U.S. Fish and Wildlife Service

Icicle Creek Fish Passage Evaluation for The Leavenworth National Fish Hatchery

U.S. Fish and Wildlife Service
Columbia River Fisheries Program Office
Vancouver, Washington 98683

Icicle Creek Fish Passage Evaluation for
The Leavenworth National Fish Hatchery

Final Clean Water Act Section 401 Certification Order No. 7192
for the Leavenworth National Fish Hatchery
Icicle Creek, Chelan County, Washington

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Disclaimers

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Executive Summary

The purpose of this fish passage assessment was to characterize the physical and hydraulic conditions associated with a range of Icicle Creek streamflows at Structure 2, Structure 5, structures at the intake (low-head dam, fishway, diversion conveyance system), and open channel flows in the Icicle Creek historical channel adjacent to the Leavenworth National Fish Hatchery. These locations all have unique characteristics that produce variable conditions over a range of streamflows with respect to fish passage for coho salmon, spring/summer Chinook salmon, steelhead/rainbow trout, bull trout, Westslope cutthroat trout, mountain whitefish, Pacific lamprey, and suckers.

Methods used to estimate physical and hydraulic conditions at Structure 2 consisted of equations to relate critical depth, critical velocity, discharge, and water surface elevation. A separate set of equations was used to estimate depth and critical velocity conditions at Structure 2 with a range of radial gate settings, discharges, and water surface elevations. Rating curves were developed for Structure 5 to estimate water surface elevations associated with a range of streamflows and the corresponding depths over the foundation of the structure. Observations, drawings, and photographs were accumulated over a range of streamflows at the intake to characterize conditions including the location of the fishway. Empirical data were collected to characterize fishway conditions. Hydrodynamic modeling was conducted to quantify passage depths over a range of streamflows in the Icicle Creek historical channel. The results of these analyses were compared to passage criteria compiled from the literature to determine streamflows that were potentially limiting for fish passage.

The unique conditions associated with each of the structures or locations resulted in variable limitations on fish passage. Species periodicity, passage criteria, and streamflows ranging from the 90% exceedance flow to the 10% exceedance flow for Icicle Creek were integrated by month to identify depth and velocity passage limitations at the structures and in the historical channel. These results are presented in detailed tables that will allow managers and stakeholders to determine when passage limitations occur, and whether options exist to eliminate barriers or improve passage conditions at the structures or within the Icicle Creek historical channel.

Fish passage is not a binary situation, and the results of these analyses are based on the passage criteria used, and are not intended to imply absolute passage or not. Interpretation of these results and development of options to improve fish passage should be jointly conducted by the technical experts, managers, and stakeholders to determine actions that will meet the multiple goals for Icicle Creek including mitigation fish production at the Leavenworth National Fish Hatchery and preservation of the various fish populations that inhabit Icicle Creek.

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Introduction

On January 7, 2010 the Washington Department of Ecology (WDOE) issued Clean Water Act (CWA) 401 Certification Order number 7192 to the U.S. Fish and Wildlife Service (FWS) for the Leavenworth National Fish Hatchery (LNFH). The certification includes assessments and studies pertaining to water temperatures and fish habitat in Icicle Creek including fish passage that may be affected by hatchery operations. This report describes the evaluation of fish passage conditions at the three sites specified in the CWA certification; structures at the intake (low-head dam, fishway, diversion conveyance system), Structure 2, and Structure 5. The study plan for the fish passage evaluation was approved by WDOE with conditions on December 1, 2011. For these structures, passage conditions were characterized over a range of streamflows from the 90% exceedance monthly flow to the 10% exceedance monthly flow based on the period of record for the Icicle Creek hydrograph as measured at the USGS station #12458000, and/or the corresponding flows as modeled for the historical channel of Icicle Creek. Passage conditions associated with operations described in the *Biological Assessment for the Operation and Maintenance of Leavenworth National Fish Hatchery* (U.S. Fish and Wildlife Service 2011a), and in the *Biological Opinion for the Operations and Maintenance of the Leavenworth National Fish Hatchery* (U.S. Fish and Wildlife Service 2011b) were included in this evaluation. Passage conditions were evaluated for the structures as they are currently configured. If results suggest that fish passage is not adequate, changes in the structures may be needed. This study does not propose to evaluate alternative engineering solutions to inadequate passage conditions.

Goal and Objectives

The overall goal of the Icicle Creek Fish Passage Evaluation is to characterize the physical and hydraulic conditions associated with a range of streamflows and operations at the LNFH intake structures, Structure 2 (S2), and Structure 5 (S5), and relate those conditions to passage criteria for the relevant species/lifestages. Following are the specific Objectives for the passage evaluation.

Objectives

- Characterize physical and hydraulic conditions over a range of streamflows at the LNFH intake including conditions over the diversion dam, tailrace conditions, fish ladder conditions, and fish ladder location. Relate these conditions to species-specific passage and fish ladder criteria.

- Characterize physical and hydraulic conditions over a range of streamflows at S2 including conditions with and without the radial gates adjusted. Relate these conditions to species-specific passage criteria.

➢ Characterize physical and hydraulic conditions over a range of streamflows at S5 including conditions with and without the pickets installed. Relate these conditions to species-specific passage criteria.

➢ Assess passage conditions associated with a range of streamflows in the historical channel of Icicle Creek and relate those conditions to species-specific passage criteria.

Project Description

The LNFH is located in North Central Washington adjacent to Icicle Creek at river mile (RM) 3.0 and is two miles south of Leavenworth, Washington. In the 1930's, the 160 acre LNFH was authorized by Congress as mitigation for fish losses associated with the construction of Grand Coulee Dam. LNFH withdraws surface water from Icicle Creek at RM 4.5, utilizes it for fish production at the hatchery, and returns it to Icicle Creek at RM 2.8 (Figure 1). The hatchery annually produces 1.2 million juvenile spring Chinook salmon and provides acclimation facilities for coho salmon. These salmon contribute to commercial, sport, and tribal in-river and ocean fisheries alike.

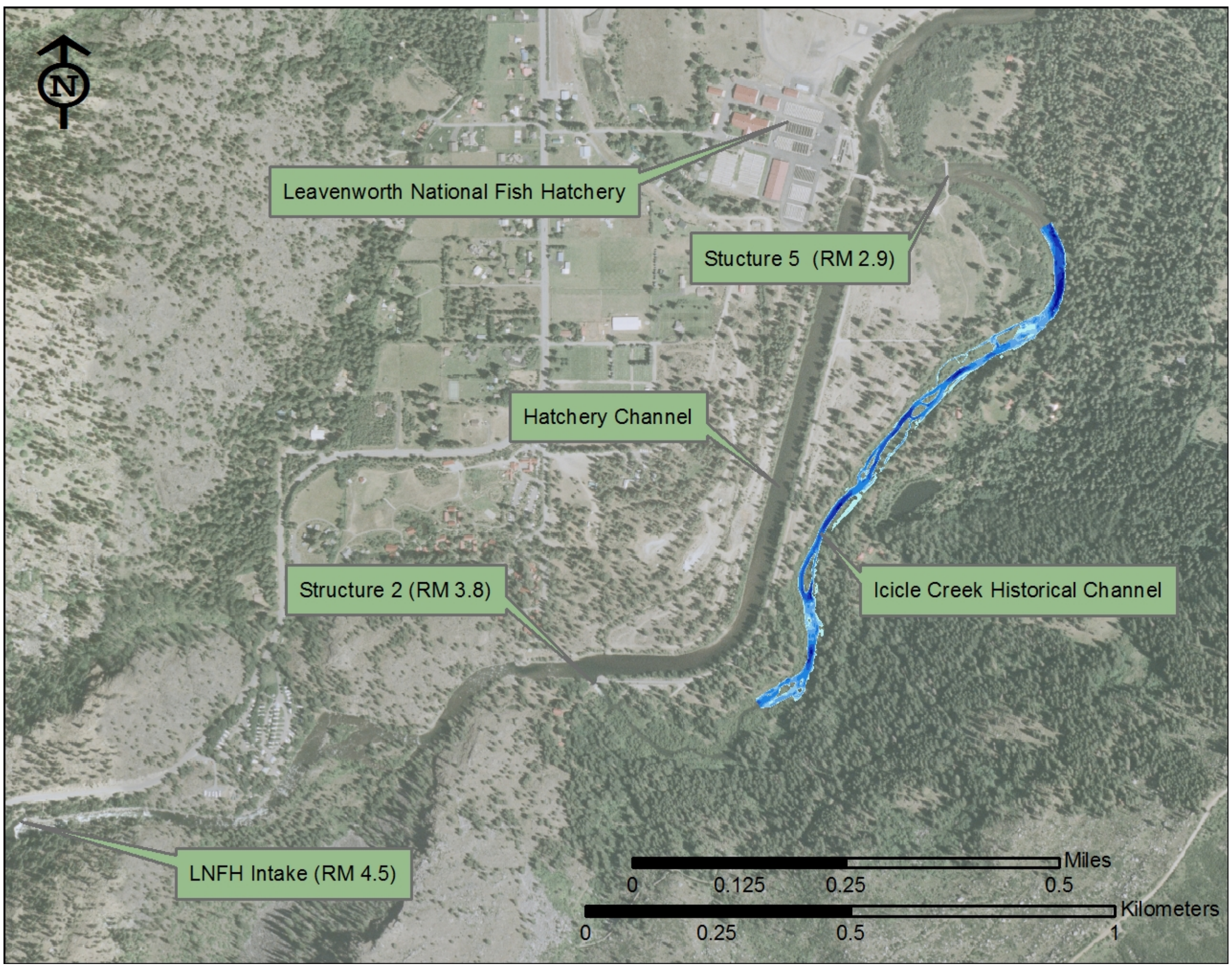

Figure 1. Study site overview depicting the location of LNFH, Icicle Creek, and Structures 2, 5, and the hatchery intake.

Hydrology

The Icicle Creek drainage is located on the eastern flanks of the Cascade Mountain Range and the watershed encompasses an area of 193 square miles. The Icicle Creek watershed is a high elevation drainage with 14 glaciers, 102 lakes, and 85 tributaries. The hydrology is primarily driven by snowmelt, and peak flows as measured by the USGS Gage #12458000 (Icicle Creek above Snow Creek near Leavenworth, WA) occur during late spring, while low flows occur during late summer, fall, and winter (Figure 2). Extremes for the period of record range from a minimum of 44 cubic feet per second (cfs) to a maximum of 19,800 cfs, with a mean annual flow of 624 cfs. The USGS gage at RM 5.8 is located above all major points of diversion. Icicle Creek streamflows downstream from the USGS gage are reduced by water diversions. The City of Leavenworth and the Icicle-Peshastin Irrigation District divert water above the Snow Lakes trailhead (RM 5.7), and LNFH and Cascade Orchards Irrigation Company divert water below the trailhead (RM 4.5). These irrigation diversions can remove up to 48% and 79% of the mean monthly August and September streamflows, respectively (Mullan *et al.* 1992). To assure adequate water for LNFH, a supplementary water supply (~16,000 acre-feet) was developed in Upper Snow Lake, about seven miles upstream from LNFH. Without the water release of approximately 50 cfs from Upper Snow Lake from early July through early October, the downstream reaches of Icicle Creek could go dry in some years.

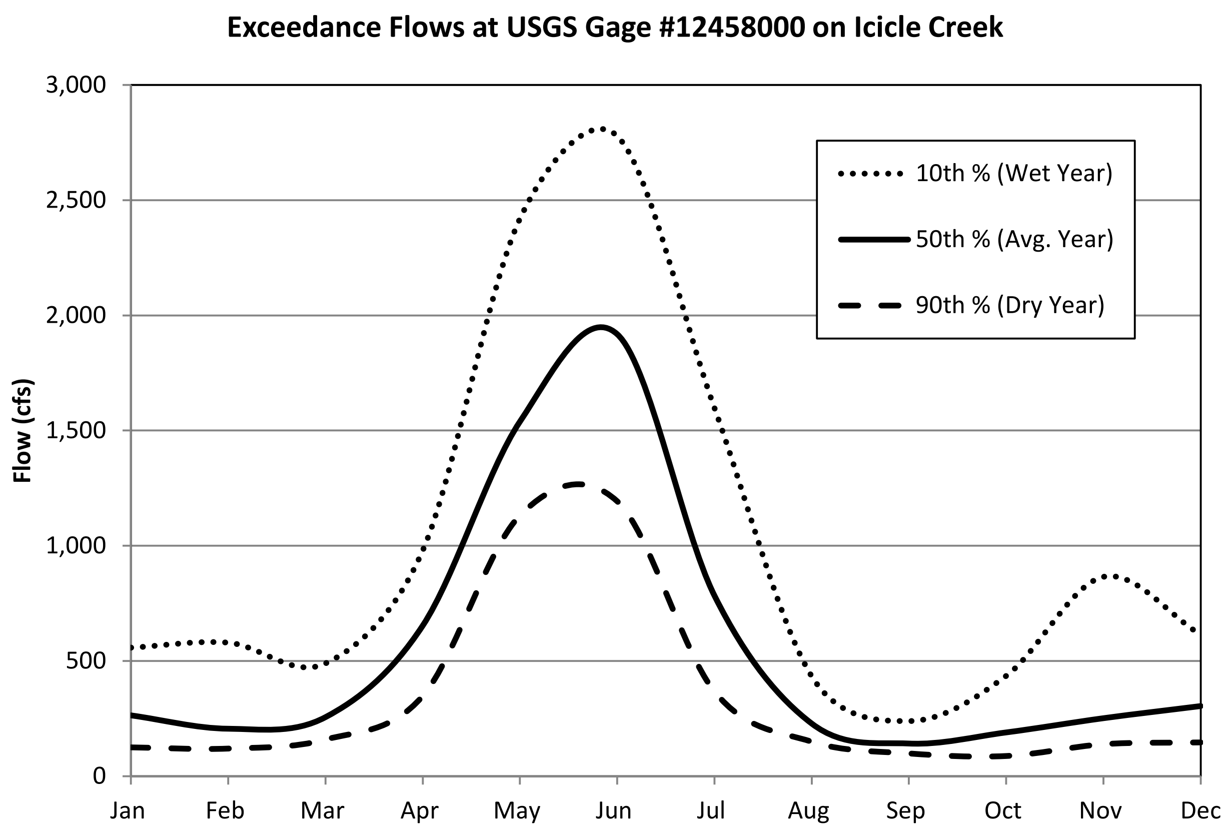

Figure 2. Exceedance flows as measured at USGS Gage #1245800 on Icicle Creek near Leavenworth, WA for an average, wet, and dry year for the period of record (1936 – 2012). Mean annual flow is 624 cfs.

Passage Evaluation Site Descriptions

Following are detailed descriptions of the three sites included in this passage evaluation. The LNFH water intake structure is located approximately one river mile upstream from the hatchery itself, and from the location where the hatchery channel and historical channel diverge (Figure 1). S2 is located at the point of divergence of the two channels, and at the upstream end of the historical channel. S5 is located near the downstream end of the historical channel, approximately one river mile from S2.

LNFH Water Intake Structure

LNFH shares a point of diversion with Cascade Orchard Irrigation Company (Cascade) on Icicle Creek at RM 4.5 (Figure 1). LNFH maintains and operates the intake diversion dam and its associated intake structures. Cascade has a 1905 water right for 12.4 cfs during the irrigation season (approximately May 1 through October 1) and LNFH holds a 1942 water right to divert 42 cfs all year long.

LNFH's intake facilities are comprised of several components. Primary to the water intake system is a low rubble masonry diversion dam with a concrete spillway crest across Icicle Creek. The dam impounds and raises water surface elevations several feet allowing a portion of the streamflow to be diverted both into a pool and weir fish ladder with water control structure and through a trash rack (six inch bar spacing) and into a concrete water conveyance channel (Figure 3). Water which enters the conveyance channel is transported down gradient into a 33-inch-diameter buried pipeline. Approximately 1,260 feet down gradient from the beginning of the pipe system is a bifurcation that allows water to flow into Cascade's delivery system. A maximum of 42 cfs of river water that does not enter Cascade's water delivery system is transported through a 31-inch-diameter buried pipeline approximately 5,200 feet to a sand settling basin at the hatchery, through fish screens, and then to the rearing units. When rearing units are cleaned, effluent is discharged through the pollution abatement pond.

Figure 3. LNFH intake structure located on Icicle Creek at RM 4.5. Left image is looking downstream at the fish ladder and the right image is of the low head dam with the ladder visible in the lower left. The location of the water conveyance channel is not depicted in the figure but it is located to the right and just downstream of the ladder when looking upstream.

Passage Assessment

The primary focus of the upstream passage assessment for the intake structure was conditions associated with the pool and weir fish ladder. For the downstream fish passage assessment, there are three possible routes of passage. The first route is over the diversion dam itself. This is the likely route of passage at higher streamflows. The second route of passage is downstream, through the fish ladder. The third route of passage is through the trash rack, into the concrete conveyance channel, and through the pipeline, into either the Cascade water delivery system, which is unlikely due to the bifurcation configuration, or into the hatchery settling basin.

Structure 2

S2 is a concrete water control structure with two steel radial gates located at RM 3.8 in Icicle Creek (Figure 4). It was designed to control flow into the historical channel, and a hatchery channel was built to bypass excess Icicle Creek streamflow. The hatchery channel parallels the historical channel until both channels reconnect downstream from S5 at RM 2.8. In recent times, the gates at S2 have been fully opened most of the year. The few exceptions are discussed below.

Figure 4. LNFH Structure 2 located on Icicle Creek at RM 3.8. Image is looking upstream at one of two spill bays with the spill gate open.

Structure 2 Operations

S2 operations are described in the "Biological Assessment for the Operation and Maintenance of Leavenworth National Fish Hatchery" (FWS 2011a) on species that are federally protected under the Endangered Species Act of 1973 (ESA), as amended, and in the "Biological Opinion for the Operations and Maintenance of the Leavenworth National Fish Hatchery" (FWS 2011b) on effects to the threatened bull trout (*Salvelinus confluentus)* and its designated critical habitat. NOAA-Fisheries also requires S2 to remain open for the first two weeks in March for potential upstream passage for ESA-listed Upper Columbia River steelhead. Operations described in the Biological Assessment and Biological Opinion may be conducted for the various purposes described below. The specific operations, resulting streamflows, and time periods described in the Biological Assessment and Biological Opinion will be included in the conditions that are evaluated for this passage assessment.

Broodstock Collection/Tribal Fishing

Adjustments at S2 can occur between mid-May and late June (FWS 2011b) when hatchery origin spring Chinook salmon return to Icicle Creek and to the hatchery. Much of the Icicle Creek streamflow could be directed into the hatchery channel during this time period by partially lowering the radial gates. With the gates open at S2, increased flows through the historical channel may decrease attraction capabilities of the hatchery fish ladder and attract spring Chinook salmon up the historical channel. Adjustments to the radial gates at S2 that result in increased flows in the hatchery channel during the broodstock collection time period may also provide tribal fishing opportunities to members of the Yakama Nation and Wenatchee Band of the Colville Confederated Tribes. Recently, when no adjustments were made at S2, no significant straying of spring Chinook salmon into the historical channel was observed, and no noticeable loss of fishing opportunities was observed. Currently, the Service coordinates with the Washington Department of Fish and Wildlife, NOAA Fisheries, the Yakama Nation, and the

Colville Confederated Tribes on the timing of the adjustments to S2 for broodstock collection and tribal fishing.

Smolt Emigration

Recently, during the mid to late April fish release period, the S2 gates have been open, and all Icicle Creek streamflow has gone through the historical channel. This resulted in delayed emigration of fish released from the hatchery and was a cause of some concern. To assist in the emigration and outmigration of these fish if needed, the S2 gates may be partially closed to direct some of the flow through the hatchery channel. This has been effective in stimulating emigration in the past, and when conducted, the operation typically lasts for a few days in late April or early May. Although the radial gates at S2 can be partially closed to assist emigration of smolts if needed, other strategies have been developed that have reduced or eliminated the need to make this adjustment.

Aquifer Recharge

S2 controls the distribution of flow between the historical and hatchery channels. When the gates are open during higher streamflows, water flows into both the historical and hatchery channels, but at lower flows, most of the water flows into the historical channel as a result of the elevation difference between the head ends of the two channels. Water in the hatchery channel affects the recharge of the shallow aquifer in hydraulic continuity with it. Observations by hatchery staff and others over last 20 years suggest the hatchery channel recharges the shallow alluvial aquifer of the Icicle Creek floodplain in and around the hatchery property (GeoEngineers 1995). Preventing water from flowing into the hatchery channel reduces this recharge, and causes water levels in the hatchery production wells to drop, thus reducing the pumping capacity of the wells.

Since S2 gates must be adjusted to direct water into the hatchery channel to recharge the aquifer, the gates have not been closed more than two weeks at one time in order to maintain flows in the historical channel. However, hatchery staff have found that more than two weeks are required to significantly influence recharge.

High Flow Events

Floods and/or high streamflow events in Icicle Creek usually occur in the spring and fall and can also occur in winter with a rain on snow event (FWS 2011a). High discharge events generally last less than two weeks. To reduce potential flood damage to downstream infrastructure, the radial gates at S2 may be lowered when water levels approach within one foot of the bottom of the bridge deck at S5 or when excessive amounts of debris accumulate on S2 or S5.

Maintenance of Structure 5

Large wood and debris can accumulate on the upstream side of S5 and may need to be removed. If necessary, S2 can be operated to control streamflow into the historical channel to allow for the removal of debris and ensure worker safety (FWS 2011a). When there is a need for this activity, it would likely occur during high streamflow conditions and would last less than one week. This activity has occurred once or twice a year in the past, however, LNFH expects the frequency of this activity to increase as the extent of time S2 is opened increases (FWS 2011a).

Passage Assessment

The focus of the upstream passage assessment for S2 was the range of hydraulic conditions that occur as a function of streamflows through the structure with the radial gates both open, and with the gates adjusted at a range of settings. Conditions in the entry pool just downstream from the structure were also assessed. For the downstream fish passage assessment, the primary factor was the range of physical depths of water through the structure associated with various streamflows and gate settings. It was assumed that with the gate open, there will be no downstream passage impediments.

Structure 5

S5 is located near the downstream end of the historical channel at RM 2.9 and functions as a specialized bridge with a foundation to support racks or pickets, dam boards, and/or fish traps (Figure 5). The hatchery channel reconnects with the historical channel approximately 0.1 RM downstream from S5. Currently, racks or pickets, dam boards, and/or fish traps are removed from S5 most of the year except as discussed below. This management strategy can impact the Service's ability to meet some of the operational needs of the hatchery such as broodstock collection.

Figure 5. LNFH Structure 5 located on Icicle Creek at RM 2.9. Top left image shows the upstream side of Structure 5 with debris accumulation, top right image shows downstream side of Structure 5 with staff gage on far concrete wall, and bottom image is looking upstream at Structure 5.

Broodstock Collection/Tribal Fishing

Racks or pickets, dam boards, and/or fish traps can be installed at S5 from mid-May through late June to manage upstream fish passage when hatchery origin spring Chinook salmon return to Icicle Creek and to the hatchery. This configuration facilitates brood stock collection at the hatchery by preventing spring Chinook from moving into the historical channel. This action can also improve fishing opportunities for members of the Yakama Nation and Wenatchee Band of the Colville Confederated Tribes by maintaining the fish in the only accessible area, downstream, near the confluence of the hatchery and historical channels. Currently, the Service coordinates with the Washington Department of Fish and Wildlife, NOAA Fisheries, the Yakama Nation, and the Colville Confederated Tribes on the timing of installations at S5 for broodstock collection and tribal fishing.

Passage Assessment

The assessment of upstream and downstream passage at Structure 5 without racks or pickets, dam boards, and/or fish traps consisted of an evaluation of hydraulic conditions associated with open channel flow using the bathymetry associated with the foundation to support the racks, etc. The assessment of upstream and downstream passage with the racks, etc. installed required an evaluation of the modified conditions present as a result of these structures to determine if the conditions produce depth, velocity, and/or width (e.g. between pickets) limitations to fish passage.

Methods

Fish Passage Assessment Methods

Both upstream and downstream passage assessments were conducted for the expected range of streamflows that may occur based on the period of record at USGS Gage #12458000. Lifestage periodicity (Table 1) determined the specific months and the corresponding streamflows that were relevant for each of the species/lifestages. Both empirical data and modeling were used to describe the physical and hydraulic conditions at S2 and S5 over the range of expected streamflows. Conditions at the intake structure and fishway were assessed with empirical data and observations. Open channel fish passage through the historical channel was assessed using the results of hydrodynamic modeling conducted for the Icicle Creek Instream Flow and Fish Habitat Analysis for the Leavenworth National Fish Hatchery (Skalicky et al. 2013). Fish passage criteria were developed from an extensive literature survey and compiled for passage depths, passage velocities, and fishway criteria. Following is a description of the detailed methods used to characterize conditions at each site, and the passage and fishway criteria used to evaluate those conditions.

Structure 2

Passage conditions at the water control S2 consist of depths and velocities over the structure (broad-crested weir) with the double radial gates open, or with the radial gates adjusted to various degrees. The following process was used to relate measured/monitored water surface elevations to Icicle Creek discharge through S2, and to calculate the depths and velocities on the weir at S2 for each of the discharges. Equations developed by Sverdrup (2000) were used to estimate discharge through the structure. The discharge equation for EACH radial gate opening when the gates are open and completely out of the flow path is:

$$Q = C * W * H^{1.5} \quad \text{Equation 1}$$

Where:
Q = discharge in cubic feet per second (cfs)
C = discharge coefficient (2.8 based on field verification)
H = height of water surface above structure base (ft)
W = width of opening (16 ft)

Since there are two gate openings, Equation 1 was multiplied by two to determine total discharge. Height of the water surface, *H*, was measured upstream from the weir for the calculation of discharge in the previous equation. Critical depth (h_c), or depth on the weir itself was the condition required for the passage evaluation. Figure 6 shows the relative locations of *H* and h_c. Equation 2 was used to determine critical depth (h_c) on the weir for each discharge:

$$h_c = ((Q/W)^2/g)^{0.333} \quad \text{Equation 2}$$

Where:
h_c = critical depth (ft)
Q = discharge in cubic feet per second (cfs)
W = width of opening (16 ft)
g = acceleration due to gravity (32.2 ft/s^2)

The critical velocity (v_c) on the weir was then calculated using Equation 3:

$$v_c = Q/(h_c W) \quad \text{Equation 3}$$

Where:
v_c = critical velocity (ft/s)
Q = discharge in cubic feet per second (cfs)
h_c = critical depth (ft)
W = width of opening (16 ft)

Equations 1, 2, and 3 were used to calculate discharge for a range of measured *H* values, and the corresponding average critical depth and critical velocity for each discharge. Equation 1 was verified by field measurements conducted by FWS hydrology staff (FWS 2012). One set of empirical depths and velocities was collected on the weir itself at a relatively low flow of approximately 150 cfs for comparison to calculated critical depths and velocities.

Equation 4 was used to calculate the discharge when the radial gates are lowered and in contact with the water surface. Both gates are lowered simultaneously, resulting in identical dimensions for each gate opening.

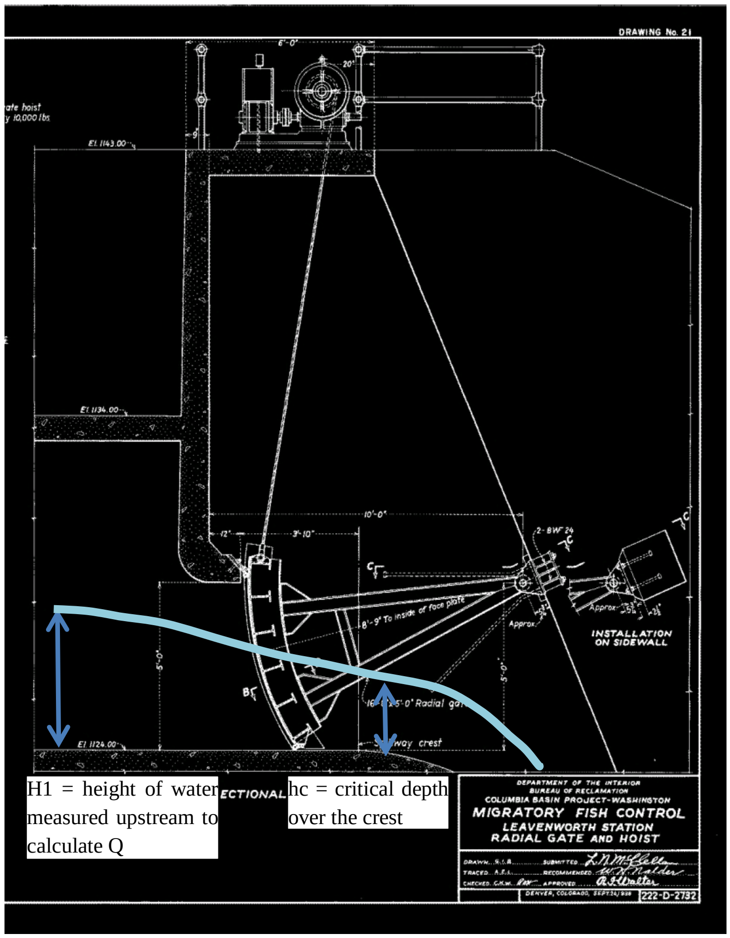

Figure 6. Relative locations of *H* and h_c on the weir at S2. (Drawing courtesy of Mary Lindenberg, FWS)

The discharge equation for EACH radial gate when the gate is within the flow path is:

$$Q = B * C * W * \sqrt{(2 * g) * H} \quad \text{............ Equation 4}$$

Where:
- Q = discharge (cfs)
- C = coefficient (0.5 based on field verification)
- H = height of water surface above structure base (ft)
- W = width of opening (16 ft)
- B = depth of opening under the radial gate (ft)
- g = acceleration due to gravity (32.2 ft/s^2)

Since there are two gate openings, Equation 4 was multiplied by two to determine total discharge. Height of the water surface, *H*, was measured upstream from the weir for the calculation of discharge in Equation 4. Figure 6 shows the location of *H* relative to the radial gate opening. Critical depth, or depth on the weir itself was the condition required for the passage evaluation. In this case, since the radial gates are in contact with the water surface over the weir, *B* from Equation 4 above set the critical depth on the weir.

The critical velocity (v_c) on the weir was then calculated using Equation 5:

$v_c = Q/(B*W)$ .... Equation 5

Where: v_c = critical velocity (ft/s)
Q = discharge in cubic feet per second (cfs)
B = depth of opening under the radial gate (ft)
W = width of opening (16 ft)

Equations 4 and 5 were used to calculate discharge for a range of measured *H* values and *B* values, and the corresponding critical depth (*B*) and critical velocity (v_c) for each discharge. Equation 4 was verified by field measurements conducted by FWS hydrology staff (FWS 2012).

A stage recorder was installed by FWS hydrology staff to collect and record continuous hydraulic head (*H*) data at the site to develop a rating curve, and to provide *H* values for the equations above. This rating curve was then used to calculate a hydrograph for the historical channel with the radial gates open.

Width and length of the pool just downstream of S2 were measured at several streamflows. Turbulence conditions in the pool at higher discharges were such that the water surface elevation was variable and surging, and depth measurements were not possible. A low flow depth was measured when the water surface was relatively flat and turbulence was reduced.

These calculated physical and hydraulic conditions associated with the range of Icicle Creek streamflows between the 10% and 90% exceedance flow levels during the relevant months for each species and lifestage were compared to passage criteria to evaluate passage conditions at S2.

Structure 5

Depths and velocities over the foundations at S5 represent the potential limiting passage conditions at this site without pickets installed. Depths, velocities, and water surface elevations were measured on the foundation sills just upstream and downstream from S5 at three streamflows. The elevations of the sills were also surveyed for calculation of depths from modeled water surface elevations. The water surface elevation and discharge data were used to build a rating curve for each foundation. The rating curve was then used to determine water surface elevations for a range of discharges to identify the discharges associated with depth and velocity passage criteria for each species and lifestage.

When pickets are installed at the site, conditions will be modified, and an additional factor was the width of the openings through the pickets. Widths of these openings limit passage based on the physical size of any particular species or lifestage. Since pickets are not installed during low flow time periods, passage depths were not expected to be limiting. We used a modified width based on the dimensions of the pickets and the reduced cross sectional area to re-calculate the average velocity for a range of discharges.

The calculated physical and hydraulic conditions associated with the range of Icicle Creek streamflows between the 10% and 90% exceedance flow levels during the relevant months for each species and lifestage were compared to passage criteria to evaluate passage conditions at S5.

LNFH Water Intake Structure

The primary passage issues at the LNFH intake are the suitability of the pool and weir fishway for upstream passage, passage over the dam itself, and downstream passage routes.

The purpose of the fishway at the LNFH diversion dam is to allow upstream passage around the approximately six foot tall, low head diversion dam that supplies water to the hatchery. Among the factors that were assessed are the fishway entrance location, attraction flows, transportation channels/pools, weirs between the pools to control hydraulic drop, and an exit at the top. Specific data collected included depths, widths, velocities, hydraulic drop between the fish ladder pools, weir crest depth and velocity, and sediment deposition within fishway pools.

Flow patterns across the tailrace downstream from the diversion dam were observed over a range of streamflows and described on drawings of the dam/tailrace area to depict the most likely routes of passage used by upstream migrants. These flow patterns were useful for evaluating the location of the entrance to the fishway and provided insight into where passage over the dam at higher flows might take place.

For the downstream passage assessment, there are three routes of passage; over the diversion dam, through the fish ladder, and into the diversion conveyance system. At higher flows the assumption is that relatively more migrants will pass over the diversion dam, and at lower flows, relatively more migrants will be diverted into the diversion conveyance system. Since no modeling was planned for the intake structure site, we collected empirical data at the diversion dam to evaluate the physical depth of water over the dam to determine if/when the primary downstream passage route shifted from the diversion dam to the diversion conveyance system.

These physical and hydraulic conditions were compared to passage criteria for each relevant species/lifestage to determine if/when passage is restricted for the various routes.

Open Channel Fish Passage

We compiled depth grids from the GIS that were produced from the hydrodynamic modeling conducted for the Icicle Creek Instream Flow and Fish Habitat Analysis for the Leavenworth National Fish Hatchery (Skalicky et al. 2013) to determine the relationship between streamflow and the depth passage criteria in the Icicle Creek historical channel. We reviewed the grids for each streamflow with respect to minimum passage depths of 0.4, 0.5, 0.6, 0.8, and 1.0 feet to determine the lower flow that did not satisfy criteria, and the next higher flow that did satisfy criteria. Although 0.4 and 0.6 feet were not included in the minimum passage criteria used for this assessment, we included them in the results to provide continuity in how passage conditions change in the historical channel across the range of lower streamflows.

Fish Passage Criteria

Eight fish species were proposed for passage evaluation in Icicle Creek. These species include bull trout, steelhead/rainbow trout, coho salmon, summer Chinook salmon, spring Chinook salmon, mountain whitefish, suckers *spp*., and Pacific lamprey. These species along with their known periodicity and the relevant lifestage are depicted in Table 1. Shaded boxes depict species periodicity for the corresponding use.

Table 1. Proposed fish species and relevant lifestages with corresponding periodicity for fish passage evaluation.

		USE		Proposed Monthly Periodicity											
Species	Life-Stage	Migration	Spawning	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Bull Trout	Adult/Subadult	■					■	■	■	■	■	■	■	■	■
	Adult/Subadult Rearing			■	■	■	■	■	■	■	■	■	■	■	■
Steelhead and Rainbow Trout	Adult	■		■	■	■	■	■	■	■	■	■	■	■	■
			■				■	■	■						
	Juvenile Rearing			■	■	■	■	■	■	■	■	■	■	■	■
Coho	Adult	■										■	■	■	■
			■									■	■	■	■
	Juvenile Rearing			■	■	■	■	■	■	■	■	■	■	■	■
Summer Chinook	Adult	■									■	■	■		
			■									■	■		
	Juvenile Rearing			■	■	■	■	■	■	■	■	■	■	■	■
Spring Chinook	Adult	■						■	■	■					
			■							■	■	■			
	Juvenile Rearing			■	■	■	■	■	■	■	■	■	■	■	■
Mountain Whitefish	Adult	■						■	■	■					
			■							■	■	■			
	Juvenile Rearing			■	■	■	■	■	■	■	■	■	■	■	■
Sucker Spp.	Adult	■						■	■	■					
			■							■	■	■			
	Juvenile Rearing			■	■	■	■	■	■	■	■	■	■	■	■
Pacific Lamprey	Adult	■							■	■	■	■	■		
			■				■	■	■						
Westslope Cutthroat Trout	Adult	■		■	■	■	■	■	■	■	■	■	■	■	■
			■					■	■						
	Juvenile Rearing			■	■	■	■	■	■	■	■	■	■	■	■

Fish passage criteria for these target species were reviewed from multiple sources and compiled into tables consisting of passage minimum depths, passage maximum velocities, and fishway criteria. Criteria were not identified for several of the target species. When this occurred, criteria for a related species were used as described below.

Depth Passage Criteria

Minimum depth criteria were identified from seven literature sources as indicated in Table 2.

Table 2. Minimum depth passage criteria considered and used for the passage evaluation.

Criteria Source	Adult Trout (ft)	Juvenile Salmonids (ft)	Steelhead (ft)	Coho (ft)	Chinook (ft)	Sucker Spp. (ft)	Pacific lamprey (ft)
Hotchkiss and Frei 2007-Washington	0.8		1.0	1.0	1.0		
Hotchkiss and Frei 2007-California	0.67	0.5 Upstream	1.0	1.0	1.0		
Hotchkiss and Frei 2007-Oregon	0.67 Fluvial		1.0	0.83	1.0		
Everest et al. 1985-Oregon/Washington			0.79	0.59	0.79		
Bates et al. 2003-Washington culverts	0.8		1.0	1.0	1.0		
ODFW 2006		0.33 Downstream				1.0 Fishways	
ODFW 2004-culverts	0.8 Fluvial 0.67 resident		1.0		1.0		
California 2002-culverts	0.67	0.5	1.0	1.0	1.0		
Thompson 1972	0.6 Fluvial 0.4 resident		0.6	0.6	0.8		
Criteria used for the LNFH passage evaluation	**Resident 0.5 Fluvial 0.8**	**0.5 upstream 0.33 downstream**	**1.0**	**1.0**	**1.0**	**0.5**	**0.5**

Depth criteria for culverts were included in this review. These criteria were judged to be appropriate for passage through open channel areas as well as passage over S2 and S5. Criteria that were not developed for culverts were based on data and observations from open channel situations or from the literature. Species-specific depth criteria were not identified for all of the individual species. We opted to use a depth criteria of 1.0 feet for salmon and steelhead. The only criteria identified for suckers (*Catostomus* spp., *Chasmistes* spp. – ODFW 2006) were associated with fishways. We included suckers with Pacific lamprey, resident trout, and juvenile salmonids in the group with a depth criteria of 0.5 feet. The adult trout criteria were used to evaluate conditions for subadult bull trout, rainbow trout, Westslope cutthroat trout, and mountain whitefish. Since no depth criteria for Pacific lamprey were identified, we used resident trout depth criteria as a reasonable condition for lamprey passage. The depth criteria for fluvial bull trout was set to 0.8 feet. Minimum water depth criteria are typically intended to provide sufficient depth to fully accommodate the body size of the fish for generation of maximum thrust and to prevent contact with the river bottom. Minimum depth values are assumed to accommodate the range of body sizes within each species or category along with some additional depth to fully submerge the fish without interacting with the river bottom.

<u>Velocity Passage Criteria</u>

Maximum velocity criteria were identified from seven literature sources as indicated in Table 3.

Table 3. Maximum velocity passage criteria considered and used for the passage evaluation.

Criteria Source	**Adult trout (ft/s)**	**Juvenile trout (ft/s)**	**Steelhead (ft/s)**	**Coho (ft/s)**	**Chinook (ft/s)**	**Sucker Spp. (ft/s)**	**Pacific Lamprey (ft/s)**	**Mtn. whitefish (ft/s)**
Haro et al. 2004; white sucker						9.8-11.5		
ODFW 2006						4.0 fishways	<8.0 fishways	
ODFW 2004-culverts	4.0		6.0	6.0	6.0			
California 2002-culverts	4.0	1.0	6.0	6.0	6.0			
Bates et al. 2003-Washington culverts (10-60 ft)	4.0		6.0	6.0	6.0			
Thompson 1972	Fluvial 8.0 Resident 4.0		8.0	8.0	8.0			
Bell 1991								2.9 average sustained
Criteria used for the LNFH passage evaluation	**Fluvial 8.0 Resident 4.0**	**1.0**	**8.0**	**8.0**	**8.0**	**4.0**	**4.0**	**2.9**

Velocity criteria for culverts were included in this review. These criteria were judged to be appropriate for passage through open channel areas as well as passage over S2 and S5. Criteria that were not developed for culverts were based on data and observations from open channel situations, experimentation (Haro et al. 2004; white sucker), or from the literature. Species-specific velocity criteria were not identified for all of the individual species. The adult trout criteria were used to evaluate conditions for subadult bull trout, rainbow trout, and Westslope cutthroat trout. The fluvial trout criteria were used for fluvial adult bull trout. A criteria of 8 ft/s was used for salmon, steelhead, and fluvial bull trout. Mountain whitefish criteria were calculated as the average velocity from the sustained velocity range identified by Bell (1991). The sustained velocity range represents the condition that can be maintained from a few minutes up to several hours.

The only velocity criteria identified for Pacific lamprey (ODFW 2006) suggested that fishway conditions approaching 8.0 ft/s were appropriate. Research on lamprey passage at the mainstem Columbia River dam fishways has documented efficient lamprey passage through the fishway weir orifices at velocities of 8.0 ft/s (Moser et al. 2005). Video monitoring of lamprey passage in the McNary Dam Oregon shore fishway (USACE 2011) also documented lamprey attaining a burst speed of at least 8.0 ft/s to pass through the orifices to reach a hold on the upstream side. Keefer et al. (2012) observed lamprey using attach and burst behaviors to pass through the 1-2 foot length associated with the orifice velocity condition (8 ft/s). These situations reflect the burst speed that lamprey are capable of attaining. A maximum velocity of 4.0 ft/s has been discussed as a more appropriate condition that can be sustained by lamprey in the mainstem Columbia fishways. In addition, Mesa et al. (2003) found that velocities greater than 5 – 6 ft/s were difficult to negotiate and swim through for adult Pacific lamprey. As a result, we used 4.0 ft/s as the criteria for this passage evaluation.

These maximum water velocity criteria are conservative, and they are intended to accommodate passage for the range of fish sizes and associated swimming capabilities within each species or category.

Fishway Criteria

Fishway criteria were identified from six literature sources as indicated in Table 4.

Table 4. Fishway criteria considered and used for the passage evaluation.

Criteria Source	Entrance Head Differential (ft)	Entrance Depth (ft)	Entrance velocity (ft/s)	Transport channel velocity (ft/s)	Pool head differential (ft)	Weir Depth (ft)	Weir velocity-nappe (ft/s)
Bell 1991			4.0-8.0	1.0-2.0		1.0 adults; 0.5 juveniles	8.0
Clay 1995		1.6-4.0	4.0-8.0		1.0		8.0
NMFS 2011	1.0-1.5 adults; 0.13-0.33 juveniles	6.0		1.5-4.0	1.0 adults; 0.7-1.0 juveniles	1.0	1.5-4.5 juveniles
ODFW 2006				1.0-2.0	1.0 Salmon, steelhead; 0.5 other species	1.0 adults; 0.5 juveniles	8.0
ODFW 2004					1.0 Salmon, steelhead; 0.5 other species		
WDFW 2000	1.0-1.5 (1.2) Streaming flow-adults			1.0-4.0 (2.0)	1.0 Salmon, trout; 0.25 grayling	1.0 normal; 0.25 leaping fish	
Criteria used for the LNFH fishway evaluation	**1.0-1.5 (1.2) Streaming flow-adults 0.13-0.33 juveniles**	**1.6-6.0**	**4.0-8.0**	**1.0-4.0**	**1.0 Salmon, steelhead; 0.5 other species**	**1.0 adults; 0.5 subadults, juveniles**	**8.0; 1.5-4.5 juveniles**

These fishway criteria are largely a function of the standards set by Washington, Oregon, NMFS, and the U.S. Army Corps of Engineers. Charles Clay (Clay 1995) is a professional engineer with experience in fishway design in Canada and the Pacific Northwest. The purpose of the fishway at the LNFH diversion dam is to allow upstream passage around the approximately six foot tall diversion dam. The target conditions for this fishway (criteria) will be the same as the conditions for any other fishway in the Pacific Northwest, although the length required to traverse the elevation change of six feet is relatively short. The components of the LNFH diversion fishway include the entrance and attraction flows, transportation channels/ pools, weirs between the pools to control hydraulic drop, and an exit at the top. The primary factors associated with the fishway entrance are location and attraction flow. The primary factor associated with the fishway exit is the location.

Results

Structure 2

Both Radial Gates Open

Critical depths on the weir at S2 over a range of streamflows with the radial gates open are shown in Figure 7. A minimum discharge of approximately 64 cfs is required for upstream passage of resident trout (including mountain whitefish), subadult bull trout, sucker *spp*., Pacific lamprey, and juvenile salmonids, a minimum discharge of approximately 132 cfs is required for upstream passage of fluvial bull trout, and a minimum discharge of approximately 181 cfs is required for upstream passage of salmon and steelhead. The downstream passage criteria for juvenile salmonids (0.33 ft) occurs at a discharge of approximately 37 cfs.

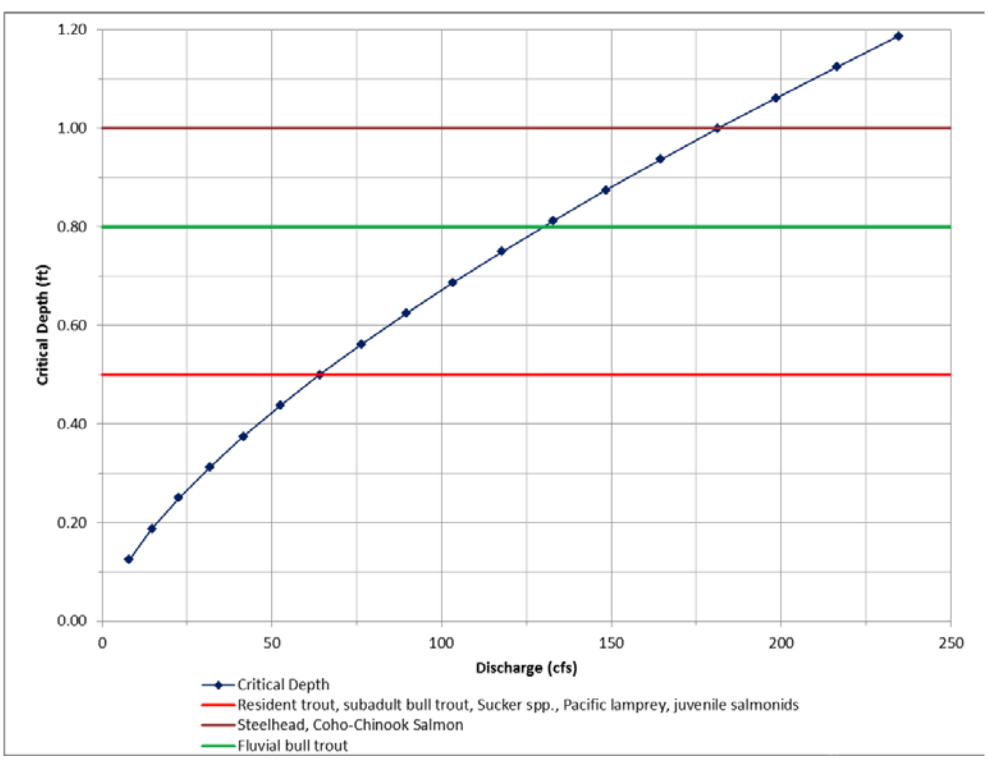

Figure 7. Relationship between discharge (cfs) and critical depth (ft) over the weir at Structure 2 with the radial gates open. Also shown are the depth passage criteria from Table 2.

Critical velocities on the weir at S2 over a range of streamflows with the radial gates open are shown in Figure 8. The lowest discharge modeled produced a critical velocity of 2.01 ft/s at a discharge of 8 cfs. Thus, upstream passage of juvenile salmonids over S2 does not appear to be possible. Mountain whitefish swimming capabilities are less robust than the other resident salmonids. The maximum velocity criteria used for mountain whitefish occurs at a discharge of approximately 23 cfs. The maximum velocity criteria of 4 ft/s used for resident trout, subadult bull trout, sucker *spp*., and Pacific lamprey occurs at a discharge of approximately 64 cfs, and the maximum velocity criteria of 8 ft/s used for salmon, steelhead, and fluvial bull trout occurs at a discharge of approximately 512 cfs.

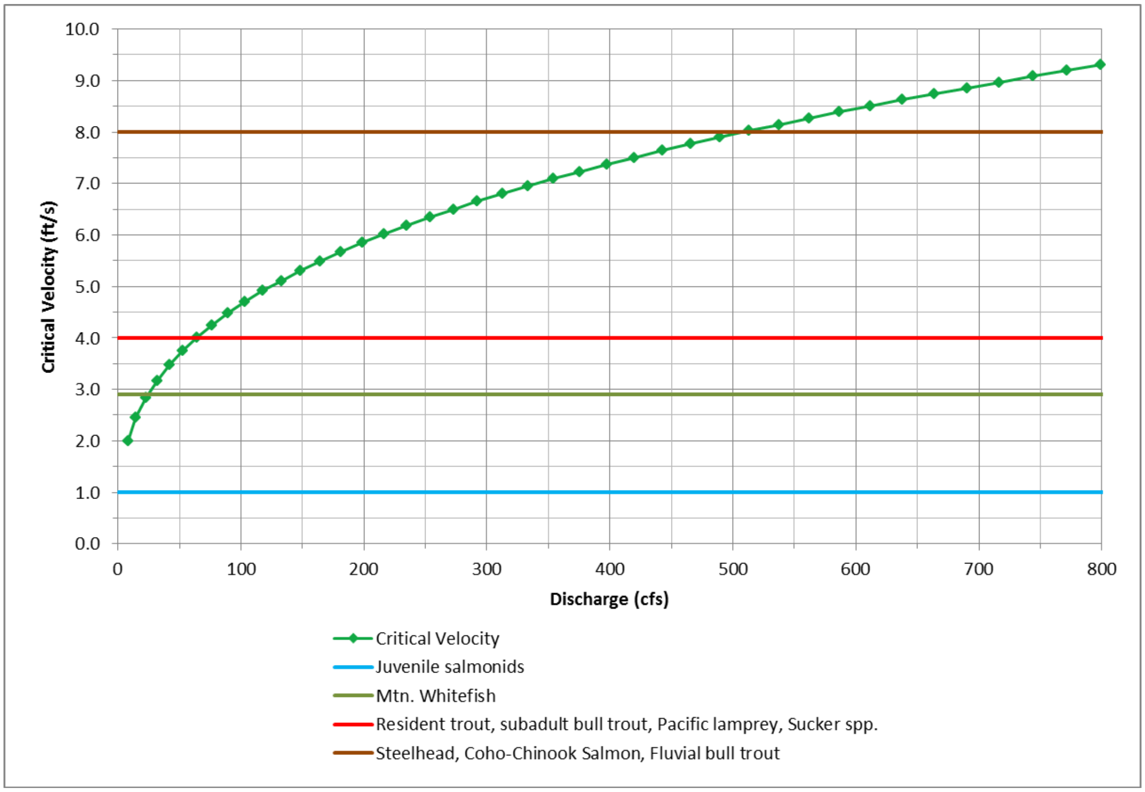

Figure 8. Relationship between discharge (cfs) and critical velocity (ft/s) over the weir at Structure 2 with the radial gates open. Also shown are the velocity passage criteria from Table 3.

We planned to measure depths and velocities on the weir at S2 for comparison to the modeled data. One set of depths and velocities was measured at a discharge of approximately 150 cfs at the locations shown in Figure 9. Conditions on the weir were hazardous, even at this relatively low flow. In addition, it was not possible to collect these data on the weir crest because of the conditions. Data were collected on the upstream surface of the weir. Measured depths at 150 cfs ranged from 0.65 – 1.00 feet, and measured velocities ranged from 4.71 – 7.01 ft/s. Icicle Creek turns right as it enters S2, resulting in an uneven distribution of depths and velocities across the weir at the locations of these measurements. In addition, the concrete on the weir appeared to be worn in a pattern that may have resulted in an uneven surface rather than the flat surface that was likely present following construction. These conditions precluded our effort to verify modeled depths and velocities.

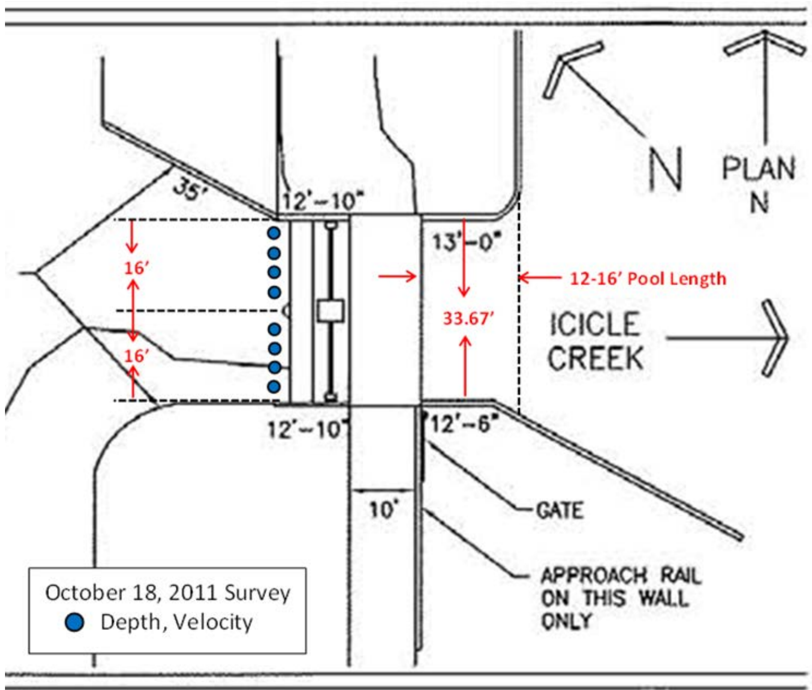

Figure 9. Plan view of S2 showing dimensions of the structure, the two 16-foot radial gate bays, the exit pool, and the location of depth and velocity measurements collected on October 18, 2011.

<u>Both Radial Gates Adjusted</u>

Depth and velocity conditions on the weir at S2 with the radial gates closed to varying degrees were a function of the incoming streamflow and water surface elevation, and the size of the gate opening. A requirement for this modeling and the associated equations was that the discharge and water surface elevation had to be higher than the gate opening so that the gates were within the flow path. In this case, the gate opening establishes the depth on the weir. The minimum gate opening we modeled was one foot, thus accommodating passage by all species. As a result, the focus of this modeling was velocity conditions on the weir. The hydraulic head (H) or water surface elevation used in Equation 4 determines the average velocity across the weir, regardless of the size of the gate opening. At a constant water surface elevation, as the gate opening is increased, both the discharge and cross-sectional area increase resulting in the same average velocity as a smaller gate opening with a lower discharge and smaller cross sectional area. Table 5 shows the relationship between water surface elevation (H) and average velocity across the weir.

With our minimum modeled gate opening of one foot, a discharge of approximately 167 cfs was the lowest flow that resulted in a water surface elevation that was higher than the gate opening (Figure 10). This resulted in an average velocity of 5.23 ft/s. Thus, with the one foot gate opening minimum, passage velocities (8.0 ft/s) were met for only steelhead, salmon, and fluvial bull trout. Velocities between 5.23 and 8.0 ft/s can occur at gate openings of 1.0, 1.5, and 2.0

feet, water surface elevations from 1.7 – 4.0 feet, and discharges up to 514 cfs (Table 5, Figure 10).

Table 5. Average velocity (V) as a function of water surface elevation (H_1) with the radial gates closed.

H_1 WSE (ft)	Average V (ft/s)	H_1 WSE (ft)	Average V (ft/s)
1.6	5.08	4.9	8.88
1.7	5.23	5	8.97
1.8	5.38	5.1	9.06
1.9	5.53	5.2	9.15
2	5.67	5.3	9.24
2.1	5.81	5.4	9.32
2.2	5.95	5.5	9.41
2.3	6.09	5.6	9.50
2.4	6.22	5.7	9.58
2.5	6.34	5.8	9.66
2.6	6.47	5.9	9.75
2.7	6.59	6	9.83
2.8	6.71	6.1	9.91
2.9	6.83	6.2	9.99
3	6.95	6.3	10.07
3.1	7.06	6.4	10.15
3.2	7.18	6.5	10.23
3.3	7.29	6.6	10.31
3.4	7.40	6.7	10.39
3.5	7.51	6.8	10.46
3.6	7.61	6.9	10.54
3.7	7.72	7	10.62
3.8	7.82	7.1	10.69
3.9	7.92	7.2	10.77
4	8.02	7.3	10.84
4.1	8.12	7.4	10.92
4.2	8.22	7.5	10.99
4.3	8.32	7.6	11.06
4.4	8.42	7.7	11.13
4.5	8.51	7.8	11.21
4.6	8.61	7.9	11.28
4.7	8.70	8	11.35
4.8	8.79		

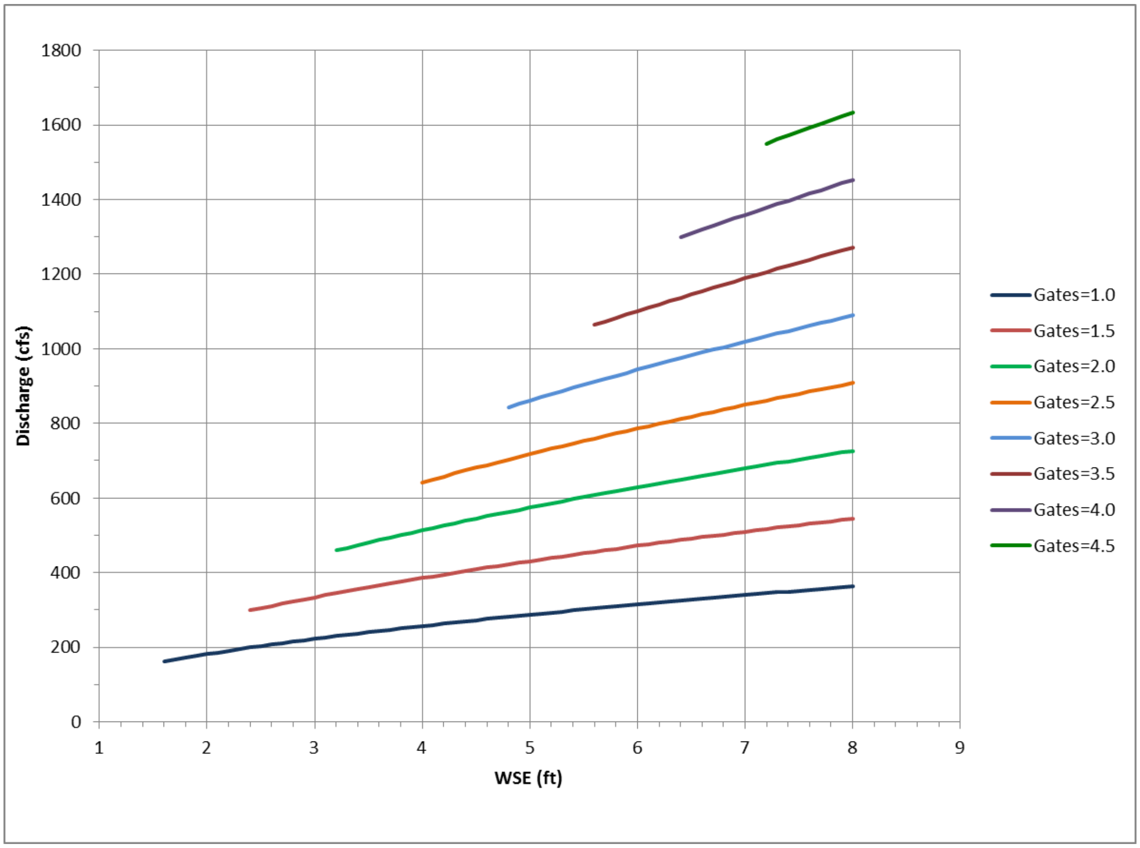

Figure 10. Relationship between water surface elevation (WSE) upstream from Structure 2 and discharge (cfs) through the two 16-ft radial gate bays at gate openings from 1.0 feet to 4.5 feet.

Downstream Pool

The pool immediately downstream from the weir at S2 was designed as a stilling basin to dissipate energy from flow over the weir. It is approximately 16 feet in length with dentate structures (Figure 11) at the downstream margin to dissipate energy and prevent scour below the structure. At high flows (Figure 12) the pool is highly turbulent and supersaturated with air. Even at low flows (Figure 13) the pool is turbulent and highly aerated. This type of condition is not conducive to efficient fish passage. Depth and velocity measurements were not possible except at the lowest flows. Depth was measured as 3.3 feet, and velocities ranged from -1.6 – 3.8 ft/s on September 17, 2012 at a flow of approximately 45 cfs.

Fish have been observed attempting to jump from this pool onto the weir to pass S2. The jumping behavior could be a response to either shallow depths on the weir, high velocities on the weir, or the turbulence in the pool below. One issue associated with this method of passage is physical injury from impacts with the steel radial gates or concrete structure. Hatchery personnel have deployed tarps in the past (Figure 14) to prevent injury to jumping fish.

Figure 11. Dentates at the downstream end of the pool below the weir at S2.

Figure 12. Downstream pool at S2 at approximately 1500 cfs on June 5, 2012.

Figure 13. Downstream pool at S2 at approximately 220 cfs on August 14, 2012.

Figure 14. Tarps deployed to protect jumping fish from impact injury on the steel radial gates or the concrete weir.

Structure 5

Surveyed elevations, depths, and velocities were measured on the upstream and downstream sill foundations of S5 as shown in Figure 15. Data were collected at streamflows of 42.6, 149, and 238 cfs. Rating curves were developed for each sill, and the WSE was determined for a range of flows including the flows required to provide depths to meet the passage criteria. The rating curve for the upstream sill is shown in Figure 16, and the rating curve for the downstream sill is shown in Figure 17. Since the flow range modeled was relatively narrow, both rating curves had linear relationships.

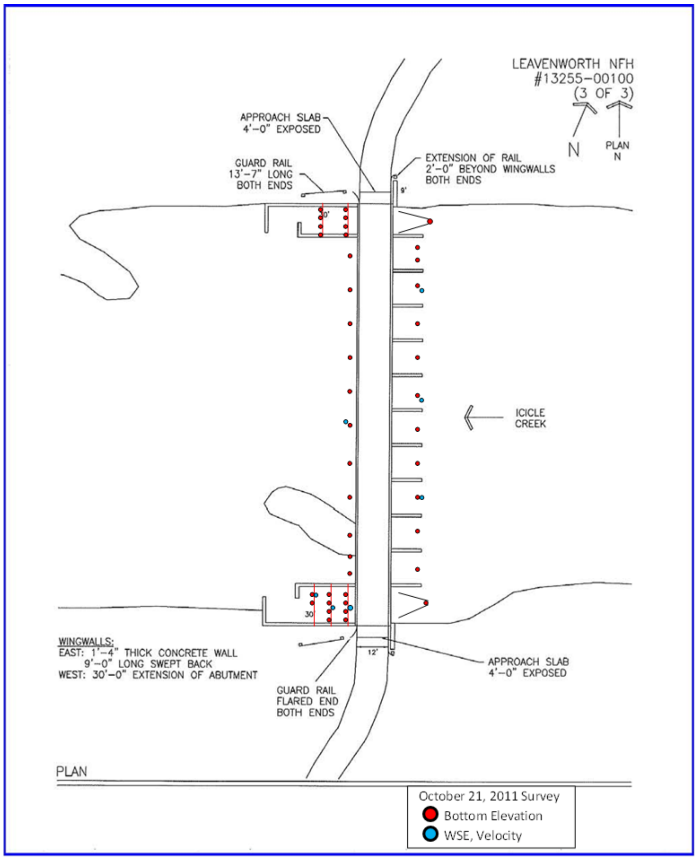

Figure 15. Plan view of Structure 5 showing locations of survey points on the upstream and downstream footings and the fish trap/fish passage structures on each river bank. Also shown are the locations of water surface elevation (WSE) points and velocity measurements

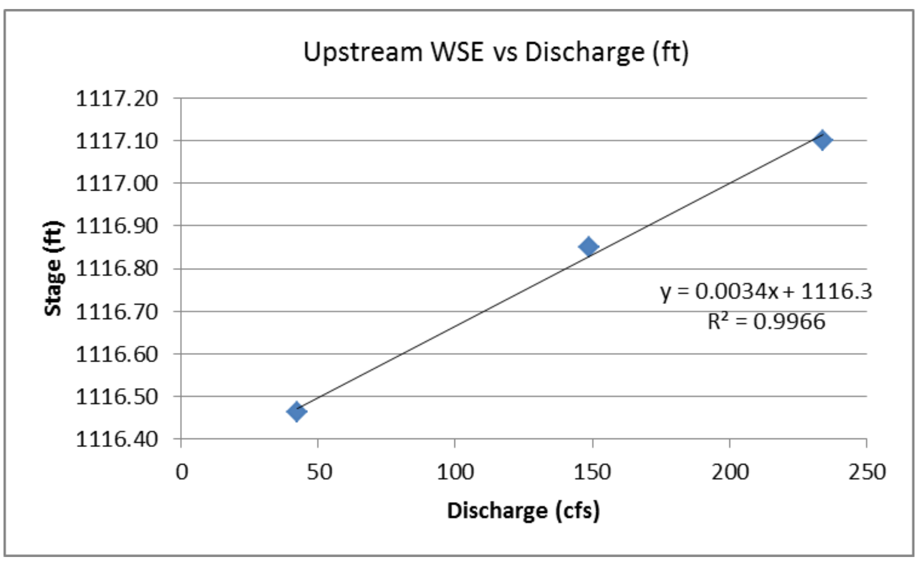

Figure 16. Rating curve for the upstream foundation sill at S5.

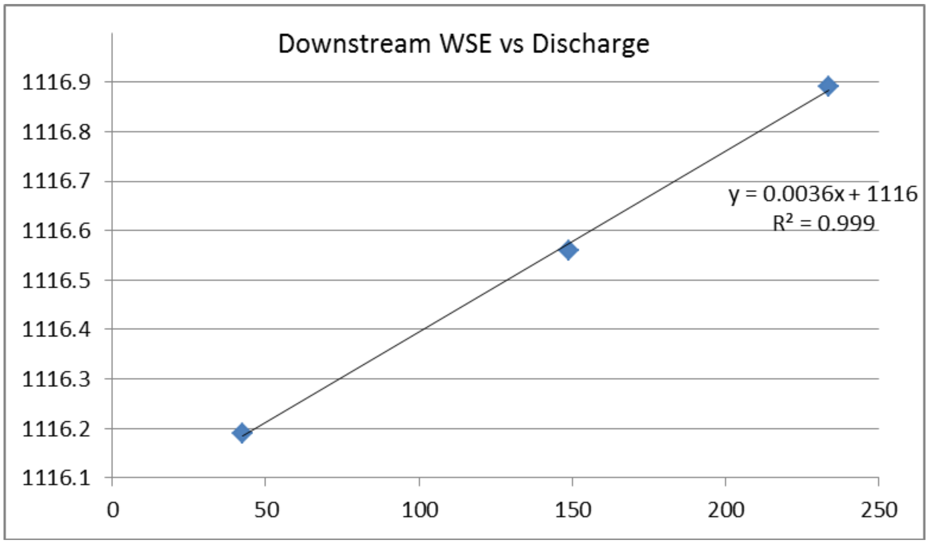

Figure 17. Rating curve for the downstream foundation sill at S5.

The streamflows and depth distribution data that resulted in average depths across the sills that met passage criteria are shown in Table 6 and Table 7. No velocity modeling was conducted, and velocities were measured at different locations at each flow to avoid the effect of debris and foundation structure components on measurements. Average velocities are shown for each flow in Table 8.

Table 6. Discharge, water surface elevation (WSE), depth distribution, and average depth for the upstream sill at Structure 5.

Discharge	95 cfs	180 cfs	250
WSE	1116.62	1116.912	1117.15
Depth	0.53	0.83	1.06
Depth	0.51	0.80	1.04
Depth	0.53	0.82	1.06
Depth	0.49	0.78	1.02
Depth	0.55	0.85	1.08
Depth	0.55	0.85	1.08
Depth	0.50	0.80	1.03
Depth	0.48	0.77	1.01
Depth	0.48	0.77	1.01
Depth	0.47	0.76	1.00
Depth	0.49	0.78	1.02
Average Depth	0.51	0.80	1.04

Table 7. Discharge, water surface elevation (WSE), depth distribution, and average depth for the downstream sill at Structure 5.

Discharge	125.00	205.00	260.00
WSE	1116.45	1116.74	1116.94
Depth	0.50	0.79	0.99
Depth	0.50	0.79	0.99
Depth	0.52	0.81	1.01
Depth	0.52	0.81	1.00
Depth	0.53	0.82	1.01
Depth	0.54	0.83	1.02
Depth	0.54	0.83	1.03
Depth	0.53	0.82	1.02
Depth	0.50	0.78	0.98
Depth	0.51	0.79	0.99
Depth	0.52	0.81	1.01
Average Depth	0.52	0.81	1.00

Table 8. Discharge and average velocity on the upstream (US) and downstream (DS) sills at Structure 5.

Discharge (cfs)	Average Velocity (ft/s)
42.6	US 1.70
	DS 1.67
149	US 1.93
	DS 2.07
238	US 2.40
	DS 2.39

Pickets may be installed during some years at S5 to control escapement of spring Chinook salmon into the historical channel. Limiting passage of other species is not the intent of this action, but is a consequence. Weirs and fish traps are installed on each bank at S5 to overcome this unintended consequence. The openings between the pickets measure 0.125 feet. The physical size of this spacing would eliminate passage of most adult fish species except possibly smaller resident trout, whitefish, suckers, and juvenile lifestages. If pickets were installed, it typically would occur between mid-May and late June when streamflows range between 1,000 and 2,000 cfs. At these flows, velocities through the pickets would likely limit passage by smaller fish species or juveniles even though the physical spaces between the pickets might not be limiting. We used modeled water surface elevation and depth data from the rating curves described above along with modified cross sectional area based on the size of the pickets to estimate velocities with the pickets installed. The graph in Figure 18 shows the estimated velocities for both conditions.

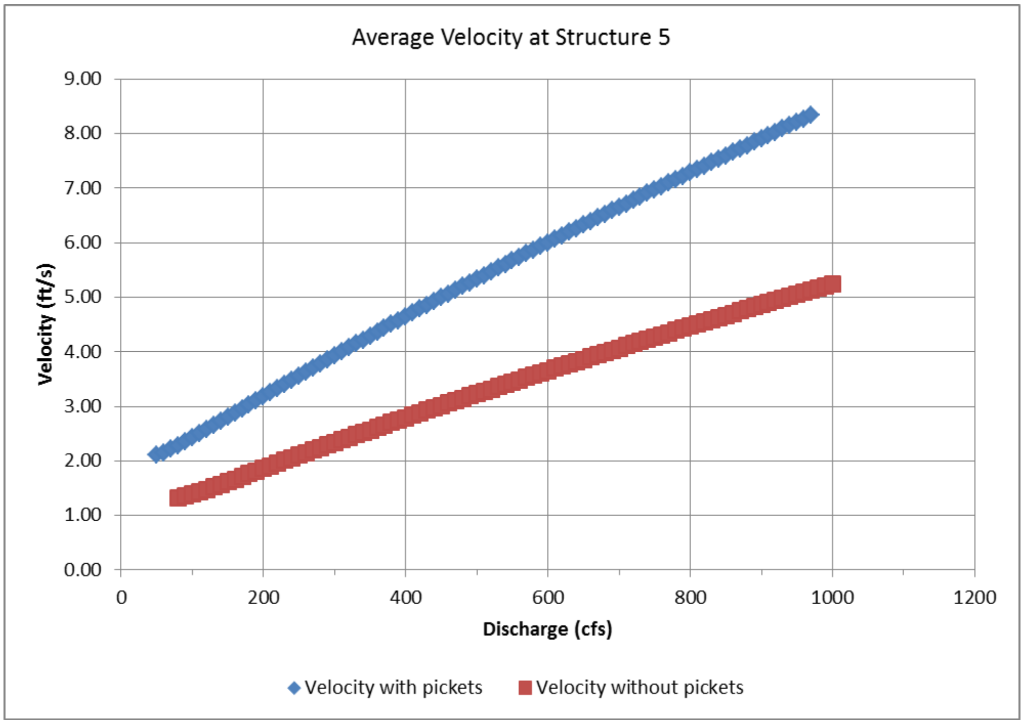

Figure 18. Average velocity at S5 with and without pickets installed.

LNFH Water Intake Structure

The primary passage issues at the LNFH intake are the suitability of the pool and weir fishway for upstream passage, passage over the dam itself, and downstream passage routes.

Pool and Weir Fishway, Diversion Dam Passage

The purpose of the fishway at the LNFH diversion dam is to allow upstream passage around the approximately six foot tall, low head diversion dam that supplies water to the hatchery and Cascade Orchards Irrigation Company. Among the factors that were assessed are the fishway entrance location, attraction flows, transportation channels/pools, weirs between the pools to control hydraulic drop, and an exit at the top. Specific data collected included depths, widths, velocities, hydraulic drop between the fishway pools, weir crest depth and velocity, and sediment deposition within fishway pools. The diagram in Figure 19 shows the weir and pool structure of the fishway that corresponds to fishway conditions shown in Table 9 and Table 10. Figure 20 shows the dimensions of the notched weir crest.

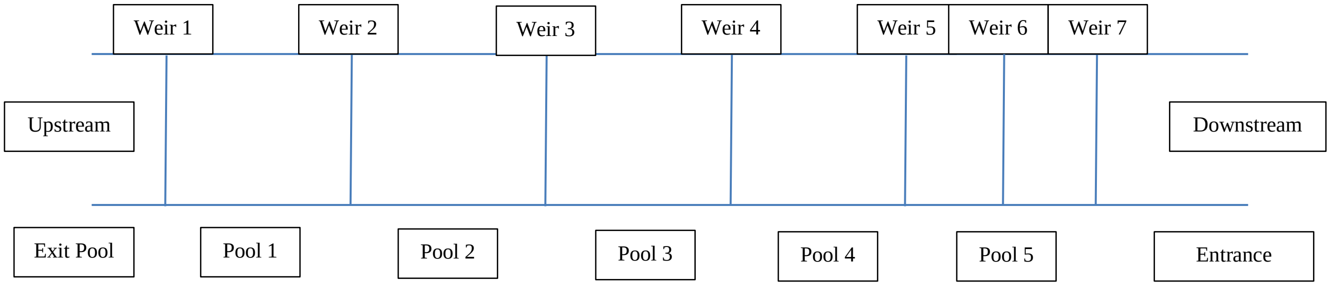

Figure 19. Diagram of the fishway at the LNFH intake.

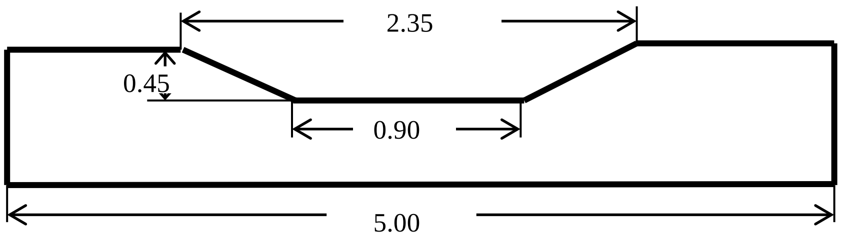

Figure 20. Weir top dimensions for the LNFH fishway weirs.

Table 9 lists the physical characteristics of the weirs and pools in the fishway as well as the entrance conditions in August 2012. Icicle Creek streamflow on August 14, 2012 was approximately 324 cfs as measured at the USGS gage #12458000. The setting for the water control structure at the top of the fishway resulted in a fishway flow of approximately 4.5 cfs.

The head differential between pools was generally within criteria for salmon and steelhead (Table 4) with the exception of weirs 1 and 3. Migration periodicity (Table 1) suggests summer Chinook, fluvial bull trout, Pacific lamprey, and adult/juvenile rainbow and cutthroat trout could be moving upstream and attempting to use the fishway during August. The criteria for head differential from Table 4 for species other than salmon and steelhead is 0.5 feet. Since both conditions cannot be met, priorities may need to be established to determine the target condition.

The passage depth over the notches in each weir averaged 0.64 feet. This depth does not meet the criteria for fluvial bull trout or summer Chinook (Table 2), or the criteria for fishway weir depth for adult salmonids (Table 4). Fishway discharge could be increased to bring weir depths up to 0.8 or 1.0 feet to meet the passage depth criteria. Weir notch velocities averaged 2.68 ft/s, and nappe velocities averaged 8.02 ft/s. Notch velocities were within the maximum velocity criteria (Table 3) for each species with the exception of juvenile salmonids. Nappe velocities were within fishway criteria (Table 4) with the exception of juvenile salmonids. Pacific lamprey may be capable of attaining the fishway velocity criteria of 8 ft/s as a burst speed, but passage over a weir for lamprey is more common via the concrete side walls (or through an orifice if one is present) than over the weir.

Pool length and depth was variable. With a fishway bottom slope of 0%, head differential between pools is controlled by subsequently shorter weir heights, thus the gradually declining average pool depth. The depth range in each pool was a function of sediment accumulation. The average velocity through the pools was 0.20 ft/s. Fishway transport channel velocity criteria were used as a reference for pool velocity conditions in this fishway. The criteria in Table 4 include a range of 1.0 – 4.0 ft/s. Velocities in the fishway pools should be slow enough to provide resting areas for migrating fish, but should also be fast enough for fish to maintain orientation and direction. Fishway discharge could be increased to produce pool velocities closer to 1.0 ft/s. Energy dissipation was not calculated for the pools because pool volume was far greater than required at a head differential of one foot and a discharge of 4.5 cfs.

Data collected downstream from the last fishway weir characterize fishway entrance conditions. These data are shown in the last three rows in the Pool table (Table 9). Head differential over the last weir into the river was at the lower end of the recommended range, but the discharge was not sufficient to produce the desired streaming flow recommended by WDFW (2000) for fish attraction. The plunging flow that was present dropped vertically over the weir and did not produce velocities with much attraction potential. In fact, 2.5 feet downstream from the entrance, the velocity was negative likely due to the recirculation from the plunging flow. The average velocity out to eight feet from the last weir was 0.63 ft/s, and the maximum was 1.42 ft/s which is much lower than the entrance velocity criteria (Table 4). This was partly a result of the low discharge through the fishway and boulders near the fishway entrance (Figure 21). , A shallow shelf can be seen in front of the fishway entrance in Figure 21, and the primary flow path for upstream migrants is towards the middle of the river, or along the opposite bank. The fishway entrance depth (average 2.41 feet) was within the fishway criteria.

Table 9. Fishway characteristics on August 14, 2012 at an estimated discharge of 4.5 cfs. Weir 6 was not installed on this date. (DS=downstream)

Weir #	Width (ft)	Head Diff. (ft)	Depth-Weir (ft)	Depth-Notch (ft)	Velocity-Notch (ft/s)	Velocity-Nappe (ft/s)
1	5	0.8	0.25	0.60	3.06	7.19
2	5	1.1	0.30	0.70	2.25	8.41
3	5	0.8	0.05	0.50	2.98	7.19
4	5	1.2	0.20	0.65	2.41	8.79
5	5	1.1	0.25	0.70	2.42	8.41
6	Not used					
7	5	1.0	0.25	0.70	2.93	8.02
Average	5	1.0	0.22	0.64	2.68	8.02

Pool #	Width (ft)	Length (ft)	Depth Range (ft)	Depth-Average (ft)	Velocity-Average (ft/s)
1	5	13.4	6.10-6.80	6.50	0.14
2	5	16.1	3.90-6.10	4.70	0.19
3	5	16.0	3.60-5.40	4.80	0.19
4	5	8.0	4.20-4.20	4.20	0.21
5	5	16.1	3.00-3.30	3.20	0.28
Entrance 2.5 ft DS	5	2.5	2.55-2.90	2.70	-0.09
Entrance 4.0 ft DS	N/A	1.5	2.35-2.45	2.42	0.57
Entrance 8.0 ft DS	N/A	4.0	N/A	2.10	1.42

Figure 21. Location of the fishway entrance with conditions shown in August 2012.

Table 10 lists the physical characteristics of the weirs and pools in the fishway as well as the entrance conditions in September 2012. Icicle Creek streamflow on September 18, 2012 was approximately 121 cfs as measured at the USGS gage #12458000. The setting for the water control structure at the top of the fishway was not changed from the August setting, but with the lower Icicle Creek discharge, the forebay elevation behind the diversion dam was lower which resulted in a fishway flow of approximately 0.75 cfs.

The head differential between pools (average 0.93 feet) was close to the criteria for salmon and steelhead (Table 4) with the exception of weir 1. Migration periodicity (Table 1) suggests summer Chinook, fluvial bull trout, Pacific lamprey, coho salmon, and adult/juvenile rainbow and cutthroat trout could be using the fishway during September. The criteria for head differential from Table 4 for species other than salmon and steelhead is 0.5 feet. Since both conditions cannot be met, priorities may need to be established to determine the target condition.

The passage depth over the notches in each weir averaged 0.34 feet. This depth does not meet the minimum depth criteria for any of the relevant species (Table 2), or the criteria for fishway weir depth for adult or juvenile salmonids (Table 4). Fishway discharge could be increased to bring weir depths up to meet the minimum passage depth criteria and fishway weir depth criteria. Weir notch velocities averaged 1.37 ft/s, and nappe velocities averaged 7.74 ft/s. Notch velocities were within the maximum velocity criteria (Table 3) for each species, and close to the criteria for juvenile salmonids. Nappe velocities were close to fishway criteria (Table 4) with the exception of juvenile salmonids. Pacific lamprey may be capable of attaining the fishway velocity criteria of 8 ft/s or the actual velocity of 7.74 ft/s as a burst speed, but passage over a weir for lamprey is more common via the concrete side walls (or through an orifice if it exits) than over the weir.

Pool length and depth was variable. The depth range in each pool was a function of sediment accumulation. The sediment did not reduce any pool depth below minimum depth criteria. The average velocity through the pools was 0.04 ft/s. Fishway transport channel velocity criteria were used as a reference for pool velocity conditions in this fishway. The criteria in Table 4 include a range of 1.0 – 4.0 ft/s. Velocities in the fishway pools should be slow enough to provide resting areas for migrating fish, but should also be fast enough for fish to maintain orientation and direction. At this fishway discharge of 0.75 cfs, the pools were essentially slack water. Fishway discharge could be increased to produce pool velocities closer to 1.0 ft/s. Energy dissipation was not calculated for the pools because pool volume was far greater than required at a head differential of one foot and a discharge of 0.75 cfs.

Data collected downstream from the last fishway weir characterize fishway entrance conditions. These data are shown in the last three rows in the Pool table (Table 10). Head differential over the last weir into the river was slightly lower than the recommended range, but the discharge was not sufficient to produce the desired streaming flow recommended by WDFW (2000) for fish attraction. The plunging flow that was present dropped vertically over the weir and did not produce velocities with much attraction potential. The average velocity out to 6.5 feet from the last weir was 0.10 ft/s, and the maximum was 0.36 ft/s. This was primarily a result of the low discharge through the fishway (Figure 22). Figure 22 shows the boulder near the fishway entrance, and the placement of the entrance on a shallow shelf with a rocky hydraulic control between the shelf and the primary flow path for upstream migrants on the opposite side of the river. The fishway entrance depth (average 1.54 feet) was close to the minimum fishway criteria.

Table 10. Fishway characteristics on September 18, 2012 at an estimated discharge of 0.75 cfs. (DS=downstream; US=upstream)

Weir #	Width (ft)	Head Diff. (ft)	Depth-Weir (ft)	Depth-Notch (ft)	Velocity-Notch (ft/s)	Velocity-Nappe (ft/s)
1	5	0.75	0	0.30	1.60	6.97
2	5	1.10	0	0.40	1.41	8.41
3	5	0.95	0	0.30	1.10	7.82
4	5	0.90	0	0.35	1.46	7.60
5	5	0.90	0	0.35	1.23	7.60
6	5	1.00	0	0.30	1.42	8.02
7	5	0.90	0	0.35	1.35	7.60
Average	5	0.93	0	0.34	1.37	7.74

Pool #	Width (ft)	Length (ft)	Depth Range (ft)	Depth-Average (ft)	Velocity-Average (ft/s)
1	5	13.4	6.05-6.75	6.39	0.02
2	5	16.1	3.80-5.40	4.54	0.03
3	5	16.0	3.50-5.10	4.60	0.03
4	5	8.0	4.55-4.55	4.55	0.03
5-US	5	8.1	3.40-3.40	3.40	0.04
5-DS	5	8.0	2.40-2.40	2.40	0.06
Entrance 2.5 ft DS	5	2.5	1.60-1.60	1.60	0.36
Entrance 4.0 ft DS	N/A	1.5	1.40-1.80	1.63	-0.17
Entrance 6.5 ft DS	N/A	2.5	1.20-1.60	1.40	0.12

Figure 22. Location of the fishway entrance with conditions shown in September 2012.

We observed conditions in the tailrace of the diversion dam and near the fishway over a range of flows from 2,663 cfs to 121 cfs, made sketches of those conditions including the primary flow paths, and collected photos as recommended by WDFW (2000). The following drawings and photos show the primary flow paths over the dam and through the tailrace along with the location of the fishway.

At the highest flow we observed (2,663 cfs) in June 2012, the entire fishway and water control structure at the top of the fishway were washed out (Figure 23). The fishway weirs had been removed to allow sediment to wash downstream. Thus, fish passage was not the objective at this flow level. The water surface elevation differential between the forebay and tailrace was estimated to be approximately 2.5 feet at this flow, likely allowing passage directly over the dam. The primary flow path for upstream migrants appeared to be on the opposite side of the river from the fishway (Figure 24).

Figure 23. Figure 20.7. LNFH diversion, fish ladder, and streamflow conditions on June 5, 2012 at a streamflow of 2,663 cfs.

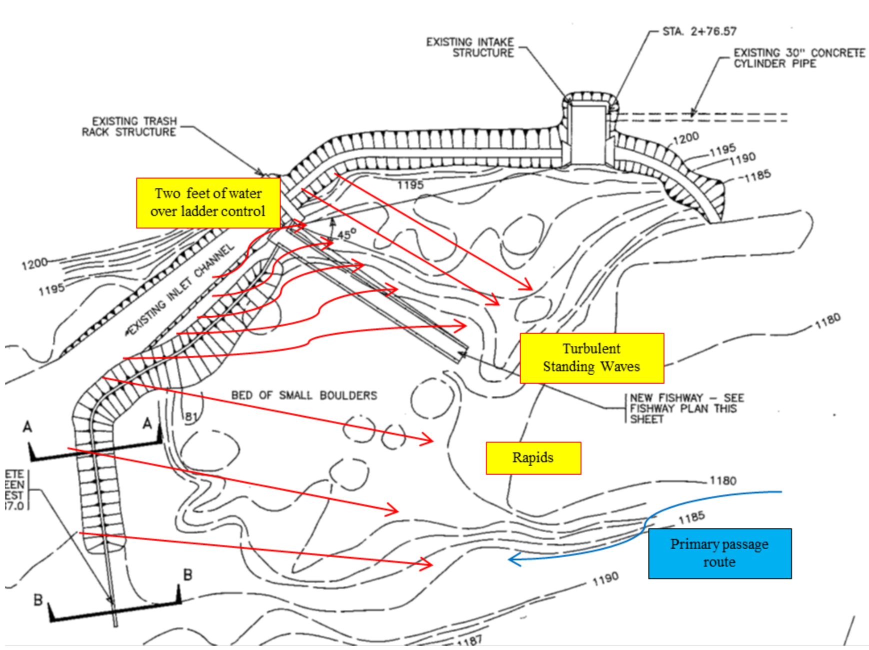

Figure 24. LNFH diversion, fish ladder, and streamflow conditions on June 5, 2012 at a streamflow of 2,663 cfs. Red arrows indicate the direction of flow over the dam, through the tailrace, and over the fish ladder (washed out). The blue arrow indicates the most likely route for upstream migrants.

The next lower flow we observed was 1,271 cfs in July 2012. At this flow, the fishway weirs were still absent, and the lower end of the fishway and water control structure at the top of the fishway were washed out (Figure 25). Thus, fish passage was not the objective at this flow level. The water surface elevation differential between the forebay and tailrace was estimated to be approximately 3.5 feet at this flow, continuing to allow passage directly over the dam. Two primary flow paths were evident for upstream migrants at this flow (Figure 26), both on the opposite side of the river, and in a thalweg roughly mid-channel.

Figure 25. LNFH diversion, fish ladder, and streamflow conditions on July 20, 2012 at a streamflow of 1,271 cfs.

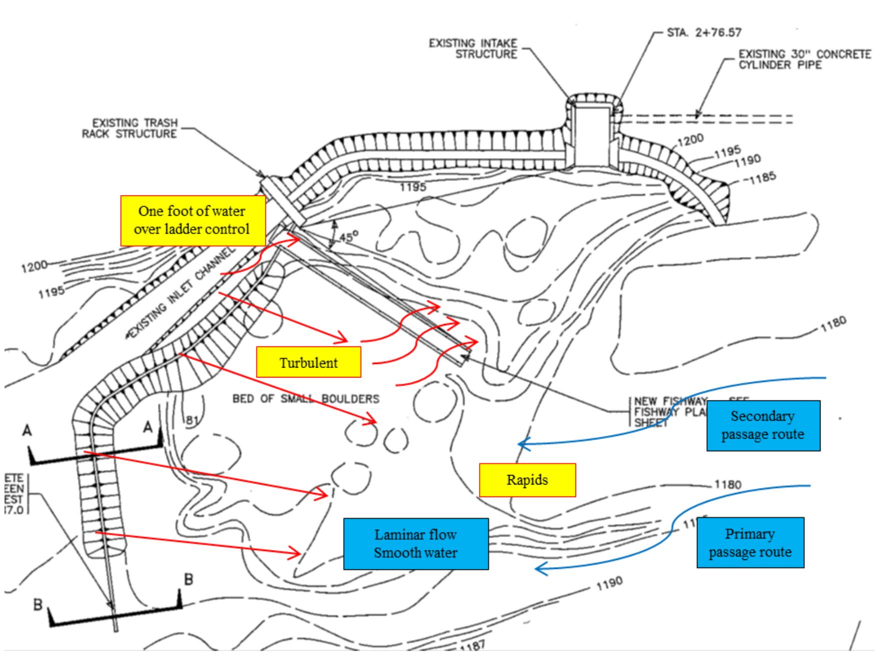

Figure 26. LNFH diversion, fish ladder, and streamflow conditions on July 20, 2012 at a streamflow of 1,271 cfs. Red arrows indicate the direction of flow over the dam, through the tailrace, and over the fish ladder (washed out-lower end). Blue arrows indicate the most likely routes for upstream migrants.

The next lower flow we observed was 324 cfs in August 2012. At this flow, the fishway weirs were in place, and the fishway and water control structure at the top of the fishway were not affected by flow over the dam. The location of the fishway entrance relative to the main river flow can be seen in Figure 27. Also apparent is a hydraulic control downstream from the entrance to the fishway that blocks a direct flow path to the entrance. The water surface elevation differential between the forebay and tailrace was estimated to be approximately 4.5 feet at this flow, and fish that do not use the fishway would have to jump the dam to move upstream. The same two primary flow paths were evident for upstream migrants at this flow (Figure 28), both on the opposite side of the river, and in the thalweg roughly mid-channel.

Figure 27. LNFH diversion, fish ladder, and streamflow conditions on August 14, 2012 at a streamflow of 324 cfs.

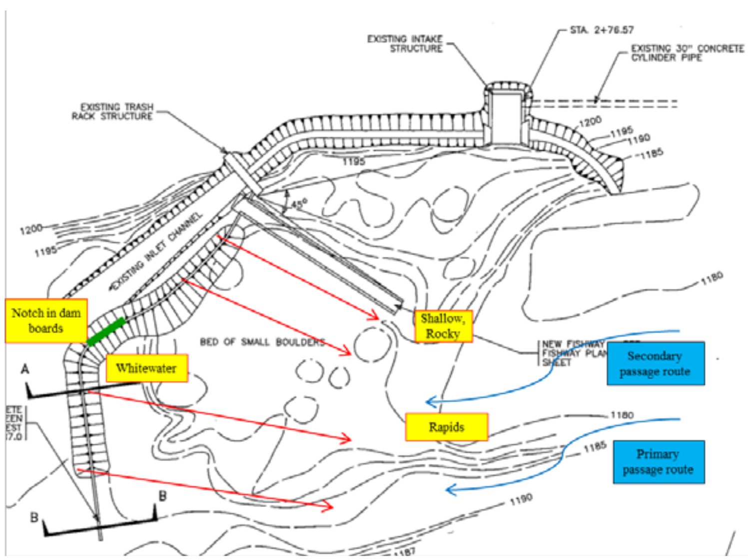

Figure 28. LNFH diversion, fish ladder, and streamflow conditions on August 14, 2012 at a streamflow of 324 cfs. The green bar is the location of the notch in the dam boards and spillway. Red arrows indicate the direction of flow over the dam and through the tailrace. Blue arrows indicate the most likely routes for upstream migrants.

The lowest flow we observed was 121 cfs in September 2012. The location of the fishway entrance relative to the main river flow can be seen in Figure 29. It is apparent from this photo that the fishway is perched on a shelf on the near side of the river, and the same two main flow paths are evident. The water surface elevation differential between the forebay and tailrace was estimated to be approximately 5.5 feet at this flow, and fish that do not use the fishway would have to jump the dam to move upstream. The same two primary flow paths were evident for upstream migrants at this flow (Figure 30), one on the opposite side of the river, and a second in the thalweg roughly mid-channel. Also shown in Figure 24 is the depth of potential jump pools. Hotchkiss and Frei (2007) cited a criteria that the State of Oregon uses for jump pool depth as "1.5 times jump height, or a minimum of 0.6 m (2 ft) depth (Robison et al. 1999). All of these pools met the two feet minimum depth criteria, but none met the 1.5 times jump height (7.65 feet) criteria.

Figure 29. LNFH diversion, fish ladder, and streamflow conditions on September 18, 2012 at a streamflow of 121 cfs.

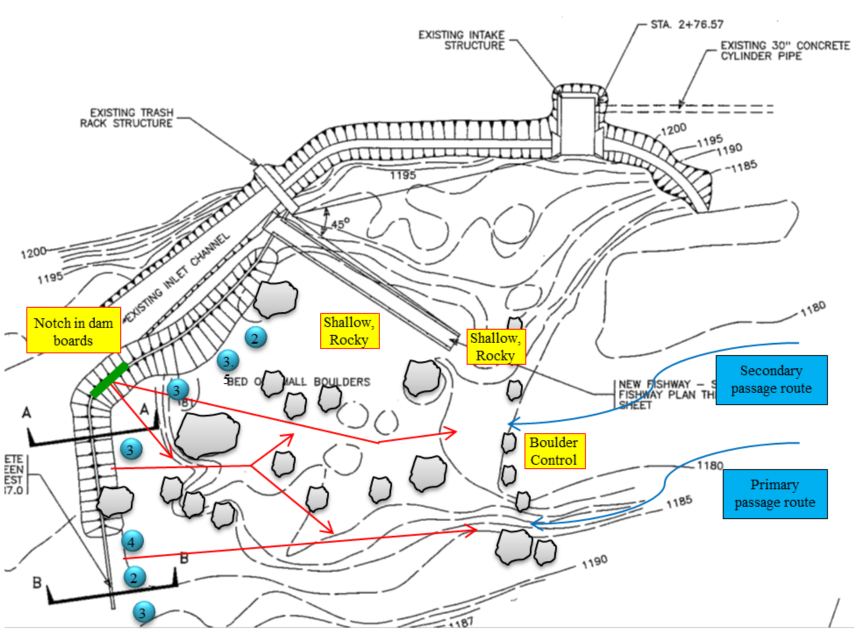

Figure 30. LNFH diversion, fish ladder, and streamflow conditions on September 18, 2012 at a streamflow of 121 cfs. The green bar is the location of the notch in the dam boards and spillway. Red arrows indicate the direction of flow over the dam and through the tailrace. Blue arrows indicate the most likely routes for upstream migrants. Primary boulders are shown in gray. Numbers within the blue circles indicate depth of jump pools fish could use to breach the dam.

Downstream Passage

Downstream passage at the LNFH intake can occur through the fishway, over the diversion dam, or via the diversion conveyance system. Downstream passage through the fishway is unimpeded, although the volume of water moving through the fishway is not likely to attract downstream migrants. When the weirs are removed for sediment flushing, downstream passage via this route may be more likely. With the large volume of water moving over the diversion dam, particularly at higher flows, this is the most likely route of downstream passage. Observations at the diversion dam in August 2012 indicated spill was sufficient for downstream passage at 324 cfs (Figure 31). Depth over the notch was measured as 1.20 feet, and depth over the flashboards was measured as 0.3 feet. Considering that the diversion flow is approximately 50 cfs, spill over the dam would have been approximately 274 cfs. Observations at the diversion dam in September 2012 at a streamflow of 121 cfs (Figure 32) show spill at the notch in the dam flashboards, but only leakage under the boards across the rest of the dam. If diversion flow is approximately 50 cfs, spill through the notch and leakage would amount to approximately 71 cfs. Under this condition with the small area of spill at the notch only, it is likely that a larger proportion of downstream migrants would be diverted into the conveyance system.

Figure 31. Spill over the LNFH diversion dam in August 2012 at a streamflow of 324 cfs. The notch in the dam flashboards is visible in the center of the photo.

Figure 32. Spill over the LNFH diversion dam in September 2012 at a streamflow of 121 cfs. The notch in the dam flashboards is visible near the right side of the photo.

Since the conveyance system has only trash racks at the diversion, one with a bar spacing of 0.5 feet, and one with a bar spacing of 0.125 feet, juvenile and subadult fish that do not spill over the diversion dam are likely entrained into the conveyance system and transported through a 2.75 foot diameter pipe 1,260 feet down gradient to the divergence of the Cascade Orchards Irrigation Company system. Entrained fish that are diverted to the Cascade Orchards system, are subjected to a drum screen and bypass system that is not presently up to date, although this is unlikely due to the configuration of the system. Entrained fish that are not diverted to the Cascade Orchards system, continue down gradient for approximately 5,200 feet in a 2.58 foot diameter pipe to the LNFH. The primary concerns with this system are diversion of fish from the natural stream channel into a pipeline, and the effect of the pipeline on the diverted fish. An inspection of the pipeline conducted in 2008, revealed that the condition of the pipeline was poor (FWS 2011a). The effect of these poor conditions on the survival of entrained fish is unknown.

Open Channel Fish Passage

The lowest minimum depth passage condition we assessed was 0.4 feet. Figure 33 shows the Icicle Creek historical channel with one location near the downstream end of the study reach that did not meet the criteria. The insets show that the passage was not continuous through the reach at 30 cfs, and at 40 cfs, the break in passage was eliminated. The downstream passage criteria in Table 2 for juvenile salmonids is 0.33 feet, and these results show that passage is continuous for downstream migrants at 40 cfs.

Figure 33. Fish passage in the historical channel based on the 0.4 foot depth criteria.

For a minimum passage depth of 0.5 feet, the same downstream location in the Icicle Creek historical channel did not meet the criteria at 50 cfs (Figure 34). The insets show that the break in passage was eliminated at 60 cfs. These results suggest that 60 cfs is required for continuous passage through the historical channel for rainbow trout, Westslope cutthroat trout, mountain whitefish, subadult bull trout, suckers, and Pacific lamprey.

Figure 34. Fish passage in the historical channel based on the 0.5 foot depth criteria.

For a minimum passage depth of 0.6 feet, the same downstream location in the Icicle Creek historical channel did not meet the criteria at 60 cfs (Figure 35). The insets show that the break in passage was eliminated at 70 cfs. Although 0.6 feet was not used as a target for this assessment, Figure 35 shows that the same location in the historical channel continued to be limiting.

Figure 35. Fish passage in the historical channel based on the 0.6 foot depth criteria.

For the minimum passage depth of 0.8 feet, the same downstream location in the Icicle Creek historical channel did not meet the criteria at 100 cfs (Figure 36). The insets show that the break in passage was eliminated at 120 cfs. The upstream passage criteria for fluvial trout (i.e. bull trout) from Table 2 is 0.8 feet and these results suggest that 120 cfs is required for continuous passage through the historical channel.

Figure 36. Fish passage in the historical channel based on the 0.8 foot depth criteria.

For the minimum passage depth of 1.0 foot, the same downstream location in the historical channel did not meet the criteria at 180 cfs (Figure 37). The insets show that the break in passage was eliminated at 200 cfs. The upstream passage criteria for adult steelhead, coho, and Chinook from Table 2 is 1.0 foot and these results suggest that 200 cfs is required for continuous passage through the historical channel.

Figure 37. Fish passage in the historical channel based on the 1.0 foot depth criteria.

The same location in the historical channel limited fish passage with all of the minimum depth criteria we assessed. In this particular area, the channel was braided and several side channels were present. Thus the total streamflow was apportioned to multiple channels, leaving relatively less in the "main" channel. In addition, the main channel was a wide, shallow riffle without a well-defined thalweg (Figure 38).

Figure 38. A riffle in the main channel of the Icicle Creek historical channel that was the limiting passage location for all target species.

Discussion

A variety of physical, hydrologic, and biologic considerations determine whether any particular obstruction is passable to fish (WDFW 2000). This fish passage assessment was based on the physical and hydraulic characteristics of Structure 2, Structure 5, and the LNFH intake system. Biological criteria were compiled for the target species for comparison to the physical and hydraulic characteristics. Biological criteria are designed to provide for the swimming capabilities of the relevant species and to accommodate the weakest individual within that species. The goal is to provide efficient passage with minimal physical stress so that survival and the ability to reproduce are not compromised. Upstream passage criteria are designed to optimize passage conditions based on selecting the optimum conditions (WDFW 2000). Along with the evaluation of the effect of conditions at these structures on the target fish species, we integrated the periodicity of each species with the range of streamflow conditions (monthly 10% to 90% exceedance flows) expected to occur during the relevant months to determine when the structures would, or would not be passable. Recognizing that fish passage is not a binary situation, these results reflect whether the selected criteria were met, and are not intended to imply absolute passage or not.

The primary purpose for functional upstream fish passage for anadromous fish in Icicle Creek is to allow access to spawning habitat. Steelhead, Chinook salmon, coho salmon, and Pacific lamprey have already moved nearly 500 miles upstream from the ocean to arrive at the Icicle Creek drainage. Feeding stops when these species enter fresh water, and whatever energy reserves they have at that point need to be sufficient for them to reach the spawning grounds if successful reproduction is expected. Typically, their swimming ability decreases as distance traveled increases (Tillinger and Stein 1996). (Powers and Orsborn (1984) proposed using a coefficient of fish condition as a modifier to velocity targets for fish passage. Although they applied the modifier to maximum burst speeds reported by Bell (1991), we think the concept is valid regardless of the specific swimming speed it is applied to. Their proposed levels of condition are shown in Table 11.

Table 11. Coefficient of fish condition (Cfc) proposed by Powers and Orsborn (1984).

Fish Condition	Coefficient (Cfc)
Bright; fresh out of saltwater or still a long distance from spawning grounds; spawning colors not yet developed	1.00
Good; in the river for a short time; spawning colors apparent but not fully developed; still migrating upstream	0.75
Poor; in the river for a long time; full spawning colors developed and fully mature; very close to spawning grounds	0.50

The deteriorating condition of anadromous fish as they move upstream from the ocean towards their spawning tributary, may be the most important reason to “optimize” passage conditions.

Fish passage for resident and fluvial species includes the need to access spawning grounds for fluvial migrants, and the need for both fluvial and resident species to move locally for foraging purposes, redistribution due to density, and to access suitable habitat. Bull trout are the primary fluvial species in Icicle Creek, although Westslope cutthroat trout, rainbow trout, mountain whitefish, and suckers may also conduct local migrations for spawning.

Rearing juveniles or subadults occur for all of the target species within Icicle Creek. These lifestages generally require shallower depths and slower velocities than adults, and they are present for the entire year, thus experiencing the full range of flow conditions.

The time series of 90% - 10% exceedance flows by month for S2 is presented in Appendix A in tables that indicate whether depth, velocity, or both were limiting factors for each of the target species.

Structure 2

Discussion of passage and limiting factors by month refer to the tables in Appendix A.

S2 was designed as a water control structure to manage flow conditions in the historical channel for fish production. In more recent times, it has been used for aquifer recharge for the hatchery ground water supply and to control high flows. It has satisfied these purposes reasonably well. S2 was not designed to accommodate fish passage. Thus, it is not surprising that the physical and hydraulic conditions on S2 can be challenging for the array of target species we evaluated. This structure is functionally a broad-crested weir with fixed concrete dimensions and radial gates. When the radial gates are not in use, the entire discharge in Icicle Creek flows through the structure and into the historical channel up to approximately 1,000 cfs. At about 300 cfs, S2 starts to back up water into the hatchery channel, and at total flows greater than 1,000 cfs, water begins to flow over the spillway at the downstream end of the hatchery channel. The weir at S2 is relatively smooth concrete with no roughness or complexity. It conveys water efficiently resulting in shallow depths and high velocities at low flows.

The target depth for rearing and local movements of resident trout, subadult bull trout, mountain whitefish, and suckers, occurred at the same discharge (64 cfs) that produced the maximum velocity condition (Figures 7 and 8). This suggests that movement upstream past S2 is very limited for these species. Considering that the maximum velocity criterion for juvenile salmonids is 1.0 ft/s, upstream passage is not possible. The Appendix A tables indicate that high velocities were the limiting factor for these species across all months except during October when the 90% exceedance flow dipped to 59 cfs.

Higher depth and velocity criteria were used for fluvial adult bull trout because of their larger size. Since the minimum depth was met at a flow of 132 cfs and the maximum velocity was not exceeded until flows reached 512 cfs, there were windows during certain time periods when passage was not limited. From January through March, depth was only limiting at flows less than the median flow, and velocity was not limiting. Along with the higher flows that occur during April, velocity was a limiting factor at flows higher than the median flow. The higher flow conditions that occur from May through July produced a velocity limitation at all flows except for lower flows below the median that occur in July. Fluvial adults attempting to access the headwater spawning grounds during these months may have been affected by these conditions. From August through December, lower frequency flows below the median could result in limiting depths for passage, but high velocities were only limiting at flows much higher than the median flow in November.

Steelhead were evaluated for the longest time period for the anadromous species. From January through March, the lower end of the flow range was associated with limiting passage depths at S2. The higher end of the flow range in April, and the entire flow range in May and June resulted in maximum velocity limitations for steelhead.

Spring Chinook are present during the higher flow months of May through July. High velocities could limit passage at S2 during these months except at the lower end of the flow range modeled for July.

Since summer Chinook are present from August through October, lower flows during these months present a possible depth passage limitation except at the higher end of the flow range above the median flow. Velocities were not limiting during these months.

Coho are present from fall through early winter, and during September low flows, depth could limit passage over nearly the entire flow range. During October through December, depth may only be limiting at flows lower than the median flow. High velocities were only potentially limiting for coho passage during high flow conditions that occur in November during some years.

Pacific lamprey could be present from June through October which includes both high and low flow months. Since the target limiting velocity for lamprey was 4.0 ft/s, high velocities were the limiting factor across all months except October when the 90% exceedance flow dipped to 59 cfs. Depth could be limiting for lamprey at S2 under the same October low flow conditions, but only during the lowest flow years.

When the radial gates are used at S2, a range of depth, velocity, and discharge conditions are possible based on the incoming streamflow and a range of gate settings. We limited our modeling to a gate opening of one foot or greater, thus passage depth was not limited for any species. When the radial gates are blocking the incoming water column, average velocities associated with a range of gate opening greater than one foot range from 5.23 ft/s to over 11 ft/s. Under these conditions, passage is likely only for steelhead, salmon, and fluvial bull trout with a maximum velocity target of 8.0 ft/s. Considering the possible range of combinations of streamflow and gate settings, passage could be managed so it would not be limiting until streamflow exceeded approximately 900 cfs. This suggests there may be situations when the gates could be used to reduce velocities over those conditions otherwise present without using the gates when the target velocity of 8.0 ft/s is exceeded at approximately 512 cfs.

The “entrance” pool downstream from S2 accomplishes the purpose it was designed for; to dissipate energy and avoid scour and down-cutting of the stream channel downstream. Similarly to the structure itself, it was not designed to facilitate fish passage. The pool was turbulent and highly aerated at all flows. Turbulence and aerated water can be a barrier to fish passage (WDFW 2000). It can result in disorientation and loss of direction in migrating fish. This pool may be as much of an impediment to efficient fish passage as the weir itself. The choices are limited for how to improve this condition. Whether the jumping behavior observed in the past is related to the pool or conditions on the weir is unknown. If the pool conditions cannot be improved, a modification of the downstream face of the radial gates could be made to limit injury to jumping fish. Otherwise, tarps have worked reasonably well in the past.

Structure 5

Discussion of passage and limiting factors by month refer to the tables in Appendix B.

S5 was also designed for purposes other than efficient fish passage. It was designed to limit fish passage for brood stock collection and other purposes (FWS 2011b). Thus, it is not surprising that the physical and hydraulic conditions on S5 can be challenging, particularly at low flows for the array of target species we evaluated. The hydraulics of the water movement over the two limiting foundations at S5 resulted in the most limiting depth passage conditions at the downstream foundation. We used the depth passage criteria for the target species to relate passage limitations to streamflow as measured at S2. The results are presented in the tables in Appendix B.

The limiting condition for passage of steelhead and salmon at S5 was a flow of 260 cfs or greater. For passage of fluvial bull trout, 205 cfs or greater was required, and for passage of resident trout, subadult bull trout, suckers, Pacific lamprey, and juvenile salmonids, 125 cfs or greater was required.

For January through March, passage was limited for all three groups of fish over some portion of the flow range. The limitation for the smaller species and Pacific lamprey, passage was only limited at the lower end of the flow range modeled. Passage for fluvial bull trout was limited at the median and lower flows, and for steelhead, passage was limited at some flows higher than the median (Appendix B).

Passage was not a limiting factor for any of the target species during the higher flow months of April through July.

In August as flows declined, the lowest flow 90% exceedance flow became limiting for the smaller resident species and Pacific lamprey. Fluvial bull trout passage depth was limiting at the median and lower flows, and summer Chinook passage was depth-limited at all flows except the two highest flows near the 10% exceedance level.

September is the lowest flow month of the year, and it presented a depth passage limitation for the smaller resident species and Pacific lamprey at the median and lower flows. Passage was eliminated for fluvial bull trout, coho, and summer Chinook over the entire flow range based on the target criteria of 0.8 and 1.0 feet, respectively.

The lower end of the flow range in October is similar to September, except that the 10% exceedance flows are substantially higher. Depth was limiting for the smaller resident species and Pacific lamprey at the lower end of the flow range below the median flow level. Fluvial bull trout passage was not limited at higher flows, but depths for coho and summer Chinook passage were only sufficient near the 10% exceedance flow.

Passage depths were suitable for the smaller resident species and Pacific lamprey at all but the 90% exceedance flow in November and December. Fluvial bull trout and coho passage depths were suitable during these months at flows near the median and higher flows.

Pickets can be installed during some years, under specific conditions (FWS 2011b) for brood stock collection. The pickets are intended to limit fish passage. When the pickets are installed, weirs and fish traps are also installed so that non-target fish species can be captured and moved upstream to the appropriate location. This action reduces or eliminates passage concerns at S5 for species other than spring Chinook salmon when the pickets are installed. It is possible that some of the smaller resident species could physically pass through the spaces between the individual pickets when they are installed. However, with the resulting reduced cross-sectional area, velocities would increase. Picket spacing is sufficient to eliminate passage by steelhead, salmon, and fluvial bull trout. If physical passage was possible by the smaller resident species, the velocity target (4.0 ft/s) would be exceeded at approximately 685 cfs under normal conditions. This same velocity target would occur at approximately 340 cfs with the pickets installed. The target velocity of 2.9 ft/s that we used for mountain whitefish would be exceeded at approximately 425 cfs under normal conditions. With pickets installed, the velocity target would be exceeded at approximately 195 cfs. Since the weirs and fish traps would provide passage, these conditions may not be a concern.

LNFH Water Intake Structure

Fish passage through the fishway at the intake structure is certainly possible, but there are some important aspects of the fishway design and location that could be improved. Our observations indicated that the fishway was partially washed out at flows of approximately 1,200 cfs or greater. In addition, the weirs were removed for sediment flushing at this flow and at higher flows. Steelhead, spring Chinook, fluvial bull trout, and Pacific lamprey could be moving upstream during the time period that the fishway is washed out, but passage directly over the dam is possible at these higher flows, with the exception of Pacific lamprey. At lower flows less than 1,000 cfs when the fishway is no longer washed out, the weirs could be re-installed when it is safe to do so, and fish passage would again be possible. During these lower flow conditions, summer Chinook, coho, Pacific lamprey, fluvial bull trout, and adult/juvenile rainbow and cutthroat trout could be moving upstream. The recommended head differential between fishway pools is 1.0 feet for salmon and steelhead, and 0.5 feet for other species including resident salmonids and juveniles. In addition, recommended weir (nappe) velocities for the two groups are 8.0 ft/s and 1.5-4.5 ft/s, respectively. Since the two sets of conditions cannot be met at the same time, priorities may need to be established to determine target conditions. Passage for Pacific lamprey in a weir and pool type fishway is typically accomplished with bottom-oriented orifices. No orifices are currently present in these fishway weirs. Modifications to create orifices are possible, but fishway flow would likely need to be adjusted accordingly. The most significant issue we observed for the fishway was entrance location and attraction flow. Related to the attraction flow, is fishway discharge. The entrance location is out of any direct flow paths that migrating fish would likely be following when they approach the dam. There is very shallow water at lower flows, and an abundance of boulders that obstruct a direct route to the fishway entrance from downstream. Attraction flow is non-existent. Average velocity near the entrance was less than 1.0 ft/s during one survey at a fishway flow of approximately 4.5 cfs, and less than 0.5 ft/s during a second survey at a fishway flow of approximately 0.75 cfs. These velocities and flow rates are not sufficient to attract fish from the tailrace area without significant searching. Conditions within the fishway were also inadequate relative to the criteria during both surveys. Fishway discharge is one fundamental problem. The water control structure at the top of the fishway does not appear to be functional for controlling fishway discharge, although it functions as designed for sediment flushing. And no design discharge was identified for the fishway. With a discharge between 5 – 10 cfs, conditions within the fishway might be suitable for passage, but the entrance location and attraction flow issues would still exist.

Passage of the majority of downstream migrants is likely over the diversion dam during higher flow time periods. From August through December, when a higher proportion of the total flow is diverted, particularly during low flow years, any downstream migrants are likely entrained into the conveyance system. And the condition of the conveyance system is so poor (FWS 2011a, 2011b), that negative effects on any entrained fish are highly likely. The preferred option would be to screen fish out of the conveyance system and into a bypass back to the river near the point of diversion, thus not subjecting them to conditions within the conveyance system. There may be challenges to maintaining a screening system because of the seasonal low temperatures, sediment accumulation, and other maintenance issues, but some mechanism is needed to keep fish out of the conveyance system.

Open Channel Fish Passage

Flows of 60 cfs are required to provide continuous passage through the Icicle Creek historical channel for resident trout, subadult bull trout, suckers, Pacific lamprey, and juvenile salmonids. This flow (or higher) occurs during every month except October, and then only during a 90% exceedance year. Fluvial bull trout require a flow of 120 cfs to meet the minimum depth criteria throughout the entire historical channel. Flows less than 120 cfs can occur from January through March, August, November, and December during low flow years. Steelhead and salmon require a flow of 200 cfs to meet the minimum depth criterion throughout the historical channel. From January through March, this condition is near the median flow. This flow level is exceeded during all types of flow years from April through July. When summer Chinook are present in August, this flow level only occurs during years with flows slightly higher than the median flow level. Coho and summer Chinook are both present in September when 200 cfs is higher than the 10% exceedance flow. Flows typically increase in October, but the 200 cfs level only occurs during higher flow years. In November and December when coho are still present, the median flow is approximately 200 cfs, providing continuous passage except in low flow years.

Conclusions

The detailed results of these analyses are presented in the Appendix tables, and collectively, they will assist managers and stakeholders in determining when passage limitations occur, and whether options exist to eliminate barriers or improve passage conditions at Structures 2 and 5, the intake, or within the Icicle Creek historical channel.

Fish passage is not a binary situation, and the results of these analyses are based on the passage criteria used. Interpretation of these results and development of options to improve fish passage should be jointly conducted by the technical experts, managers, and stakeholders to determine actions that will meet the multiple goals for Icicle Creek including mitigation fish production at the Leavenworth National Fish Hatchery and preservation of the various fish populations that inhabit Icicle Creek.

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Appendix A

Structure 2 Passage Conditions

Species occurrence and 90% - 10% exceedance flows for the USGS Gage #12458000 and Structure 2 by month.

Flows that did not meet depth and velocity criteria are indicated by a "D" or "V", respectively.

Approximates median flow

Flows (cfs)		Migration-Spawning	January Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D,V
na	30	D	D	D,V	D	D	D	D,V
na	40	D	D	D,V	D	D	D	D,V
na	50	D	D	D,V	D	D	D	D,V
88	60	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	D	V	V
115	80	D	V	V	V	D	V	V
129	90	D	V	V	V	D	V	V
142	100	D	V	V	V	D	V	V
168	120	D	V	V	V	D	V	V
193	140	D	V	V	V		V	V
218	160	D	V	V	V		V	V
243	180		V	V	V		V	V
266	200		V	V	V		V	V
325	250		V	V	V		V	V
382	300		V	V	V		V	V
437	350		V	V	V		V	V
491	400		V	V	V		V	V
544	450		V	V	V		V	V
596	500		V	V	V		V	V
648	550	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

January Exceedance flows at Structure 2 (90-10%) 87 to 463 cfs

Flows (cfs)		Migration-Spawning	February					
			Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D,V
na	30	D	D	D,V	D	D	D	D,V
na	40	D	D	D,V	D	D	D	D,V
na	50	D	D	D,V	D	D	D	D,V
88	60	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	D	V	V
115	80	D	V	V	V	D	V	V
129	90	D	V	V	V	D	V	V
142	100	D	V	V	V	D	V	V
168	120	D	V	V	V	D	V	V
193	140	D	V	V	V		V	V
218	160	D	V	V	V		V	V
243	180		V	V	V		V	V
266	200		V	V	V		V	V
325	250		V	V	V		V	V
382	300		V	V	V		V	V
437	350		V	V	V		V	V
491	400		V	V	V		V	V
544	450		V	V	V		V	V
596	500		V	V	V		V	V
648	550	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

February Exceedance flows at Structure 2 (90-10%) 84 to 483 cfs

Flows (cfs)		Migration-Spawning	March Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D,V
na	30	D	D	D,V	D	D	D	D,V
na	40	D	D	D,V	D	D	D	D,V
na	50	D	D	D,V	D	D	D	D,V
88	60	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	D	V	V
115	80	D	V	V	V	D	V	V
129	90	D	V	V	V	D	V	V
142	100	D	V	V	V	D	V	V
168	120	D	V	V	V	D	V	V
193	140	D	V	V	V		V	V
218	160	D	V	V	V		V	V
243	180		V	V	V		V	V
266	200		V	V	V		V	V
325	250		V	V	V		V	V
382	300		V	V	V		V	V
437	350		V	V	V		V	V
491	400		V	V	V		V	V
544	450		V	V	V		V	V
596	500		V	V	V		V	V
648	550	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

March Exceedance flows at Structure 2 (90-10%) 114 to 398 cfs

Flows (cfs)		Migration-Spawning	April					
			Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D,V
na	30	D	D	D,V	D	D	D	D,V
na	40	D	D	D,V	D	D	D	D,V
na	50	D	D	D,V	D	D	D	D,V
88	60	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	D	V	V
115	80	D	V	V	V	D	V	V
129	90	D	V	V	V	D	V	V
142	100	D	V	V	V	D	V	V
168	120	D	V	V	V	D	V	V
193	140	D	V	V	V		V	V
218	160	D	V	V	V		V	V
243	180		V	V	V		V	V
266	200		V	V	V		V	V
325	250		V	V	V		V	V
382	300		V	V	V		V	V
437	350		V	V	V		V	V
491	400		V	V	V		V	V
544	450		V	V	V		V	V
596	500		V	V	V		V	V
648	550	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V
749	650	V	V	V	V	V	V	V
799	700	V	V	V	V	V	V	V
848	750	V	V	V	V	V	V	V
896	800	V	V	V	V	V	V	V
944	850	V	V	V	V	V	V	V
1,024	900	V	V	V	V	V	V	V
1,115	950	V	V	V	V	V	V	V
1,215	1,000	V	V	V	V	V	V	V
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

April Exceedance flows at Structure 2 (90-10%) 270 to 873 cfs

Flows (cfs)		Migration-Spawning		May Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Spring Chinook	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D,V
na	30	D	D	D	D,V	D	D	D	D,V
na	40	D	D	D	D,V	D	D	D	D,V
na	50	D	D	D	D,V	D	D	D	D,V
88	60	D	D	D	D,V	D	D	D	D,V
101	70	D	D	V	V	V	D	V	V
115	80	D	D	V	V	V	D	V	V
129	90	D	D	V	V	V	D	V	V
142	100	D	D	V	V	V	D	V	V
168	120	D	D	V	V	V	D	V	V
193	140	D	D	V	V	V		V	V
218	160	D	D	V	V	V		V	V
243	180			V	V	V		V	V
266	200			V	V	V		V	V
325	250			V	V	V		V	V
382	300			V	V	V		V	V
437	350			V	V	V		V	V
491	400			V	V	V		V	V
544	450			V	V	V		V	V
596	500			V	V	V		V	V
648	550	V	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V	V
749	650	V	V	V	V	V	V	V	V
799	700	V	V	V	V	V	V	V	V
848	750	V	V	V	V	V	V	V	V
896	800	V	V	V	V	V	V	V	V
944	850	V	V	V	V	V	V	V	V
1,024	900	V	V	V	V	V	V	V	V
1,115	950	V	V	V	V	V	V	V	V
1,215	1,000	V	V	V	V	V	V	V	V
1,315	1,050	V	V	V	V	V	V	V	V
1,425	1,100	V	V	V	V	V	V	V	V
1,525	1,150	V	V	V	V	V	V	V	V
1,640	1,200	V	V	V	V	V	V	V	V
1,760	1,250	V	V	V	V	V	V	V	V
1,890	1,300	V	V	V	V	V	V	V	V
2,020	1,350	V	V	V	V	V	V	V	V
2,150	1,400	V	V	V	V	V	V	V	V
2,300	1,450	V	V	V	V	V	V	V	V
2,440	1,500	V	V	V	V	V	V	V	V

May Exceedance flows at Structure 2 (90-10%) 959 to 1490 cfs

		June								
Flows (cfs)		Migration-Spawning			Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Spring Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D	D,V
na	30	D	D	D	D	D,V	D	D	D	D,V
na	40	D	D	D	D	D,V	D	D	D	D,V
na	50	D	D	D	D	D,V	D	D	D	D,V
88	60	D	D	D	D	D,V	D	D	D	D,V
101	70	D	D	V	V	V	V	D	V	V
115	80	D	D	V	V	V	V	D	V	V
129	90	D	D	V	V	V	V	D	V	V
142	100	D	D	V	V	V	V	D	V	V
168	120	D	D	V	V	V	V	D	V	V
193	140	D	D	V	V	V	V		V	V
218	160	D	D	V	V	V	V		V	V
243	180			V	V	V	V		V	V
266	200			V	V	V	V		V	V
325	250			V	V	V	V		V	V
382	300			V	V	V	V		V	V
437	350			V	V	V	V		V	V
491	400			V	V	V	V		V	V
544	450			V	V	V	V		V	V
596	500			V	V	V	V		V	V
648	550	V	V	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V	V	V
749	650	V	V	V	V	V	V	V	V	V
799	700	V	V	V	V	V	V	V	V	V
848	750	V	V	V	V	V	V	V	V	V
896	800	V	V	V	V	V	V	V	V	V
944	850	V	V	V	V	V	V	V	V	V
1,024	900	V	V	V	V	V	V	V	V	V
1,115	950	V	V	V	V	V	V	V	V	V
1,215	1,000	V	V	V	V	V	V	V	V	V
1,315	1,050	V	V	V	V	V	V	V	V	V
1,425	1,100	V	V	V	V	V	V	V	V	V
1,525	1,150	V	V	V	V	V	V	V	V	V
1,640	1,200	V	V	V	V	V	V	V	V	V
1,760	1,250	V	V	V	V	V	V	V	V	V
1,890	1,300	V	V	V	V	V	V	V	V	V
2,020	1,350	V	V	V	V	V	V	V	V	V
2,150	1,400	V	V	V	V	V	V	V	V	V
2,300	1,450	V	V	V	V	V	V	V	V	V
2,440	1,500	V	V	V	V	V	V	V	V	V

June Exceedance flows at Structure 2 (90-10%) 994 to 1610 cfs

Flows (cfs)		July							
		Migration-Spawning		Movement-Resident spawning, rearing					
USGS	Structure 2	Spring Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D,V
na	30	D	D	D	D,V	D	D	D	D,V
na	40	D	D	D	D,V	D	D	D	D,V
na	50	D	D	D	D,V	D	D	D	D,V
88	60	D	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	V	D	V	V
115	80	D	V	V	V	V	D	V	V
129	90	D	V	V	V	V	D	V	V
142	100	D	V	V	V	V	D	V	V
168	120	D	V	V	V	V	D	V	V
193	140	D	V	V	V	V		V	V
218	160	D	V	V	V	V		V	V
243	180		V	V	V	V		V	V
266	200		V	V	V	V		V	V
325	250		V	V	V	V		V	V
382	300		V	V	V	V		V	V
437	350		V	V	V	V		V	V
491	400		V	V	V	V		V	V
544	450		V	V	V	V		V	V
596	500		V	V	V	V		V	V
648	550	V	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V	V
749	650	V	V	V	V	V	V	V	V
799	700	V	V	V	V	V	V	V	V
848	750	V	V	V	V	V	V	V	V
896	800	V	V	V	V	V	V	V	V
944	850	V	V	V	V	V	V	V	V
1,024	900	V	V	V	V	V	V	V	V
1,115	950	V	V	V	V	V	V	V	V
1,215	1,000	V	V	V	V	V	V	V	V
1,315	1,050	V	V	V	V	V	V	V	V
1,425	1,100	V	V	V	V	V	V	V	V
1,525	1,150	V	V	V	V	V	V	V	V
1,640	1,200	V	V	V	V	V	V	V	V
1,760	1,250	V	V	V	V	V	V	V	V
1,890	1,300	V	V	V	V	V	V	V	V
2,020	1,350								
2,150	1,400								
2,300	1,450								
2,440	1,500								

July Exceedance flows at Structure 2 (90-10%) 288 to 1180 cfs

		August							
Flows (cfs)		Migration-Spawning		Movement-Resident spawning, rearing					
USGS	Structure 2	Summer Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D,V
na	30	D	D	D	D,V	D	D	D	D,V
na	40	D	D	D	D,V	D	D	D	D,V
na	50	D	D	D	D,V	D	D	D	D,V
88	60	D	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	V	D	V	V
115	80	D	V	V	V	V	D	V	V
129	90	D	V	V	V	V	D	V	V
142	100	D	V	V	V	V	D	V	V
168	120	D	V	V	V	V	D	V	V
193	140	D	V	V	V	V		V	V
218	160	D	V	V	V	V		V	V
243	180		V	V	V	V		V	V
266	200		V	V	V	V		V	V
325	250		V	V	V	V		V	V
382	300		V	V	V	V		V	V
437	350		V	V	V	V		V	V
491	400		V	V	V	V		V	V
544	450		V	V	V	V		V	V
596	500		V	V	V	V		V	V
648	550	V	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V	V
749	650								
799	700								
848	750								
896	800								
944	850								
1,024	900								
1,115	950								
1,215	1,000								
1,315	1,050								
1,425	1,100								
1,525	1,150								
1,640	1,200								
1,760	1,250								
1,890	1,300								
2,020	1,350								
2,150	1,400								
2,300	1,450								
2,440	1,500								

August Exceedance flows at Structure 2 (90-10%) 106 to 346 cfs

Flows (cfs)		September								
		Migration-Spawning			Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Summer Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D	D,V
na	30	D	D	D	D	D,V	D	D	D	D,V
na	40	D	D	D	D	D,V	D	D	D	D,V
na	50	D	D	D	D	D,V	D	D	D	D,V
88	60	D	D	D	D	D,V	D	D	D	D,V
101	70	D	D	V	V	V	V	D	V	V
115	80	D	D	V	V	V	V	D	V	V
129	90	D	D	V	V	V	V	D	V	V
142	100	D	D	V	V	V	V	D	V	V
168	120	D	D	V	V	V	V	D	V	V
193	140	D	D	V	V	V	V		V	V
218	160	D	D	V	V	V	V		V	V
243	180			V	V	V	V		V	V
266	200			V	V	V	V		V	V
325	250			V	V	V	V		V	V
382	300			V	V	V	V		V	V
437	350			V	V	V	V		V	V
491	400			V	V	V	V		V	V
544	450			V	V	V	V		V	V
596	500			V	V	V	V		V	V
648	550	V	V	V	V	V	V	V	V	V
699	600									
749	650									
799	700									
848	750									
896	800									
944	850									
1,024	900									
1,115	950									
1,215	1,000									
1,315	1,050									
1,425	1,100									
1,525	1,150									
1,640	1,200									
1,760	1,250									
1,890	1,300									
2,020	1,350									
2,150	1,400									
2,300	1,450									
2,440	1,500									

September Exceedance flows at Structure 2 (90-10%) 68 to 177 cfs

		October								
Flows (cfs)		Migration-Spawning			Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Summer Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D	D,V
na	30	D	D	D	D	D,V	D	D	D	D,V
na	40	D	D	D	D	D,V	D	D	D	D,V
na	50	D	D	D	D	D,V	D	D	D	D,V
88	60	D	D	D	D	D,V	D	D	D	D,V
101	70	D	D	V	V	V	V	D	V	V
115	80	D	D	V	V	V	V	D	V	V
129	90	D	D	V	V	V	V	D	V	V
142	100	D	D	V	V	V	V	D	V	V
168	120	D	D	V	V	V	V	D	V	V
193	140	D	D	V	V	V	V		V	V
218	160	D	D	V	V	V	V		V	V
243	180			V	V	V	V		V	V
266	200			V	V	V	V		V	V
325	250			V	V	V	V		V	V
382	300			V	V	V	V		V	V
437	350			V	V	V	V		V	V
491	400			V	V	V	V		V	V
544	450			V	V	V	V		V	V
596	500			V	V	V	V		V	V
648	550	V	V	V	V	V	V	V	V	V
699	600									
749	650									
799	700									
848	750									
896	800									
944	850									
1,024	900									
1,115	950									
1,215	1,000									
1,315	1,050									
1,425	1,100									
1,525	1,150									
1,640	1,200									
1,760	1,250									
1,890	1,300									
2,020	1,350									
2,150	1,400									
2,300	1,450									
2,440	1,500									

October Exceedance flows at Structure 2 (90-10%) 59 to 348 cfs

Flows (cfs)		November						
		Migration-Spawning	Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D,V
na	30	D	D	D,V	D	D	D	D,V
na	40	D	D	D,V	D	D	D	D,V
na	50	D	D	D,V	D	D	D	D,V
88	60	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	D	V	V
115	80	D	V	V	V	D	V	V
129	90	D	V	V	V	D	V	V
142	100	D	V	V	V	D	V	V
168	120	D	V	V	V	D	V	V
193	140	D	V	V	V		V	V
218	160	D	V	V	V		V	V
243	180		V	V	V		V	V
266	200		V	V	V		V	V
325	250		V	V	V		V	V
382	300		V	V	V		V	V
437	350		V	V	V		V	V
491	400		V	V	V		V	V
544	450		V	V	V		V	V
596	500		V	V	V		V	V
648	550	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V
749	650	V	V	V	V	V	V	V
799	700	V	V	V	V	V	V	V
848	750	V	V	V	V	V	V	V
896	800	V	V	V	V	V	V	V
944	850	V	V	V	V	V	V	V
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

November Exceedance flows at Structure 2 (90-10%) 98 to 768 cfs

Flows (cfs)		Migration-Spawning	December					
			Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D,V
na	30	D	D	D,V	D	D	D	D,V
na	40	D	D	D,V	D	D	D	D,V
na	50	D	D	D,V	D	D	D	D,V
88	60	D	D	D,V	D	D	D	D,V
101	70	D	V	V	V	D	V	V
115	80	D	V	V	V	D	V	V
129	90	D	V	V	V	D	V	V
142	100	D	V	V	V	D	V	V
168	120	D	V	V	V	D	V	V
193	140	D	V	V	V		V	V
218	160	D	V	V	V		V	V
243	180		V	V	V		V	V
266	200		V	V	V		V	V
325	250		V	V	V		V	V
382	300		V	V	V		V	V
437	350		V	V	V		V	V
491	400		V	V	V		V	V
544	450		V	V	V		V	V
596	500		V	V	V		V	V
648	550	V	V	V	V	V	V	V
699	600	V	V	V	V	V	V	V
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

December Exceedance flows at Structure 2 (90-10%) 103 to 517 cfs

Appendix B

Structure 5 Passage Conditions

Species occurrence and 90% - 10% exceedance flows for the USGS Gage #12458000 and Structure 2 by month.

Flows that did not meet depth criteria are indicated by a “D”.

Approximates median flow

Flows (cfs)		January						
		Migration-Spawning	Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D
168	120	D				D		
193	140	D				D		
218	160	D				D		
243	180	D				D		
266	200	D						
325	250	D						
382	300							
437	350							
491	400							
544	450							
596	500							
648	550							
699	600							
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

January Exceedance flows at Structure 2 (90-10%) 87 to 463 cfs

Flows (cfs)		Migration-Spawning	February Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D
168	120	D				D		
193	140	D				D		
218	160	D				D		
243	180	D				D		
266	200	D						
325	250	D						
382	300							
437	350							
491	400							
544	450							
596	500							
648	550							
699	600							
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

February Exceedance flows at Structure 2 (90-10%) 84 to 483 cfs

Flows (cfs)		Migration-Spawning	March					
			Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D
168	120	D				D		
193	140	D				D		
218	160	D				D		
243	180	D				D		
266	200	D						
325	250	D						
382	300							
437	350							
491	400							
544	450							
596	500							
648	550							
699	600							
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

March Exceedance flows at Structure 2 (90-10%) 114 to 398 cfs

Flows (cfs)		Migration-Spawning	April Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D
168	120	D				D		
193	140	D				D		
218	160	D				D		
243	180	D				D		
266	200	D						
325	250	D						
382	300							
437	350							
491	400							
544	450							
596	500							
648	550							
699	600							
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

April Exceedance flows at Structure 2 (90-10%) 270 to 873 cfs

Flows (cfs)		Migration-Spawning		May Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Spring Chinook	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D	D
168	120	D	D				D		
193	140	D	D				D		
218	160	D	D				D		
243	180	D	D				D		
266	200	D	D						
325	250	D	D						
382	300								
437	350								
491	400								
544	450								
596	500								
648	550								
699	600								
749	650								
799	700								
848	750								
896	800								
944	850								
1,024	900								
1,115	950								
1,215	1,000								
1,315	1,050								
1,425	1,100								
1,525	1,150								
1,640	1,200								
1,760	1,250								
1,890	1,300								
2,020	1,350								
2,150	1,400								
2,300	1,450								
2,440	1,500								

May Exceedance flows at Structure 2 (90-10%) 959 to 1490 cfs

Flows (cfs)		June								
		Migration-Spawning			Movement-Resident spawning, rearing					
USGS	Structure 2	Steelhead	Spring Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D	D	D
168	120	D	D					D		
193	140	D	D					D		
218	160	D	D					D		
243	180	D	D					D		
266	200	D	D							
325	250	D	D							
382	300									
437	350									
491	400									
544	450									
596	500									
648	550									
699	600									
749	650									
799	700									
848	750									
896	800									
944	850									
1,024	900									
1,115	950									
1,215	1,000									
1,315	1,050									
1,425	1,100									
1,525	1,150									
1,640	1,200									
1,760	1,250									
1,890	1,300									
2,020	1,350									
2,150	1,400									
2,300	1,450									
2,440	1,500									

June Exceedance flows at Structure 2 (90-10%) 994 to 1610 cfs

Flows (cfs)		July Migration-Spawning		Movement-Resident spawning, rearing					
USGS	Structure 2	Spring Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D	D
168	120	D					D		
193	140	D					D		
218	160	D					D		
243	180	D					D		
266	200	D							
325	250	D							
382	300								
437	350								
491	400								
544	450								
596	500								
648	550								
699	600								
749	650								
799	700								
848	750								
896	800								
944	850								
1,024	900								
1,115	950								
1,215	1,000								
1,315	1,050								
1,425	1,100								
1,525	1,150								
1,640	1,200								
1,760	1,250								
1,890	1,300								
2,020	1,350								
2,150	1,400								
2,300	1,450								
2,440	1,500								

July Exceedance flows at Structure 2 (90-10%) 288 to 1180 cfs

Flows (cfs)		August							
		Migration-Spawning		Movement-Resident spawning, rearing					
USGS	Structure 2	Summer Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D	D
168	120	D					D		
193	140	D					D		
218	160	D					D		
243	180	D					D		
266	200	D							
325	250	D							
382	300								
437	350								
491	400								
544	450								
596	500								
648	550								
699	600								
749	650								
799	700								
848	750								
896	800								
944	850								
1,024	900								
1,115	950								
1,215	1,000								
1,315	1,050								
1,425	1,100								
1,525	1,150								
1,640	1,200								
1,760	1,250								
1,890	1,300								
2,020	1,350								
2,150	1,400								
2,300	1,450								
2,440	1,500								

August Exceedance flows at Structure 2 (90-10%) 106 to 346 cfs

Flows (cfs)		September								
		Migration-Spawning			Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Summer Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D	D	D
168	120	D	D					D		
193	140	D	D					D		
218	160	D	D					D		
243	180	D	D					D		
266	200	D	D							
325	250	D	D							
382	300									
437	350									
491	400									
544	450									
596	500									
648	550									
699	600									
749	650									
799	700									
848	750									
896	800									
944	850									
1,024	900									
1,115	950									
1,215	1,000									
1,315	1,050									
1,425	1,100									
1,525	1,150									
1,640	1,200									
1,760	1,250									
1,890	1,300									
2,020	1,350									
2,150	1,400									
2,300	1,450									
2,440	1,500									

September Exceedance flows at Structure 2 (90-10%) 68 to 177 cfs

Flows (cfs)		October								
		Migration-Spawning			Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Summer Chinook	Pacific lamprey	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D	D	D
168	120	D	D					D		
193	140	D	D					D		
218	160	D	D					D		
243	180	D	D					D		
266	200	D	D							
325	250	D	D							
382	300									
437	350									
491	400									
544	450									
596	500									
648	550									
699	600									
749	650									
799	700									
848	750									
896	800									
944	850									
1,024	900									
1,115	950									
1,215	1,000									
1,315	1,050									
1,425	1,100									
1,525	1,150									
1,640	1,200									
1,760	1,250									
1,890	1,300									
2,020	1,350									
2,150	1,400									
2,300	1,450									
2,440	1,500									

October Exceedance flows at Structure 2 (90-10%) 59 to 348 cfs

Flows (cfs)		November						
		Migration-Spawning	Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D
168	120	D				D		
193	140	D				D		
218	160	D				D		
243	180	D				D		
266	200	D						
325	250	D						
382	300							
437	350							
491	400							
544	450							
596	500							
648	550							
699	600							
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

November Exceedance flows at Structure 2 (90-10%) 98 to 768 cfs

Flows (cfs)		Migration-Spawning	December Movement-Resident spawning, rearing					
USGS	Structure 2	Coho	Trout Adult	Whitefish Adult	Sucker Adult	Bull Trout Fluvial	Bull Trout Subadult	Juvenile Rearing
na	20	D	D	D	D	D	D	D
na	30	D	D	D	D	D	D	D
na	40	D	D	D	D	D	D	D
na	50	D	D	D	D	D	D	D
88	60	D	D	D	D	D	D	D
101	70	D	D	D	D	D	D	D
115	80	D	D	D	D	D	D	D
129	90	D	D	D	D	D	D	D
142	100	D	D	D	D	D	D	D
168	120	D				D		
193	140	D				D		
218	160	D				D		
243	180	D				D		
266	200	D						
325	250	D						
382	300							
437	350							
491	400							
544	450							
596	500							
648	550							
699	600							
749	650							
799	700							
848	750							
896	800							
944	850							
1,024	900							
1,115	950							
1,215	1,000							
1,315	1,050							
1,425	1,100							
1,525	1,150							
1,640	1,200							
1,760	1,250							
1,890	1,300							
2,020	1,350							
2,150	1,400							
2,300	1,450							
2,440	1,500							

December Exceedance flows at Structure 2 (90-10%) 103 to 517 cfs