characteristics and trends, and (3) recent passage evaluations relevant to upstream passage of adult Pacific lampreys would be fundamental in developing recommendations. A lack of information precludes a similar approach to juvenile lampreys, although as data are forthcoming the Passage Standards Subgroup will reassess technologies to address gaps in passage objectives.

This document is solely intended to provide supporting information for the Passage Metrics Subgroup in their consideration of developing recommendations for passage objectives for adult Pacific lamprey in the Columbia River Basin.

# Relevant Geography

## Hydroelectric Projects

### Columbia River

A total of nine (9) hydroelectric projects with adult upstream passage facilities (i.e., fish ladders) are located on the mainstem of the Columbia River. Construction of these projects began with Rock Island in 1933 and finished with John Day in 1971. Project locations range from Bonneville at river mile (RM) 146, ending at Wells at RM 516. Chief Joseph Hydroelectric Project (RM 545) upstream of Wells does not have upstream fish passage facilities (Table 1).

### Snake River

A total of four (4) hydroelectric projects with adult upstream passage facilities are located on the mainstem of the Snake River. Construction of these projects began with Ice Harbor in 1962 and finished with Lower Granite in 1975. Project locations range from Ice Harbor 334 RM from the ocean, ending at Lower Granite, 432 RM from the ocean (Table 1).

## Tributaries

Several tributaries to the Columbia River Basin exist downstream of Chief Joseph at RM 545. The number and size of tributaries between each hydroelectric project varies greatly. For example, 13 of the 29 major tributaries are below Bonneville, totaling more than 600 miles in length. In contrast, no major tributaries exist between Wanapum and Rock Island. Other reservoirs – such as McNary’s Lake Wallula – have few tributaries, but cover more drainage than all other tributaries combined. The length of the Snake (1,040 miles), Yakima (214 miles), and Walla Walla (61 miles) rivers represent close to 50% of the combined length of all Columbia River tributaries downstream of Chief Joseph.

Juvenile lampreys have been identified in most tributaries below Chief Joseph, from the Okanogan River to rivers below Bonneville. Crab Creek, a tributary to Priest Rapids Lake, is the only tributary where lampreys have not been identified, and many of the tributaries below Bonneville have not been surveyed. Particular tributaries likely have varying levels of suitability for lampreys, though a basin-wide survey has not been conducted to date. Likewise, it is not known what extent the hundreds of miles of reservoirs in the Columbia River Basin contributes to larval, juvenile, or adult spawning habitat. Table 2 lists major tributaries and hydroelectric projects, along with their relative location, length, and presence or absence of Pacific lamprey.

Table 1. List of Columbia and Snake (shaded) river basin mainstem hydroelectric projects with adult salmon upstream passage facilities, 2011.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Project** | **Year built** | **Miles upstream** | **Full forebay elevation (ft)** | **Spillway** | **Nameplate capacity (MW)** | **Owner** |
| BON | 1938 | 146.1 | 77.0 | 1450 feet, 18 gates | 1,050 | U.S.A.C.E., Portland District |
| TDA | 1960 | 191.5 | 160.0 | 1380 feet, 23 gates | 1,780 | U.S.A.C.E., Portland District |
| JDA | 1971 | 215.6 | 268.0 | 1228 feet, 20 gates | 2,160 | U.S.A.C.E., Portland District |
| MCN | 1957 | 292.0 | 356.5 | 1310 feet, 22 gates | 980 | U.S.A.C.E., Walla Walla District |
| IHR\* | 1962 | 333.7 | 446.0 | 590 feet, 10 gates | 603 | U.S.A.C.E., Walla Walla District |
| LMN\* | 1969 | 365.6 | 548.3 | 572 feet, 8 gates | 810 | U.S.A.C.E., Walla Walla District |
| LGS\* | 1970 | 394.3 | 646.5 | 512 feet, 8 gates | 810 | U.S.A.C.E., Walla Walla District |
| PRD | 1961 | 397.1 | 486.0 |  | 956 | Grant County PUD No. 2 |
| WAN | 1964 | 415.8 | 570.0 |  | 1,038 | Grant County PUD No. 2 |
| LWG\* | 1975 | 431.5 | 746.5 | 512 feet, 8 gates | 810 | U.S.A.C.E., Walla Walla District |
| RIS | 1933 | 453.4 | 613.0 | 31 gates | 623 | Chelan County PUD No. 1 |
| RRH | 1961 | 473.7 | 707.0 | 12 gates | 1,347 | Chelan County PUD No. 1 |
| WEL | 1967 | 515.8 | 781.0 | 10 gates | 774 | Douglas County PUD No. 1 |

\* Based on Snake River confluence at Columbia River Mile 324.

Table 2. Columbia River tributaries and potential use by Pacific lamprey.



# Describing the Migration

## Counts and Trends

Between 2001 and 2010, nearly a half million adult lampreys have been enumerated in the Columbia River Basin (Table 3). Average annual counts are greatest at Bonneville, and descend upstream in the Columbia and Snake rivers (Table 4). Following a four-fold increase of adult lampreys observed at Bonneville between 2001 and 2003, annual counts have declined to a record low of 6,234 fish in 2010 (excluding LPS counts). Despite the lack of precision in adult enumeration at many projects, an obvious decline in the number of adults returning to the Columbia River has occurred over the past decade (Figure 1).

Table 3. Annual counts of adult Pacific lamprey in the Columbia River Basin by project, 2001-2010.

|  | **Project** | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **YEAR** | **BON** | **TDA** | **JDA** | **MCN** | **IHR** | **LMN** | **LGS** | **PRD** | **WAN** | **LWG** | **RIS** | **RRH** | **WEL** |
| 2001 | 27,947 | 9,061 | 4,005 | 2,539 | 203 | 59 | 104 | 1,624 | . | 27 | 1,460 | 805 | 262 |
| 2002 | 100,476 | 23,417 | 26,821 | 11,282 | 1,127 | 284 | 365 | 4,007 | . | 138 | 4,878 | 1,842 | 342 |
| 2003 | 117,029 | 28,995 | 20,922 | 13,325 | 1,702 | 476 | 660 | 4,340 | . | 282 | 5,000 | 2,521 | 1,410 |
| 2004 | 61,780 | 14,873 | 11,663 | 5,888 | 805 | 194 | 243 | 2,647 | . | 122 | 2,362 | 1,043 | 403 |
| 2005 | 26,667 | 8,361 | 8,312 | 4,158 | 461 | 222 | 213 | 2,598 | . | 42 | 2,267 | 404 | 214 |
| 2006 | 38,941 | 6,894 | 9,600 | 2,459 | 277 | 175 | 125 | 4,383 | 4,381 | 35 | 1,326 | 370 | 21 |
| 2007 | 19,304 | 6,083 | 5,753 | 3,454 | 290 | 138 | 72 | 6,593 | 4,771 | 34 | 1,300 | 696 | 35 |
| 2008 | 14,562 | 4,599 | 6,625 | 1,530 | 264 | 145 | 104 | 5,083 | 1,519 | 61 | 880 | 368 | 7 |
| 2009 | 8,622 | 2,318 | 2,044 | 676 | 57 | 58 | 34 | 2,713 | 718 | 12 | 375 | 278 | 9 |
| 2010 | 6,234 | 1,726 | 1,662 | 833 | 114 | 44 | 29 | 1,114 | 707 | 15 | 318 | 268 | 2 |
| **All** | **421,562** | **106,327** | **97,407** | **46,144** | **5,300** | **1,795** | **1,949** | **35,102** | **12,096** | **768** | **20,166** | **8,595** | **2,705** |

Table 4. Descriptive statistics of annual counts of adult Pacific lamprey in the Columbia River Basin by project, 2001-2010.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Annual adult Pacific lamprey counts** | | | | | |
| **Project** | **N** | **Min** | **Max** | **Median** | **Mean** | **Std Err** |
| BON | 10 | 6,234 | 117,029 | 27,307 | 42,156 | 12,267 |
| TDA | 10 | 1,726 | 28,995 | 7,628 | 10,633 | 2,879 |
| JDA | 10 | 1,662 | 26,821 | 7,469 | 9,741 | 2,594 |
| MCN | 10 | 676 | 13,325 | 2,997 | 4,614 | 1,382 |
| IHR | 10 | 57 | 1,702 | 284 | 530 | 167 |
| LMN | 10 | 44 | 476 | 160 | 180 | 41 |
| LGS | 10 | 29 | 660 | 115 | 195 | 61 |
| PRD | 10 | 1,114 | 6,593 | 3,360 | 3,510 | 529 |
| WAN | 5 | 707 | 4,771 | 1,519 | 2,419 | 895 |
| LWG | 10 | 12 | 282 | 39 | 77 | 27 |
| RIS | 10 | 318 | 5,000 | 1,393 | 2,017 | 532 |
| RRH | 10 | 268 | 2,521 | 550 | 860 | 240 |
| WEL | 10 | 2 | 1,410 | 125 | 271 | 135 |













Figure 1. Annual adult Pacific lamprey counts at Columbia River Basin projects by region (lower, middle, and Snake River) and project, 2001-2010.

## Seasonal Distribution

The adult Pacific lamprey migration generally begins in early June when 10% of the run has typically passage Bonneville. Adults arrive at each project later in the season as fish move upstream, ending at Wells when adults begin arriving in early- to mid-August (Table 5; Figure 2). The migration tapers off as fish move upstream and near the overwintering period: median passage dates at Wells are over two months later than those observed at Bonneville. The migration of adult lampreys in the Snake River is generally earlier than median counts observed in Columbia River projects similar distances from the ocean: Average runs at Little Goose (RM 394) are 13 days earlier than at Priest Rapids (RM 397), and runs at Lower Granite (RM 431) are 18 days earlier than at Wanapum (RM 416). Despite the varying timing of the migration, the average temperature during observations at each project is typically 19-20°C, with cooler temperatures observed at Bonneville (earlier in the year) and middle-Columbia River projects (later in the year), and warmer temperatures observed in the Snake River (Table 7).

Table 5. Passage dates (quantiles) of adult Pacific lamprey at Columbia and Snake (shaded) river basin mainstem hydroelectric projects, 2001-2010.

| **Project** | **Minimum** | **10%** | **25%** | **Median** | **75%** | **90%** | **Maximum** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| BON | 01/01 | 06/10 | 06/22 | 07/09 | 07/25 | 08/18 | 11/02 |
| TDA | 01/01 | 06/30 | 07/11 | 07/23 | 08/09 | 08/28 | 10/30 |
| JDA | 01/01 | 07/05 | 07/16 | 07/29 | 08/17 | 09/05 | 11/01 |
| MCN | 01/01 | 07/14 | 07/25 | 08/09 | 08/26 | 09/12 | 12/31 |
| IHR | 01/01 | 07/14 | 07/23 | 08/05 | 08/20 | 09/04 | 12/30 |
| LMN | 01/01 | 07/01 | 07/22 | 08/03 | 08/19 | 09/06 | 12/30 |
| LGS | 01/01 | 07/06 | 07/24 | 08/07 | 08/25 | 09/13 | 12/30 |
| PRD | 01/01 | 07/25 | 08/06 | 08/20 | 09/04 | 09/17 | 12/30 |
| WAN | 01/08 | 07/29 | 08/12 | 08/25 | 09/07 | 09/20 | 11/10 |
| LWG | 01/01 | 07/05 | 07/27 | 08/07 | 08/21 | 09/03 | 12/31 |
| RIS | 01/01 | 08/04 | 08/14 | 08/26 | 09/06 | 09/21 | 12/30 |
| RRH | 01/01 | 08/05 | 08/15 | 08/27 | 09/07 | 09/21 | 12/30 |
| WEL | 01/01 | 08/10 | 08/27 | 09/16 | 10/19 | 10/31 | 12/30 |

Table 6. Passage dates (means and standard deviation) of adult Pacific lamprey at Columbia and Snake (shaded) river basin mainstem hydroelectric projects, 2001-2010.

| **Project** | **Number** | **Mean** | **Std Dev (days)** |
| --- | --- | --- | --- |
| BON | 42,1562 | 07/11 | 26 |
| TDA | 106,327 | 07/26 | 22 |
| JDA | 97,407 | 08/01 | 25 |
| MCN | 46,144 | 08/10 | 23 |
| IHR | 5,300 | 08/06 | 22 |
| LMN | 1,795 | 08/03 | 27 |
| LGS | 1,949 | 08/08 | 27 |
| PRD | 35,102 | 08/20 | 23 |
| WAN | 12,096 | 08/24 | 21 |
| LWG | 768 | 08/06 | 24 |
| RIS | 20,166 | 08/26 | 19 |
| RRH | 8,595 | 08/27 | 18 |
| WEL | 2,705 | 09/17 | 32 |

Table 7. Mean water temperature during observations of adult lampreys at Columbia and Snake (shaded) river projects, 2001-2011.

| **Level** | **Number** | **Mean** | **Std Dev** | **Std Err Mean** | **Lower 95%** | **Upper 95%** |
| --- | --- | --- | --- | --- | --- | --- |
| BON | 421,175 | 18 | 37 | 0.1 | 18 | 18 |
| TDA | 104,436 | 20 | 15 | 0.0 | 20 | 20 |
| JDA | 92,735 | 20 | 14 | 0.0 | 20 | 21 |
| MCN | 45,923 | 21 | 8 | 0.0 | 21 | 21 |
| IHR | 5,233 | 21 | 4 | 0.1 | 21 | 21 |
| LMN | 1,750 | 20 | 4 | 0.1 | 20 | 20 |
| LGS | 1,853 | 20 | 3 | 0.1 | 20 | 20 |
| PRD | 30,984 | 19 | 8 | 0.0 | 19 | 19 |
| WAN | 11,854 | 19 | 5 | 0.0 | 19 | 20 |
| LWG | 766 | 20 | 3 | 0.1 | 20 | 21 |
| RIS | 16,407 | 19 | 6 | 0.0 | 19 | 19 |
| RRH | 6,775 | 19 | 3 | 0.0 | 19 | 19 |
| WEL | 1,516 | 19 | 3 | 0.1 | 19 | 19 |



Figure 2. Passage dates (quantiles) of adult Pacific lamprey at Columbia and Snake river basin mainstem hydroelectric projects, 2001-2010.

# Passage Evaluations

## Columbia River Projects

### Bonneville

The U.S. Army Corps of Engineers initiated radio-telemetry evaluations of adult Pacific lamprey passage in the mid-1990s to understand relative route use, passage timing, and passage efficiency at the Lower Columbia dams. Radio-telemetry work in 1997 to 2002 and 2007 to 2010 showed that although a median 88% of tagged lamprey were detected in the dam tailrace following release, median passage efficiency at Bonneville Dam (the percentage of lamprey that successfully passed over the dam of those that approached the dam base) was only 42% (Clabough et al. 2011). Lamprey migration times are highly variable throughout the system, but tend to be longer at dams, with rapid migration through reservoir reaches. Bonneville Dam passage times are particularly long. Overall median dam passage time (first fishway approach to top of ladder exit) across all years was 6.3 days (range = 3-12 days).

Lamprey passage rates at Bonneville and The Dalles dams indicated that during the course of the summer migration, lamprey passage rates generally increased and delays decreased (Moser et al. 2005). These data suggest that fish are most delayed during the early part of the season (May-June) and that higher river flows, lower water temperatures and large numbers of predators (sea lions and sturgeon) below Bonneville Dam may be contributing factors.

Radio-telemetry results suggest that the areas of particular concern are fishway entrances, collection channels and transition pools, and the vertical slot/serpentine weir sections at the tops of the Washington Shore and Bradford Island fish ladders of Bonneville Dam. This information has informed a variety of decisions regarding structural and operational fishway improvements for lamprey. Improvements include:

* Lamprey passage structures (LPS) in auxiliary water supply channels (upper ladders) of the Bradford Island (beginning 2002) and Washington Shore (beginning 2007) fishways to decrease the number of lamprey encountering serpentine weir sections.
* Prototype LPS downstream of a fishway entrance at Powerhouse 2 to determine efficacy of LPS systems outside fishways.
* Complete overhaul of Cascades Island Fish Ladder entrance, including variable width entrance weir, bollard (artificial rock) array to slow velocities on the fishway entrance invert, and installation of an experimental LPS that runs from the entrance channel to a forebay deck holding tank (2009).
* Reduced nighttime fishway velocities and head at Washington Shore Fish Ladder to increase fishway entrance efficiency (testing in 2007-2009; operational in 2010).
* Completing design work for prototype entrance flume/LPS system for a Washington Shore Fish Ladder entrance. Objective will be to overcome poor entrance efficiencies by attracting lamprey to a separate passage system that spans an entire fishway entrance (construction in Winter 2012-2013).

### The Dalles

Passage efficiency for lamprey that approached The Dalles Dam was consistently higher than at Bonneville Dam. Median passage efficiency for The Dalles (1997-2002, 2007-2010) averaged 69%; making it among the best performing of the mainstem Lower Columbia River dams (Clabough et al. 2011). While entrances, collection channels, and transition pools present challenges for lamprey at The Dalles fishways, the ladder sections perform quite well. Passage efficiency of lamprey from the top of the transition pool to the ladder exit of the North fishway was approximately 100% in nearly all years. It is speculated that the natural rock structure of much of the fishway and the vertical slot/submerged orifice weir design of the exit section make the North Ladder relatively easy for lamprey to navigate.

Across all study years, the median percentage of tagged lamprey that approached the North and East fishway entrances was 39% and 61%, respectively (M. Keefer, unpublished data). The median percentage of lamprey that passed via the North and East fishways was 38% and 62%, respectively, as not all fish ultimately pass the dam via the first ladder they encounter. Median passage time (time from first fishway approach to the top of the dam) was 2.3 days (range = 0.9 to 4).

Future modification efforts at The Dalles Dam will be focused on nighttime flow reductions to improve entrance efficiency and minor modifications (such as diffuser grating plating, for example) to improve passage through collection channels and transition pools. Other low-cost minor fishway modifications will also be made. For example, radio-telemetry results from 2010 suggested that some lamprey turned around in the ladder section of the East Fish Ladder, above the transition pool but below the count station (Clabough et al. 2011). To address this, metal ramps will be installed to four overflow weir orifices that are elevated off the ladder floor in the East Fish Ladder (to be completed in Winter 2011-2012).

### John Day

Lamprey passage behavior at John Day Dam is poorly understood relative to Bonneville and The Dalles, as radio-telemetry and PIT monitoring effort has been limited in some years. Overall dam passage efficiency at John Day Dam is similar to that of Bonneville Dam, underperforming relative to The Dalles and McNary dams. Median passage efficiency for John Day averaged 46% across the study years. As with other dams, the most challenging areas for lamprey at John Day are fishway entrances, collection channels, transition pools, and exit sections. Fallback (over spillways, for example) of lamprey is a concern at all dams but is particularly common at John Day, where 11-38% of tagged lamprey that pass the dam subsequently were recorded falling back (Clabough et al. 2011; M. Keefer personal communication). The causes of dam fallback behavior are poorly understood, but Keefer et al. (2008) suggested that for anadromous salmonids such as Chinook salmon, this behavior may be related to olfactory cues associated with tributaries (in this case, the John Day River).

Across all study years, the median percentage of tagged lamprey that approached the North and South fishway entrances was 9% and 91%, respectively. The median percentage of lamprey that passed via the North and South fishways was 24% and 76%, respectively, as not all fish ultimately pass the dam via the first ladder they encounter. Median passage time (time from first fishway approach to the top of the dam) was 2.4 days (range = 1.3 – 3.1).

In response to the 2008 FCRPS Biological Opinion, the U.S. Army Corps of Engineers undertook two major fishway improvement projects for the North Fish Ladder. Lamprey passage considerations were integrated into both projects. The first project, completed in 2010, was a major redesign of the count station and exit section of the ladder. Lamprey features included: (1) Removed right angle step at vertical slot and sill baffle in forebay transition section; (2) Modified second baffle (remove 2.5-foot sill and add rounded orifice) in forebay transition; (3) Removed all 18 serpentine weirs and replaced with 23 weirs with 15- to 18-inch rounded vertical slots and rounded 18- x 18-inch orifices; (4) Provided a smooth contiguous floor surface through all orifices from count station to exit; (5) Provided resting areas to wall sides of orifices; (6) Raised count station floor one foot to match invert at new weir 1 to allow for smooth floor transition; (7) Added 12-inch-wide metal plates over left side of floor diffuser grating in pool just upstream of count station; (8) Removed 23-inch ramp through count slot and lower viewing window, and; (9) Replaced antiquated crowder, adding new transition fairings and horizontal vanes to reduce confusing uplifting flows just upstream of count station slot.

The second project involves improvements to the entrance, auxiliary water supply (AWS) pumps, collection channel, and transition pool of the North Fish Ladder. Construction is scheduled for the winters of 2011-2012 and 2012-2013. Lamprey features include: (1) Install modified keyhole entrance with velocity reducing structures on the ladder floor; (2) Install LPS inside entrance; (3) Smooth and round corners wherever possible; (4) Provide safe resting areas in relatively quiet areas; (5) Replace existing diffuser gratings with ¾-inch lamprey criteria grating to prevent lamprey from getting trapped below grating; (6) Installation of diffuser plating in collection channel and lower ladder diffusers; (7) Removal of three obsolete lower ladder weirs to increase ladder flow signature and minimize passage barriers.

As the radio-telemetry results discussed above suggest, the South Fish Ladder is an important passage route for lamprey at John Day. Other fishway modifications under consideration will include nighttime flow reductions for the South Fish Ladder, possible entrance modifications, and installation of diffuser plating in the lower ladder section. To date, improvements to Bonneville Dam fishways have taken precedence.

### McNary

Researchers began monitoring radio-tagged (at Bonneville) lamprey at McNary Dam in 2000. Recognizing that handling and tag effects might bias radio-telemetry results from fish tagged at Bonneville Dam, researchers began collecting and tagging some lamprey at McNary in 2005 to supplement passage data. Bonneville-tagged lamprey passage results from 2000-2006 and 2008-2010 showed that median dam passage efficiency averaged 79% at McNary, the highest efficiency of the four mainstem Columbia River dams operated by the Corps of Engineers. Passage efficiency for McNary-tagged lamprey was 64%. Discrepancies between these results and other metrics between the different tag groups can likely be attributed to handling and tagging effects and increased tag burden on McNary-tagged fish, which were smaller (mean = 440 g) than their Bonneville counterparts (mean = 545 g) when tagged, probably due to weight/size loss associated with migration and water temperature (M. Keefer, personal communication).

The South Fish Ladder is the most important fishway for lamprey passage at McNary. Although sample sizes were relatively small for radio-telemetry studies at McNary, across all study years, the 100% and 79% of the first fishway approaches by Bonneville-tagged and McNary-tagged lamprey, respectively, were at South Fish Ladder entrances. The median percentage of lamprey that passed via the North and South fishways was 13%/21% and 87%/79% (Bonneville/McNary tagged), respectively, as not all fish ultimately pass the dam via the first ladder they encounter. Average median passage time (time from first fishway approach to the top of the dam) was 1.7 days (range = 0.8 – 2.6) for Bonneville-tagged lamprey and 2.7 days (range = 1.3 – 6) for McNary-tagged lamprey.

The Corps of Engineers has made several modifications to the South Fish Ladder, including installation of diffuser plating in the lower ladder section and cutting 18-inch wide by 3-inch tall lamprey orifices in the stem walls of the control section tilting weirs (near the ladder exit). Researchers have been evaluating the efficacy of reducing nighttime entrance velocities (by lowering entrance weirs) and plans are underway to modify at least one South Fish Ladder entrance.

### Wanapum and Priest Rapids

In 2001, Grant PUD conducted an assessment of Pacific lamprey migratory behavior at the Priest Rapids Hydroelectric Project (Nass et al. 2002). The primary purpose of the study was to assess the migration and passage timing of lamprey at Wanapum and Priest Rapids dams. Pacific lamprey were captured and radio-tagged during the period 23 July – 8 September 2001, and 23 July – 7 September 2002 at Priest Rapids Dam on the mid-Columbia River. A total of 51 and 74 fish were tagged and released in the Priest Rapids Dam area in 2001 and 2002, respectively. A combination of fixed station monitoring at both dams and extensive mobile tracking were used to determine migration and passage characteristics. Of the 51 lamprey released in 2001, 18 had detection histories in Priest Rapids fishways, and 3 were observed in Wanapum fishways. A total of eight radio-tagged lamprey passed Priest Rapids Dam, and 3 passed Wanapum Dam. Of the 74 lamprey released in 2002, 48 had detection histories in Priest Rapids fishways, and 27 were observed in Wanapum fishways. A total of 41 radio-tagged lamprey passed Priest Rapids Dam, and 23 passed Wanapum Dam. Overall passage success (proportion of individuals approaching the fishway that exit) was 30% and 70% at Priest Rapids, and 100% and 51% at Wanapum in 2001 and 2002, respectively. Overall median dam passage time (first at entrance to last at exit) was 1.2 d and 1.1 d at Priest Rapids, and 1.1 d and 1.8 d at Wanapum in 2001 and 2002, respectively.

In the fishways at Priest Rapids, the visual counting stations and the first orifice walls in the lower fishway appeared to be the locations of greatest passage delay and in the fishways at Wanapum, locations that appeared to delay passage were less pronounced than at Priest Rapids; on the left-bank the visual counting station caused the largest delays, and on the right-bank no area caused substantial delays (Nass et al. 2002). The areas identified during the 2001-2002 studies as potential impediments to lamprey migration in the Priest Rapids and Wanapum fishways were modified during the 2009-2010 winter outage to improve lamprey passage. These structural modifications in the Priest Rapids and Wanapum fishways include installation of plating on the edges of diffusion grating that extends to the vertical wall of the fishway; plating on and through the fishway floor of weir orifices; plating in the form of a ramps where the weir orifice is elevated above the fishway floor(perched); and redesign of the counting station structure. The intent of these modifications is to provide conditions that improve lamprey passage.

More recently, during the third year of implementation of Grant PUD’s Pacific Lamprey Management Plan, an assessment of Pacific lamprey behavior and passage efficiency was conducted at Priest Rapids and Wanapum dams. First, underwater video imagery collected in 2010 at two locations in the Priest Rapids right bank fish ladder was reviewed and analyzed. Cameras captured lamprey approaching and passing weir orifices and the fish count station, and provided a means to assess the use of the aluminum plating and new fish count station crowders by lamprey. Biological assessment of the imagery concluded that the plating was effective in facilitating lamprey passage.

For a second year, the study also evaluated passage success and travel times of lamprey through the fishways using HDX-PIT technology. Due to continued low numbers of returning adult lamprey to the mid-Columbia River in 2011, the PRFF again decided to implement a passive monitoring approach instead of actively trapping, handling and tagging test fish at the Project. This approach included monitoring for adult lamprey that had originally been tagged at Bonneville Dam on strategic arrays deployed at Priest Rapids and Wanapum dams. For the 2010-2011 monitoring period, a total of 67 and 38 HDX-PIT tagged lamprey were detected at Priest Rapids and Wanapum dams, respectively. Overall, estimated fish passage efficiency for lamprey is 82% at both facilities, and median passage time is approximately 2.2 days.

### Rock Island

HD-PIT detection arrays were installed in the Rock Island adult fishway during 2010 for monitoring passage of adult lampreys. Due to the low run sizes in recent years, only limited information has been gathered.

### Rocky Reach

A fishway evaluation of adult lamprey passage was conducted at Rocky Reach Hydroelectric Project during the 2004 migration (Stevenson et al. 2005). Adult lampreys were trapped in the fishway, outfitted with radio-telemetry tags (Lotek NTC-4-2L), and released at three locations approximately 7 km downstream of Rocky Reach Dam between August and October. Of the 125 radio-tagged lampreys released, 117 (93.6%) were detected at the project, and 110 entered the fishway (94.0% entrance ratio). Seventeen fallbacks occurred, though many lampreys were able to successfully re-ascend the fishway. Ultimately, 55 (47.0%) of the radio-tagged lampreys detected in the tailrace in 2004 were able to successfully ascend the project prior to tag expiration. Implementation of measures to facilitate upstream passage of adult lampreys at the project began in 2010. Aluminum plating strategically placed over diffuser grates and ramping at perched orifices in the fishway will be completed prior to the 2011 migration. HD PIT arrays will be installed prior to the 2012 migration, and other technologies are currently being considered for evaluating improvements..

### Wells

In 2004, Douglas PUD conducted a lamprey radio-telemetry study at Wells Dam in coordination with Chelan PUD, which was conducting a similar study at Rocky Reach Dam (Nass et al. 2005). A total of 150 lamprey were radio-tagged and released at or below Rocky Reach Dam. The 2004 study at Wells Dam was implemented through a combination of fixed-station monitoring at the dam and fixed-stations at tributary mouths. Collectively, these monitoring sites were used to determine migration and passage characteristics of lamprey entering the Project Area. Of the 150 adult lamprey released at or below Rocky Reach in 2004 (42-48 miles downstream of Wells Dam), 18 (12% of 150) were detected in the Wells Dam tailrace, and ten (56% of 18) of these were observed at an entrance to the fishways at Wells Dam. A total of 3 radio-tagged lamprey passed Wells Dam prior to expiration of the tags (45-day tag life), resulting in a Fishway Efficiency estimate of 30% (3 of 10) for the study period.

Subsequent radio-telemetry investigations of lamprey behavior and passage efficiency took place in 2007 and 2008 (LGL and Douglas PUD 2008; Robichaud et al. 2009). The 2007-2008 indicated that entrance efficiency over the two years of study averaged 27% (14% in 2007 to 33% in 2008). Lower fishway passage efficiency was 33% over both years, although 2008 trapping operations that resulted in complete exclusion of passage in the middle portion of the fishway may have significantly biased these results. Upper fishway passage efficiency (fishway portion above the collection gallery) was 100% and passage times were relatively fast (median passage times = 6.7 h) indicating that little or no passage impediments exist in this portion of the Wells fishways. A majority of lamprey may be uncounted at Wells Dam as 73% (11/15) of radio-tagged lamprey ascending the upper fishway bypassed the adult counting stations. No fallbacks were observed over all study years including in 2004. These passage times are excellent compared to studies at other Columbia Basin dams where median passage times reported were up to 7.6 days (Keefer et al. 2008). Overall, results indicate that potential passage impediments are restricted to the entrance and lower fishway.

In 2009 and 2010, Douglas PUD evaluated the effects of velocity reductions on lamprey entrance efficiency at Wells Dam. Dual-frequency Identification Sonar (DIDSON) was used to passively assess adult Pacific lamprey passage behavior in response to operational modifications at the Wells Dam fishway entrances (Johnson and Le, 2011). Lamprey passage was examined relative to variable head differential treatments and entrance velocities. In 2009 three head differential treatments were tested: existing high (0.46 m; or 3.0 m/sec), moderate (0.31 m; or 2.4 m/sec) and low condition (0.15 m; or 1.8 m/sec). In 2010 only two of the 2009 treatments were used: existing high, and a moderate condition. Combining both years, a total of seven lamprey observations were recorded where lamprey were observed to encounter the entrance sill heading upstream (N = 5 in 2009; and N = 2 in 2010). Overall, five of the seven observations showed successful entry into the fishways (71%). During reduced head differential treatments, five observations were recorded with four of the five resulting in successful entry (80% efficiency). Three of three observations with the moderate head differential treatment resulted in successful entry (100% entrance efficiency). During high head differential treatments, one of the two lamprey observed entered a fishway (50% efficiency). Extremely low Columbia River basin lamprey runs in 2009 and 2010 resulted in few fish observed at Wells Dam (the ninth and last hydroelectric project on the Columbia River [river mile 516] with fish passage). Low sample sizes precluded statistical evaluation of these results. Nonetheless, operational modifications implemented in these two years of study suggest that entrance efficiency may be increased with lower head conditions.

Wells Dam has two adult fish ladders, one on each side of the dam immediately adjacent to the right and left banks of the Columbia River. The ladders were built during the original construction of the dam. Each ladder contains 73 fishway weirs. They descend one foot per pool and discharge a constant 48 cubic feet per second of river flow through the ladder. This discharge flows from one pool to another over the walls and through submerged orifices.

Each of the two fish ladders has a single entrance for fish, which is located at the bottom of each ladder’s collection gallery. Each entrance opens into a collection gallery that is flooded with water in excess of that flowing in the fish ladders. This excess “attraction water” is designed to attract migrating fish into the collection gallery and ultimately into the fish ladder. As fish move up the ladders, provisions for sorting and trapping fish are located adjacent to Pool 40. This area is equipped with a holding box and adult Passive Integrated Transponder (PIT) tag detectors. In addition, the traps are also equipped with slide gates to either retain fish or return them to the ladder. This area is used for brood stock collection, for fish tagging and for other research opportunities. Pool 64 contains facilities for fish counting, including a viewing window, video cameras and a light panel. Pools 67 and 68 are equipped with PIT tag detection devices that interrogates each fish for a PIT tag and, once detected, will record the presence of each tag as the fish ascend the ladders.

Research to date at Wells Dam indicates that areas of potential passage impediments for Pacific lamprey are in the collection gallery and at the fishway entrance. Although Douglas PUD is awaiting the issuance of a new FERC operating license (expected in May 2012) which also includes a Pacific Lamprey Management Plan (PLMP), early implementation of some components of the PLMP have been implemented as described above. Upon issuance of a new license, Douglas PUD will begin formal implementation of its PLMP which includes the potential for additional operational and structural measures to address entrance efficiency, diffuser grating, transition zones, ladder exits and pools that may adversely affect passage of adult Pacific lamprey.

## Snake River Projects

### Ice Harbor Dam

Radio-telemetry studies showed that in 2005 and 2006, only 59.1% of adult lamprey that encountered a ladder entrance actually passed Ice Harbor Dam (Cummings et al. 2008). The median passage time from the first approach until exit into the forebay for adult lamprey was more than 2.0 days.

In an effort to improve monitoring of Pacific lamprey in the basin, HDX-PIT tag monitoring sites were deployed at several dams, including Ice Harbor, in 2005 (Cummings 2007).

The entrainment of juvenile lamprey in the turbine cooling water strainers was first identified as a concern in February of 2009, when approximately 400 juvenile lamprey mortalities were found in one of the unit strainers at Ice Harbor. The USACE now conducts monthly cooling water strainer inspections and documents the numbers of each fish species found. The number of lamprey found has been quite variable, with none or a few found per strainer during August to December, but typically ranging from 0 to over 100 lamprey during January to July. 701 lamprey were removed from the Ice Harbor strainers on Feb. 2, 2010, which is the highest number counted during an inspection so far. Occasionally a few live lamprey are recovered and released back to the river.

Recent improvements to the facilities at Ice Harbor Dam include:

* North Shore ladder diffuser plating; Similar to work on south shore fish ladder, install full diffuser plating on unnecessary diffusers and partial plating on diffusers currently being used at north shore fish ladder.
* Modification of vertical slot and orifice pit tag antennas in upper fishways: Provide 2-1/2" to 3" x 16-18” lamprey orifice openings on one weir wall of the vertical slot sections of both fishways.
* Rounding of corners in ladder; fillet or knock off sharp corners, typically at existing fish orifices with hand-held grinding tools.
* Elevate Picketed lead gates; Measure existing gap between picketed lead panel and fish ladder bottom, and then raise and retain picketed lead panels to provide 1-1/2" total gap.
* Counting window clean-up: Remove Flow Vane control structure near picketed lead at the North Shore Fishway
* Cooling Water Intake Screening; Development of Alternatives to Screening of cooling water intakes in turbine unit scroll cases.

### Lower Monumental Dam

Obtained/improved baseline passage metric information at Snake River dams to better determine passage problem locations.

### Little Goose Dam

Obtained/improved baseline passage metric information at Snake River dams to better determine passage problem locations.

### Lower Granite Dam

Obtained/improved baseline passage metric information at Snake River dams to better determine passage problem locations.

• Continued nighttime lamprey video window counts at Lower Granite (LWG).

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