Icicle Creek Instream Flow Study Plan for The Leavenworth National Fish Hatchery

AMENDED FINAL STUDY PLAN

Amendment reflects a 25% reduction in spatial extent of model only to account for budgetary shortfall.

Final 401 Certification Order No. 7192
Certification of the Leavenworth National Fish Hatchery (NPDES Permit No. WA-000-190-2) on Icicle Creek, Chelan County, Washington

Submitted to:
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Introduction

On January 7, 2010 the Washington Department of Ecology issued Order number 7192, in the matter of granting a Water Quality Certification to the U.S. Fish and Wildlife Service (USFWS) for the Leavenworth National Fish Hatchery (Leavenworth NFH). The certification includes limits and treatment requirements pertaining to water temperatures and fish habitat in Icicle Creek including an instream flow study to determine the effect of hatchery operations on fish habitat. This Study Plan describes the Leavenworth NFH's plans to evaluate fish habitat with an instream flow study as required in the Water Quality Certification. A prior study plan submitted to Washington Department of Ecology (WDOE) detailed plans to evaluate fish passage in Icicle Creek and is not discussed here, but the results of this instream flow study will be integral to the passage evaluations.

Instream Flow Study Planning

On November 15, 2010 an instream flow study approach and logistics meeting was held in Lacey, WA at the WDOE office. In attendance were representatives from WDOE-Water Resources Program, Washington Department of Fish and Wildlife (WDFW) Instream Flow Group, USFWS-Leavenworth NFH, USFWS Mid-Columbia River Fisheries Resource Office (MCFRO), and USFWS Columbia River Fisheries Program Office (CRFPO). The purpose of the meeting was to discuss possible project designs, considerations, model use, and development of a study plan to assess the potential impacts of hatchery operations on instream habitat. The results of the meeting are represented in this study plan.

Goal and Objectives

The overall goal of the Icicle Creek Instream Flow Study is to quantify habitat as a function of streamflow in the Icicle Creek historical channel (hereafter referred to as historical channel) for the relevant species/lifestages, to determine streamflows required to maintain channel structure, complexity, and physical habitat, and to provide guidance regarding the integration of the target species habitat needs into a range of options for the Icicle Creek historical channel hydrograph configuration.

<u>Objectives</u>

- Produce species/lifestage specific habitat – flow relationships using a two-dimensional (2-D) hydrodynamic model and a GIS cell-based habitat model.

- Produce spatially explicit maps depicting the distribution of good and high quality habitat for each species/lifestage for streamflows from 20 – 1500 cfs in the historical channel.

- Produce tabular and graphic results that quantify species/lifestage specific habitat for each flow and the corresponding incremental gains or losses over a range of flows.

➢ Estimate flushing flows, channel maintenance flows, and channel forming flows for the Icicle Creek historical channel.

➢ Integrate species-specific habitat-flow relationships to accommodate the habitat needs for multiple target fish species/lifestages that occur simultaneously in the Icicle Creek historical channel.

➢ Assist the stakeholders with options for hydrograph configuration to accommodate the range of hydrologic conditions that occur in the Icicle Creek drainage.

Project Description

The Leavenworth NFH 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 Leavenworth NFH was authorized by Congress as mitigation for fish losses associated with the construction of Grand Coulee Dam. Leavenworth NFH 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.

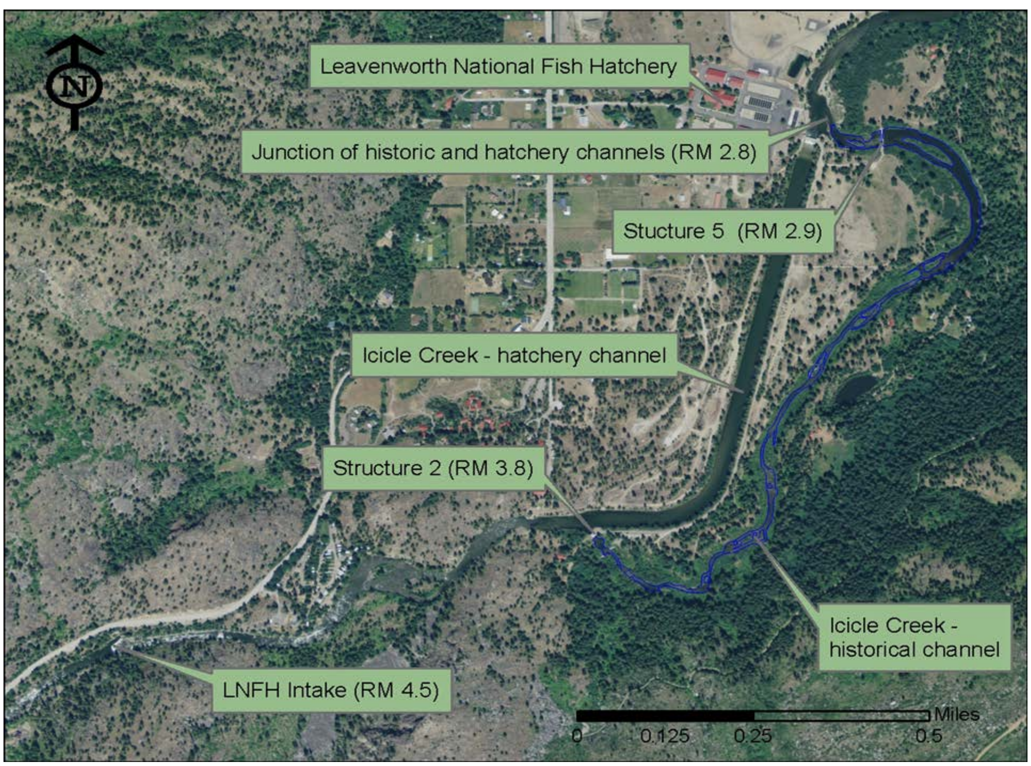

Figure 1. Project overview depicting the location of Leavenworth NFH, the hatchery intake, the Icicle Creek – historical channel, the Icicle Creek hatchery channel, and Structures 2 and 5.

Instream Flow Study Reach Description

The portion of Icicle Creek to be evaluated with an instream flow study is known as the Icicle Creek historical channel and extends approximately one mile from RM 2.8 to 3.8. Most of the historical channel will be modeled with the exception of the lower one quarter mile. The downstream model boundary requires a robust rating curve that is not hydraulically affected by other flow parameters (Icicle Creek – hatchery channel spillway or Wenatchee River backwater), islands, and/or artificial control structures (Structure 5). As such, the boundary will be upstream from the confluence of the Icicle Creek – hatchery channel (hereafter referred to as hatchery channel) and Structure 5. The reach to be modeled is depicted in Figure 2 and is the portion between the blue boundary lines. UPDATE: To account for a budgetary shortfall, the top 400 m of the study site near Structure 2 will be omitted from the hydrodynamic model; however estimates of fish habitat will still be made for the 400 m of stream using a weighting factor technique.

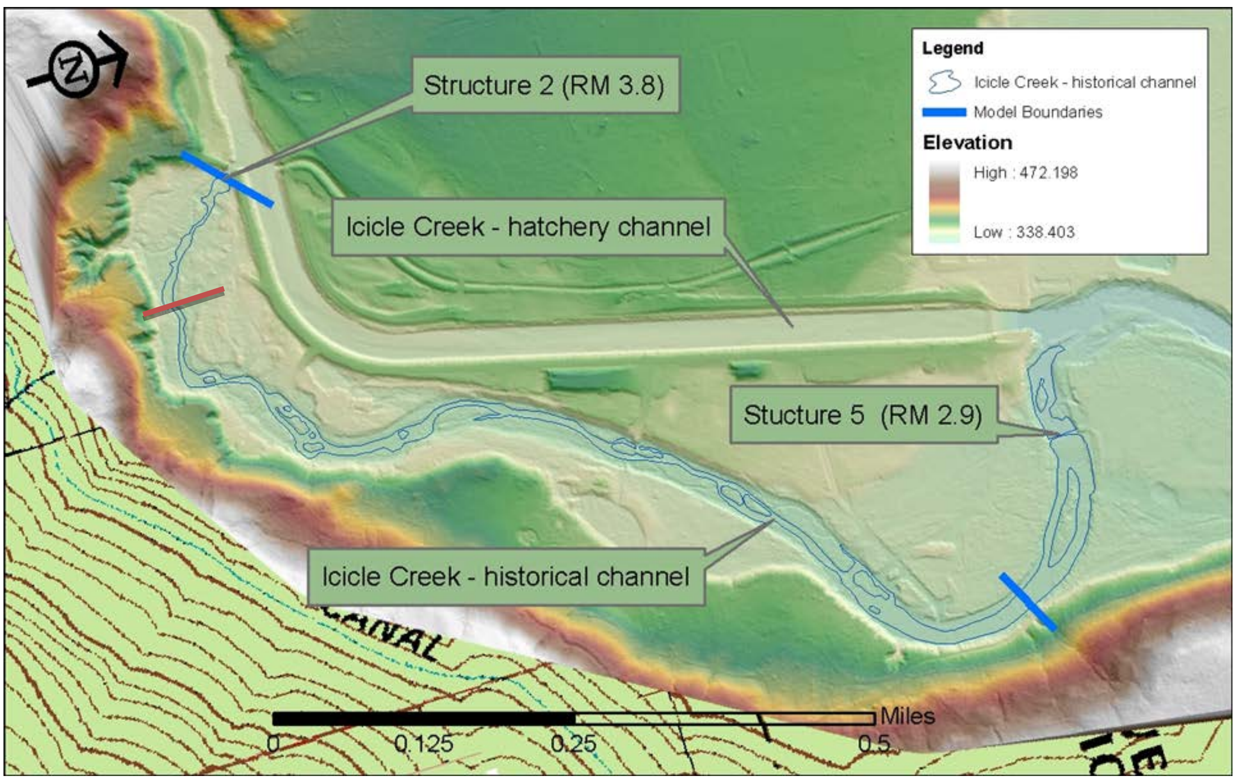

Figure 2. Overview of the instream flow study site. The Icicle Creek historical channel is outlined in blue and the blue bars depict the upstream and downstream boundaries of the instream flow study reach. (Red boundary line depicts the new upstream boundary, 400 m downstream of the original boundary at Structure 2.

In 1939, a series of small dams and control structures were built in the historical channel to function as an actual instream hatchery and to assist with the capture of migrating spring Chinook for hatchery broodstock. A separate channel (hatchery channel) was also built adjacent to the Icicle Creek historical channel (Figure 2) to control flows between the two channels for hatchery operations. This regulation of streamflow induced sediment deposition in the historical channel and led to subsequent colonization of the stream channel and banks by riparian plants (Lorang 2005). The historical channel was used for fish production from the 1940's to the late 1970's, and seasonally, as recently as 2005. In the 1970's, a modern off-channel hatchery with concrete raceways was constructed, and this is where most of the hatchery production currently occurs. The small dams have since been removed but two structures remain at the terminal ends of the Icicle Creek historical channel, Structures 2 and 5 (Figure 2). Due to the flow regulation, the historical channel has not benefited from channel forming flows and undercut banks are far more extensive than they otherwise might be (Jim Craig, pers. comm. 2010). Some historic sedimentation from the former dams also persists. Extensive undercut banks can be challenging to incorporate into a hydraulic model and alternative methods to represent them may require further discussion.

Hydrology

The Icicle Creek drainage is located on the eastern flanks of the Cascade Mountain Range and the hydrology encompasses an area of 193 square miles. Icicle Creek 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 3). Extremes for the period of record range from a minimum of 44 cubic feet per second (cfs) to a maximum of 19,800 cfs, and the mean annual flow is 613 cfs. The USGS gage at RM 5.8 is located above all major points of diversion. Icicle Creek streamflows below the USGS gage are altered by water diversions which reduce downstream flows. The City of Leavenworth and the Icicle-Peshastin Irrigation District divert water above the Snow Lakes trailhead (RM 5.7), and Leavenworth NFH and the Cascade Orchards diversion 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 the Icicle Creek historical channel and Leavenworth NFH, a supplementary water supply (~16,000 acre-feet) was developed in Upper Snow Lake, about seven miles upstream from Leavenworth NFH. Without the water release of approximately 50 cfs from Upper Snow Lake from early July through early October, the downstream reaches of the historical channel could go dry in some years.

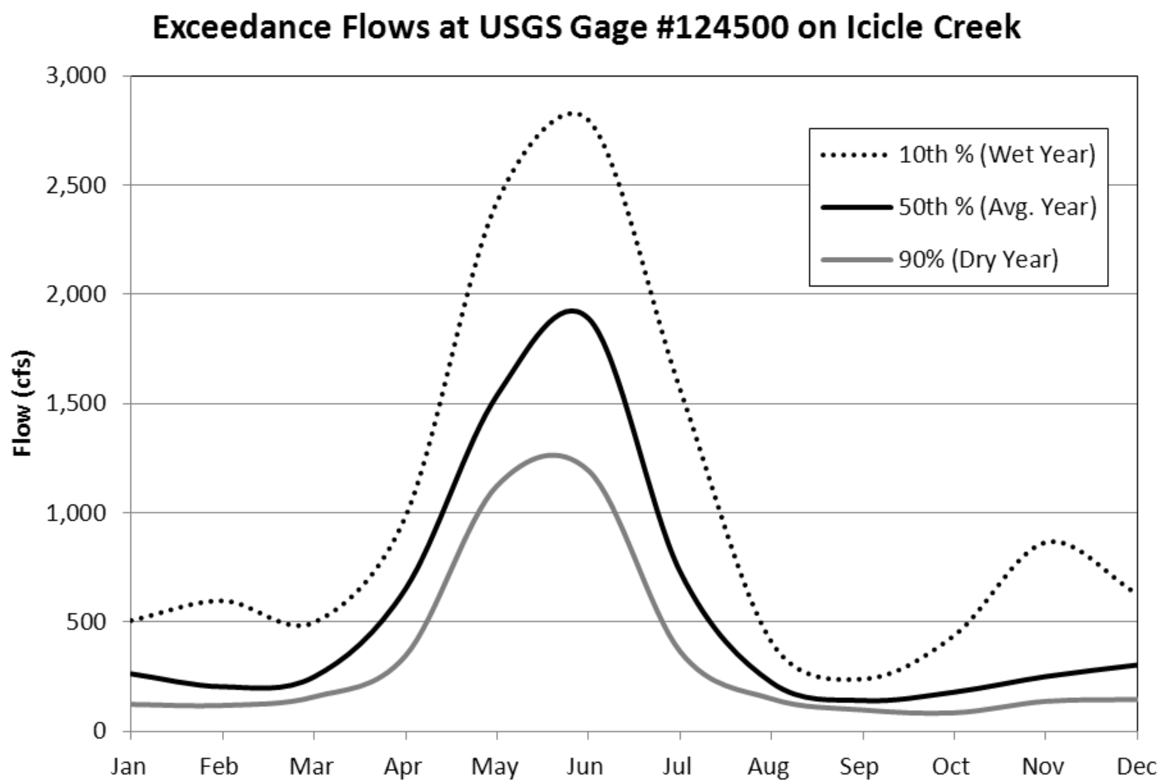

Figure 3. Exceedance flows as measured at USGS Gage #1245800 on Icicle Creek near Leavenworth, WA for an average, wet, and dry year for the period of record (1936 – 2010).

Hydrodynamic Model Introduction and Overview

The use of two-dimensional hydrodynamic models has gained wide use and acceptance in fisheries and instream flow assessments (Tharme 2003, Stewart et al. 2005, Mingelbier et al. 2008, Hatten et al. 2008, Lee et al. 2010, Waddle 2010, Ban et al. 2011). Two-dimensional flow models describe flow dynamics in two horizontal vectors whereas a one-dimensional model describes them in only one. Neither model calculates any difference in vertical conditions thus they are termed "depth-averaged" models. Transect based models do have some significant limitations. Representing a reach of stream with transects introduces ordinary statistical questions: is the sample of transects unbiased, and is it large enough to produce usefully precise estimates? Unfortunately, these questions are seldom considered in PHABSIM studies, even though most PHABSIM studies characterize streams with fewer than 15 transects (Williams 2010). Moreover, transect locations usually are selected deliberately, so estimates of available habitat will usually be biased (Williams 2010).

For the historical channel instream flow assessment, we will use the River2D hydrodynamic model (Ghanem et al. 1996, Steffler and Blackburn 2002) to simulate continuous surfaces of hydrologic parameters throughout the study site. These parameters will include depth, velocity, and water surface elevation. River2d is a two dimensional (2-D), depth averaged, finite element hydrodynamic model. As with other 2-D models, River2D uses three governing equations to solve for three unknowns; depth and mass flux in both the x and y directions. As well, the model has three basic assumptions.

1. The vertical pressure distribution is hydrostatic. This can potentially limit the accuracy of the model in areas of steep slopes and rapid changes of bed slopes. In general, bed features of horizontal size less than about 10 depths (typically dune formations) will not be modeled accurately.
2. The distributions of horizontal velocities over the depth are essentially constant (depth-averaged).
3. Wind and Coriolis forces are assumed negligible. These forces are only significant to very large bodies of water, the historical channel not being one of them.

Fundamental Concepts

Conservation of Mass. Mass conservation is the principal that at any point in the model, inflow of fluid matches outflow. This is evidenced by summing the mass flux in the x and y directions and setting the total mass flux equal to the change in depth over a smaller time increment. As such, if inflow is greater than outflow over a small time frame, the depth increases. If inflow equals outflow, the depth is unchanged, and so on. This approach is used in hydrodynamic models to allow simulation of unsteady flow conditions based on varying inflow and outflow.

Conservation of x- and y-direction momentum. A major contribution of 2-D flow models is the ability to represent physical forces acting on the fluid. Changes to the momentum in River2D are represented as a sum of forces. The forces include shear stresses, gravitation force and friction forces. The great advantage of this representation in rivers is evidenced by the representation of divided flow situations when compared to transect-based models. So where the historical channel contains islands, we can expect accurate flow representation from the 2-D model on all sides.

Frictional Forces. Friction in River2D is represented by a continuous surface or “skin” which is constructed directly from effective bed roughness height. Effective roughness height is used because it tends to remain constant over a wider flow range than other measures of roughness including Manning’s n and it can be approximated from dominant bed material.

The ability of River2D to accurately model supercritical flow and edge wetting is an additional advantage over transect based modeling. In the event that the historical channel study site has any supercritical flows we can be confident that the model will accurately simulate them. River2D uses a Petrov_Galerkin upwinding formulation to solve the flow-field. With this feature, the model can represent situations where upstream flow conditions limit the water surface at a downstream point. This enables the model to accurately simulate hydraulic conditions over sills, steep bars and other conditions that could possibly be present in the historical channel.

The historical channel study site may also have side channels that are only wet at certain discharges. This is a difficult process for numerical models and River2D has a unique and robust method of estimating this. The depth of flow is a dependent variable and is not known in advance when performing a two-dimensional flow simulation. As such, the horizontal range of the water coverage is therefore unknown. Additionally, significant computational difficulties are encountered when the depth is very shallow or it is dry at part of the modeled area. Various methods have been proposed to deal with this "edge wetting" problem. For example, some models simply neglect or drop out partially wet edge elements; others declare edge elements to be porous. The River2D model handles these occurrences by incorporating a simplified ground water model with the surface water model. In these wet/dry areas, the model changes the surface flow equations to groundwater flow equations. This allows a mesh element to have some nodes that are under surface water using the open-channel flow equation of mass conservation and some that are under the land surface using a sub-surface representation for mass conservation. A continuous free surface with positive (above ground) and negative (below ground) depths is calculated. This unique approach allows calculations to carry on without changing or updating the boundary conditions as water levels fluctuate.

Icicle Creek Hydrodynamic Modeling Methods

Hydrodynamic modeling methods will comprised of the following six steps:

1. Develop a digital elevation model (DEM) of the Icicle Creek historical channel study site
2. Collect hydrologic boundary data (paired inflow and outflow WSE's)
3. Collect representative roughness data
4. Develop a computational mesh
5. Calibrate and validate the flow model
6. Simulate unmeasured flows

1. Digital Elevation Model Development

River2D requires a digital elevation model (DEM) of the stream channel to build a computational mesh and simulate streamflows. The preexisting topographic information consists of LiDAR data collected in 2006 (Watershed Sciences 2006). LiDAR does not penetrate water and heavy vegetation so in those areas, other methods will be used to describe the topography and bathymetry of the stream channel and stream banks. For the wetted, in-channel portion of the study site we will use a combination of on the ground surveying techniques to collect topographic and bathymetric data including Real Time Kinematic (RTK) GPS, total stations, and hydroacoustic tools to collect data in deeper, unwadeable stream segments. Data will be collected along natural stream and channel breaks depicting the topography of the stream channel. Due to the dense overgrown riparian zone, surveying of stream channel and stream banks is expected to be more involved than a more open stream channel. As such, some of the surveys will be conducted in the late fall and early winter after leave drop. The final DEM, including data from all data sets, will be collected or reprojected into a common projection and coordinate system, Lambert Conformal Conic and Washing State-plane North, respectively. In addition, the Horizontal Datum, North American Datum of 1983 (NAD83) as well as the Vertical Datum, North American Vertical Datum of 1988 (NAVD88) will be used. All units for modeling purposes will be meters. Figure 4 depicts graphically how all the raw data is initially compiled and a DEM is subsequently produced.

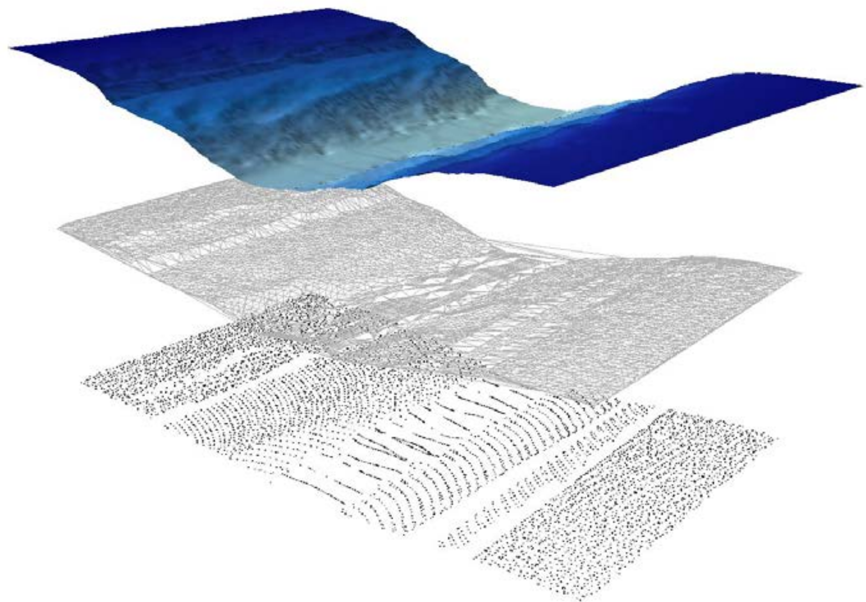

Figure 4. This example graphic depicts the process of building a DEM of the stream channel. The bottom plate depicts the raw data comprised of multiple field sampling techniques with each dot representing a single survey point with an X, Y and Z coordinate. The middle plate is an intermediate step whereas each point is geographically connected to neighboring points using a triangulated irregular network (TIN). The top plate depicts how the final DEM of the stream channel would look in a three dimensional context.

2. Collect Boundary Data (Paired inflow and outflow WSE's)

Efforts to collect representative boundary data are underway. Staff from both the USFWS, Water Resources Division and Leavenworth NFH have jointly been collecting hydrologic data in the historical channel in conjunction with other hydrologic evaluations related to hatchery operations. River2D requires two conditions for hydrodynamic simulation at a given discharge. These conditions include an inflow discharge at the upstream boundary and the paired downstream water surface elevation. Standard practice is to develop a rating curve so that all flow conditions between the lowest and highest flow can be simulated with the required data pairs (streamflow and water surface elevation).

3. Collect Representative Roughness Data

Frictional bed forces within a moving body of water have a direct effect on the fluids moving past them. Large boulders will slow water down more than small pebbles due their greater height into the water column (roughness height). River2D requires a skin or layer of roughness heights to accurately estimate hydrodynamic conditions. We will use measurements of substrate type and their associated roughness heights to characterize these conditions. Substrate will be mapped among classes matching WDFW's generic substrate codes (WDFW and WDOE 2008). The field effort will occur in conjunction with the topographic and bathymetric mapping.

4. Develop a Computational Mesh

The computational mesh, with its intersecting nodes is the numerical framework for which all the hydrodynamic computations both occur and are produced. In 2D hydrodynamic modeling, there is a trade-off between the density of nodes in the computational mesh, the required accuracy to represent the study site, and the time required to arrive at a solution for a single discharge. Generally, to obtain the best fit to the main channel and other significant or complex habitat areas, the mesh density will vary among locations and channel configurations (Figure 5). It is desirable to have a minimum of 8 to 10 nodes across channels carrying significant amounts of water to ensure the model can adequately convey flow downstream without calculating too much of the flow at any one node. The upstream and downstream model boundaries usually need to be subdivided into 20 or more nodes to again, ensure that no node carries too much of the computational burden. Some sites in the historical channel may have numerous side channels or large boulders and it may thus be necessary to increase the mesh/node density to capture and adequately represent the natural complexity.

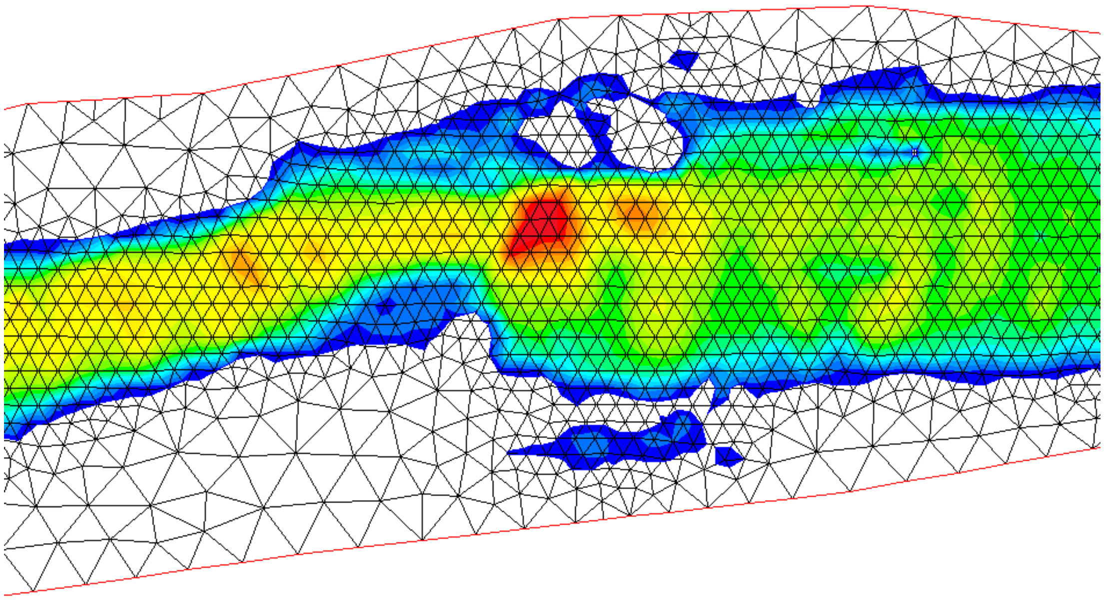

Figure 5. Example of a computational mesh with varying node densities across the channel. The intersections of the mesh elements (triangles) define the computation domain and are called nodes.

5. Calibrate and Validate the Flow Model

When compared to the real world all models contain some amount of error. In hydrodynamic modeling, this error can arise from assumptions built into the model itself, but predominantly, errors arise from misrepresentations of the stream channel (DEM). Most error results from an under-representation of the stream bathymetry, bed interpolation related errors, and/or actual errors in bathymetry measurement. In 2D hydrodynamic modeling, the general calibration process consists of calibrating the model to three separate and bounding conditions; a low, average, and high flow condition. This is done by comparing empirical field measurements of water surface elevation, velocity, and depth to the corresponding modeled calibration flows. Like many other models, roughness values are used to adjust the model output to more closely match measured conditions. In practice this is a balancing act given that an adjustment of water surface elevation will have a direct effect on velocities and depth. For the historical channel, we will run each of the three calibration flows to steady state convergence and then bed roughness will be adjusted for each specific calibration flow until we achieve the best match between observed and simulated water surface profiles. We will then compare observed and simulated velocities to determine if additional adjustment of roughness values is warranted. If additional adjustment is warranted, we will adjust roughness values to accomplish the best fit for matching both simulated water surface elevations and velocities to the empirical data. We propose to collect field data for model calibration and validation including water surface elevations every

100 m longitudinally (upstream to downstream) which equals 11 (formerly 15) sites, and velocity profiles every 300 m or 4 sites (formerly 5). We will use survey grade instruments to collect water surface elevations and an Acoustic Doppler Current Profiler (ADCP) to collect the velocity profiles perpendicular to the flow direction. After each calibration flow is adjusted to the best fit, production modeling will be completed, and model error for simulated depths and velocities relative to measured (empirical) depths and velocities will be quantified and reported as the root mean squared error (RMSE).

6. Simulate Unmeasured Flows

Once the model has been calibrated to the best fit, simulation of unmeasured flows can ensue. This is simply done by adjusting the boundary conditions (discharge and water surface elevation) of the nearest calibration flow to that of the unmodeled flow and running the model to solution. This process will be repeated until all unmeasured flows have been simulated.

Icicle Creek Habitat Modeling Methods

Integration of the results of hydrodynamic modeling and physical parameter distribution (substrate, cover, slope) with habitat preference or suitability criteria for the fish species/lifestages of interest is required to develop the relationship between streamflow and the amount, quality, and distribution of physical habitat. While some physical parameters remain largely fixed across a range of streamflows, the hydraulic parameters of depth and velocity vary, and the corresponding amounts and locations of species-specific habitat also vary.

Habitat suitability criteria (HSC) that define the suitability (on a scale of 0 to 1) of physical and hydraulic factors such as water depth and velocity, substrate, cover, slope and temperature can be developed in many forms ranging from frequency distributions of habitat use for each parameter, to complex models using combinations of parameters to predict the probability of habitat use. The WDFW and WDOE have compiled habitat preference curves for a wide range of species and lifestages in the publication, Washington State Instream Flow Study Guidelines (WDFW and WDOE 2008) that consist of observations of fish use relative to parameter availability. This approach more accurately describes selection of specific conditions, or preference for those conditions compared to simple frequency analysis of field observations (habitat utilization curves). By accounting for both habitat use and habitat availability, the resulting curves tend to be much less site-specific than utilization curves (Bovee 1986, Bovee and Zuboy *eds*. 1988).

HSC for the species/lifestages of interest in the historical channel will be compared to physical parameter characteristics and hydrodynamic modeling output for a range of streamflows in a GIS to produce coverages or maps of the distribution of suitable habitat as a function of habitat quality. Tabular output will also be produced to quantify the amount of habitat for each species/lifestage and streamflow.

Water temperature data for the study area will be compiled and compared to criteria for each species/lifestage to determine the approach to be used for integration of temperature suitability into overall habitat estimates. Although various water management actions associated with the water supply for Leavenworth NFH have been shown to have an effect on Icicle Creek water temperatures (Kelly-Ringel 2006, 2007; Hall and Kelly-Ringel 2011), constructing a temperature model to evaluate these effects on subsequent habitat characteristics is beyond the scope of this study.

Candidate Fish Species/lifestages

Fish species/lifestages to be evaluated for the historical channel instream flow study have been discussed by staff from the Leavenworth NFH, MCFRO and CRFPO, WDFW, and WDOE. The list of species/lifestages in Table 1 is a starting point for this study. We expect that during the review and comment period for this draft study plan, this list will be refined and the final study plan will define the species/lifestages to be evaluated.

Table 1. Candidate fish species/lifestages for habitat assessment in the Icicle Creek historical channel.

Species	**Lifestage**
Coho	Spawning Adult-holding Juvenile-rearing
Summer Chinook	Spawning Adult-holding Juvenile-rearing
Spring Chinook	Spawning Adult-holding Juvenile-rearing
Steelhead/rainbow	Spawning Adult-holding Juvenile-rearing
Bull trout	Adult-rearing Juvenile-rearing
Westslope Cutthroat	Spawning Adult-rearing Juvenile-rearing
Mountain whitefish	Spawning Adult-rearing Juvenile-rearing
Pacific lamprey	Spawning Adult
Largescale sucker	Spawning Adult-rearing Juvenile-rearing
Bridgelip sucker	Spawning Adult-rearing Juvenile-rearing

Icicle Creek Fish Periodicity

The various lifestages for each species occur in the historical channel during specific time periods. These time periods (Table 2) will be the focal point for physical conditions and habitat estimates for each species/lifestage.

Table 2. Periodicity for the candidate fish species/lifestages for habitat assessment in the Icicle Creek historical channel.

Species	Life-Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bull Trout	Adult-rearing	■	■	■	■	■	■	■	■	■	■	■	■
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Steelhead/ rainbow	Adult hold/rear	■	■	■	■	■	■	■	■	■	■	■	■
	Adult spawning				■	■	■						
	Incubation					■	■	■	■				
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Coho	Adult holding									■	■	■	■
	Adult spawning									■	■	■	■
	Incubation	■	■	■	■					■	■	■	■
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Summer Chinook	Adult holding								■	■	■		
	Adult spawning									■	■		
	Incubation	■	■	■	■					■	■	■	■
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Spring Chinook	Adult holding					■	■	■					
	Adult spawning							■	■	■			
	Incubation	■	■	■	■				■	■	■	■	■
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Mountain Whitefish	Adult spawning							■	■	■			
	Incubation	■	■	■	■				■	■	■	■	■
	Adult rearing	■	■	■	■	■	■	■	■	■	■	■	■
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Largescale sucker Bridgelip sucker	Adult spawning							■	■	■			
	Incubation	■	■	■	■	■			■	■	■	■	■
	Adult rearing	■	■	■	■	■	■	■	■	■	■	■	■
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Westslope Cutthroat	Adult spawning					■	■						
	Adult rearing	■	■	■	■	■	■	■	■	■	■	■	■
	Juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Lamprey	Adult holding	■	■	■			■	■	■	■	■	■	■
	Adult spawning				■	■	■						

Physical Parameters

Characterization of the component physical parameters and their spatial distribution is the primary task leading to an evaluation of habitat suitability. While some physical parameters remain fixed in space, others vary with streamflow. Depth and velocity are the primary variable parameters. Other parameters include: substrate, cover, slope and temperature. Depth and velocity will be produced from River2D (Figure 6), substrate and cover will be mapped in the field with survey grade GPS (RTK), and slope will be produced from the bathymetric surface (DEM). Dominant, sub-dominant and % dominant substrates will be consistent with WDFW's preference curves (Table 3). Water temperature will be obtained from Leavenworth NFH's thermographs placed in the historical channel. All of these parameters will be exported into ArcGIS for subsequent habitat assessment and quantification as individual habitat grids. The cell size of each grid will be one square foot.

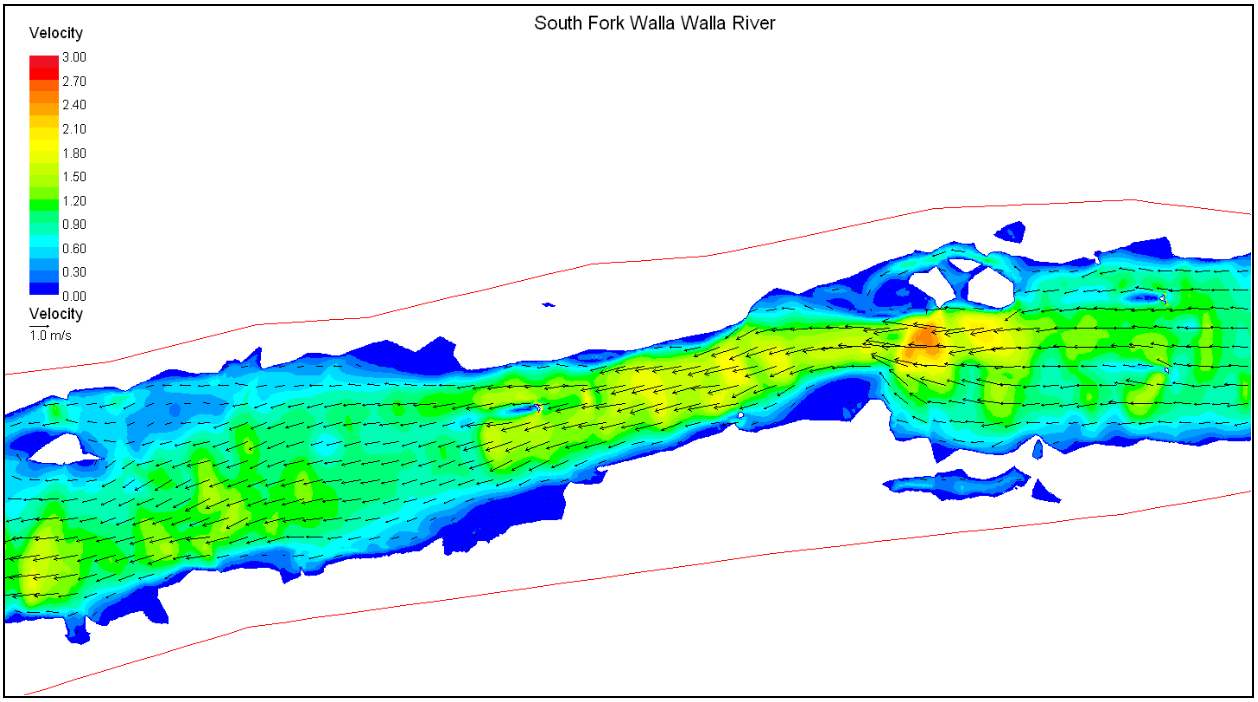

Figure 6. Example of velocity magnitude as produced from the River2D hydrodynamic model.

Table 3. Generic cover and substrate codes with preference values.

Substrate Code	Description	Size (inch)	Spawning				Rearing		Holding
			salmon	steelhead	resident trout	bull trout	fry	juv.	adult
1	silt, clay, or organic		0.00	0.00	0.00	0.00	0.10	0.10	0.10
2	sand		0.00	0.00	0.00	0.00	0.10	0.10	0.10
3	sm gravel	0.1 - 0.5	0.30	0.50	0.80	1.00	0.10	0.10	0.10
4	med gravel	0.5 - 1.5	1.00	1.00	1.00	1.00	1.00	0.30	0.30
5	lrg gravel	1.5 - 3.0	1.00	1.00	0.80	1.00	1.00	0.30	0.30
6	sm cobble	3.0 - 6.0	1.00	1.00	0.50	0.70	1.00	0.50	0.30
7	lrg cobble	6.0 - 12.0	0.50	0.30	0.00	0.70	1.00	0.70	0.30
8	boulder	>12.0	0.00	0.00	0.00	0.00	1.00	1.00	1.00
9	bedrock	NA	0.00	0.00	0.00	0.00	0.10	0.30	0.30

Cover Code	Description (Note: Cover codes are not used for spawning)	Rearing		Holding
		fry	juv	adult
00.1	undercut bank	1.00	1.00	1.00
00.2	overhanging vegetation	1.00	1.00	1.00
00.3	root wad (including partly undercut)	1.00	1.00	1.00
00.4	log jam/submerged brush pile	1.00	1.00	1.00
00.5	log(s) parallel to bank/Rip-rap	0.30	0.80	0.80
00.6	aquatic vegetation	1.00	0.80	0.80
00.7	short (<1') terrestrial grass	0.40	0.10	0.10
00.8	tall (>3') dense grass	0.70	0.70	0.10
00.9	vegetation beyond the bank-full waters edge	0.20	0.20	0.20

Habitat Suitability Criteria

We plan to use the State fallback HSC shown in Table 4 as a starting point for the historical channel habitat assessment. Alternative HSC identified prior to habitat modeling may be used, if appropriate. HSC are yet to be identified for several species/lifestages including Pacific lamprey and sucker spp. Following concurrence by the relevant entities on the species/lifestages to be modeled for the study, we plan to conduct a search to locate HSC where deficiencies exist. This will be conducted with input and approval from WDFW and WDOE.

Table 4. Candidate fish species/lifestages and fallback HSC curve set (WDFW and WDOE 2008; Appendix) for habitat assessment in the Icicle Creek historical channel (D-depth, V-velocity, S-substrate, C-cover).

Species	Lifestage	Preference Curve Sets
Coho	Spawning	Coho – D, V, S Generic Salmon – S
	Adult-holding	Adult Holding – C/S D, V??
	Juvenile-rearing	Coho – D, V Juvenile Salmon and Trout – C/S
Summer Chinook	Spawning	Generic Chinook – D, V Generic Salmon – S
	Adult-holding	Adult Holding – C/S D, V??
	Juvenile-rearing	Generic juvenile Chinook – D, V Juvenile Salmon and Trout – C/S
Spring Chinook	Spawning	Generic Chinook – D, V Generic Salmon – S
	Adult-holding	Adult Holding – C/S Spring Chinook – D, V
	Juvenile-rearing	Generic juvenile Chinook – D, V Juvenile Salmon and Trout – C/S
Steelhead/rainbow	Spawning	Steelhead – D, V, S
	Adult-holding	Adult Holding – C/S D, V??
	Adult-rearing (rainbow trout)	Resident rainbow trout juvenile/adult – D, V Juvenile Salmon and Trout – C/S
	Juvenile-rearing	Steelhead – D, V Resident rainbow trout juvenile/adult – D, V Juvenile Salmon and Trout – C/S
Bull trout	Adult-rearing	Bull trout/Dolly Varden juvenile/adult – D, V Juvenile Salmon and Trout – C/S
	Juvenile-rearing	Bull trout/Dolly Varden juvenile/adult – D, V Juvenile Salmon and Trout – C/S
Westslope Cutthroat	Spawning	Cutthroat – D, V Generic trout – S
	Adult-rearing	Cutthroat juvenile/adult – D, V Juvenile Salmon and Trout – C/S
	Juvenile-rearing	Cutthroat juvenile/adult – D, V Juvenile Salmon and Trout – C/S
Mountain whitefish	Spawning	D, V, S??
	Adult-rearing	Mountain whitefish adult – D, V C, S??
	Juvenile-rearing	Mountain whitefish juvenile – D, V C, S??
Pacific lamprey	Spawning	??
	Adult	??
Largescale sucker Bridgelip sucker	Spawning	??
	Adult-rearing	??
	Juvenile-rearing	??

Slope and water temperature are "macro" variables that are more or less important depending on the species/lifestage. Slope has commonly been used as a limiting factor on salmonid spawning habitat (Geist et al. 2000). In the absence of traditional suitability criteria and/or species-specific information, we may use binary criteria and a slope threshold. Water temperature suitability starts with species-specific criteria that may range from preferred to sub-lethal effects, to lethal levels. Water temperature criteria have been developed from both laboratory and field studies, most commonly for salmonid species. The approach we use for modeling temperature-conditioned physical habitat will depend on the nature of the available criteria.

Habitat Modeling

The framework for habitat modeling will originate from the computational mesh used to conduct the hydrodynamic modeling. The result of this modeling will be a grid of the historical channel with an anticipated cell size of one square foot. Each cell will be populated with the fixed parameters of substrate, cover, and slope, and the variable parameters of depth and velocity by flow. Water temperature will be characterized on a larger scale, depending on the nature of the empirical data. To generate continuous, spatially explicit habitat maps of the study area, these parameters will be compared to HSC for the species/lifestages of interest for streamflows from 20 – 1,500 cfs. Modeled flow increments will be 10 cfs at the lower end of the range, and 50 cfs at the higher end (Table 5).

Table 5. Proposed flows to model in the Icicle Creek historical channel.

Proposed Historical Icicle Creek Flows to Model (cfs)			
20	140	550	1,050
30	160	600	1,100
40	180	650	1,150
50	200	700	1,200
60	250	750	1,250
70	300	800	1,300
80	350	850	1,350
90	400	900	1,400
100	450	950	1,450
120	500	1,000	1,500

Output from the integration of HSC with physical and hydraulic parameters will consist of preferences, or suitability for each parameter. The product of these suitabilities is the composite suitability index or CSI for each cell. The CSI can range from 0.0 to 1.0, and is an index of habitat quality (Figure 7). We plan to produce habitat maps for two CSI bins at each modeled flow; 0.50 – 0.75, and 0.76 – 1.00. These could be defined as good quality habitat and high quality habitat, respectively. The process of combining all levels of suitable habitat (e.g. the worst with the best or weighted usable area – WUA), limits the interpretation of the results, and is of limited utility to managers. Tabular and graphic output will also be produced along with the two habitat maps for each species/lifestage at each flow.

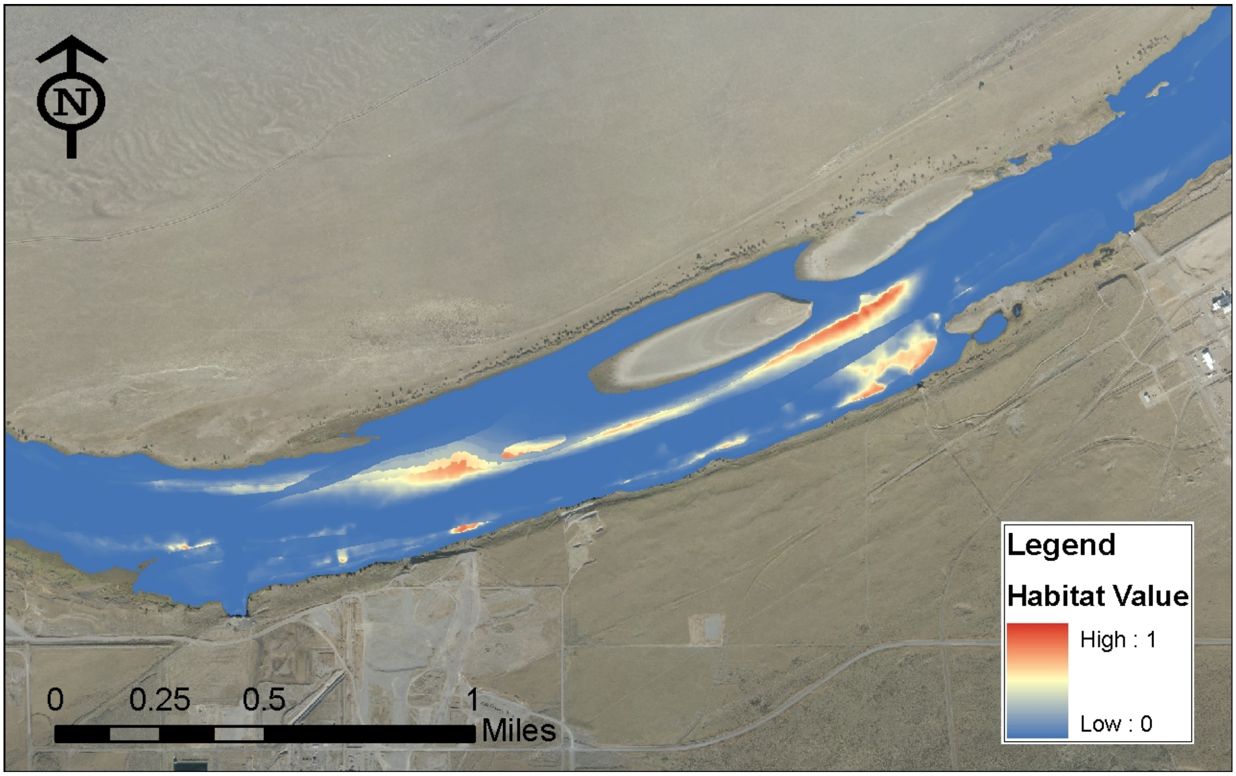

Figure 7. Example of composite suitability index values (CSI) for fish habitat with values ranging from 0.0 to 1.0.

Forty hydrodynamic simulations will be required for a range of flows from 20 – 1500 cfs (Table 5), and with a total of 28 candidate species/lifestages (Table 4) for habitat modeling, the result would be 1,120 habitat simulations. Even though the actual number of habitat simulations would likely be less than 1,120 because all lifestages would not be present across the entire range of flows, we may need to reduce the number of flows modeled, or focus the habitat modeling on a subset of species/lifestages to control the number of modeling iterations required.

Habitat Estimates – Top 400 m of Study Area omitted from physical and habitat modeling.

Estimates of fish habitat will be made for the 400 m of the study area omitted from direct modeling by using a traditional weighting factor technique. Based on an assessment of aerial photos, the omitted portion appears to be quite similar to the modeled portion of the study area. The weighting factor technique is similar to how estimates of habitat are expanded from cross section based models to the portion of the stream in between cross sections. Estimates of fish habitat will be calculated for the modeled section and a ratio of fish habitat to stream length will be derived. This ratio will then be multiplied by the 400 m section not modeled to produce estimates of habitat for each species and lifestage for the entire study site originally proposed.

Channel Maintenance flows

Channel maintenance flows are comprised of higher streamflows that generally occur at a lower frequency in a natural, unaltered hydrograph, but are important for maintaining the geomorphology and physical channel structure and form which supports the ecological function of the stream network. These lower frequency, higher flows maintain the basic physical characteristics that comprise physical habitat for the biological community. They provide functions important for stream habitat such as channel flushing, sediment transport, wood recruitment, and maintenance of riparian and floodplain habitat (Wald 2009). Instream flow recommendations for high flows should include high flow pulses and flushing flows for in-channel functions, channel maintenance flows for in-channel and riparian functions, and channel forming flows for side-channel and floodplain functions (Wald 2009).

Channel maintenance flows are typically derived using either of two basic methods. Analysis of empirical streamflow data from gaging stations can provide statistics such as mean annual discharge and streamflow frequency, duration, and recurrence interval. These statistics have been used in a number of different methodologies for developing channel maintenance flows (e.g. Tennant 1975, Wesche and Rechard 1980, Orsborn 1982, Rosgen 1982). The second basic method is based on the relationship between hydraulic forces and the physical characteristics of the stream channel and existing substrate, or sediment. It consists of determining the force (velocities and streamflow) required to mobilize and entrain various sediment sizes.

For streams in the State of Washington, Wald (2009) recommends three different levels of streamflow for maintaining channel function and floodplain processes, creating and maintaining physical habitat, and facilitating fish migration and flushing fines from the stream channel for maintenance of spawning and rearing habitat. His recommendations include the following specific guidance (Wald 2009):

<u>*Fish migration and spawning flows*</u> *– High flow pulses to facilitate salmon spawning and migration should provide adequate water temperature, sufficient flow depth, appropriate seasonality and diurnal conditions, and sufficient flow duration for adult fish to migrate upstream to suitable spawning or holding areas and for juvenile fish to migrate downstream when necessary.*

<u>*Flushing flows*</u> *– Flushing flows to improve gravel quality for spawning and incubation habitat provide the greatest benefit when they occur at the beginning of spawning seasons. Flushing flows in the fall remove organic matter and fines that accumulate during the summer. Flushing flows in the spring provide migration flows while they reduce the amount of fines in spawning gravels. The author recommends preserving or providing the mean annual discharge as a flushing flow for 6 to 12 hours duration during specified seasons and at intervals of at least 2 per year if not provided naturally.*

<u>*Channel maintenance flows*</u> *– Channel maintenance flows for activating geomorphic processes are greater in magnitude and duration than flows necessary for initiation of bedload movement.*

The author recommends preserving or providing the 2-year frequency peak flow or 200% of mean annual discharge for at least 24 hours duration at specified seasons as a channel maintenance flow at intervals of 2 years if not provided naturally. Release rates should be controlled according to specified ramping rates (Hunter 1992).

<u>*Channel forming flows*</u> *– The author recommends preserving or providing the 10-year frequency peak flow for at least 24 hours duration at specified seasons as a channel forming flow at intervals of 10 years if not provided naturally. Release rates should be controlled according to specified ramping rates (Hunter 1992).*

We plan to follow Wald's (2009) guidelines for developing the historical channel, channel maintenance flows in the historical channel. *Fish migration and spawning flows* will be developed using results from our hydrodynamic modeling and species-specific passage criteria. *Flushing flow, channel maintenance flow, and channel forming flow* recommendations will be developed from analysis of the hydrograph at the USGS Gage #12458000, Icicle Creek above Snow Creek near Leavenworth, Washington. This will include an assessment accounting for the apportion of flows that are diverted away from the historical channel by Structure 2 and the hatchery channel which may functionally limit the effect of channel flushing, channel maintenance and channel forming a flows.

Species/lifestage priority

Prioritizing species/lifestages is a step that may be required to develop flow recommendations following completion of the habitat analysis. Two approaches to accommodate multiple species/lifestages during the same time period are flow balancing, or prioritization. Flow balancing consists of optimizing the recommended flow for a given time period without significantly compromising habitat conditions for any single species/lifestage. Prioritization is developing a flow recommendation based on the relative "importance" of several species/lifestages that occur simultaneously during the same time period.

If this step is required, we will develop the balancing approach or prioritized list of species/lifestages in concurrence with the WDFW, WDOE, NOAA, USFWS, USBOR and other relevant stakeholders in this process.

Instream Flow Study Implementation Schedule

Table 6 describes the tasks and associated work schedule proposed to complete the instream flow study from the initial field work to a final report. This is a draft schedule and tasks are subject to change with respect to flow and weather conditions on the study site. For several months of the year, the entire study site is usually under snow, thus limiting field work. Field staff will attempt to complete work around the winter snow season.

Table 6. Proposed Icicle Creek historical channel Instream Flow study implementation schedule.

Task	*Oct-2011*	*Nov-2011*	*Dec-2011*	*Jan-2012*	*Feb-2012*	*Mar-2012*	*Apr-2012*	*May-2012*	*Jun-2012*	*Jul-2012*	*Aug-2012*	*Sep-2012*	*Oct-2012*	*Nov-2012*	*Dec-2012*	*Jan-2013*
Initiation of Study	■															
Collect Model Boundary Data (S/Q pairs)	■		■		■				■	■						
Collect Bathymetry, Substrate and Cover	■	■			■	■		■	■							
Collect WSE & Velocity Validation Data	■	■						■	■							
DEM & Mesh Production									■	■						
Model Validation & Calibration										■						
Simulate Unmeasured Flows											■					
Physical Parameters - GIS		■				■						■				
Habitat Quantification by Spp. / Q													■	■		
Report Production															■	
Final Report Due Jan 7, 2013																■

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