U.S. Fish and Wildlife Service
Columbia River Fisheries Program Office

Pacific Lamprey and Bull Trout Passage Assessment at Warm Springs National Fish Hatchery

2014 Report

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On the cover: Fishway on the Warms Springs River. Photograph by Joe Skalicky.

The correct citation for this report is:

Gallion, D. and J. Skalicky. 2014. Pacific Lamprey and Bull Trout Passage Assessment at Warm Springs National Fish Hatchery. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, WA. 43 pp.

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2014 REPORT

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Final
June 20, 2014

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Abstract

The fishway at Warm Springs National Fish Hatchery was designed and constructed in the mid-1970's before modern fish passage standards were established, including those for Pacific lamprey. Consequently, our fishway evaluation at the hatchery demonstrates significant passage deficiencies for Pacific lamprey, likely delaying and limiting passage through the fishway. Passage limitations for bull trout through the fishway were not as significant. Additional biological assessments including telemetry and video monitoring could quantify the most significant issues in the fishway and subsequent modification of fish physical structures could improve passage conditions. The most significant passage issues observed for Pacific lamprey in the hatchery were: probable delay and entrainment issues at turning pool B1, high water velocities through the vertical slot weirs, a passage-limiting design at the vertical slot weir leading into the transport channels, lack of adequate attachment substrate at the fishway entrance, a passage limiting design of the fishway exit, and a lack of rounded edges and corners throughout the fishway. For Pacific lamprey, an alternative solution would be a Lamprey Alternative Passage System or (LAPS) that could be installed to circumvent all of the passage concerns in the fishway. Considering the dramatic declines in Pacific lamprey numbers and the time and resources required to conduct the fishway assessments, a LAPS may be a more cost-effective and efficient fish passage alternative.

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Introduction

In 2006, the U.S. Fish and Wildlife Service (USFWS) Pacific Region Hatchery Review Team's assessment of Warm Springs National Fish Hatchery (WSNFH) recommended that the effects of the barrier dam and fish ladder on distribution and upstream and downstream movement of native fish be evaluated (USFWS 2006) including effects on Pacific lamprey and bull trout. In response, on October 17th, 2011 a visual inspection of the barrier dam and fish ladder at WSNFH was conducted as an initial attempt to identify potential areas of concern for Pacific lamprey passage at the facility (USFWS 2011). The 2011 inspection consisted of a walkthrough of the hatchery passage facilities, starting from the fish ladder entrance and ending at the water intake. This visual inspection was limited because the ladder was watered up and operational and full ladder detail could not be seen. The concerns identified in that inspection were the impetus for a more detailed evaluation which was conducted and is described in this report. Additionally, in 2012, four of six lamprey documented in the fishway were dead (Columbia River information System) warranting scrutiny. The goal of this study was to address these recommendations and concerns by conducting a comprehensive physical fish passage evaluation of the fishway at WSNFH to describe the suitability of the fishway conditions for passage of Pacific lamprey and bull trout.

Background

The Warm Springs River drains approximately 1,361 km^2 of land on the eastern flanks of the Cascade mountain range and flows into the Deschutes River at river kilometer (rkm) 135 (Figure 1). The river is contained entirely within the Warm Springs Indian Reservation. Peak flows occur in February and low flows in September and October (Figure 2). Including tributaries, an estimated 111 rkm of stream habitat is available to anadromous fish above the barrier dam (Cates 1992).

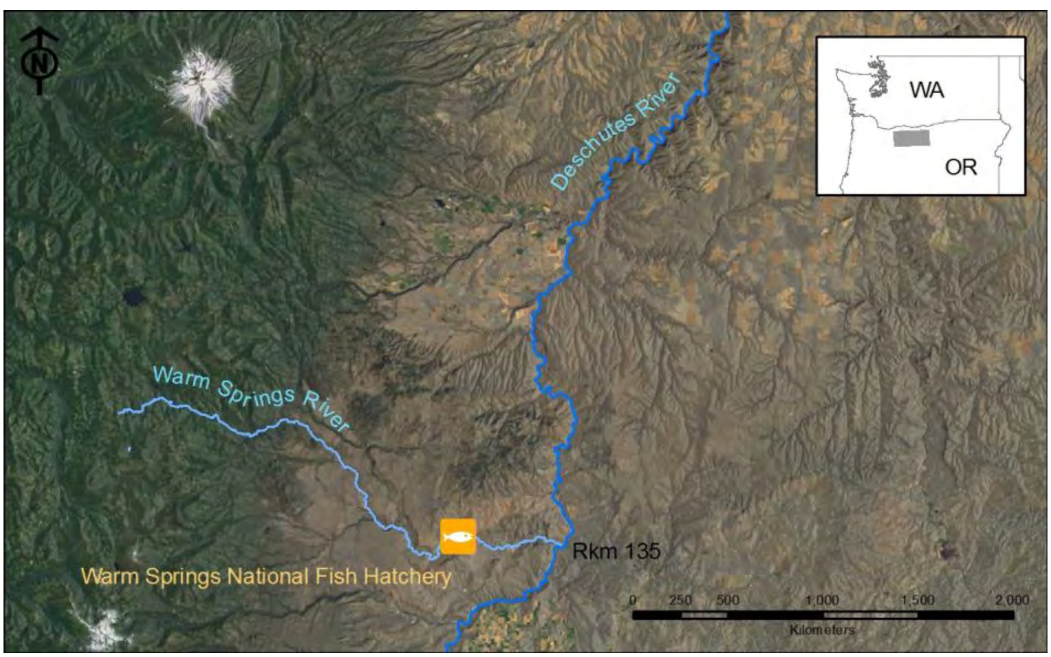

Figure 1. Location of the Warm Springs National Fish Hatchery on the Warm Springs River.

The hatchery is on the Warm Springs River at rkm 16 and became fully operational in 1978. The hatchery program is cooperatively managed by the Confederated Tribes of the Warm Springs Reservation of Oregon and the USFWS. The hatchery currently produces spring Chinook salmon for sport and Tribal harvests. A fish barrier dam located adjacent to WSNFH at rkm 16 of the Warm Spring River completely blocks all upstream migration of fish and directs them into the fishway. No detailed evaluations of upstream passage or passage delay have been conducted at the fishway. Fish entering the ladder are either directed into holding ponds at the hatchery or continue through the fishway and pass upstream of the barrier dam into the forebay. During the spring Chinook migration period, generally from 15 April to 30 September, an automated fish passage system is used to passively separate returning hatchery spring Chinook salmon from wild salmon. The passage system works by detecting coded-wire tags in returning hatchery spring Chinook salmon and diverting them into holding ponds while allowing untagged fish to pass upstream through the fish ladder and above the barrier dam. When the automated passage system is in use, a video monitoring system is used to identify and count fish passing upstream.

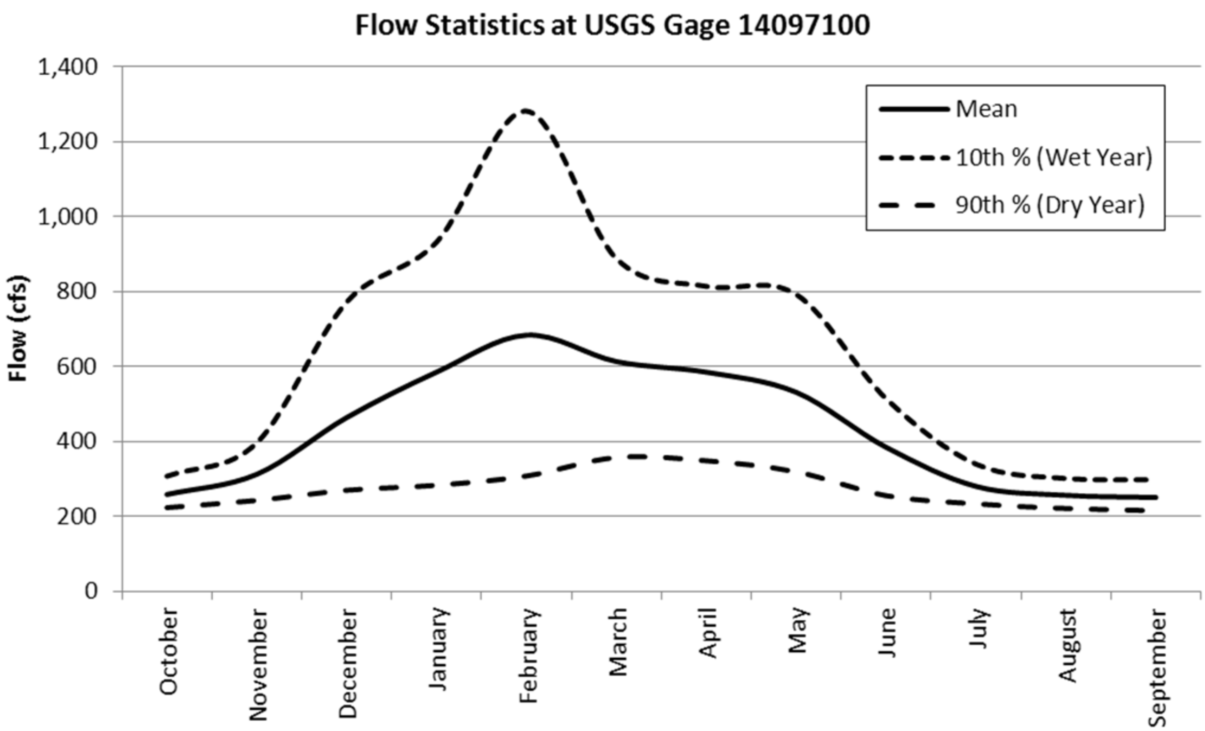

Figure 2. Flow statistics at USGS Gage 14097100 including monthly: mean, the 10th and 90th percentile exceedance flows.

Bull trout and Pacific lamprey distribution and migration timing

Bull trout (*Salvelinus confluentus)* which were officially listed as a threatened species under the Endangered Species Act (ESA) in 1998 and Pacific lamprey (*Entosphenus tridentatus*) are a species of special concern. Both species are native and present in the Warm Springs River. Both the migratory and resident life histories of bull trout are found in the Warm Springs River.

Migratory bull trout spawn and rear in the upper reaches of the Warm Springs River and use the lower portions of the watershed as a migration corridor between the Deschutes River and the upstream spawning areas. The resident segment of the population does not migrate to the Deschutes River but instead spends its entire life in the upper reaches of the Warm Springs River (U.S. Fish and Wildlife Service 2003).

Little is known about the life history of Pacific lamprey in the Warm Springs River. In the Columbia River, however, at least 50% of adult Pacific lamprey migrating past The Dalles Dam do so by mid-July through early August (Table 1). An unknown proportion of these lamprey migrate up the Deschutes and Warm Springs rivers. To describe emigration patterns of macropthalmia and ammocoetes, the Confederated Tribes of the Warm Springs Reservation operated a rotary screw trap at rkm 1.5 in the Warm Springs River during April-June and September-March (Graham and Brun 2003). Seventy-nine percent of the lampreys captured were identified as Pacific lampreys, and ammocoetes made up 80% percent of the catch (Figure 3.).

Table 1. Migration timing characteristics of Pacific lamprey at The Dalles Dam.

	Passage Dates							
Year	**First**	**1%**	**5%**	**10%**	**50%**	**90%**	**95%**	**Last**
2003	30-May	12-Jun	27-Jun	3-Jul	23-Jul	27-Aug	10-Sep	30-Oct
2004	23-May	8-Jun	22-Jun	26-Jun	15-Jul	26-Aug	12-Sep	26-Oct
2005	11-May	11-Jun	19-Jun	26-Jun	**12-Jul**	12-Aug	26-Aug	26-Oct
2006	1-Jun	14-Jun	25-Jun	30-Jun	23-Jul	29-Aug	9-Sep	17-Oct
2007	25-Apr	10-Jun	29-Jun	8-Jul	17-Jul	15-Aug	26-Aug	3-Nov
2008	18-Jun	26-Jun	1-Jul	4-Jul	26-Jul	24-Aug	31-Aug	16-Oct
2009	5-Jun	12-Jun	18-Jun	23-Jun	19-Jul	21-Aug	3-Sep	10-Oct
2010	12-Jun	22-Jun	30-Jun	4-Jul	25-Jul	31-Aug	9-Sep	25-Oct
2011	17-Jun	3-Jul	13-Jul	19-Jul	**8-Aug**	3-Sep	12-Sep	19-Oct
2012	15-Jun	26-Jun	8-Jul	11-Jul	6-Aug	8-Sep	16-Sep	19-Nov

Columbia River DART, Columbia Basin Research, University of Washington. (2014). Available from http://www.cbr.washington.edu/dart/query/adult_hrt

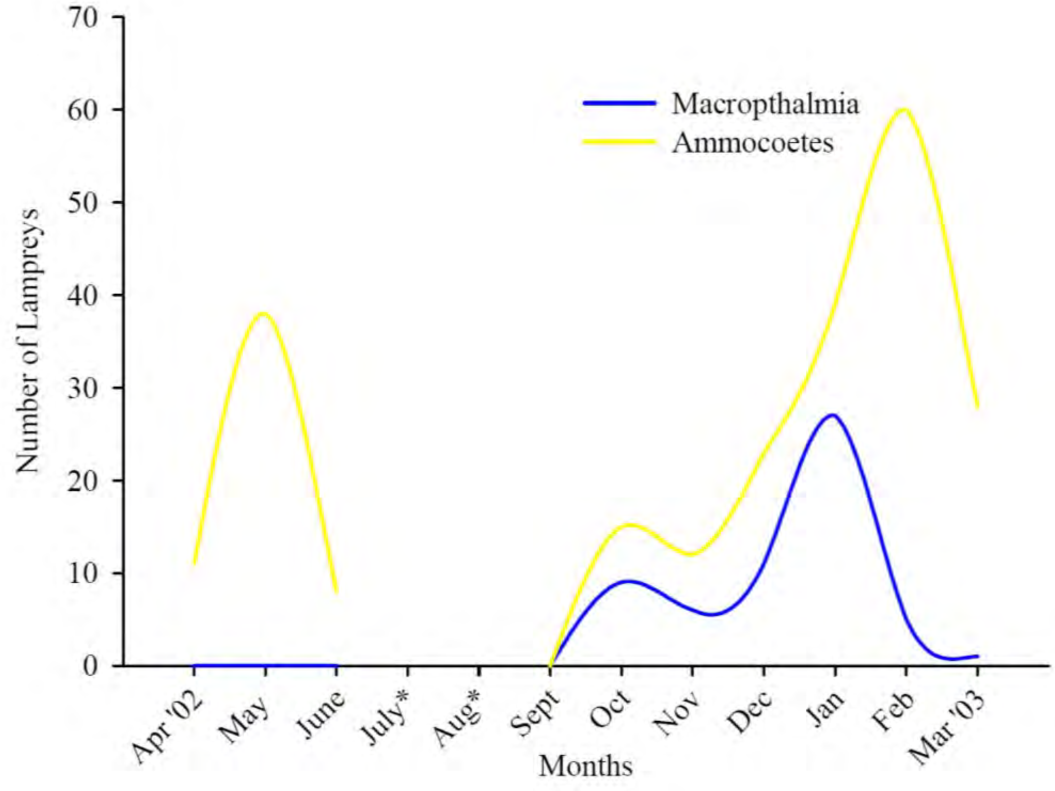

Figure 3. Movement patterns of Pacific lamprey macropthalmia and ammocoetes in the Warm Springs River, 2002-2003 (Graham and Brun 2003).

Bull trout have been observed in the WSNFH passage facility from May through September (Figure 4). These observations only include bull trout handled by hatchery personnel or recorded by the video system in the fish counting station. These observations likely represent primarily adult upstream migrants. Presumably adults could also be migrating downstream over the WSNFH spillway from October through April, for which no monitoring occurs. Subadult bull trout typically disperse downstream from spawning/early rearing areas associated with increased stream flow during the fall until the end of the spring freshet. In the Warm Springs River this is from December through June. The Confederated Tribes of the Warm Springs Indian Reservation (2011) only captured two out-migrating bull trout near the mouth of the Warm Springs River from 1998 to 2009. Trap efficiency was not reported, but typically the traps were operated from March through June annually. Movement patterns of subadult bull trout in the Warm Springs river are largely unknown, but may be similar to those observed in Mill Creek, WA. Subadult bull trout in Mill Creek, WA were primarily downstream migrants, reared and then returned upstream to spawn as adults (Howell et al. 2009). Presumably subadult bull trout could be migrating downstream over the WSNFH spillway from December through June, for which no monitoring occurs.

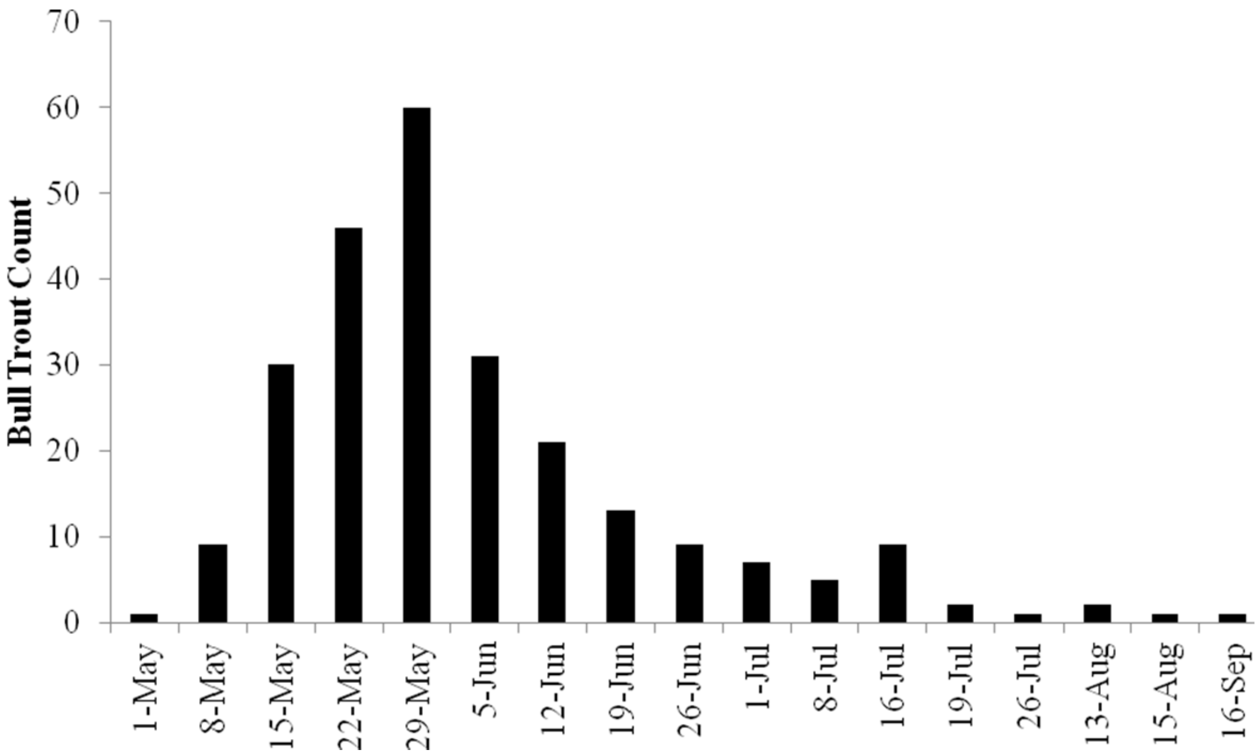

Figure 4. Immigration timing of bull trout at WSNFH ladder 2000-2009. (Confederated Tribes of the Warm Springs Reservation of Oregon 2011)

Table 2 summarizes the monthly upstream and downstream periodicity of both bull trout and Pacific lamprey from bull trout observations at WSNFH and juvenile lamprey captures in the Warm Springs River (Graham and Brun 2003). Adult lamprey movements are based on patterns observed at The Dalles Dam and professional judgment. Table 3 summarizes the annual counts of fish through the adult catch ponds at WSNFH. In 2012 four of the six lamprey observed in the fishway were dead.

Table 2. Peak (black) and non-peak (grey) migration timing of bull trout and Pacific lamprey past WSNFH.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adults Upstream												
Bull Trout												
Lamprey												
Downstream-Juveniles												
Bull Trout												
Lamprey												

Table 3. Counts of fish through the adult catch ponds at WSNFH.

Year	Lamprey	Bull Trout	Whitefish	Suckers
1993	0	1	4	138
1994	0	2	182	133
1995	0	5	103	252
1996	0	5		738
1997	0	7		195
1998	0	7	9	641
1999	0	13	81	302
2000	0	28	179	494
2001	0	25	198	202
2002	0	30	572	418
2003	0	33	88	967
2004	3	27	493	394
2005	0	41	122	819
2006	8	22	291	1,157
2007	1	34		406
2008	0	9	88	480
2009	0	5	743	111
2010	0	2	527	106
2011	0	18	392	266
2012	6	10	176	536
2013	1	9	163	697

Warm Spring National Fish Hatchery - Facility

A barrier dam at the hatchery spans the width of the river, blocking all upstream fish passage (Figure 5) (USFWS 2004). The fish passage facility is directly adjacent to the barrier dam, and including the dam, consists of seven main components: the dam, the fishway entrance, the ladder, the transport channels, the counting station, the fishway exit and the water intake screens. Components within the ladder can be further described as the entrance, vertical slot weirs, orifice weirs and turning pools (Figure 5 and Figure 6). Photos of the vertical slot weirs and orifice weirs dewatered for maintenance in 2012 are depicted in Figure 7.

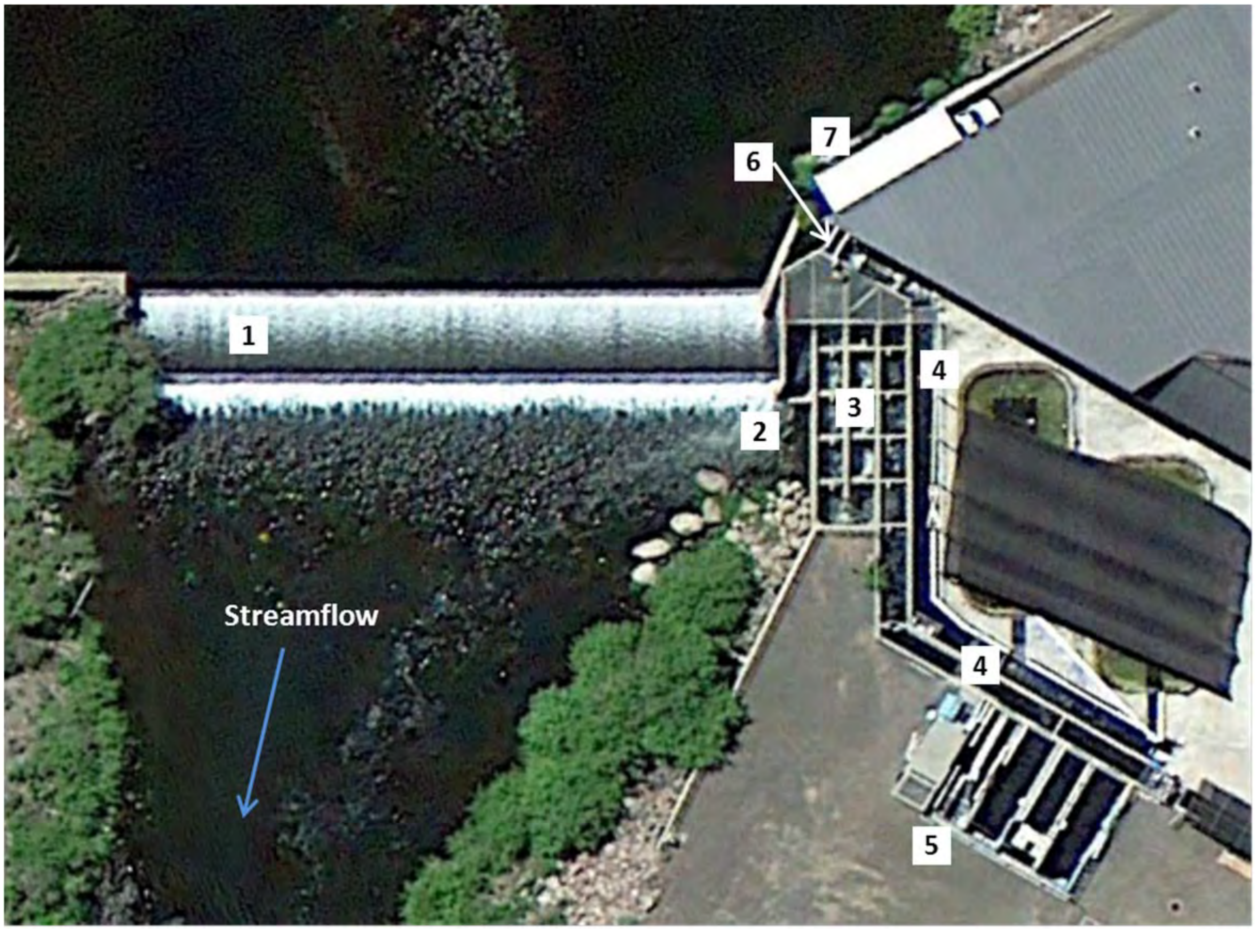

Figure 5. Aerial view of Warm Springs National Fish Hatchery fishway showing: (1) The barrier dam (2) Fishway entrance (3) The ladder (4) Transport channels (5) Counting station (6) Fishway exit and (7) Intake screens.

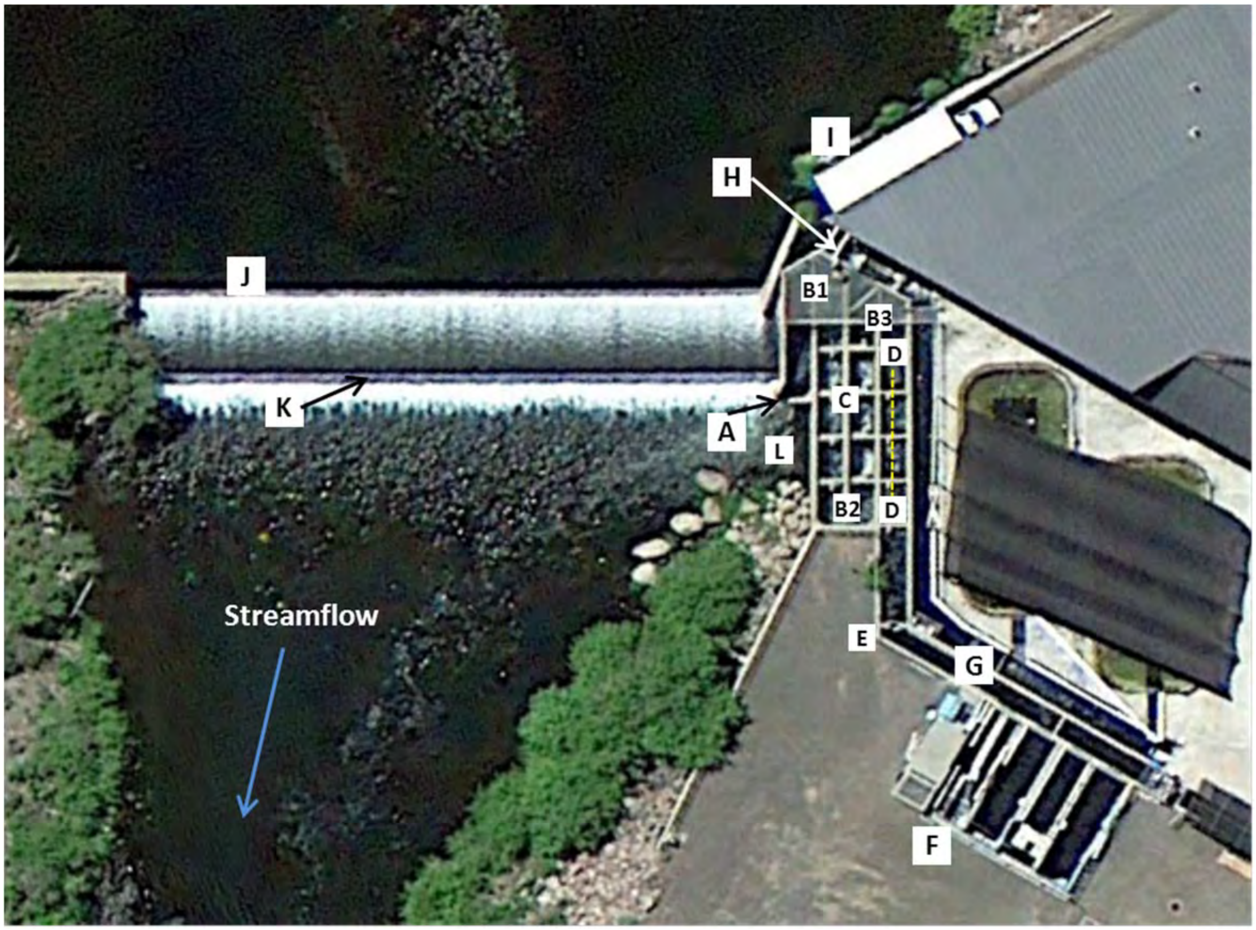

Figure 6. WSNFH fishway and barrier dam components: (A) Fishway entrance (B) Turning pools {B1, B2 and B3} (C) Vertical slot weirs, with two separate sections running between turning pools B1 to B2 and B2 to B3 (D) Orifice weirs, dashed yellow section (E) Vertical slot weir leading to the entrance to catch ponds and Denil-steeppass weir (F) The counting station (G) Transport channels (H) Fishway exit into the Warm Springs River (I) Hatchery water intake screens (J) Spillway crest with (K) Spillway apron and (L) Outflow from juvenile rearing ponds.

Plate-A Plate-B Plate C

Figure 7. Weir types present at WSNFH. Plates A and B depict the two types of orifices within the orifice weir section of the ladder and Plate C depicts the vertical slot weirs. The arrows depict the direction of streamflow through the ladder and weirs.

Water enters the fishway at three locations: the fishway exit, turning pool B1 and the most from turning pool B3 (Figure 6). Water is withdrawn from the river at the intake screens. After being screened, water first enters the fish passage system at the fishway exit (Figure 8). The fishway exit is above the elevation of the barrier dam pool, so water is pumped to this location. These pumps also supply water to the transport channels and the orifice weir section of the ladder. Unscreened water enters the fish ladder at the turning pool B1 (Figure 6) via a large Auxiliary Water Supply (AWS) pipe, and grates prevent adults from swimming into the pipe (Figure 9). Lastly, unscreened surface water flows from the barrier dam pool into the ladder at turning pool B2 (Figure 10). Juvenile fish and adult lamprey small enough to pass through the grates and exit the passage facility can do so at turning pool B2 (Figure 6) or swim through the rest of the fishway. Annually, these grates are opened to all fish from mid-December through February due to icing issues further up in the fishway.

Figure 8. View of the fishway exit dewatered (left) and operational (right) at WSNFH.

Figure 9. Water input into the fishway at turning pool B1 is conveyed from an Auxiliary Water Supply (AWS) behind the grate and to the right. The input end of the AWS is in the forebay and adjacent to the intake drum screen and is not pictured.

Figure 10. Fishway exit and grated gate at turning pool B3. Water enters the fishway at both of these locations.

Migrating fish nearing WSNFH encounter the barrier dam [K and J] and eventually enter the fishway at entrance [A] (Figure 6). After navigating through the entrance they encounter turning pool B1. After the turning pool, they then begin to ascend the sections of vertical slot weirs [C] between turning pools B1 and B2, and B2 and B3. After turning pool B3, fish ascend the orifice weir section [D]. Weirs in this section have two orifice openings, one at the surface, and another at the bottom, flush with the floor (Figure 7, Plate A and B). At turning pool B3 lampreys and fish small enough to pass through the grates, including some bull trout, can bypass about half of the fishway and enter the forebay and continue their upstream migration. These two paths through the fishway are depicted in Figure 11. After the orifice weir section, fish navigate through a single vertical slot weir fitted with a passive integrated transponder (PIT) antenna [E] and enter into the first section of the transport channel [G]. The transport channel leads to the fish counting station [F] with a Denil-steeppass weir. Wild fish not destined for the hatchery are passed through the second section of transport channel and exit the hatchery at the fishway exit [H] (Figure 9).

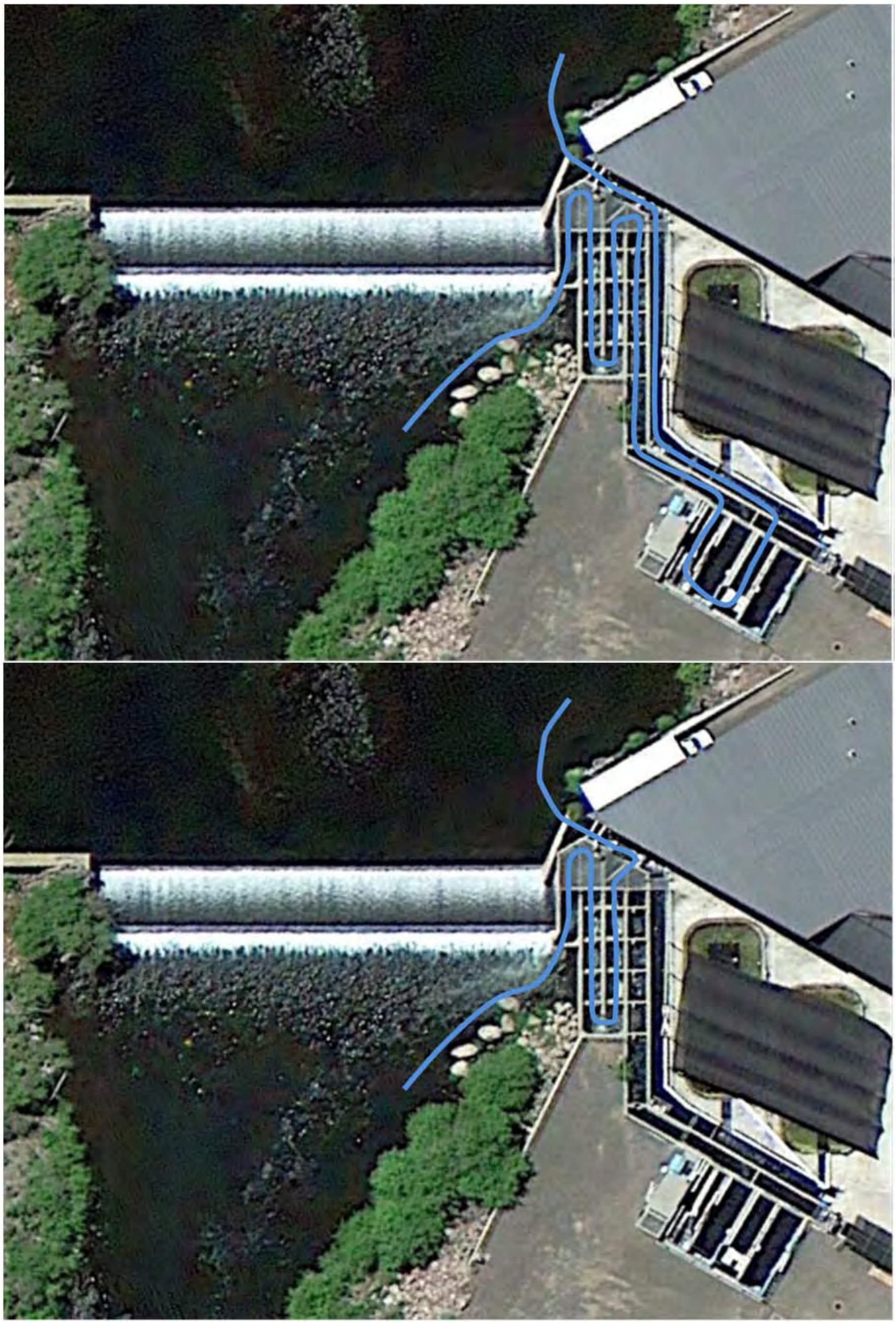

Figure 11. Two potential routes of passage through the WSNFH fishway partially dependent upon fish size and when the grates are open. Annually these grates are opened to all fish from mid-December through February.

Methods

Upstream passage

Species specific passage criteria for both bull trout and Pacific lamprey were not published or available when this evaluation was conducted. However, adult fluvial bull trout are similar in size to some adult anadromous salmonids, and criteria identified in the National Marine Fisheries Service Anadromous Salmonid Passage Design document (NMFS 2011) and the Oregon Administrative Rules (ODFW) were used to evaluate conditions at the facility for bull trout. These criteria are also similar to those used in other evaluations (Table 4). For lamprey passage, the following criteria were used: 1) 4 inch radius rounded corners, 2) absence of vertical and horizontal 90° angles, 3) water velocity less than ~4 ft/s, and 4) an appropriate substrate to which lamprey can attach.

Table 4. Sources of fish passage criteria.

Criteria Source	Adult trout (ft/s)	Juvenile trout (ft/s)
ODFW 2004-culverts	4.0	
California 2002-culverts	4.0	1.0
Bates et al. 2003-Washington culverts (10-60 ft)	4.0	
Thompson 1972	Fluvial 8.0 Resident 4.0	
Criteria used for the WSNFH passage evaluation	**Fluvial 8.0 Resident 4.0**	**1.0**

The following seven components of the fishway at WSNFH were physically assessed for upstream passage.

1. Barrier dam
2. Fishway entrance
3. Ladder weirs
4. Ladder pools
5. Transport channel
6. Counting station
7. Fishway exit

Barrier Dam

The barrier dam was visually inspected at low flow to assess if fish passage was likely. Physical measurements of the lip were made as well.

Fishway Entrance

The most critical aspects of the fishway entrance are the approach channel immediately downstream of the entrance, the entrance location in relation to the barrier dam, its shape and amount of flow discharged from the entrance, and the flexibility in operating the entrance to accommodate variations in tailrace elevation, streamflow conditions, and project operations.

Fishway entrances should have an approach channel, and be located in a relatively deep, tranquil area. The approach channel was only assessed visually from the surface. Attraction flow coming from the fish ladder should be a large percentage of total streamflow (up to 100%). Discharge was calculated and compared with total streamflow at USGS Gage #14097100 (Warm Springs River near Kahneeta Hot Springs). In general, entrances should be 4 feet wide and 6 feet deep, but should be shaped to accommodate specific site conditions. Streamflow at the entrance should be streaming flow not plunging flow with a head differential of 1.0 to 1.5 feet for adult salmon, steelhead, and fluvial bull trout, and 0.13 to 0.30 feet for juvenile salmonids. There should be low flow and high flow entrances and staff gages should be located in the entrance pool and tailwater outside of the fishway entrance. Water velocities between the fishway entrance and the first weir should be between 1.5 and 4.0 ft/s. In the actual fishway entrance, depth, width and average velocity were measured. The number of ladder entrances was identified and pool head differential at the entrance was measured.

Ladder Weirs

There are a total of 13 weirs in the fish ladder. The first eight weirs upstream of the entrance are vertical slot weirs and the last five weirs are orifice weirs. To assess passage conditions, water velocities were measured in weirs 5-7, 11 and 13. No velocity data was collected in weirs 1-4 because of equipment limitations used to take measurements. In the vertical slot weirs, only mean column velocity was measured. It is likely that nose velocity, which could be important for lamprey passing at the bottom of the weir, may be similar to mean column velocity given the uniform nature of the vertical slot and smooth bottom of the channel. In the orifice section of the fish ladder, both mean column and nose velocity in the top and bottom orifices were measured. Water velocities were assessed at weirs 11 and 13 to describe variation within the orifice section of the ladder.

Ladder Pools

We examined characteristics of two types of pools in the fish ladder, turning pools and weir pools. There are three turning pools and 10 weir pools in the fishway. Turning pools B1, B2, and B3 (Figure 6) are the 180° turns in the ladder and weir pools are formed between each of the successive weirs in the ladder. Pool 2 is the first pool upstream of the turning pool B1 and pool 13 is the most upstream orifice weir pool.

All turning pools (B1, B2, and B3) were assessed for pool length. Pool bends within the ladder should have a minimum radius of 2 feet and be twice the length of standard pools. Pool bend length was assessed using the formula: *Pool length = 3.14 x radius.*

We also assessed pool drop or head differential, in 6 of the 10 weir pools in the ladder; three pools in the vertical slot weir section (pools 2, 3, and 4), and three pools in the orifice weir section (pools 10, 12, and 13). A 1.0 foot head differential between pools is recommended for adult salmonids, and 0.7 feet is recommended for juveniles (NMFS 2011). To determine the head differential between pools, water surface elevations were measured using a traditional surveying stadia rod.

To describe resting areas within a pool, nose velocity and mean column velocity were measured along two transects within pool 13. Transects 1 and 2 were located approximately, 6 feet and 3 feet respectively, downstream of weir 13. Measurements were collected at five points across each transect approximately 1.0 foot apart. Due to equipment limitations, this was not possible in pools between vertical slot weirs.

Transport Channels

Fish transport channels should be of open design with dimensions of 5 feet deep and 4 feet wide. Velocity should be between 1.5 and 4.0 ft/s. The channels should be free of exposed edges that protrude from the walls. Width and depth measurements were collected and the channel walls were inspected for protruding edges.

Fish Counting Station

A counting station should provide a location to observe and enumerate fish utilizing the fish passage facility, but must not interfere with the normal operation of the ladder or increase fish passage delay (NMFS 2011). The WSNFH counting station (Figure 12) consists of a Denil-steeppass ladder, a drop tube for retaining coded wire tagged hatchery fish, and a camera box.

Figure 12. Oblique photo (left image) and lateral photo (right image) of the WSNFH fish counting station which consists of a Denil-steeppass ladder[A], drop tube [B], and a camera box [C].

Archibald (2013) identified specific problems with the equipment used in the fish counting station at WSNFH that could increase delay or jeopardize the goal of limiting upstream migration of hatchery adults. The counting station was not operational during our site visit so a hydraulic assessment was not possible. Therefore, our assessment focused on pool length and orientation upstream and downstream of the counting station. The recommended pool length downstream of the counting station should be 2x the standard pool length. The recommended pool length upstream of the counting station should be 1x the standard pool length. The upstream and downstream pools should be in a straight line with the station.

Fishway Exit

The fishway exit channel should be a minimum of two standard pool lengths and located upstream of a spillway to minimize the risk of non-volitional falling back. The fishway exit should be designed such that it does not accumulate sediment or debris during normal operation (NMFS 2011).

Downstream passage

Barrier Dam Spillway

The most likely route of passage for downstream migrants is the spillway at the barrier dam. To describe passage conditions at the spillway, three measurements were collected: 1) the vertical drop from the top of the dam to the spillway apron, 2) the depth of the water on the spillway apron, 3) the vertical drop from the spillway apron to the tailwater substrate.

Ladder

There are two downstream passage routes within the ladder. Fish can enter an unscreened AWS pipe near the hatchery intake screens and enter the ladder at turning pool B1 (Figure 6), or they can enter the fishway exit channel and enter the ladder at turning pool B2. The AWS pipe supplies water at turning pool B1 to increase attraction flow of the ladder.

Intake Screens

WSNFH water intakes should be properly screened. Behind the log boom and trash racks of the water intake structure (Figure 13, Plate-A), there are two passive screens that provide screened water for the hatchery (Figure 13, Plate-B). The approach velocity, measured perpendicular to the intake screens, should not exceed 0.2 ft/s for passive screens. The sweeping velocity measured parallel to the intake screens, should exceed the approach velocity.

Plate-A Plate-B

Figure 13. The WSNFH water intake structure (plate A) and one of two water intake screens (plate B).

Results and Discussion

During September 2013, personnel from CRFPO visited WSNFH to measure fish passage conditions within the fishway system. The average daily discharge at USGS gage #14097100 (Warm Springs River near Kahneeta Hot Springs) was 233 cubic feet per second (cfs) and is typical of monthly average flows from July through October which range from 250-281 cfs. Mean annual flow is 435 cfs.

Upstream passage

<u>Barrier Dam</u>

The barrier dam (Figure 14) spans the entire width of the river and has a 4 foot lip or overhang. We measured the overhang and cross referenced the length in the original design drawings. The overhang is likely a significant passage barrier for lamprey and the corner edges of the lip are approximately 90 degree angles further limiting lamprey passage. Lamprey could spend a significant amount of time and energy trying to ascend the barrier dam with little likelihood of passing. We interviewed three hatchery staff about visual observations of lamprey passing the barrier dam at either end, and no observations could be recalled by any of the staff. To minimize any delay or injury that might occur at the barrier dam and the entire fishway, a Lamprey Alternative Passage System (LAPS) may need to be installed that would allow lamprey passage over the barrier dam. A LAPS could be installed adjacent to and on the existing fishway near the entrance, and on one or both sides of the barrier dam. Figure 15 depicts a LAPS installed on the Washington shore ladder of Bonneville dam. Upstream passage of bull trout is likely blocked by the barrier dam. The amount of time and energy bull trout spend trying to ascend the barrier dam before finding the fishway entrance is unknown.

Figure 14. Barrier Dam with four foot overhanging lip and fish ladder entrance looking upstream at WSNFH.

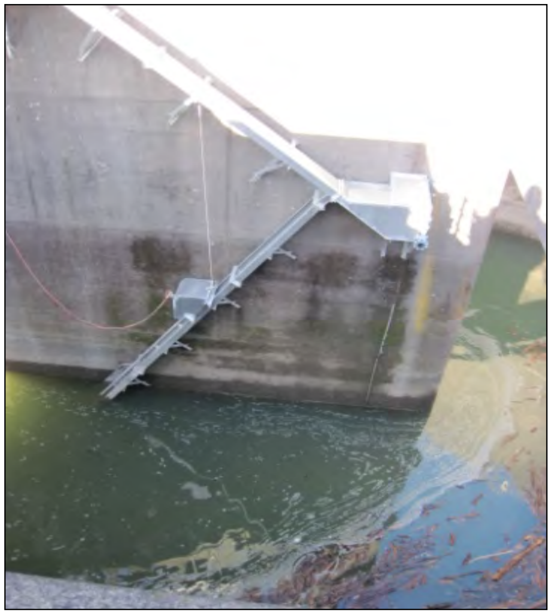

Figure 15. A LAPS installed on the Washington shore ladder of Bonneville Dam. Photo credit David Wills.

Fishway Entrance

The metrics and results used to assess the approach to the fish ladder and the ladder entrances, of which there is only one, are summarized in Table 5.

Table 5. Recommended criteria and observed conditions used to assess the approach to the WSNFH fishway.

Recommended Characteristics	Observed Characteristics
Bull Trout/Salmonids (NMFS 2011)	
Deep, tranquil approach channel	Deep approach channel
Ladder discharge a large % of total streamflow	Ladder discharge ~35% of total streamflow
Entrance 4 x 6 feet	Entrance 3 x 5 feet
Low and high flow entrance	Only one entrance
Staff gages installed to asses entrance head differential	No staff gages
Entrance head differential 1.0 - 1.5 feet (adults) 0.13-.33 feet (juveniles)	Entrance head 0.6 feet
Entrance velocity 1.5-4.0 ft/s, 4-8 ft/s[1]	~5.49 ft/s
Streaming discharge	Streaming discharge
Pacific Lamprey (David Wills, Pers. Comm.)	
4 inch rounded corners, edges	No rounded corners, edges
Absences of 90° angles	90° angles on the face of the entrance
Water velocity 4.0 ft/s	5.49 ft/s
Substrate for attachment	No substrate in close proximity

[1] Clay (1995) and Bell 1991 recommend 4.0 – 8.0 ft/s.

Based on a visual inspection only, the approach to the ladder for both Pacific lamprey and bull trout appeared to be acceptable at the streamflow levels observed during the 2013 field visit. A relatively deep channel led to the ladder entrance and a deep pool was present downstream from the ladder entrance. Water velocities were not tranquil within the pool immediately downstream of the entrance, but they appeared to be slower than velocities in the main channel of the river which were not measured (Figure 14 and Figure 16). Discharge from the ladder entrance flowed diagonally across the channel downstream, which should attract fish throughout the tail race toward the ladder.

Figure 16. View looking downstream from the barrier dam at WSNFH. The blue arrows depict the flow pattern of water exiting the fishway entrance at the lower left.

The fishway entrance dimensions are 3.0 feet wide and 14.5 feet high. During the site visit, water depth in the entrance was 5.0 feet. This is slightly less than, but similar to the recommended width/depth of 4 x 6 feet for salmonids. The average velocity in the entrance (5.49 ft/s) exceeded the NOAA (2011) recommended velocity of 4.0 ft/s but did not exceed 4.0 - 8.0 ft/s recommended by Clay (1995) and Bell (1991). The ladder entrance velocity of 5.49 ft/s likely has less negative impact on bull trout than lamprey. Lamprey have been observed attaining burst speeds of 8.0 ft/s (USACE 2011, Keefer et al. 2012) but Mesa et al. (2003) found that velocities greater than 5 – 6 ft/s were difficult to negotiate and swim through for adult Pacific lamprey. Anglin et al. (2013) used 4.0 ft/s as criteria for a lamprey passage evaluation. Discharge from the ladder entrance was 82 cfs, or approximately 35% of the total streamflow on September 11, 2013. No staff gages were present at the entrance to assess entrance head. The fishway entrance head differential was measured and was 0.6 feet, which was less than recommended for adult salmonids (1.0 to 1.5 ft) but more than what is recommended for juvenile salmonids (0.13 to 33 ft). As recommended, the entrance flows were streaming, not plunging, which is beneficial for fish entering the ladder. We did not observe the fishway entrance during high streamflow, so it is unknown if one entrance is sufficient during high and low streamflow or if an additional entrance is necessary under high streamflow.

The corners and edges of the ladder entrance were not rounded with 4 inch radii. The ladder entrance is perched above the surrounding substrate. Lamprey attach to the substrate and use swimming bursts to ascend obstacles. It is unknown if the lack of substrate in close proximity to the ladder entrance hinders lamprey entering the ladder.   Proximity of substrate for bull trout is not a known factor.

Ladder Weirs

We selected a subset of the vertical slot weirs and orifice weirs present in the ladder and assessed them for recommended minimum physical size and water velocities.

The vertical slot weirs met the recommended minimum width of 12 inches. We attempted to measure velocity in the middle of the water column of the vertical weirs but it was not always possible due to equipment limitations. As a result the measurements were made shallower. Thompson (1972) recommends a maximum velocity of 8.0 ft/s for salmon, steelhead and large trout and 4.0 ft/s for trout. All measured velocities were similar to those recommended for large trout (Table 6). Given the water velocities at the vertical slot weirs the impacts to large bull trout are likely minimal, but impacts to small adult and subadult bull trout are unknown. The corners and edges of the vertical slot weirs did not have a 4 inch rounded radius as recommended for lamprey passage, but they were beveled with a 0.75 inch chamfer. As discussed previously, lamprey have been observed attaining burst speeds of 8.0 ft/s, but what affect velocities observed at WSNFH have on adult lamprey are unknown.

Table 6. Water velocities measured in the vertical slot weir section of the fish ladder at WSNFH.

Weir #	Water Depth (ft)	Distance from surface (ft)	Velocity (ft/s)
5	5.0	2.2	6.40
6	5.0	3.0	7.62
7	5.0	2.5	7.38

The larger top orifice in the orifice weir section of the ladder is approximately 18 inches wide and 6 feet tall, meets the recommended minimum width and height. The top orifice did not have 4 inch rounded corners or edges on the top or sides as recommended for lamprey passage. The bottom of the top orifice was slightly rounded (Figure 17). The bottom orifice measured 9 inches wide and 15.5 inches tall which does not meet recommended width of 12 inches. In the bottom orifice, where lamprey are more likely to be passing, the sides and top of the orifice are slightly rounded (Figure 8 plate B). The bottom is completely open and flush with the fishway floor, allowing lamprey to move along the bottom of the ladder unimpeded. However, on both the top and bottom orifices the roughened aggregate surfaces may limit lamprey ability to maintain suction (Figure 17).

Figure 17. Detail of the slightly rounded bottom edge of top orifice.

Recommended water velocity for salmonid passage through an orifice is 8.0 ft/s. Lamprey have been observed passing through orifices with water velocities of 8.0 ft/s which may be acceptable if there are rounded corners with a 4” radius and places where lamprey can attach. All orifice velocities measured were less than the maximum recommended velocities for bull trout and lamprey (Table 7).

Table 7. Water velocity data collected in the orifice section of the fish ladder at WSNFH.

Weir #	Top orifice		Bottom orifice	
	Nose Velocity (ft/s)	Mean Velocity (ft/s)	Nose Velocity (ft/s)	Mean Velocity (ft/s)
11	2.41	3.17	3.73	3.47
13	3.05	2.45	4.38	4.31

Ladder Pools

Characteristics of all three turning pools and the weir pools were examined. Turning pools should have a minimum radius of 2 feet and should be twice the length of other pools in the ladder. Pools in the straight sections of the ladder are 9.3 feet long, so the recommended minimum length of turning pools is 18.6 feet. The outside radius of the turning pools is 6 feet resulting in a length of 18.84 feet which is similar to the recommended length. Water from the forebay enters the ladder at turning pool B1 to increase attraction flow to the ladder. The flow from the pipe could attract both lamprey and adult salmonids and could delay fish passage. The 1 3/8” grate spacing of the gate that blocks access to the pipe could allow lamprey passage. If lamprey were able to pass through or under the gate, the force of the flow could cause the lamprey to be washed downstream and possibly become impinged on the gate. It is unknown if this occurs and further investigation may be necessary. The safest and most direct route of passage for lamprey to ascend the fish passage system is to pass through or under the gate at turning pool B3 (Figure 11, Figure 10) which significantly shortens their travel time in the fishway.

Hydraulic head was measured in both vertical slot weir pools and orifice weir pools (Table 8). The recommended hydraulic head for salmonid passage is 1.0 ft. Of the pools where hydraulic head was measured, it was only exceeded in pool #2. While collecting head measurements, the water surface elevation fluctuated slightly as flow pulsed through the ladder, which may have affected our estimate. It's unclear why head would be different between pools two, three and four, assuming consistency in the vertical slot weir design. A pool head of 1.2 feet theoretically would result in a velocity of approaching 9 ft/s through the vertical slot weir, which potentially could affect lamprey and bull trout passage. The head measurement should be verified during a future site visit.

Table 8. Hydraulic head measurements between pools at the WSNFH ladder.

Pool #	Pool type	Hydraulic head
2	Vertical Slot Weir	1.2
3	Vertical Slot Weir	1.0
4	Vertical Slot Weir	1.0
10	Orifice Weir	0.6
12	Orifice Weir	1.0
13	Orifice Weir	0.8

To describe resting areas within a pool, nose velocity and mean column velocity was measured along two transects in pool 13 (Table 8). Characterizing nose velocity conditions is most relevant to bottom oriented species such as lamprey which may be attaching to the ladder substrate during upstream movements. The recommended nose velocity of 4.0 ft/s was only exceeded in measurement 1 of transect 1 (4.4 ft/s) and transect 2 (7.7 ft/s). Measurement 1 was directly downstream of the bottom orifice opening. Our measurements suggest most of the resting area for bottom oriented fish is in the upstream part of the pool. Only 20% (1 of 5 measurements) of transect 1 was < 1 ft/s, whereas 60% (3 of 5 measurements) of transect 2 were < 1 ft/s. Transect 2 is closer to the upstream weir and therefore more sheltered from flow through the orifices. Mean velocity is likely a better representation of what most bull trout experience as they ascend the ladder. None of the mean column velocity measurements exceeded recommended velocities, and 90% (9 of 10) were between -1.0 and 1.0 ft/s, suggesting most of the pool would provide adequate resting area for fish ascending the ladder mid-water column. Overall, average nose velocities for transect 1 (2.1 ft/s) and transect 2 (2.4 ft/s) were higher than average mean velocities for transect 1 (0.2 ft/s) and transect 2 (-0.2 ft/s).

Table 9. Water velocities (ft/s) measured within pool 13.

	Nose Velocity		Mean Velocity	
Measurement #	Transect 1	Transect 2	Transect 1	Transect 2
1	4.4	7.7	1.8	-0.3
2	2.5	2.4	0.3	-0.3
3	2.6	0.7	0.6	-0.3
4	1.1	0.6	-0.9	-0.2
5	-0.2	0.6	-0.7	0.1
Average	2.1	2.4	0.2	-0.2

Transport Channels

The fish transport channel at WSNFH is an open design. The channels are 6 feet wide and the water depth was 2.7 feet, which is wider but shallower than NOAA recommendations of 5 feet wide and 4 feet deep. The main areas of concern for bull trout and lamprey in the transport channel are a step and vertical slot weir where a PIT antenna has been installed, an orifice weir, and a screen box that protrudes from the wall and has exposed edges (Figure 18). The PIT antenna is installed on the downstream rather than the upstream side of the weir and thus forces lamprey to swim up and over it.

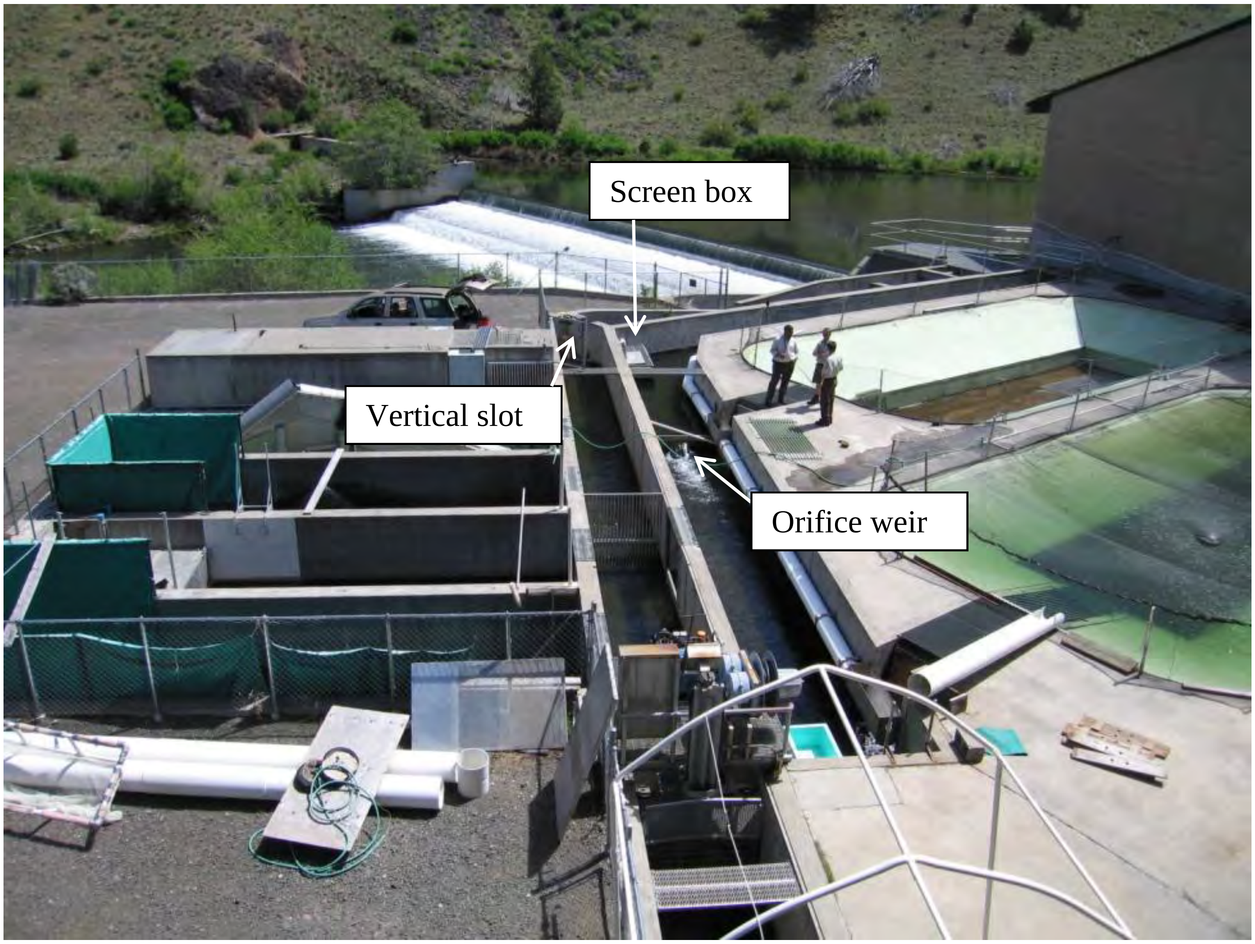

Figure 18. Location of passage impediments in transport channel.

As fish move upstream from the orifice weir section of the ladder through the fish transport channel, the first obstruction encountered is approximately a 3 foot step (Figure 19). The face of the step is constructed of steel grating with 1 inch spacing which allows water to flow from the screen box to below the PIT antenna. Above the step is a vertical slot where a PIT antenna has been installed. Nose velocity was 2.93 ft/s and mean column velocity was 3.34 ft/s on the vertical slot. No velocities were measured through the grating. Water velocities are within NOAA's recommended range of 1.5-4.0 ft/s for transport channels. The steel grating was damaged and has recently been repaired. Apparently, adult fish attracted by the flow coming through the grate were ramming the grating (Mary Bayer, USFWS personal communication.). Grate spacing of 1 inch and greater allows lamprey passage (David Wills, personal communication). If lamprey pass through the grating, they would hit a dead end in the screen box. If they don't pass through the grating and attempt to pass through the elevated vertical slot and PIT antenna, there is no substrate for attachment. The corners/edges of the vertical slot are not rounded with a 4 inch radius, but are beveled. The corners/edges of the vertical slot are covered by the PIT antenna. The grating potentially delays both lamprey and bull trout passage and could cause injury to adult salmonids and impinge lamprey. It is unknown if the elevated vertical slot, the lack of rounded corners/edges or the presence of the PIT antenna results in delayed passage. The antenna should be removed and installed on the upstream side of the vertical slot to provide a continuous and smooth surface to navigate over the weir. Further investigation may be necessary.

Figure 19. Vertical slot weir leading to the transport channel with PIT array and 3.0 foot step at WSNFH. The blue arrows depict the direction of water flow.

The second obstruction within the transport channel is an orifice weir constructed of dam boards (Figure 20). The bottom of the orifice is 1.8 feet above the bottom of the channel. The height of the orifice is 9.6 inches, with a width of 1.0 feet and mean column velocity in the orifice opening is 2.75 ft/s. Water velocity is within the recommended range of 1.5 to 4.0 ft/s and orifice width meets the recommended 1.0 feet, but the orifice height of 9.6 inches does not meet the recommend orifice height of 15 inches.

Figure 20. Orifice weir in the transport channel at WSNFH. Blue arrows depict direction of water flow.

The last obstacle within the transport channel is the screen box (Figure 21). The screen box allows water to flow between the upper and lower transport channel. The purpose of having flow between the upper and lower transport channel is unclear. The screen box has exposed edges within the transport channel, which is not recommended by NOAA.

Figure 21. Screen box in the WSNFH transport channel. Blue arrows depict direction of water flow.

<u>Fish Counting Station</u>

At the lower end of the counting station is the Denil-steeppass ladder. The downstream pool is between the counting station and the PIT antenna and is part of the transport channel. It is approximately 25 feet in length, which exceeds the recommended length of 18.6 feet. The pool upstream of the counting station between the camera box and the transport channel is approximately 20 feet in length and exceeds the recommended length of 9.3 feet. The upstream and downstream pools are not in a straight line with the counting station. Fish attempting to navigate through the counting station from the transport channel must make a 90 degree turn to the right and ascend the Denil-steeppass ladder, then make a 90 degree turn to the left to enter the drop tube, pass through the camera box and then make 90 degree turn to the left to exit the counting station. A linear orientation among the components of the fish counting station would likely reduce delay. Since the counting station was not in operation during the field evaluation it was not possible to evaluate full operational detail with respect to bull trout and lamprey passage. However, dead Pacific lamprey have been found within the counting station and additional evaluation is warranted.

Archibald (2013) identified several problems with the existing video system at WSNFH. Although the specifics of the video system were not reviewed in this report, we recommend reviewing the video monitoring system used by Gates (2004) to help determine future modifications.

<u>Fishway exit</u>

The fishway exit pool is longer than the minimum length requirement of 18.6 feet and the exit location is acceptable to minimize risk of non-volitional falling back. Fish ascending the fishway exit must pass through the exit weir before entering the forebay (Figure 8) except for fish small enough to slip through the grates at turning pool B3. The exit weir is at a higher elevation than the forebay. The higher elevation of the exit weir eliminates sediment and debris from entering the transport channel. The distance from the water surface elevation upstream of the exit weir to the bottom of the exit weir notch is approximately 1.42 feet which exceeds the recommended pool drop of 1 foot. It is unknown if this causes any delay in adult salmonids exiting the fishway, but hatchery personnel have not reported adult salmonids being “backed up” near the exit.

It is likely difficult for lamprey to pass through the fishway exit weir notch. The approach to the notch and the bottom of the notch is constructed of steel grating that lamprey cannot attach to (Figure 22). The lack of rounded corners/edges also makes it more difficult for lamprey that attempt to pass the notch if attempting to do so lateral to the grating. A perforated or partially perforated slide rather than a solid exit slide on the forebay side of the fishway exit would also make it difficult for lamprey to attach to the slide and thus force them into the forebay and prevent them from possibly re-ascending the slide.

Figure 22. Fishway exit dewatered. The arrows depict the direction of water flow.

Fishway Concrete Corner and Edge Construction

Throughout the entire fishway, no 4 inch radius corners or edges were observed. The fishway was constructed before this criterion was established for lamprey. Most corners and edges were close to 90 degrees and almost all were built with a 0.75 inch chamfer (Figure 23).

Figure 23. Two examples of corner and edge construction angles used throughout WSNFH.

Downstream passage

<u>Barrier Dam Spillway</u>

The most likely route past the WSNFH for downstream migrants, including bull trout and lamprey, is over the barrier dam spillway (Figure 24). During our site visit the daily discharge was 233 cfs and approximately 65% of the total streamflow went over the spillway. The vertical drop from the spillway crest to the spillway apron was 3.50 feet and the water depth on the spillway apron was approximately 0.17 feet. The depth on the spillway apron will increase with increasing flow. The drop from the spillway apron to the substrate in the tailrace was inferred from the original design drawings (about 6 feet). When trying to minimize impacts to downstream migrants, subjecting them to a 3.5 feet drop onto a concrete apron with a water depth of 0.17 feet is less than ideal. The conditions we observed are typical between July and October. July and August are near the end of the downstream migration period for bull trout and lamprey. Downstream migration of bull trout and lamprey is probably more predominant during March-June when streamflows are higher. The drop from spillway crest to the spillway apron, and apron water depth under high flow conditions were not measured, but undoubtedly are more favorable to downstream passage survival. This design, which appears to be less than ideal for downstream passage of lamprey and bull trout under typical summer flows, may be necessary to ensure blocking upstream passage of salmonids at higher streamflows.

Figure 24. Spillway crest and apron at the WSNFH barrier dam.

Ladder

There are two downstream passage routes within the ladder. First, fish that enter the unscreened AWS pipe near the water intake screens will enter the ladder behind the gate of turning pool B1 (Figure 9). The gate is constructed of 1.5 inch grating and has 1.375 inch spacing between grate elements. We were unable to measure water velocity in the pipe exit, but it appeared to be faster than salmonids or lamprey can swim. If fish are flushed out of the pipe, it is possible they could become impinged on the steel gate or become injured from contact with the gate. Future assessments should measure the pipe intake velocities to determine if it is likely unintentional entrainment is occurring.

Second, downstream migrants can also enter the ladder if the gate between the fishway exit and turning pool B3 is open or if they are small enough to pass through the 1.375 inch grate spacing of the gate. No problems were evident with this route of passage other than impingement on the grates, but velocities appeared to be slower here. Water velocity at the grate should be measured to determine if impingement for bull trout and lamprey is likely.

Intake Screens

The sweeping velocity of the upstream and downstream water intake screens was 1.3 ft/s and 0.6 ft/s, respectively. As recommended, both sweeping velocities exceeded the maximum recommended approach velocity of 0.2 ft/s which should prevent impingement of fish on the screens. Approach velocity was not measured during our site visit, but should be during future assessments.

Conclusions and Management Implications

A more complete understanding of passage constraints in the fishway could be attained by assessing conditions at additional discharges within the range for which the ladder is designed. Physical problems with the passage system for bull trout and Pacific lamprey have been identified in this report and are summarized in Table 10. Relatively few lamprey have been observed passing the WSNFH fishway and some have been found dead. To circumvent significant passage concerns for Pacific lamprey identified in the WSNFH fishway, a LAPS could be installed near the entrance of the fishway and over one or both sides of the barrier dam. To understand how significant these physical problems are, a biological assessment for passage of Pacific lamprey is recommended, especially if a LAPS is not installed in the near future. Since no dead bull trout have been found within the fishway, our primary concern is potential migration delay. A biological assessment for passage of bull trout is also recommended.

Future modifications to the WSNFH fish passage system should be discussed among technical experts and managers. Given the different requirements between lamprey, bull trout and spring Chinook (the hatchery target species) and juvenile and adult life stages, what may benefit one species or life stage may be detrimental to another. The potential positive and negative effects of any modifications should be considered, to determine what is best for all species present.

Table 10. Potential problems and solutions to improve bull trout and Pacific lamprey passage at WSNFH.

Location	Problem	Solution
	lamprey	
Barrier Dam	Potential migration delay	Assess delay, install LAPS or increase ladder attraction flow
Fishway Entrance	1 narrow entrance, head not appropriate, no staff gages, no rounded corners, no substrate.	Modify entrance and install staff gages
Ladder Weirs - vertical slot	water velocities exceed recommendation, may delay migration	Assess passage delay
Ladder Weirs - top orifice	No rounded corners on any weirs	Round corners
Ladder Weirs - bottom orifice	Orifice too narrow	Widen orifice
Ladder Pool	Gate at turning pool 1 could injure downstream migrants	Remove or relocate gate
Transport Channel	Step/vertical slot weir/PIT antenna/screen box could delay migration	Remove all and/or reposition PIT array
Fishway Exit	Pool drop exceeds recommendation, grated ramp	Decrease pool drop, replace with solid ramp
AWS Pipe	Unscreened	Screen
	bull trout	
Barrier Dam	Potential migration delay	Assess delay, increase ladder attraction flow
Fishway Entrance	1 narrow entrance, head not appropriate, no staff gages.	Modify entrance and install staff gages
Ladder Weirs - vertical slot	water velocities may delay migration	Assess passage delay
Ladder Weirs - bottom orifice	orifice to narrow	Widen orifice
Ladder Pool	Gate at turning pool 1 could injure downstream migrants	Remove or relocate gate
Transport Channel	Step/vertical slot weir/PIT antenna/screen box	Remove all and/or reposition PIT array
Fishway Exit	Pool drop exceeds recommendation	Decrease pool drop
AWS Pipe	Unscreened	Screen

Acknowledgements

The authors extend their appreciation to Mary Bayer and staff at the Warm Springs National Fish Hatchery for site logistics and operational information. Staff from the USFWS, Columbia River Fisheries Program Office provided technical support as well as report review including: David Hand, Dave Wills, Doug Olson and Don Anglin. Ryan Koch from the office provided field support.

Disclaimers

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June 2014