FA-05 SKAGIT RIVER GORGE BYPASS REACH HYDRAULIC AND INSTREAM FLOW MODEL DEVELOPMENT STUDY INTERIM REPORT

SKAGIT RIVER HYDROELECTRIC PROJECT FERC NO. 553

Seattle City Light

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Initial Study Report

TABLE OF CONTENTS

Section No.	Description	Page No.

List of Figures

List of Tables

Table No. **Description** **Page No.**

List of Attachments

List of Acronyms and Abbreviations

2-D	two-dimensional
ADCP	acoustic Doppler current profiler
ADV	acoustic Doppler velocimeter
cfs	cubic feet per second
City Light	Seattle City Light
DEM	Digital Elevation Model
Ecology	Washington State Department of Ecology
ESH	effective spawning habitat (model)
FAA	Federal Aviation Administration
FERC	Federal Energy Regulatory Commission
ft	foot/feet
GIS	Geographic Information System
GPS	Global Positioning System
HDR	HDR Engineering, Inc.
HEC-RAS	Hydrologic Engineering Center River Analysis System
HSC	habitat suitability criteria
IFIM	Instream Flow Incremental Method
ISR	Initial Study Report
LiDAR	Light Detection and Ranging
LP	licensing participant
LSPIV	Large Scale Particle Image Velocimetry
NAVD 88	North American Vertical Datum of 1988
NHC	Northwest Hydraulic Consultants, Inc.
PRM	Project River Mile
Project	Skagit River Hydroelectric Project
QSI	Quantum Spatial, Inc.
RSP	Revised Study Plan
RTK	real-time kinematic
SfM	Structure from Motion
SZF	stage of zero flow
UAV	unmanned aerial vehicle

USACE ......................U.S. Army Corps of Engineers

USGS .........................U.S. Geological Survey

USR............................Updated Study Report

WDFW.......................Washington Department of Fish and Wildlife

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1.0 INTRODUCTION

The FA-05 Skagit River Gorge Bypass Reach Hydraulic and Instream Flow Model Development Study (Bypass Instream Flow Model Development Study) is being conducted in support of the relicensing of the Skagit River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 553, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (City Light) on April 7, 2021 (City Light 2021). On June 9, 2021, City Light filed a "Notice of Certain Agreements on Study Plans for the Skagit Relicensing" (June 9, 2021 Notice)[1] that detailed additional modifications to the RSP agreed to between City Light and supporting licensing participants (LP) (which include the Swinomish Indian Tribal Community, Upper Skagit Indian Tribe, National Marine Fisheries Service, National Park Service, U.S. Fish and Wildlife Service, Washington State Department of Ecology [Ecology], and Washington Department of Fish and Wildlife [WDFW]). The June 9, 2021 Notice included agreed to modifications to the Bypass Instream Flow Model Development Study.

In its July 16, 2021 Study Plan Determination, FERC approved the Bypass Instream Flow Model Development Study without modification.

This interim report on the 2021 study effort is being filed with FERC as part of City Light's Initial Study Report (ISR). City Light will perform additional work for this study in 2022 and include a report in the Updated Study Report (USR) in March 2023.

[1] Referred to by FERC in its July 16, 2021 Study Plan Determination as the "updated RSP."

2.0 STUDY GOALS AND OBJECTIVES

The goal of the Bypass Instream Flow Model Development Study is to develop a flow/habitat evaluation tool for the Gorge bypass reach (defined as the reach between Gorge Dam and Gorge Powerhouse) and to develop hydraulic data necessary to support an evaluation of fish passage at two locations in the Gorge bypass reach.

Specific objectives include:

- Develop and calibrate a numerical hydraulic model (or models) of the Gorge bypass reach.
- Integrate hydraulic model outputs and observed characteristics of substrate and cover with biological (fish species, life stages, periodicities) and physical (depth, velocity) criteria to develop flow-habitat relationships for the Gorge bypass reach.
- Apply the model to provide hydraulic data to support the evaluation of fish passage, particularly at two previously identified potential upstream passage barriers[2] (Envirosphere 1989) within the Gorge bypass reach located approximately 0.6 and 1.3 miles upstream from Gorge Powerhouse.

Once the study is complete (i.e., the model has been developed), the flow/habitat model will be used to support additional discussions regarding hydraulic conditions and aquatic habitat within the Gorge bypass reach, the potential for fish passage at Gorge bypass reach existing features and, through integration with results from the FA-02 Instream Flow Model Development Study[3] (City Light 2022a), evaluation of instream flows in the mainstem Skagit River between Gorge Dam and the Sauk River.

In the following sections of this study report, two distinct models are discussed as part of the Bypass Instream Flow Model Development Study: (1) the hydraulic model of the Gorge bypass reach, referred to as the Bypass Hydraulic Model; and (2) the habitat model, which integrates hydraulic model output with habitat data, referred to as the Bypass Habitat Model.

The June 9, 2021 Notice commitments addressed in the Bypass Instream Flow Model Development Study are summarized below:[4]

- City Light will provide a planned higher flow event (4,000+ cubic feet per second [cfs]) in summer/fall if opportunistic high flow is not available. Data collected during this event will be used in calibration of the Bypass Hydraulic Model and in evaluation of fish passage under the FA-04 Fish Passage Technical Studies Program (Fish Passage Study; City Light 2022b). The report for the FA-04 Fish Passage Study will include an assessment of the impacts to fish migration, both beneficial and detrimental, of certain flow regimes.

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2 The potential upstream passage barriers are boulder cascades which, following discussion with LPs, are referred to in the study report as Existing Feature 1 and Existing Feature 2.

3 The FA-02 Instream Flow Model Development Study will develop an instream flow model for the mainstem Skagit River from Gorge Powerhouse to the confluence with the Sauk River.

4 A complete listing of June 9, 2021 Notice commitments related to the Bypass Instream Flow Model Development Study is provided in Section 6.0 of this study report.

- City Light and LPs will be treating Pacific Lamprey (*Entosphenus tridentatus*), Salish Sucker (*Catostomus catostomus*), and Dolly Varden (*Salvelinus malma*) as present in the Gorge bypass reach. City Light and LPs will be selecting species for habitat suitability criteria (HSC) analysis.

3.0 STUDY AREA

The study area extends from the Gorge Dam plunge pool at about Project River Mile (PRM) 97.15 downstream to the U.S. Geological Survey (USGS) Skagit River at Newhalem gage (USGS gage 12178000), approximately 0.5 miles downstream from Gorge Powerhouse at PRM 94.25 (Figure 3.0-1). Reach length is approximately 2.9 miles. The study area is coincident with the extents of the Bypass Habitat and Bypass Hydraulic Models (Table 3.0-1).

Table 3.0-1. Model longitudinal extents.

Model	Lower Extent	Upper Extent	Distance (miles)
Bypass Habitat Model	USGS gage Skagit River at Newhalem, WA (USGS #12178000) at PRM 94.25	Gorge Dam plunge pool at PRM 97.15	2.9
Bypass Hydraulic Model	USGS gage Skagit River at Newhalem, WA (USGS #12178000) at PRM 94.25	Gorge Dam plunge pool at PRM 97.15	2.9

The downstream limit of the hydraulic model, i.e., the USGS Skagit River at Newhalem gage, was selected to allow use of the stage-discharge rating at the gage site as a robust downstream model boundary and to overlap with the Upper Skagit Hydraulic Model which extends from just above Gorge Powerhouse at PRM 94.75 to the USGS gage Skagit River above Miller Creek near Rockport (USGS 12189700) at PRM 64.95 and is being developed under the FA-02 Instream Flow Model Development Study (City Light 2022a).

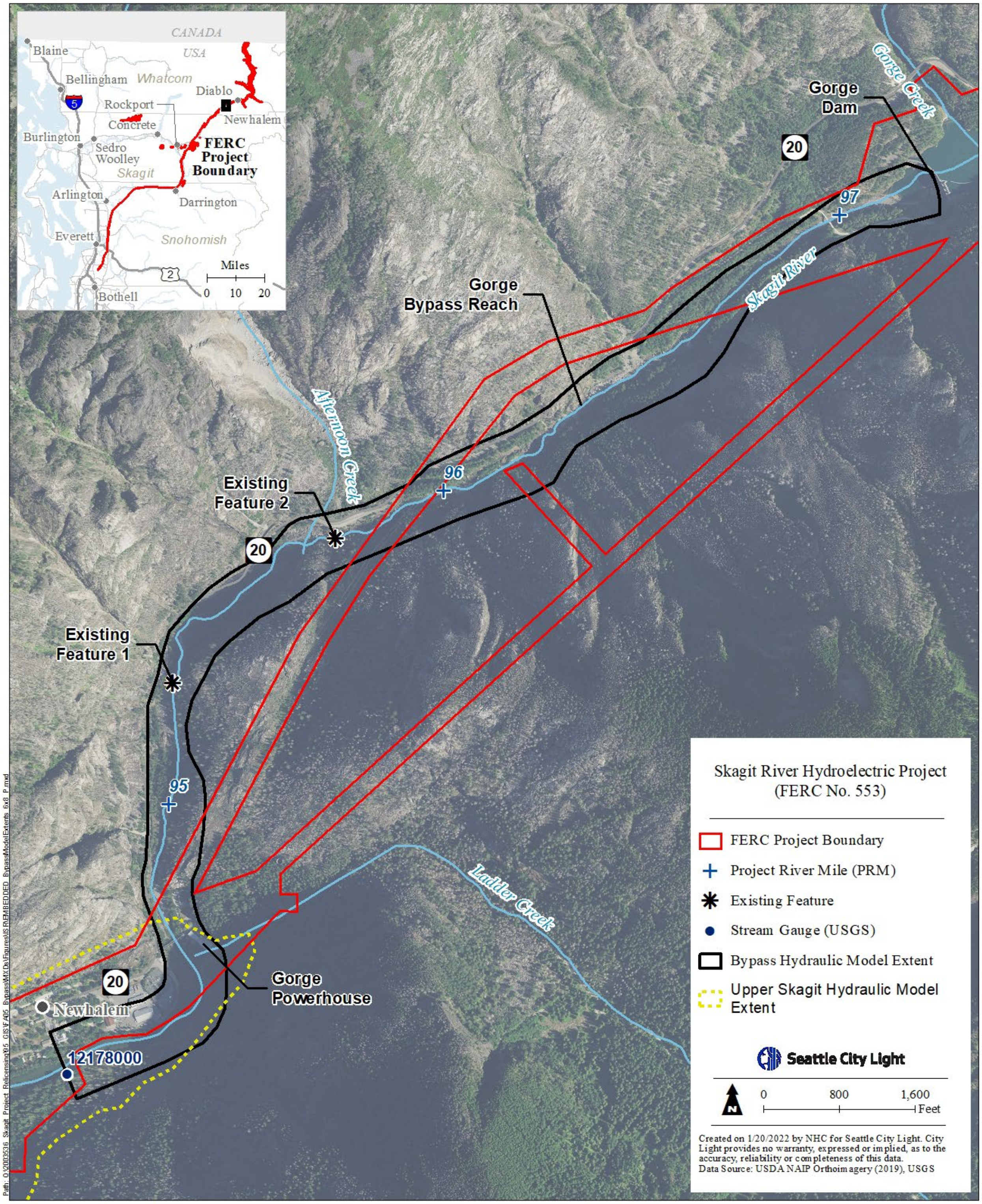

Figure 3.0-1. Overview of study area for the Bypass Instream Flow Model Development Study.

4.0 METHODS

4.1 Overview

Creation of a flow/habitat evaluation tool for the Gorge bypass reach involves the development and application of a two-dimensional (2-D) hydraulic model and HSC to analyze instream flows. The same 2-D hydraulic model (the Bypass Hydraulic Model) will also support fish passage evaluation at Existing Features 1 and 2 (Figure 3.0-1). Details concerning data collection and development efforts for the numerical model are provided in the following sections.

4.2 Data Collection

The primary components required to build a 2-D numerical model for instream flow assessment include topographic and bathymetric data, hydrologic and hydraulic data observations for model calibration, substrate mapping, and cover mapping. The following sections detail the collection and preparation of this information.

4.2.1 Topographic and Bathymetric Data

Three-dimensional terrain mapping was necessary to develop a detailed topographic surface of the river channel and overbank regions for import to the Bypass Hydraulic Model. A combination of topobathymetric Light Detection and Ranging (LiDAR) and standard LiDAR returns covering the Bypass Hydraulic Model domain were acquired as follows:

- Quantum Spatial, Inc. (QSI) topobathymetric LiDAR ("green LiDAR") contracted by City Light; acquired April 25 and 26, 2018 (QSI 2018). Topobathymetric LiDAR includes both topographic (out-of-water) and bathymetric (underwater) terrain as observed during the time of survey; and
- Quantum Spatial, Inc. topographic LiDAR ("standard" LiDAR) contracted by USGS; acquired March 2016 – September 2016 (QSI 2017).

The 2018 topobathymetric LiDAR data have an absolute non-vegetated vertical accuracy of 0.182 feet with 95 percent confidence for topographic points and a vertical accuracy of 0.366 feet with 95 percent confidence for submerged bathymetric check points. The 2016 standard LiDAR returns have an absolute non-vegetated vertical accuracy of 0.263 feet with 95 percent confidence. Full details of the LiDAR resolution and accuracy assessments can be found in the LiDAR technical data reports (QSI 2017, 2018).

The 2018 topobathymetric LiDAR was the primary terrain source for the Bypass Hydraulic Model as it provided high resolution topography and bathymetry for almost the entire study area. There are, however, several locations where underwater voids exist, either because turbid water, deep water, aerated water, vegetation cover, and/or a non-reflective channel bottom prevented adequate laser returns. These voids in the bathymetry are located at:

- A deep pool proximately 1.4 miles upstream of Gorge Powerhouse;
- The Gorge Powerhouse tailrace; and

- A short stretch of deep water between the Gorge Powerhouse and the USGS Skagit River at Newhalem gage.

The three void areas were filled by interpolating from LiDAR returns bordering each void and/or professional judgment, which likely underestimates true depth to an unknown degree. However, each of these void locations represent deeper pools under base-flow conditions where these terrain errors will not significantly impact hydraulic model results or unduly skew habitat modeling.

Four locations in the 2018 LiDAR were also identified that did not extend far enough to provide complete coverage of the channel edge and/or overbank for modeling high flows (Figure. 4.2-1). Where this is the case, the 2016 LiDAR was used to extend the data coverage as discussed in the Upper Skagit River Green LiDAR Reclassification memorandum, Attachment A (HDR Engineering, Inc. [HDR] 2022a). Use of less detailed topographic information in the extended areas is adequate as terrain features in these areas have a negligible impact on hydraulic model results and habitat modeling.

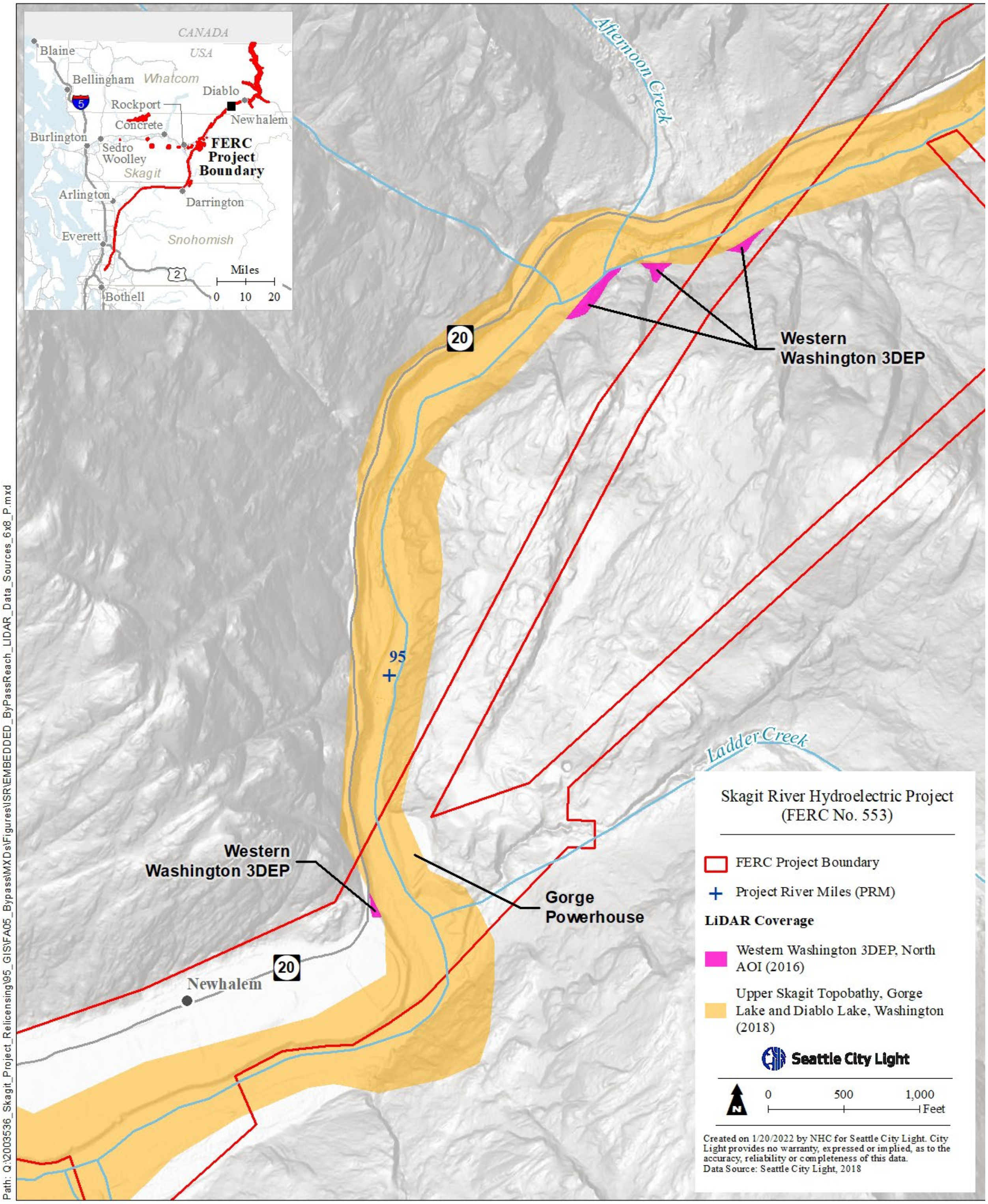

Figure 4.2-1. Terrain areas extended with 2016 LiDAR.

4.2.2 Hydrologic and Hydraulic Data

Development of the Bypass Hydraulic Model required both the collection of discharge and stage records to define model boundaries, and field observations of hydraulic characteristics to calibrate and validate the model. Collection of this information for the Gorge bypass reach was conducted during the summer and fall of 2021. Controlled spillway releases were chosen in consultation with LPs and coordinated with Gorge Dam operators from July 26-29, 2021, during an intensive field data collection effort. Stable daily flows of approximately 1,200, 500, 250, and 50 cfs were targeted for this period. An unplanned spillway release with flows exceeding 6,000 cfs occurred in late-June 2021, allowing for additional measurements at the Existing Features to extend model calibration in these areas. The following sections describe the collection and processing of hydrologic information and the coinciding field efforts to obtain hydraulic observations.

4.2.2.1 Hydrology

Hydrologic data collection for the Gorge bypass reach included acquisition of operational records of releases (spill) at Gorge Dam, stage and discharge records for the USGS Skagit River at Newhalem gage, and field measurements of stage and discharge. The primary hydrologic inputs to the Gorge bypass reach are flow releases from Gorge Dam, while discharge from Gorge Powerhouse, and stage at the USGS Skagit River at Newhalem gage, control conditions at the downstream end. Flow records for Gorge Dam spillway operations were provided by City Light while stage and discharge records for the USGS gage were obtained online from the USGS National Water Information System website. Discharges from Gorge Powerhouse were determined by computing the difference between releases from Gorge Dam and corresponding discharge at the USGS Skagit River at Newhalem gage.

Controlled releases from Gorge Dam were made by operating one spillway gate for the targeted releases of 1,200, 500, and 250 cfs, and by operating the Gorge Dam log chute for the targeted release of 50 cfs. To provide the targeted releases of 1,200, 500, and 250 cfs required very small gate openings (for example, of the order of 3 inches for a 500 cfs release), determined from computations based on the established spillway gate ratings. The actual release, as opposed to the target release, is sensitive to uncertainty in the precise opening of the spillway gate at small gate openings. Similarly, release via the log chute is sensitive to fluctuations in reservoir levels. Therefore, discharge was measured at five cableway transects selected in consultation with LPs, and at the bridge immediately below Gorge Dam to determine the actual flow during each controlled release event for input to the Bypass Hydraulic Model. Discharge measurement methods for the July 26-29, 2021 controlled releases are documented in the Gorge Bypass Reach Data Collection for Hydraulic Model Calibration memorandum, Attachment B (Northwest Hydraulic Consultants, Inc. [NHC] 2022a) and evaluation of associated uncertainty with these measurements is discussed in the Gorge Bypass Reach Discharge Measurement Uncertainty Analysis memorandum, Attachment C (NHC 2022b).

Tributary inflows between Gorge Dam and the USGS Skagit River at Newhalem Gage include Afternoon Creek and Ladder Creek; both ungaged. These tributaries provided negligible inflow during dry summer conditions when field data was collected. To bracket the contribution of these tributaries, discharge measurements were made at base flow conditions (no spill from Gorge Dam) on July 30, 2021. Measured base flow within the Gorge bypass reach was approximately 4 cfs.

4.2.2.2 Hydraulics

Field data collection efforts for hydraulic information throughout the Gorge bypass reach consisted of (1) water level logger recordings; (2) acoustic Doppler current profiler (ADCP) and acoustic Doppler velocimeter (ADV) transect surveys; and (3) unmanned aerial vehicle (UAV) photography and videography. This section summarizes the planning, application, and observations made with these technologies, while a more detailed discussion is provided in Attachment B.

Water level loggers

Onset HOBO U20 water level loggers were installed in May 2021 to measure water stage at Existing Features 1 and 2. The purpose of these data are to both support hydraulic model development and the FA-04 Fish Passage Study; (City Light 2022b). During Spring 2021, members of both the FA-04 Fish Passage Study and Bypass Instream Flow Model Development study teams visited Existing Features 1 and 2 at base-flow conditions, and during a spillway release of approximately 1,200 cfs, to identify installation locations that represent nominally stable pools and that connect a longitudinal water surface profile along the entirety of each feature. To achieve these objectives, six locations were identified at each feature (Figures 4.2-2 and 4.2-3). Level loggers began recording data on May 27, 2021, at 10-minute intervals through July 2021, at which point the recording interval was changed to 5 minutes. Figures 4.2-4 and 4.2-5 show processed water surface elevation records for the late-June/early-July 2021 unplanned spill. The corresponding spill discharges reported by City Light are shown in Figure 4.2-6. Figures 4.2-7 and 4.2-8 show processed water surface elevation records for the July 26-29, 2021 controlled releases.

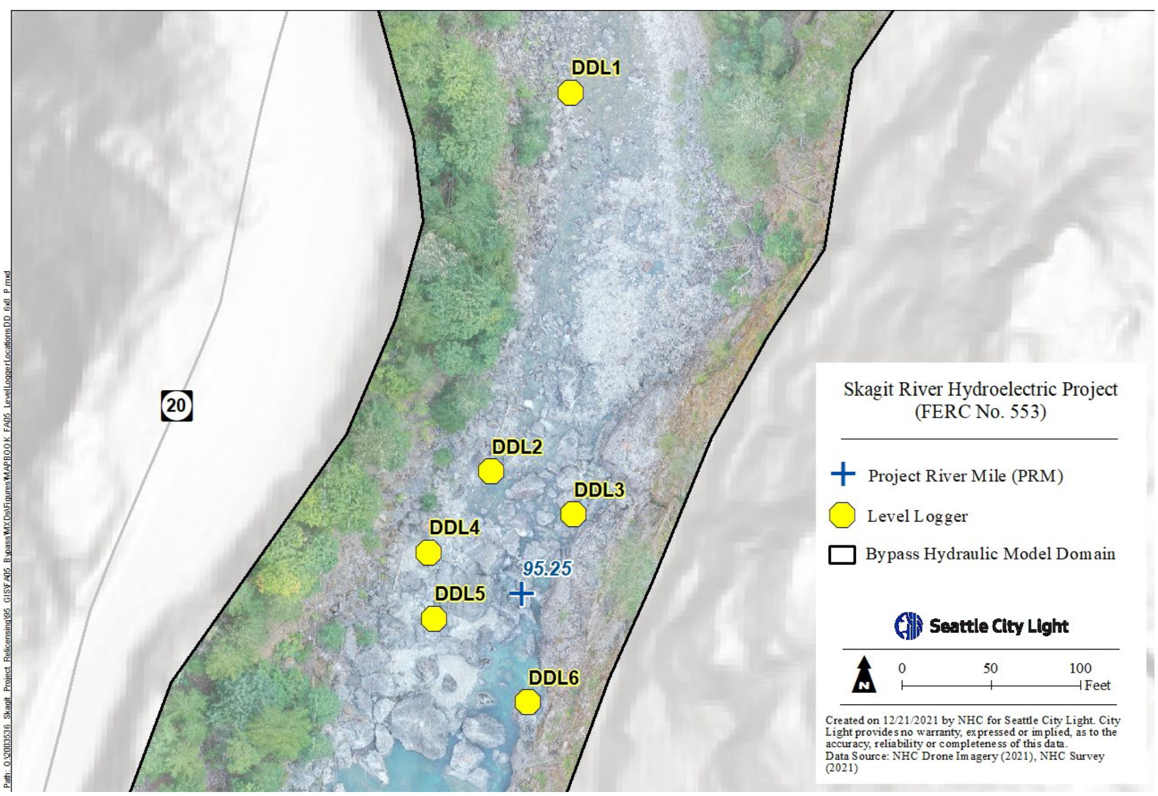

Figure 4.2-2. Level logger locations at Existing Feature 1.

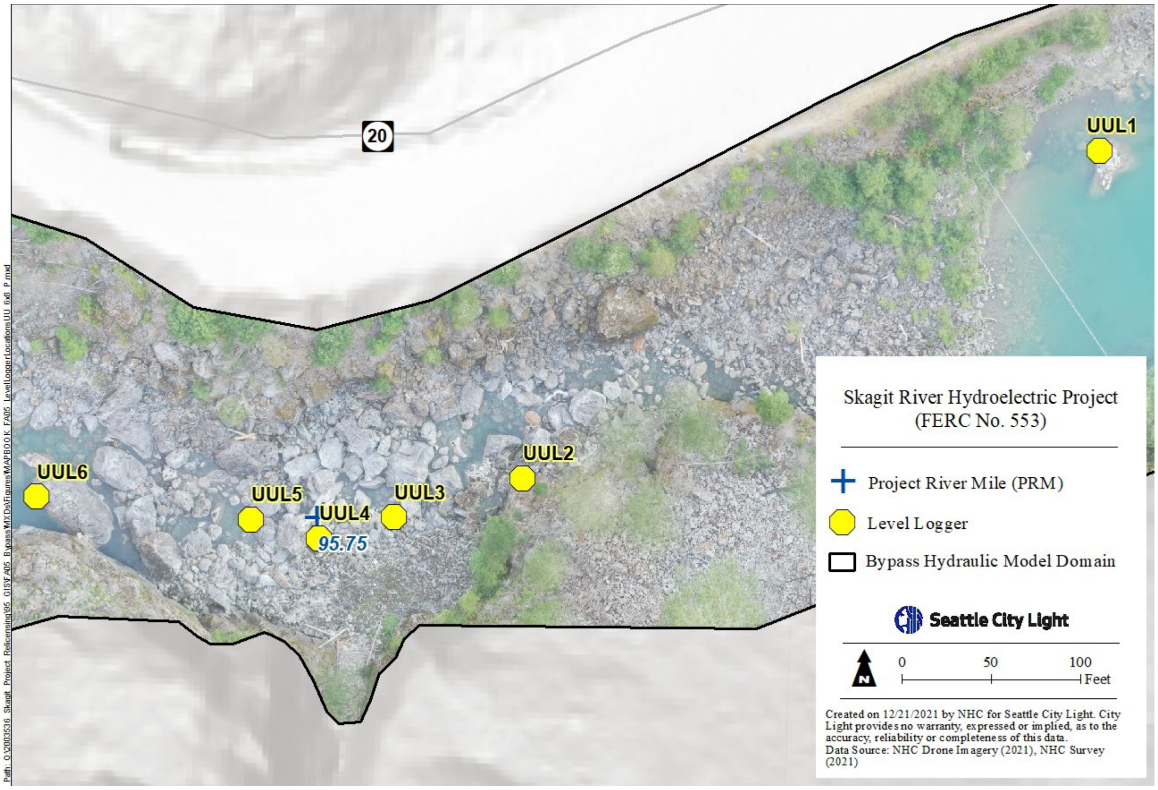

Figure 4.2-3. Level logger locations at Existing Feature 2.

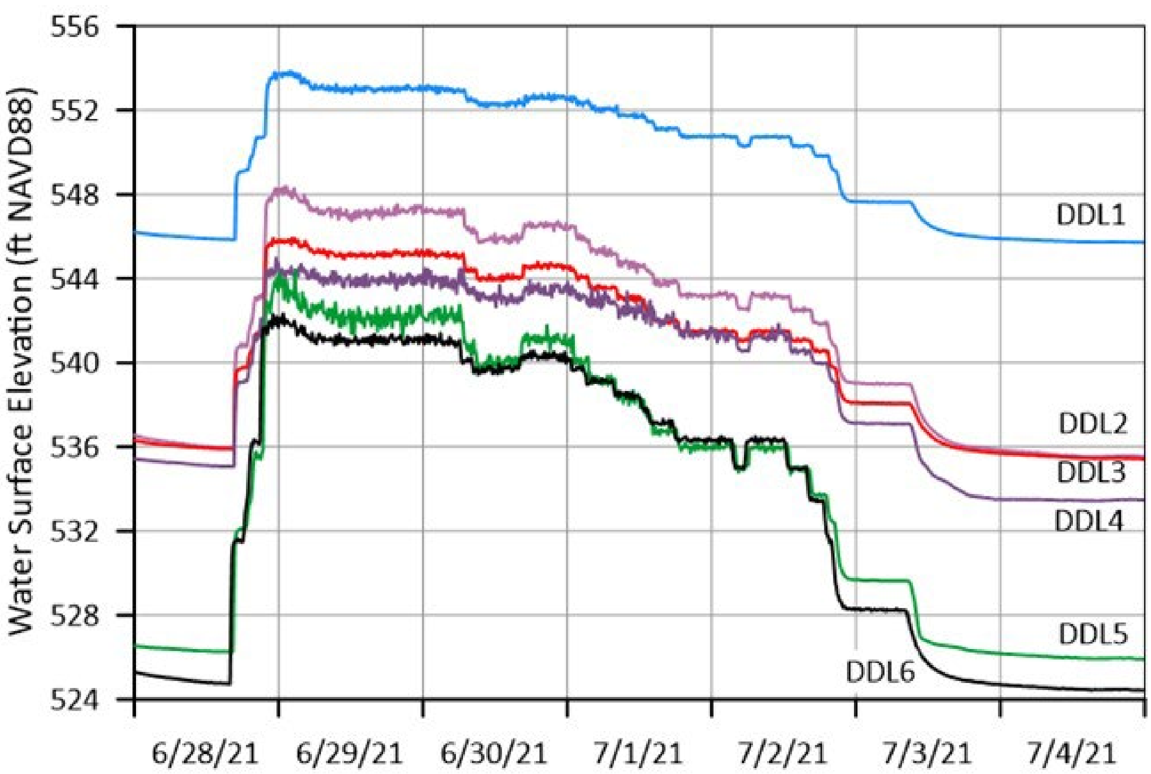

Figure 4.2-4. Level logger records at Existing Feature 1 for June 28, 2021 – July 4, 2021.

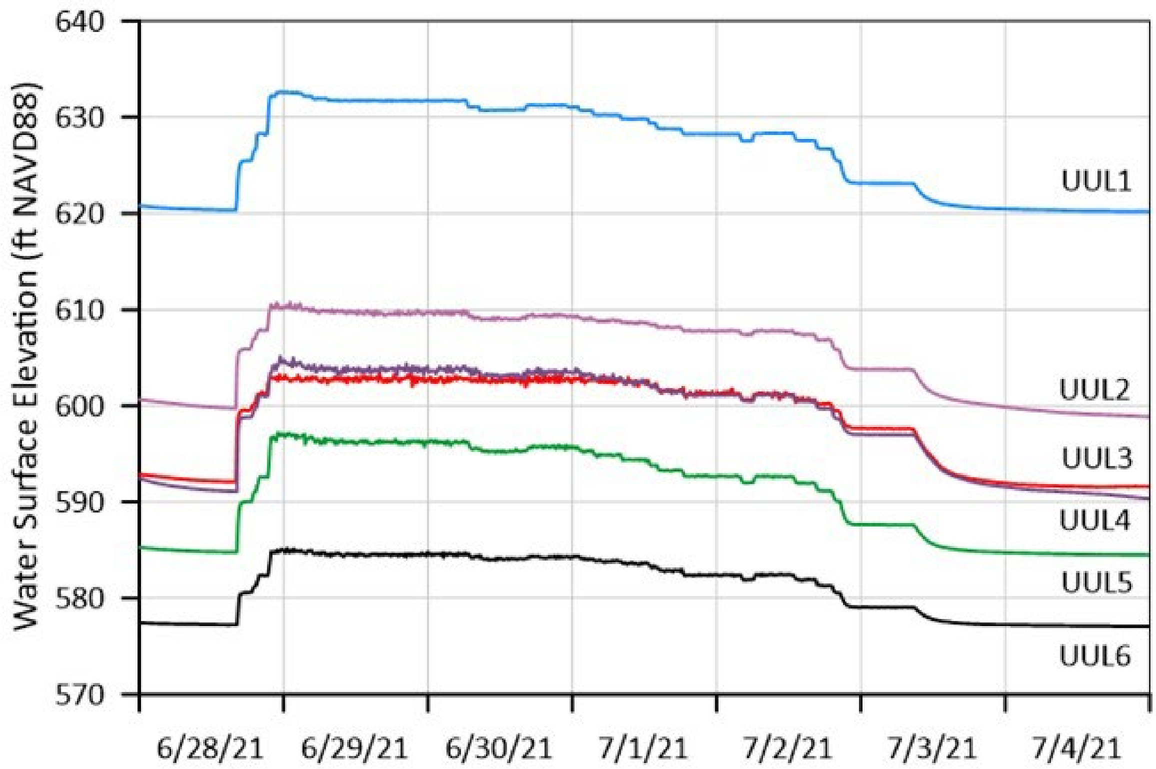

Figure 4.2-5. Level logger records at Existing Feature 2 for June 28, 2021 – July 4, 2021.

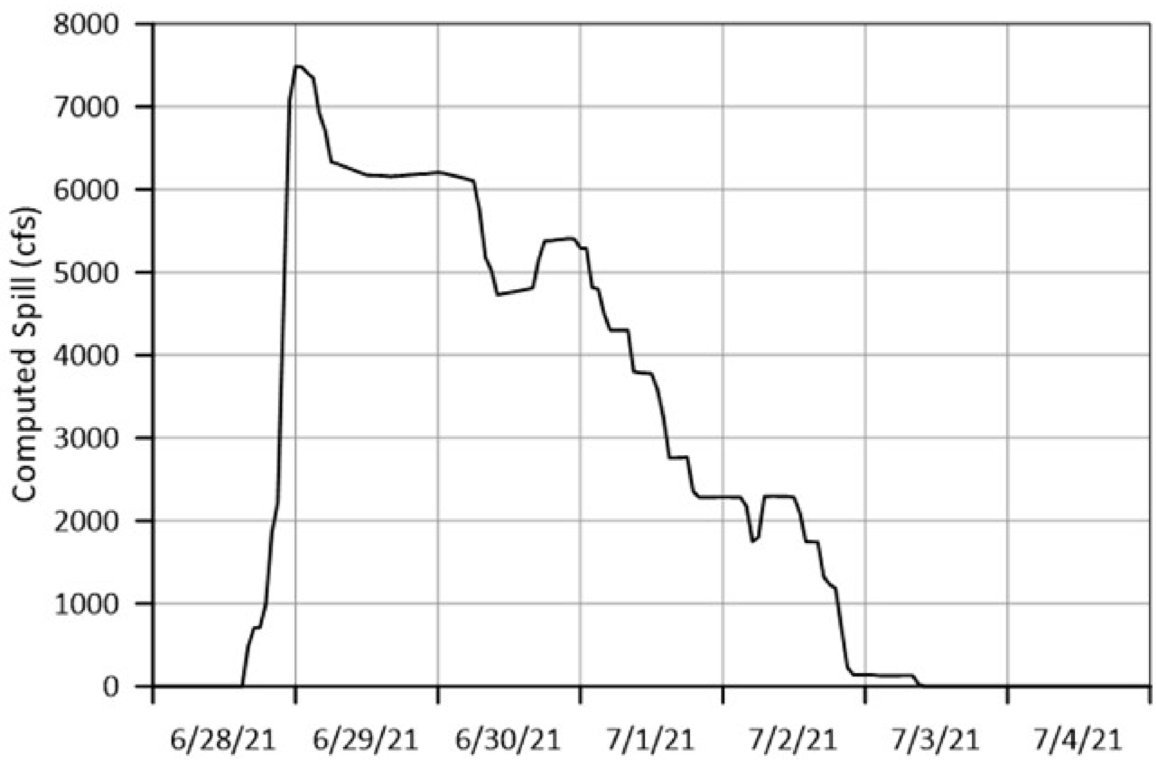

Figure 4.2-6. Gorge Dam spill for June 28, 2021 – July 4, 2021.

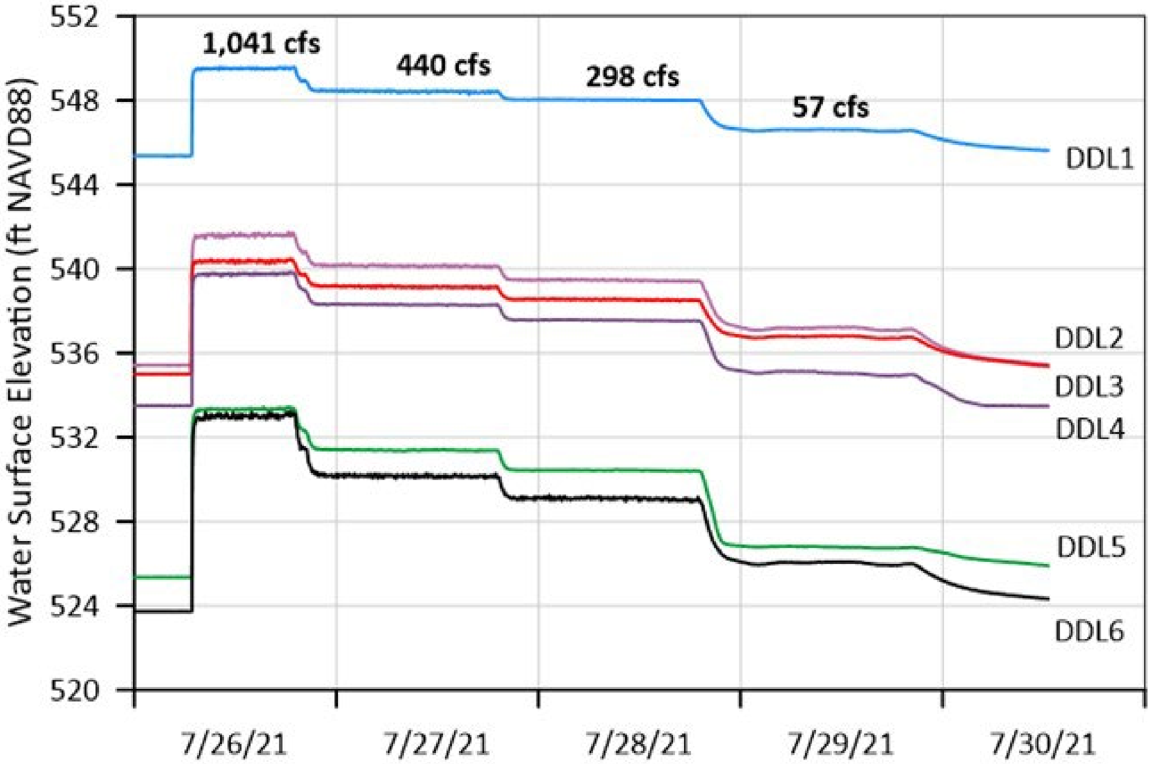

Figure 4.2-7. Level logger records at Existing Feature 1 for July 26-29, 2021 controlled releases.

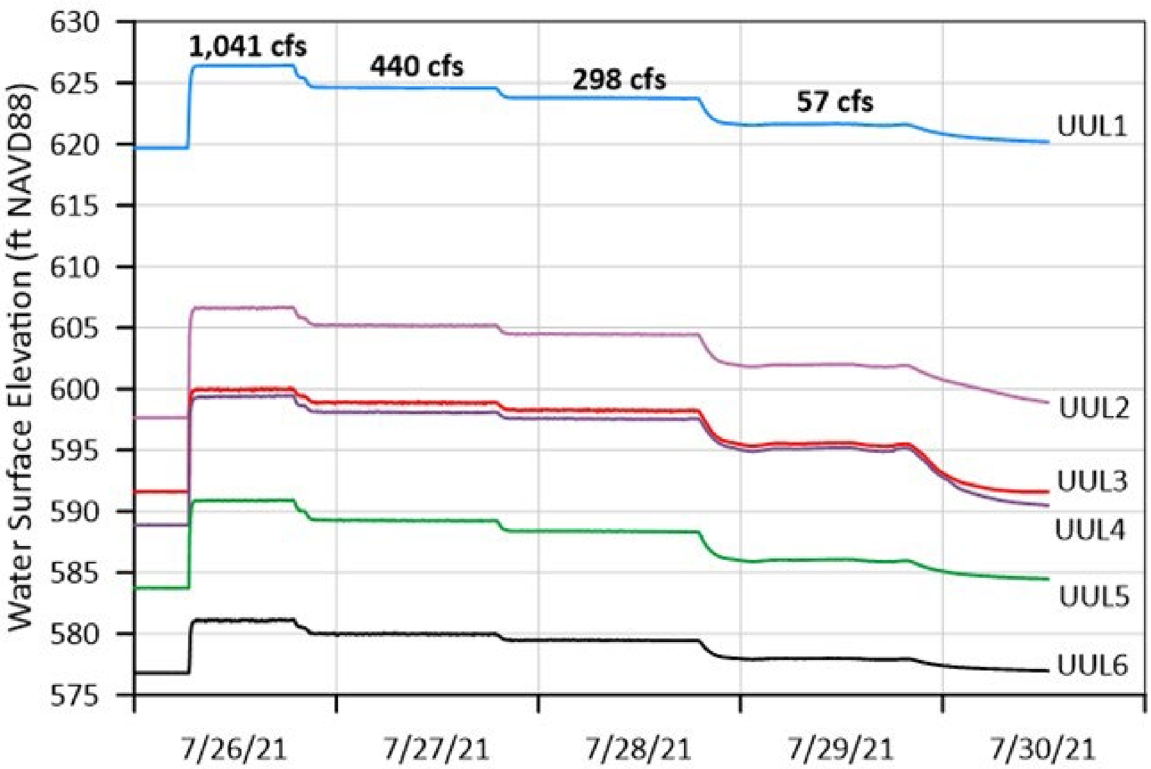

Figure 4.2-8. Level logger records at Existing Feature 2 for July 26-29, 2021 controlled releases.

Depth and Velocity Transects

Five measurement transects were established in consultation with City Light and LPs to measure depths and velocities during the July 26-29, 2021 releases (Figure 4.2-9). The primary objective for selecting the transect locations was to capture hydraulic characteristics from a variety of geomorphic units. At each transect, a bank-operated cableway was installed to deploy a raft-mounted ADCP. When transect depths were shallower than the ADCP's operational range, depth and velocity measurements were acquired with an ADV and wading rod. Velocities were measured throughout the water column at each measurement location along the cableway, with measurement recordings over a 40-second duration to account for turbulence fluctuations. Vertical profiles were then post-processed to compute a depth-averaged velocity. Depth and velocity measurements were also used to compute discharge at each transect via the USGS mid-section method (Turnipseed and Sauer 2010).

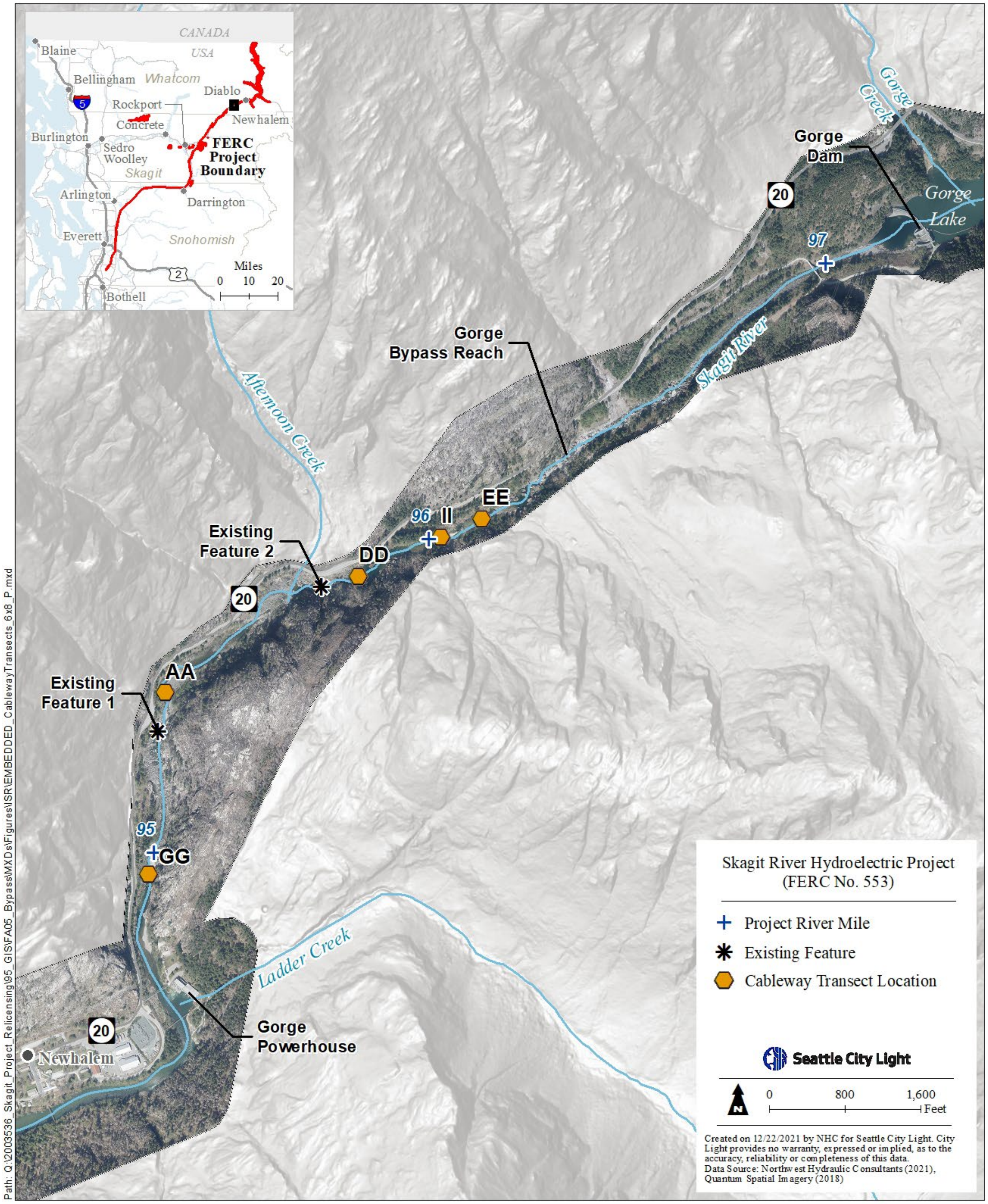

Figure 4.2-9. Transect locations.

Real-time kinematic (RTK) Global Positioning System (GPS) was not available to georeference measurement stations at the transects. Instead, the anchor points of each cableway were surveyed with a total station, and field personnel recorded the distance of each depth and velocity measurement from the right bank anchor point. This allowed measurements to be georeferenced in a Geographic Information System (GIS) by plotting measurement stations along the surveyed transect line. The ADCP raft drifted downstream of the cableway line some amount during each deployment. Photos and video were taken of the ADCP deployment at each transect to determine a downstream offset from the cableway line when georeferencing the measurements. Figure 4.2-10 provides an example set of post-processed transect measurements.

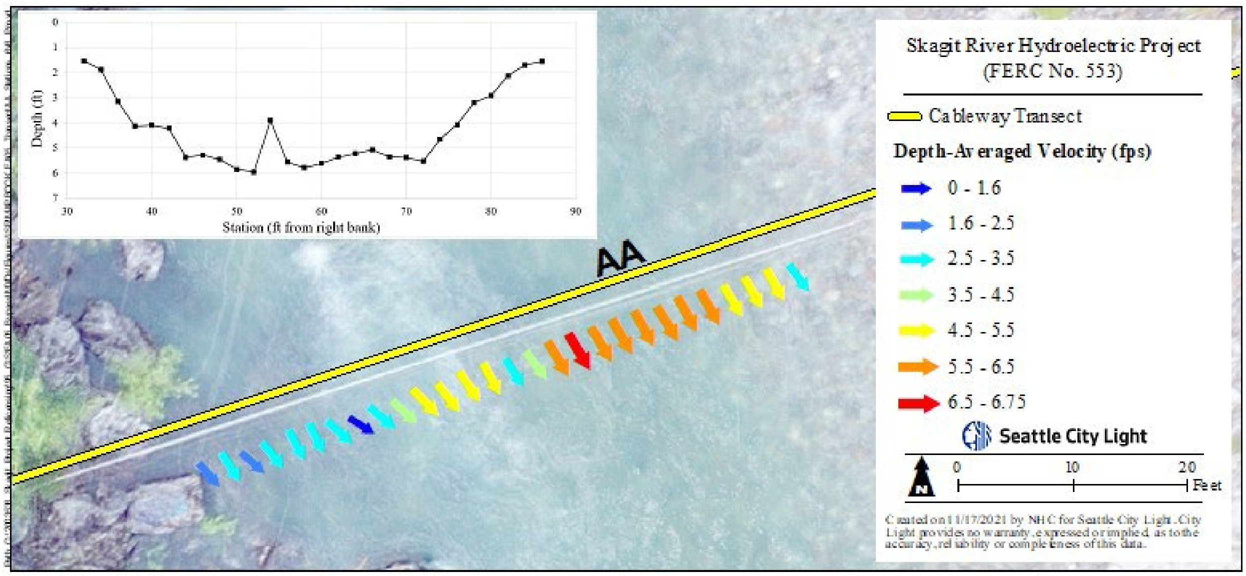

Figure 4.2-10. ADCP measurements at Transect AA for 1,200 cfs targeted flow release.

UAV Photography

Oblique and nadir (downward facing) photographs and video were taken with an UAV throughout the Gorge bypass reach during the July 26-29, 2021 releases and during base flow conditions on July 30, 2021. Surveyed control points were marked throughout the Gorge bypass reach with temporary high visibility chalk that would be easily distinguishable in UAV photos and videos for georeferencing. Nadir photos were captured throughout the Gorge bypass reach where both Federal Aviation Administration (FAA) compliance and safe drone operation could be achieved (Figure 4.2-11). These photos were processed using Structure from Motion (SfM) software to produce orthomosaic images (Figure 4.2-12) that will be used for a variety of study applications including: (1) characterization of substrate, vegetative cover, and channel characteristics for delineating hydraulic roughness zones; and (2) defining water surface elevations and inundation extents to compare with model results. These photo series were also made available for use by other relicensing studies.

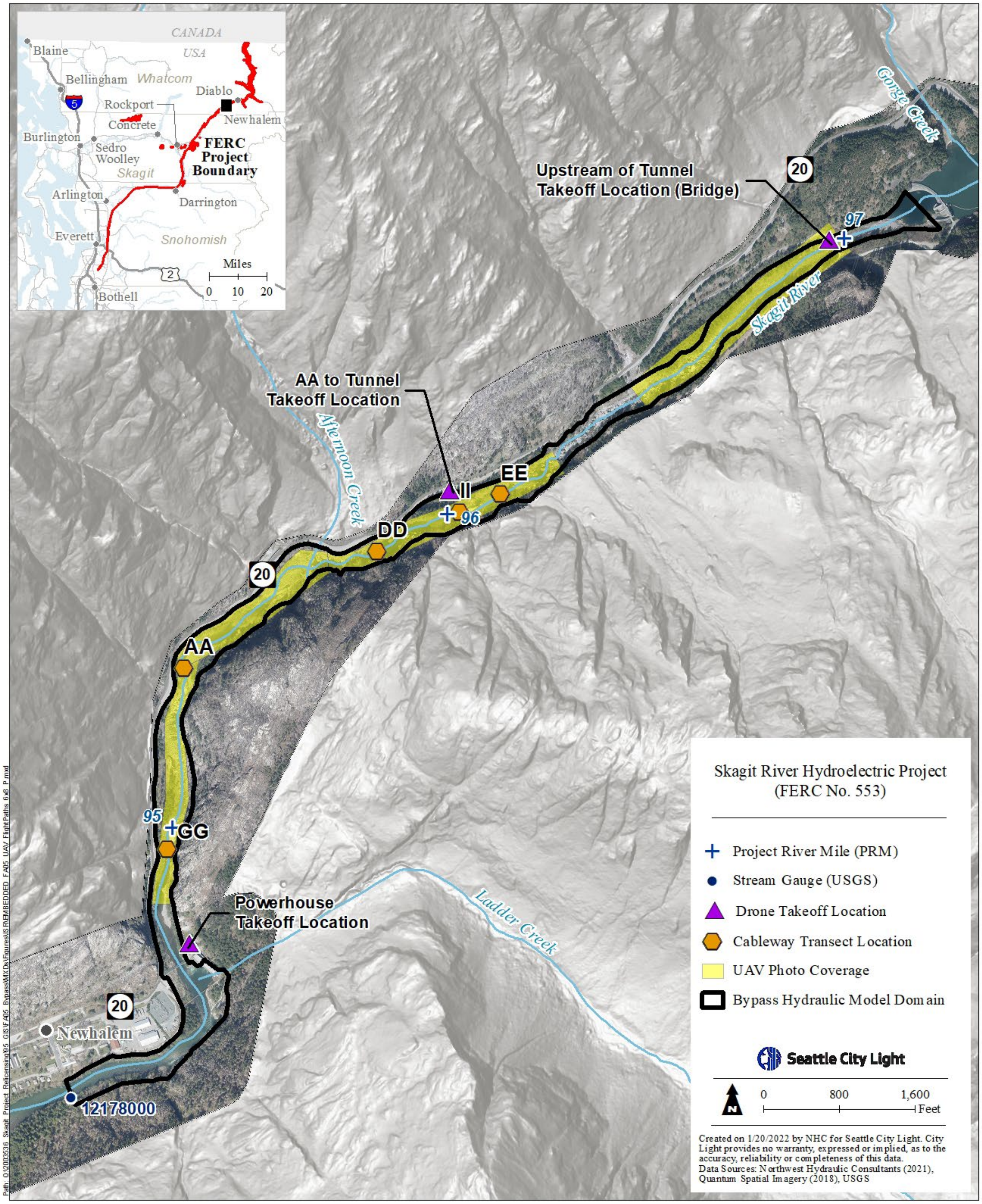

Figure 4.2-11. UAV nadir photo coverage.

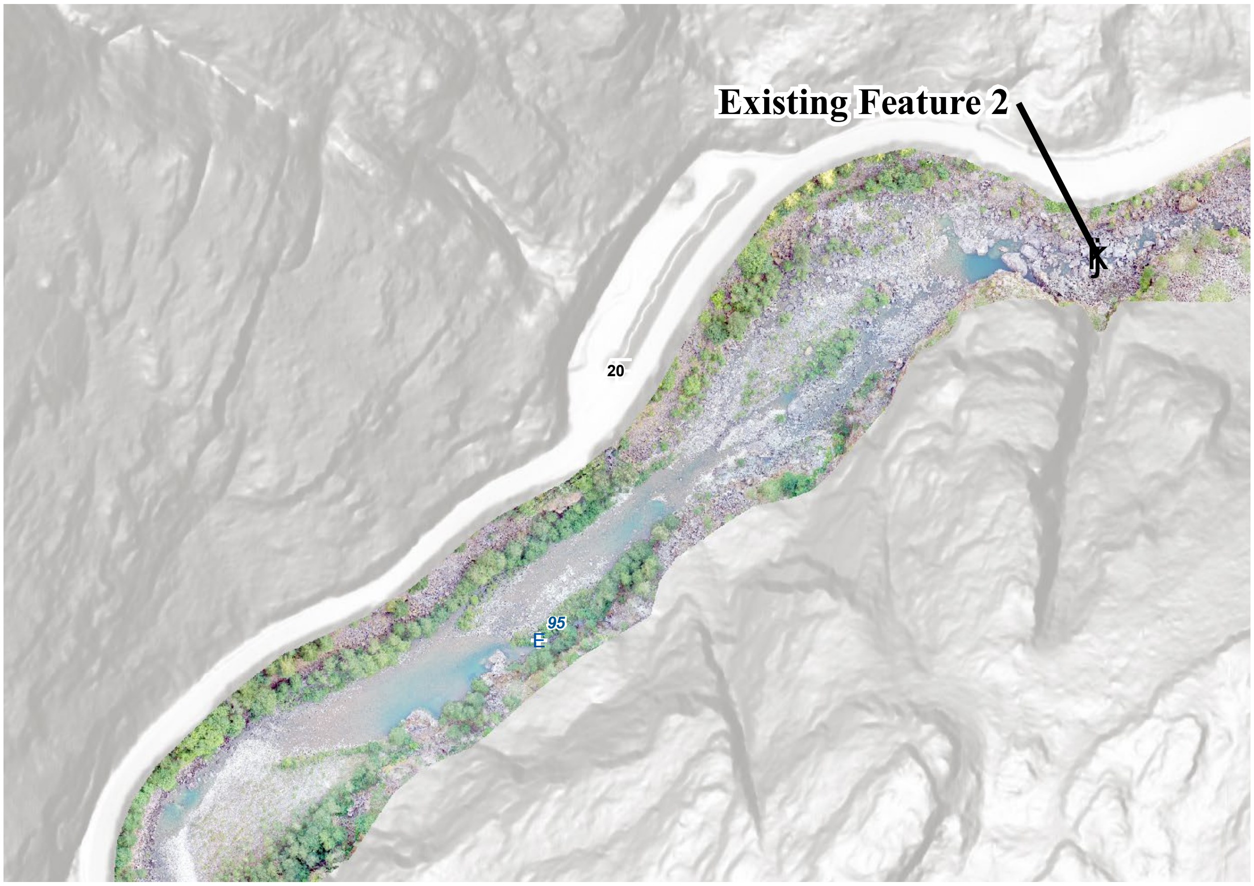

Figure 4.2-12. Processed orthoimagery from UAV photos of base flow conditions on July 30, 2021.

UAV Video

Video recordings were collected with a UAV at Existing Features 1 and 2 to support Large Scale Particle Image Velocimetry (LSPIV) analysis, which is a technique for measuring 2-D surface velocity vectors. Field data collection and analysis for LSPIV are described in Attachment B. Unfortunately, hydraulic conditions (highly turbulent flow) were such that no reliable surface velocity data could be obtained.

4.2.3 Substrate and Cover Mapping

Substrate and cover were mapped in the Gorge bypass reach using ground-based visual mapping supplemented by desktop mapping to fill in remaining data gaps after the field effort was completed.

For the 2.9-mile-long study reach, the ground-based visual mapping effort occurred during the first week of August 2021 and consisted of a two-person crew experienced in substrate and cover mapping walking the accessible portions of the Gorge bypass reach and collecting detailed information on substrate/cover types and locations. The field crew mapped approximately 70 percent of the Gorge bypass reach on-foot over a one-week period. Areas not mapped in the field were too difficult to access and/or were in areas prone to landslides and deemed not safe to work in, or nearby.

Substrate and cover types were recorded in the field using handheld iPads equipped with differential GPS and GIS software loaded with base layers of the model area including aerial imagery and digital elevation terrain information. The substrate and cover mapping effort utilized the default methodology and codes provided in Washington State's Instream Flow Study Guidelines (Beecher et al. 2016). Substrate codes used in the field effort used the format "ab.c" where "a" is the component code for dominant particle size (i.e., the type of substrate that covers the greatest area of the cell, and not necessarily the largest particle size in the cell); "b" is the component code for the subdominant particle size; and "c" is the percentage of the cell area covered by the dominant (50 percent or greater) substrate type. For example, the code 46.8 indicates 80 percent medium gravel and 20 percent small gravel. Table 4.2-1 lists codes 1 through 9, which are components of the substrate code, and 0.1 through 0.9, which are the cover codes.

Table 4.2-1. Washington State Instream Flow Study Guidelines substrate and cover codes (Beecher et al. 2016).

Substrate Code	Type of Substrate	Cover Code	Type of Cover
1	Silt, clay, or organic	00.1	Undercut bank
2	Sand	00.2	Overhanging vegetation near or touching water[1]
3	Small Gravel (0.1 - 0.5 inches)	00.3	Rootwad (including partly undercut)
4	Medium Gravel (0.5 - 1.5 inches)	00.4	Log jam/submerged brush pile
5	Large Gravel (1.5 - 3 inches)	00.5	Log(s) parallel to bank
6	Small Cobble (3 - 6 inches)	00.6	Aquatic vegetation
7	Large Cobble (6 - 12 inches)	00.7	Short (<1 ft) terrestrial grass
8	Boulder (>12 inches)	00.8	Tall (>3 ft) dense grass[2]
9	Bedrock	00.9	Vegetation >3 vertical ft above stage of zero flow

1 This includes low tree branches (<3 vertical ft above water surface elevation at stage of zero flow [SZF]) and bushes overhanging the bank-full water's edge.
2 This category refers to stout, almost bushy type grasses such as reed canary grass up to the bank-full water's edge.

After the field data collection effort was completed, the resulting substrate and cover layers (consisting of individual polygons of corresponding substrate and cover cells) were quality controlled by visual inspection of the field data, and post-processed utilizing GIS software tools to rectify overlap between adjacent polygons and to form a continuous layer of substrate and cover information. Post-processed results were then quality controlled again by field team members. Data gaps remaining after post-processing were filled in via a desktop approach which used a combination of available high resolution aerial imagery, ground-level photographs, digital elevation terrain models, and communications with personnel familiar with areas that were not accessible during the field data collection effort. Staff with specific expertise and experience with mapping substrate and cover for instream flow modeling purposes were utilized for both the quality control and data-gap-filling process.

The resulting substrate and cover mapbooks are provided in Attachment D.

4.3 Hydraulic Model Development

Hydraulic conditions in the Gorge bypass reach are being computed using the 2-D capabilities of the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) Version 6.1.0 modeling platform (USACE 2021a). HEC-RAS 2-D solves the 2-D shallow water equations using an implicit finite volume algorithm and returns depth-averaged hydraulic properties such as depth, velocity, and shear stress. The following factors, identified in the RSP, were considered in selecting the model platform:

(1) Efficiency of model development;

(2) Model resolution required to meet study objectives;

(3) Speed of model execution;

(4) Integration with other model platforms (for example, Project operations models);

(5) Availability of model support and model maintenance;

(6) Availability of visualization tools and software features for analysis, synthesis and display of model output;

(7) Efficiency with which metrics of interest for Project flow management can be generated from model output;

(8) Acceptance by the engineering community and both governmental and non-governmental institutions; and

(9) Size of user community (which relates to the pool of expertise available for model updates and application).

The following key model components of HEC-RAS 2-D are explained in the sections below.

(1) A high-resolution Digital Elevation Model (DEM) of the hydraulic model domain (referred to as a Terrain in HEC-RAS);

(2) Spatial bed roughness mapping that characterizes zones of similar hydraulic roughness;

(3) Upstream and downstream hydraulic boundary conditions;

(4) A model mesh consisting of variable polygon elements where each element incorporates both the underlying terrain and bed roughness (this mesh is what the model performs its calculations on); and

(5) Run control parameters such as the computational time step needed to initialize and simulate a scenario in a stable, accurate manner.

4.3.1 Topographic Information

A critical element of a hydraulic model is accurate topographic information, as the resolution and accuracy of the terrain limits the detail and accuracy of model results. A good terrain captures sufficient detail of elevation changes, channel shape, and obstructions to allow accurate modeling of water surface elevations, inundation extents, and flow patterns at the desired model output scale.

The Bypass Hydraulic Model terrain for the Gorge bypass reach consists of a bare earth DEM derived from the 2016 and 2018 LiDAR datasets described in Section 4.2.1 of this study report. The original processing of the 2018 topobathymetric LiDAR returns by QSI produced a ground and bathymetric bottom classified density of 0.52 points/ft^2 (QSI 2018), which was sufficient to generate a 3-foot resolution DEM. Geospatial analysts expanded upon QSI's original point classification to classify additional ground points from the 2018 LiDAR and develop a higher resolution DEM as described below and detailed in Attachment A.

The Gorge bypass reach terrain is characterized by steep slopes and large riverbed material that strongly influence flow dynamics. To improve characterization of these features, ground point density was increased along the channel bottom and bank toe below vegetated areas extending from the bridge immediately below Gorge Dam to the upstream end of Afternoon Creek pool, and from the downstream end of Afternoon Creek pool to the upstream end of the Gorge Powerhouse tailrace (Figure 4.3-1). Point density was not increased in areas classified as bathymetric bottom during the LiDAR survey as these areas that are inundated during base-flow conditions have little influence on hydraulic conditions. Ground point density in the reclassified areas is 2.51 points/ft^2 and a DEM with a 1-foot cell resolution was generated to preserve detail in areas with this higher point density. Note that outside the reclassified areas, point density remains 0.52 points/ft^2.

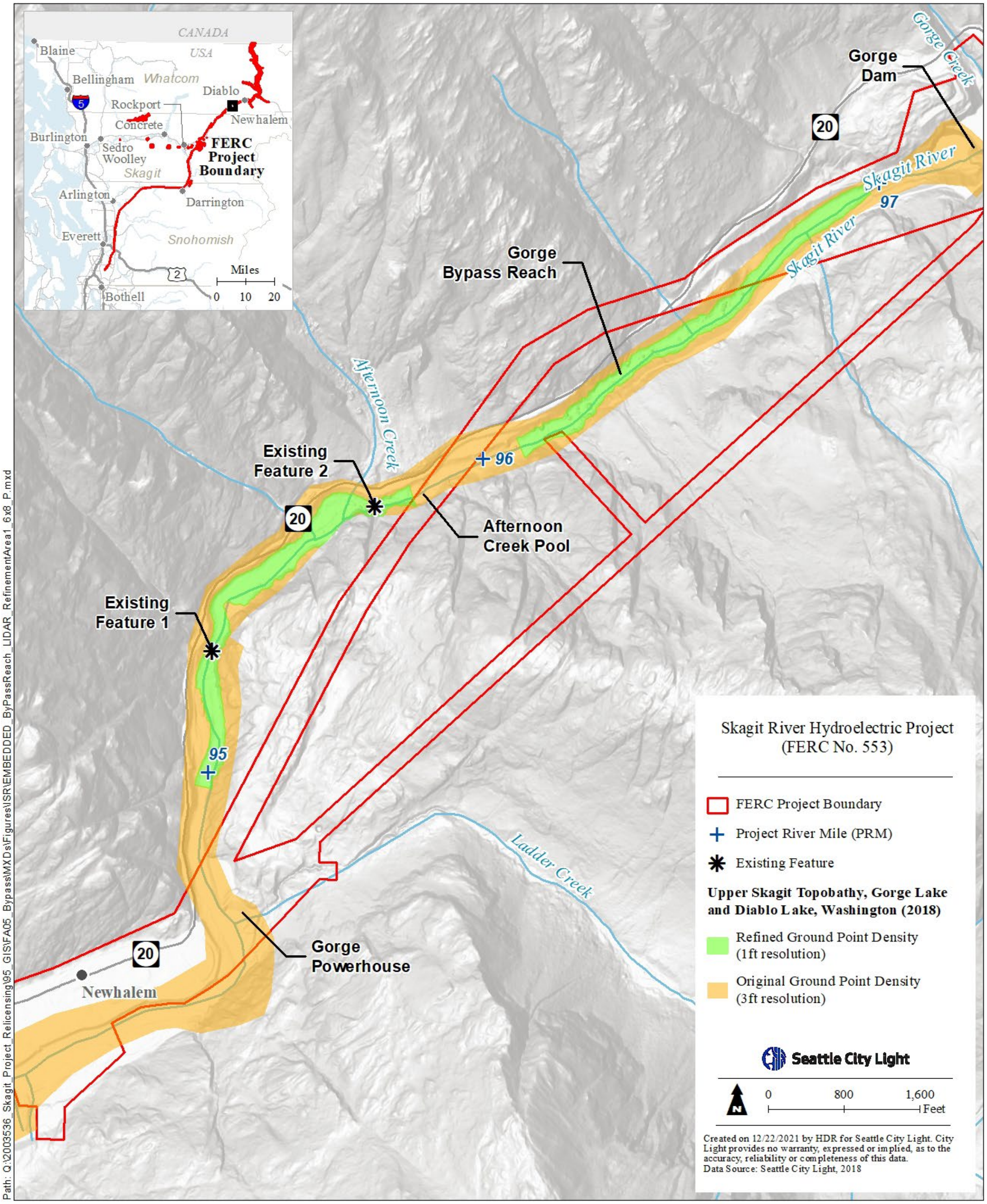

Figure 4.3-1. Refined and original 2018 LiDAR coverage.

4.3.2 Hydraulic Roughness Zones

Hydraulic roughness zones were mapped within the Bypass Hydraulic Model domain to delineate areas of varying frictional flow resistance associated with unresolved terrain features, substrate, vegetation, and any other sources of flow obstruction or drag not explicitly represented by other components of the Bypass Hydraulic Model geometry. Each zone is assigned a roughness coefficient, represented by a Manning's n value (Barnes 1967). Manning's n values are not solely linked to surface roughness but are also linked to scale, terrain resolution, and mesh element size. Representation of surface features in a hydraulic model geometry coarsens as element size increases, requiring more of the flow resistance imposed by terrain features to be accounted for with the roughness coefficient. To allow for this, roughness zones in the Bypass Hydraulic Model domain were separated into channel and bank areas, corresponding to different mesh element sizes. The area defined as "channel" corresponds to the Bypass Hydraulic Model refinement region where the mesh has a 1-foot resolution. Area defined as "bank" includes the upper bank and valley walls where the mesh has a 9-foot resolution. Within the channel and bank areas, roughness zones were delineated based on observed vegetation density from UAV-based orthoimagery. Figure 4.3-2 shows the roughness zone delineations for base model conditions that will be evaluated and potentially modified as part of model calibration.

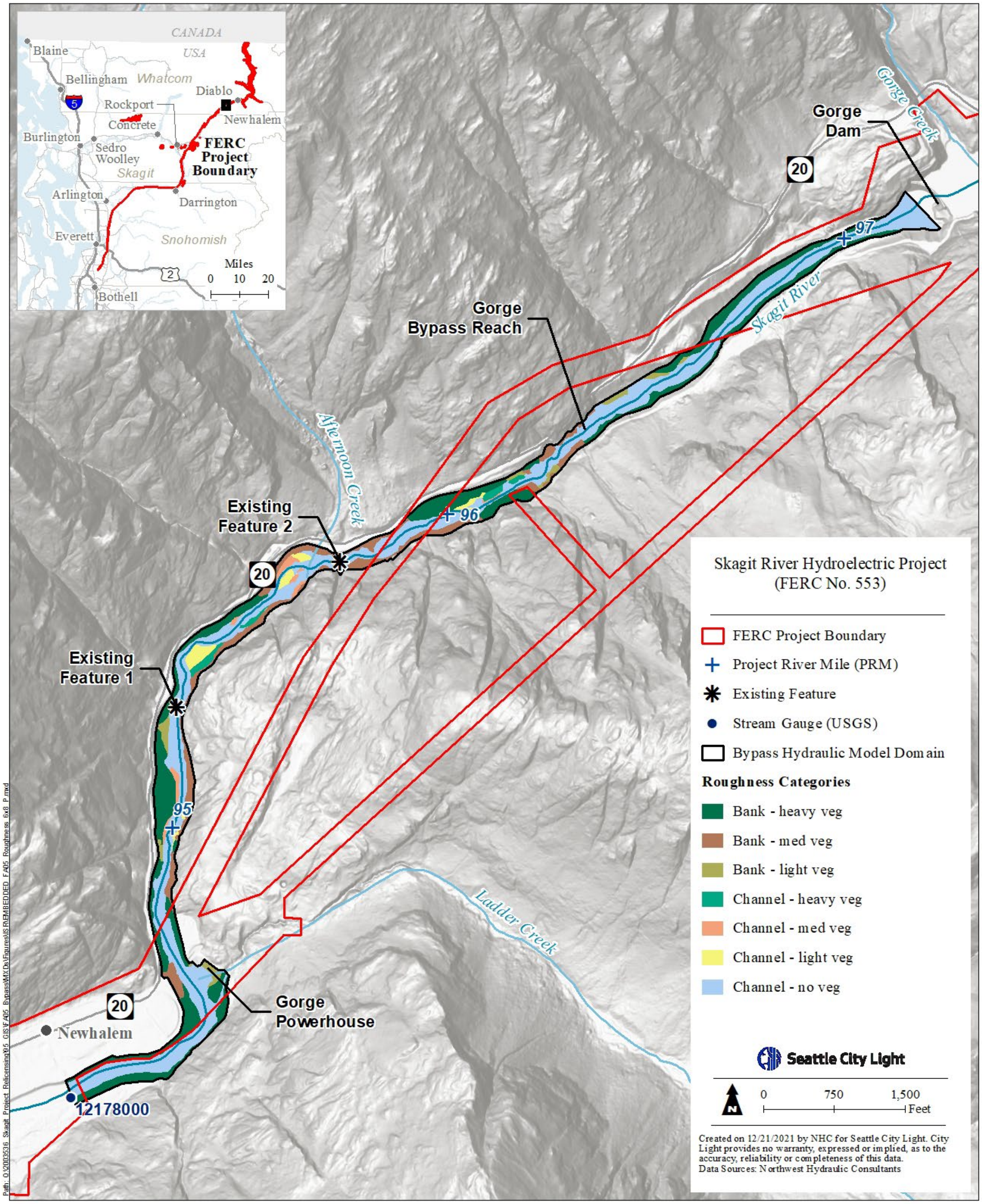

Figure 4.3-2. Roughness zone delineations for base Bypass Hydraulic Model condition.

4.3.3 Boundaries

Model boundaries identify the spatial locations at which flow either enters or exits the model mesh. Collection of hydrologic data used to define boundary conditions for the Bypass Hydraulic Model was discussed in Section 4.2.2.1 of this study report. The primary inflow boundary is spillway flow released from Gorge Dam. Inflow from local tributaries is excluded from the Bypass Hydraulic Model due to the very small flows and their negligible influence on hydraulic conditions. The Bypass Hydraulic Model's downstream boundary is the rating curve from the USGS Skagit River at Newhalem gage. An inflow source boundary for discharge from the Gorge Powerhouse is included. The Bypass Hydraulic Model was run using steady-state conditions, i.e., input for each simulation consists of a constant discharge at inflow locations and a constant stage at the downstream boundary. Event simulations include simulations for releases from Gorge Dam of approximately 4,800 cfs and 6,200 cfs during the late-June 2021 unplanned spill and the four controlled releases that occurred from July 26-29, 2021. Bypass Hydraulic Model boundaries are shown in Figure 4.3-3 and event simulation data is provided in Table 4.3-1.

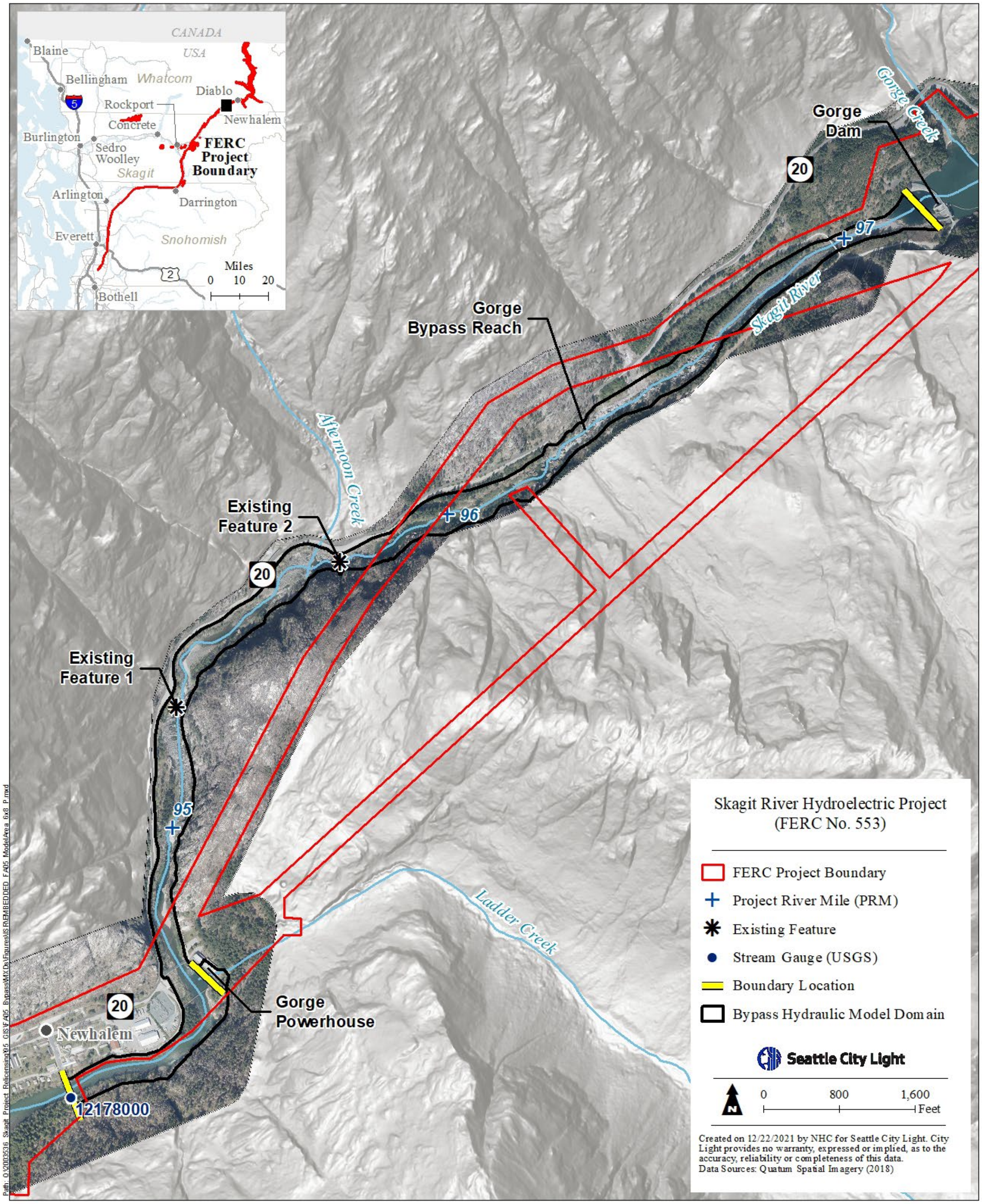

Figure 4.3-3. Bypass Hydraulic Model boundary locations.

Table 4.3-1. Bypass Hydraulic Model boundary conditions.

Event Simulation	Gorge Dam Spill (cfs)	Gorge Powerhouse Discharge (cfs)	Downstream Stage (ft NAVD 88[1])
June 29, 2021	6,175	5,537	492.99
June 30, 2021	4,770	6,430	492.78
July 26, 2021	1,113/1,041[2]	2,998	489.87
July 27, 2021	500/440[2]	2,736	489.33
July 28, 2021	322/298[2]	2,686	489.18
July 29, 2021	57	2,962	489.19

1 NAVD 88 = North American Vertical Datum of 1988.
2 Two flows modeled using separate simulations to evaluate model output against flow observed upstream and downstream of Afternoon Creek pool (see Attachment C).

4.3.4 Model Geometry

A HEC-RAS 2-D model geometry consists of a mesh of variable size polygons that encode information about the underlying terrain and hydraulic roughness. Generation of the mesh is controlled by the model domain, mesh refinement regions, and breaklines, each of which have associated mesh control parameters. No hydraulic structures such as bridges were incorporated in the Bypass Hydraulic Model.

The Bypass Hydraulic Model domain covers the Skagit River channel from the plunge pool below Gorge Dam to the USGS Skagit River at Newhalem gage (Figure 4.3-4). Preliminary model simulations informed delineation of the domain extents to ensure the range of flows being evaluated was contained within the domain. A mesh refinement region was delineated to encompass the Gorge bypass reach channel and bank toe where terrain refinement was performed (Section 4.3.1 of this study report). A 1-foot cell size was used for the mesh within the refinement region, while a 9-foot cell size was used for the rest of the Bypass Hydraulic Model domain. Selection of the cell size within the refinement region relied heavily on sensitivity testing described in Section 4.4.1 of this study report. A 9-foot cell size was selected outside the refinement region because: (1) larger cells in these areas reduces the Bypass Hydraulic Model's total cell count, decreasing simulation runtimes; and (2) areas outside of the refinement region include the upper bank/valley walls of the Gorge and deep pools/backwater areas where higher mesh resolution has negligible impact on hydraulic model results. Cell sizes along the border of the refinement region vary such that there is a smooth transition between regions of 1-foot and 9-foot cells. This improves the numerical stability of model computations between these regions. A sample of this mesh configuration is shown in Figure 4.3-5.

4.3.4.1 Model Resolution at Gorge Powerhouse

The Bypass Hydraulic Model includes inflows from Gorge Powerhouse (numeric boundary) and simulates depths and velocities in the adjacent reach sufficiently accurate for the Bypass Habitat Model. However, model resolution and accuracy are not sufficient to evaluate detailed hydraulic conditions at the draft tubes exit and surrounding the concrete structures. The modeled inflow boundary is located approximately 50 feet in front of the draft tubes where the nearby riverbed surface is interpolated through an underwater void, described in Section 4.2.1.

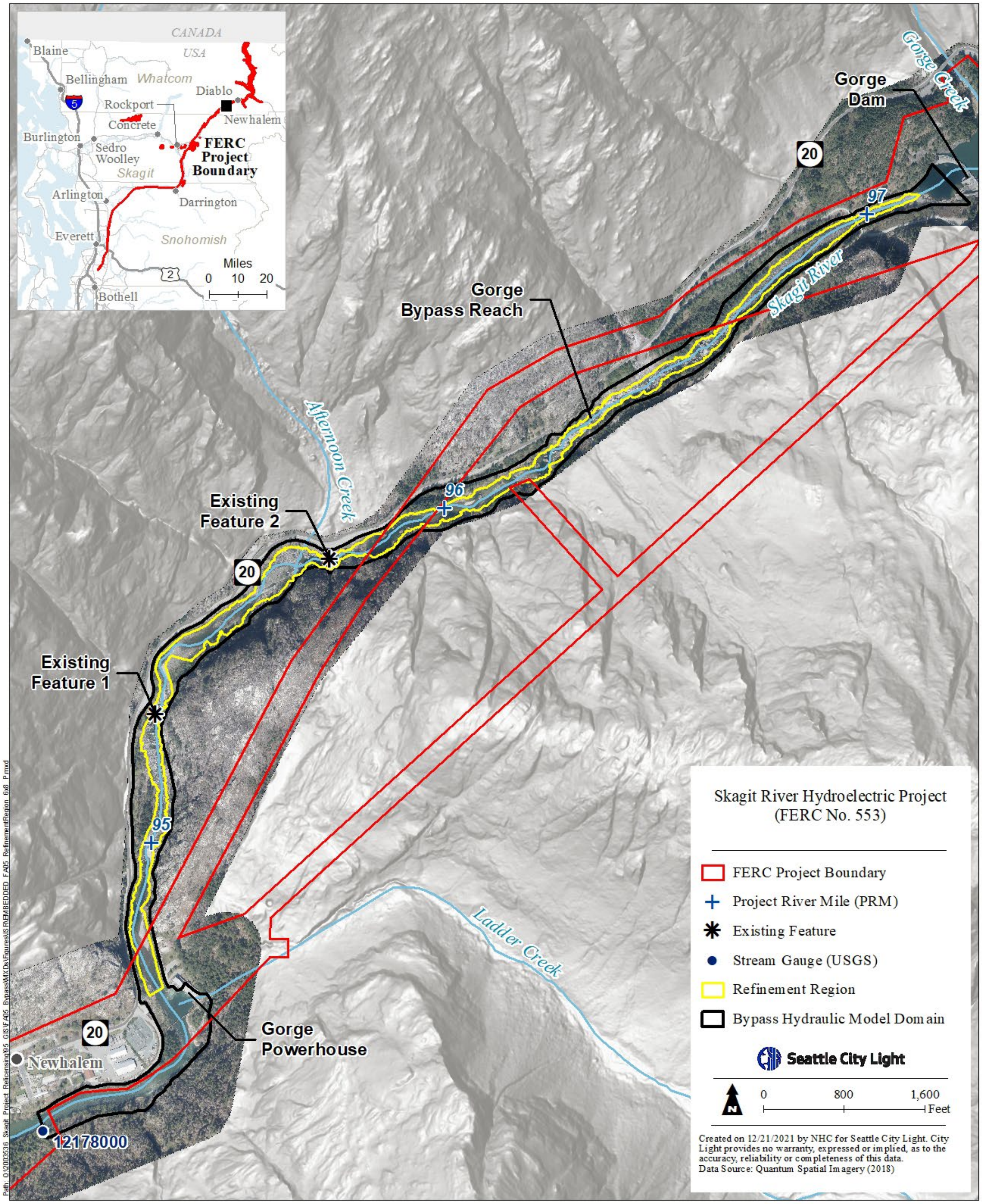

Figure 4.3-4. Bypass Hydraulic Model domain and mesh refinement region.

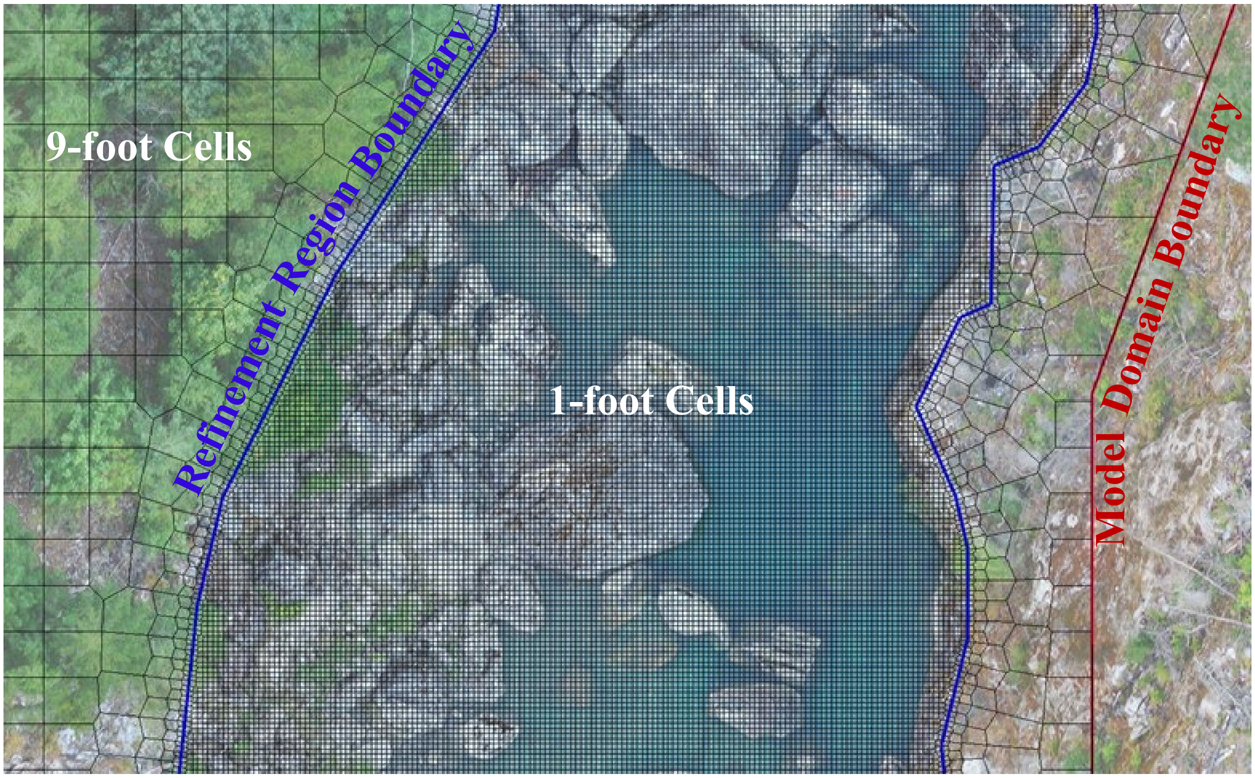

Figure 4.3-5. Example Bypass Hydraulic Model mesh configuration.

4.3.5 Run Control Parameters

Options for controlling 2-D model computations in HEC-RAS include specification of the solution equation set, initial conditions, solution weighting factor (Theta), solver tolerances and iterations, and the computational time step. The full momentum shallow water equations were selected to adequately capture momentum fluctuations that influence computed water levels and velocities. A dry channel initial condition was used for sensitivity tests and base model condition simulations, and a "ramp up" time was set to gradually increase model input from zero to the specified boundary conditions while initially distributing flow within the Bypass Hydraulic Model domain. For subsequent calibration simulations, an output file from the base Bypass Hydraulic Model or preceding calibration simulation was used for the initial condition so that extra "ramp up" time was unnecessary. Default Theta, tolerances, and solver iteration options were specified for all simulations (Table 4.3-2). Selection of the computational time step is described in Section 4.4.2 of this study report.

Table 4.3-2. Selected run control parameters for the Bypass Hydraulic Model.

Run Control Parameter	Theta	Water Surface Tolerance (ft)	Volume Tolerance (ft)	Maximum Solver Iterations
Value	1.0	0.01	0.01	40

4.4 Sensitivity Testing

The Bypass Hydraulic Model's sensitivity to several parameters was investigated to evaluate their impact on the final model solution, computational stability, and model runtime efficiency. These investigations informed parameter selection for base model conditions to be carried forward through model calibration. Four parameters were evaluated: cell size, simulation timestep, turbulence input, and roughness coefficient. Parameter sensitivities were tested for a simulation of 1,200 cfs.

4.4.1 Cell Size

The objective of evaluating sensitivity to mesh cell size is to optimize numerical accuracy while minimizing computation time. In general, smaller cell sizes incorporate more detail from the input terrain, allowing for more detailed and accurate results. However, less terrain detail is added with each incremental decrease in cell size. At some point, further mesh resolution no longer provides a significant impact on model results. Also, model results are less sensitive to cell size as channel slope and vertical variability in surface topography decrease. As cell size decreases, the total number of cells increases and the time step must be decreased, leading to increased computation time.

Cell size sensitivity testing focused on cells in the Bypass Hydraulic Model refinement region where hydraulic conditions are significantly influenced by longitudinal slope, sub-channel size features, and substrate. Nominally square computation cells were evaluated at 9, 6, 3, 2, and 1-foot sizes. The terrain resolution within the refinement region is 1 foot. Therefore, 1-foot cells were the smallest size tested, as the use of smaller cells would not provide additional terrain detail. Figure 4.4-1 depicts the scale of 9, 3, and 1-foot mesh cells relative to typical streambed composition in the Existing Features, illustrating the detail with which each mesh configuration represents the underlying channel.

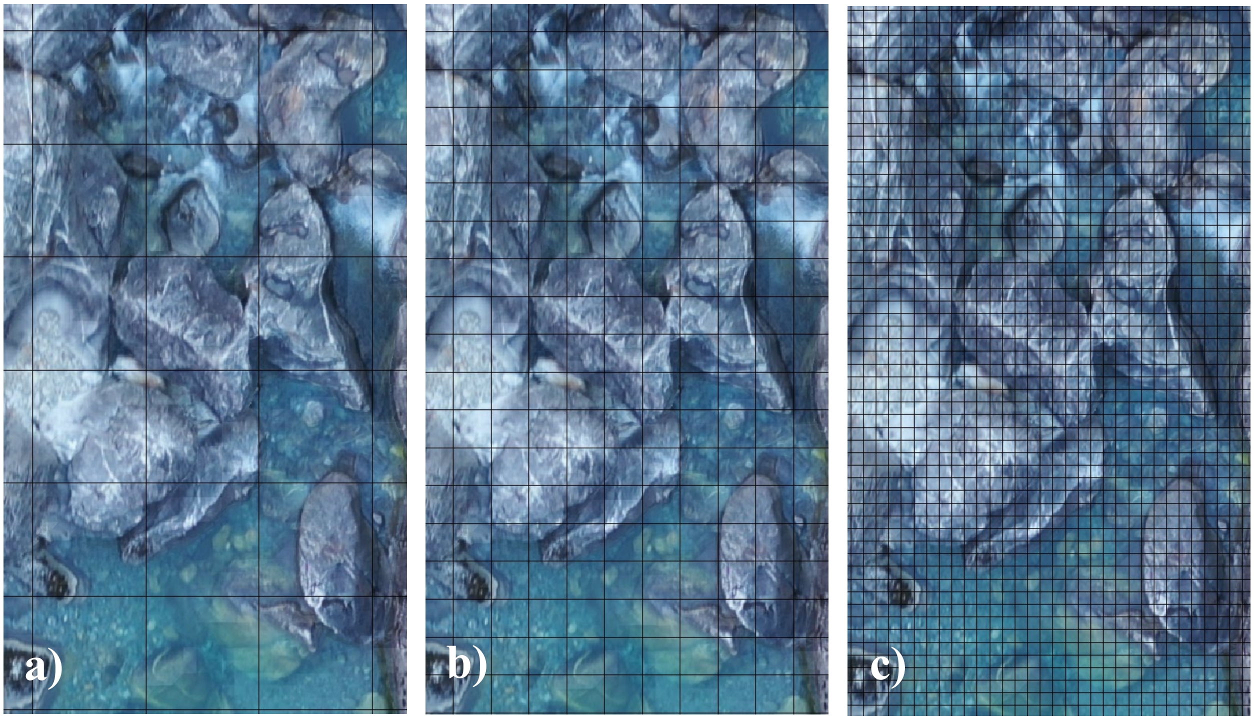

Figure 4.4-1. a) 9-foot, b) 3-foot, and c) 1-foot mesh cells overlaying scaled image of common streambed in the Gorge bypass reach.

Figure 4.4-2 illustrates how decreasing cell size in the refinement region resulted in correspondingly higher water surface elevations. There is a general converging trend in water surface elevations as cell size incrementally decreases from 9 to 1-foot, though results do not yet completely stabilize between cell sizes of 2 and 1-foot. Using a cell size smaller than 1-foot is prevented by the terrain resolution limitation described above. Figure 4.4-2 also shows the corresponding increase in computation time as mesh size decreases.

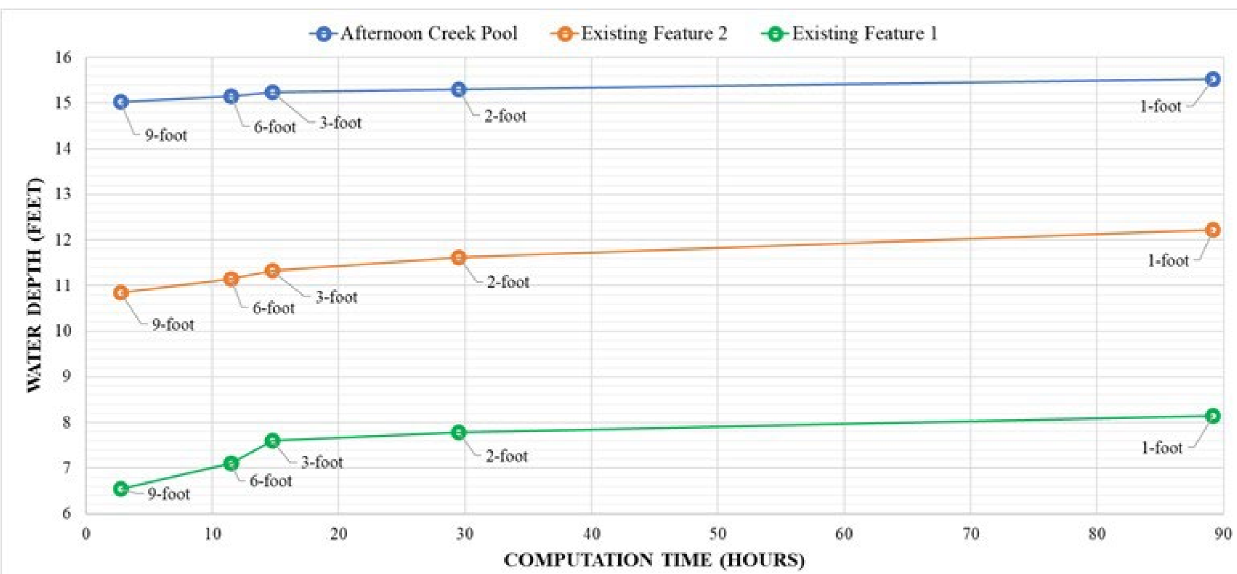

Figure 4.4-2. Computed water depth vs. computation time.

The improvement of using 1-foot cells as opposed to 2-foot cells is more clearly illustrated when spatially observing the difference in Bypass Hydraulic Model results. Figure 4.4-3 and Figure 4.4-4 illustrate the difference in water surface elevation and velocity output from refinement regions with 1-foot and 2-foot meshes. Differences in Bypass Hydraulic Model output are greatest along sections of the Gorge bypass reach with steep channel slope and large clasts or features on the channel bed. The resolution of channel topography in the 1-foot mesh significantly improves the detail of velocity output versus the 2-foot mesh (Figure 4.4-5).

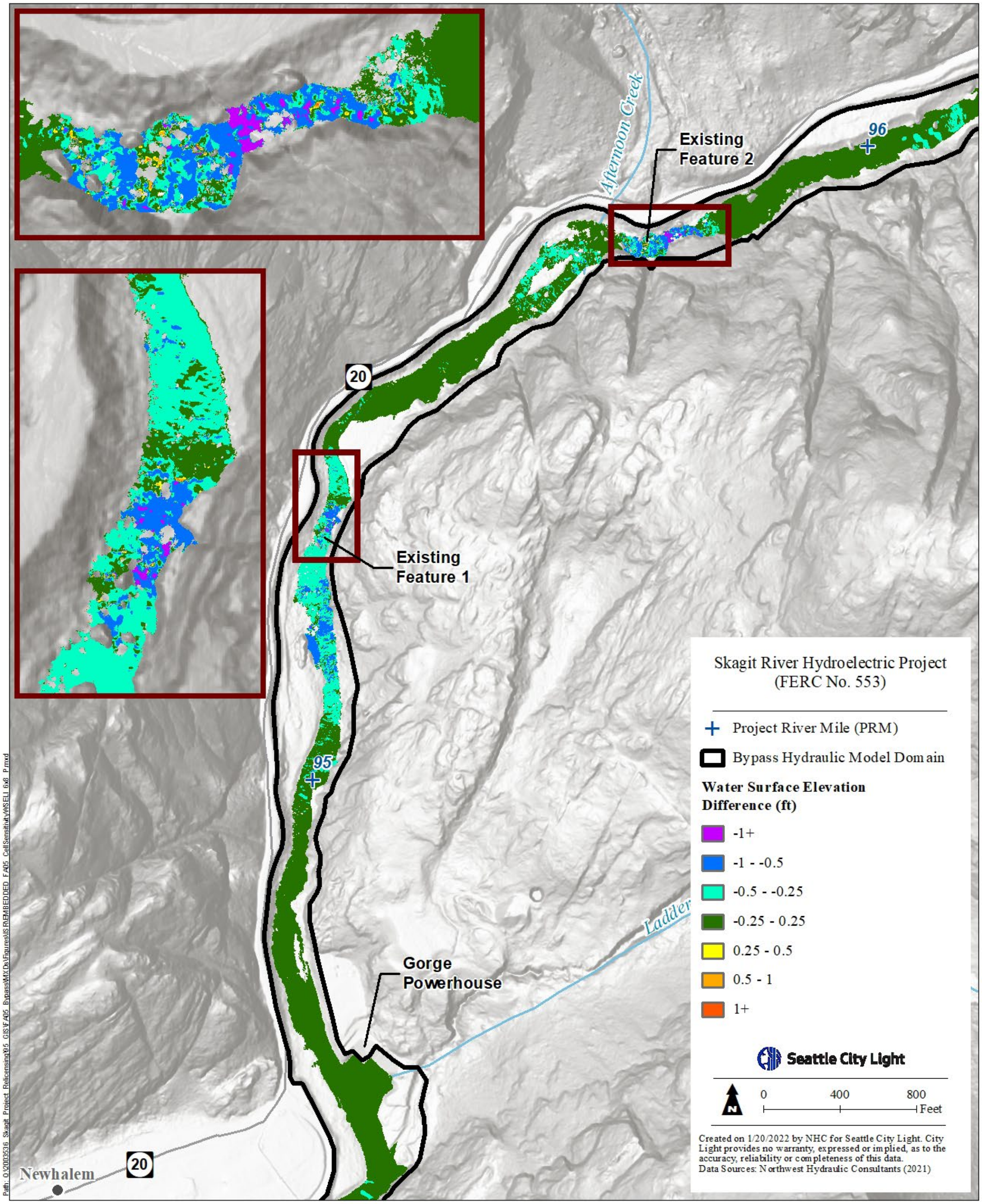

Figure 4.4-3. Difference in water surface elevation from 2-foot and 1-foot computational meshes.

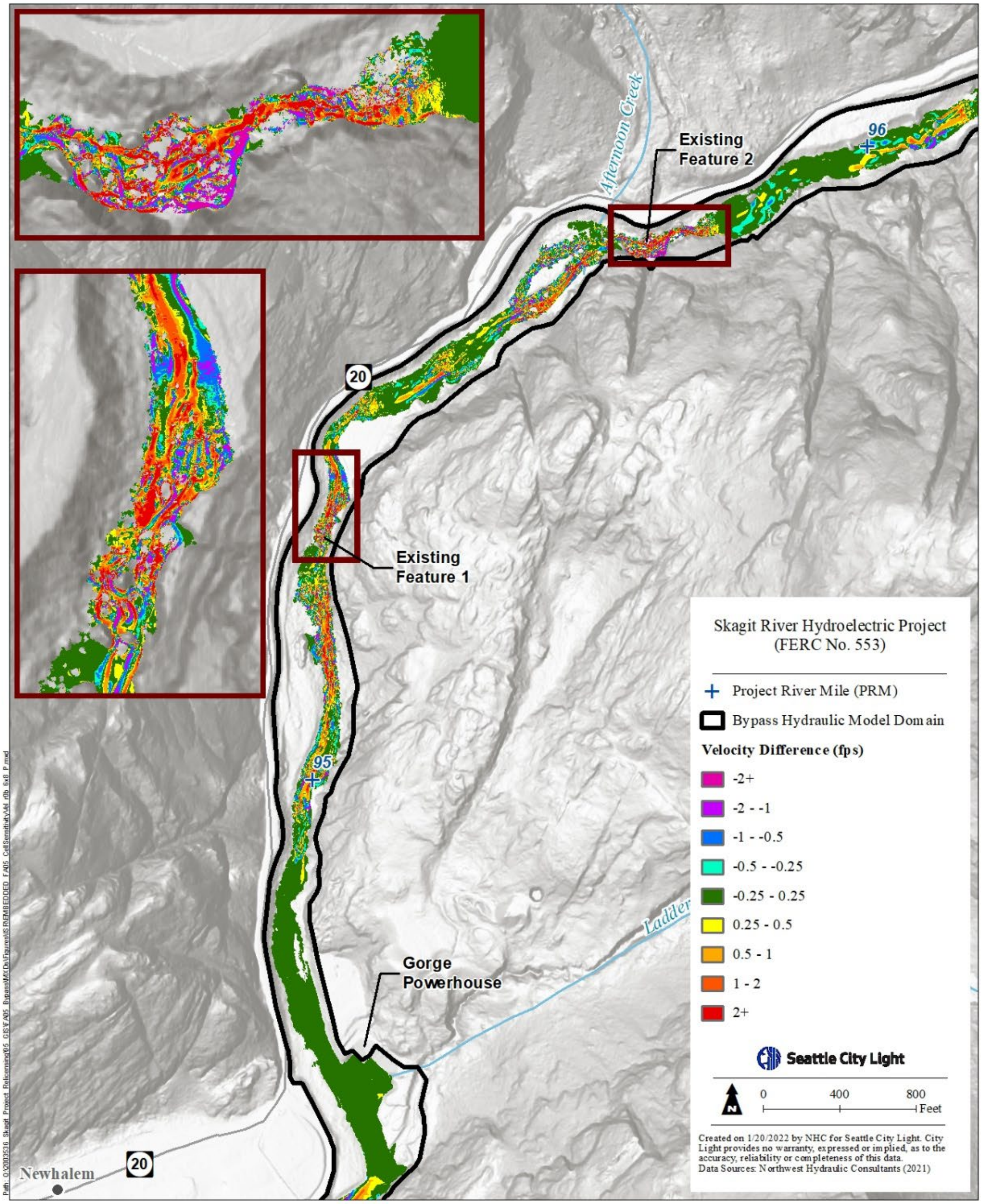

Figure 4.4-4. Difference in velocity output from 2-foot and 1-foot computational meshes.

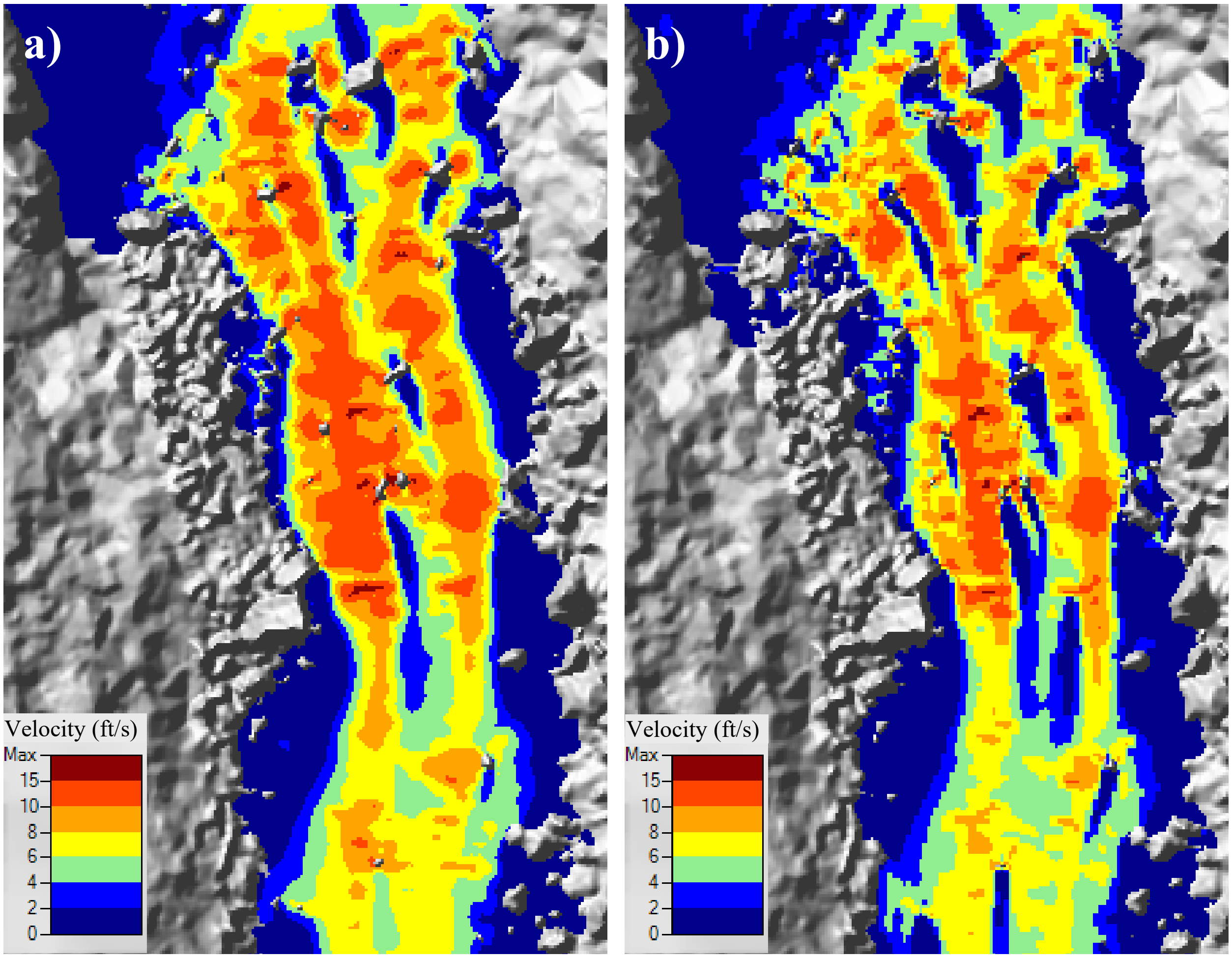

Figure 4.4-5. Computed velocities with a) 2-foot and b) 1-foot mesh cells.

Despite requiring significantly longer computation times than other tested cell sizes (four times that of the 2-foot mesh) 1-foot cells were selected for the Bypass Hydraulic Model refinement region. This cell size provides the most accurate and detailed characterization of hydraulic conditions that can be achieved given the available terrain.

4.4.2 Time Step

The time step used for Bypass Hydraulic Model computations was evaluated to ensure use of an appropriate value. Selection of an adequate time step can be evaluated by assessing Courant values associated with the mesh, where the Courant number is a function of cell size and velocity moving through the cell. For the solution scheme employed for the Bypass Hydraulic Model, the HEC-RAS guidance document recommends that Courant numbers not exceed a value of 3 to achieve stable and accurate results (USACE 2021b). Testing showed a 0.3-second time step was the maximum that could be used to avoid numerical instabilities large enough to cause simulation failure. Courant numbers exceeded 3 in multiple locations using a 0.3-second time step. Use of a 0.1-second time step achieved a Courant number less than 3 in all mesh cells. A 0.2-second time step achieved a Courant number less than 3 throughout most of the model except at some features where hydraulic conditions consist of cascading flow over large boulders and steep drops in channel elevation (Figure 4.4-6). Cascading flow is exceedingly turbulent and three-dimensional, such that even the most accurate 2-D model can only provide a crude representation of these conditions using depth-averaged computations. Therefore, a 0.2-second time step was deemed adequate for achieving good numerical accuracy while significantly improving efficiency over a 0.1-second time step, reducing runtimes nearly by half. For most simulations with a 0.2-second time step and the final mesh configuration, a stable solution can be achieved within approximately 20 hours of model runtime.

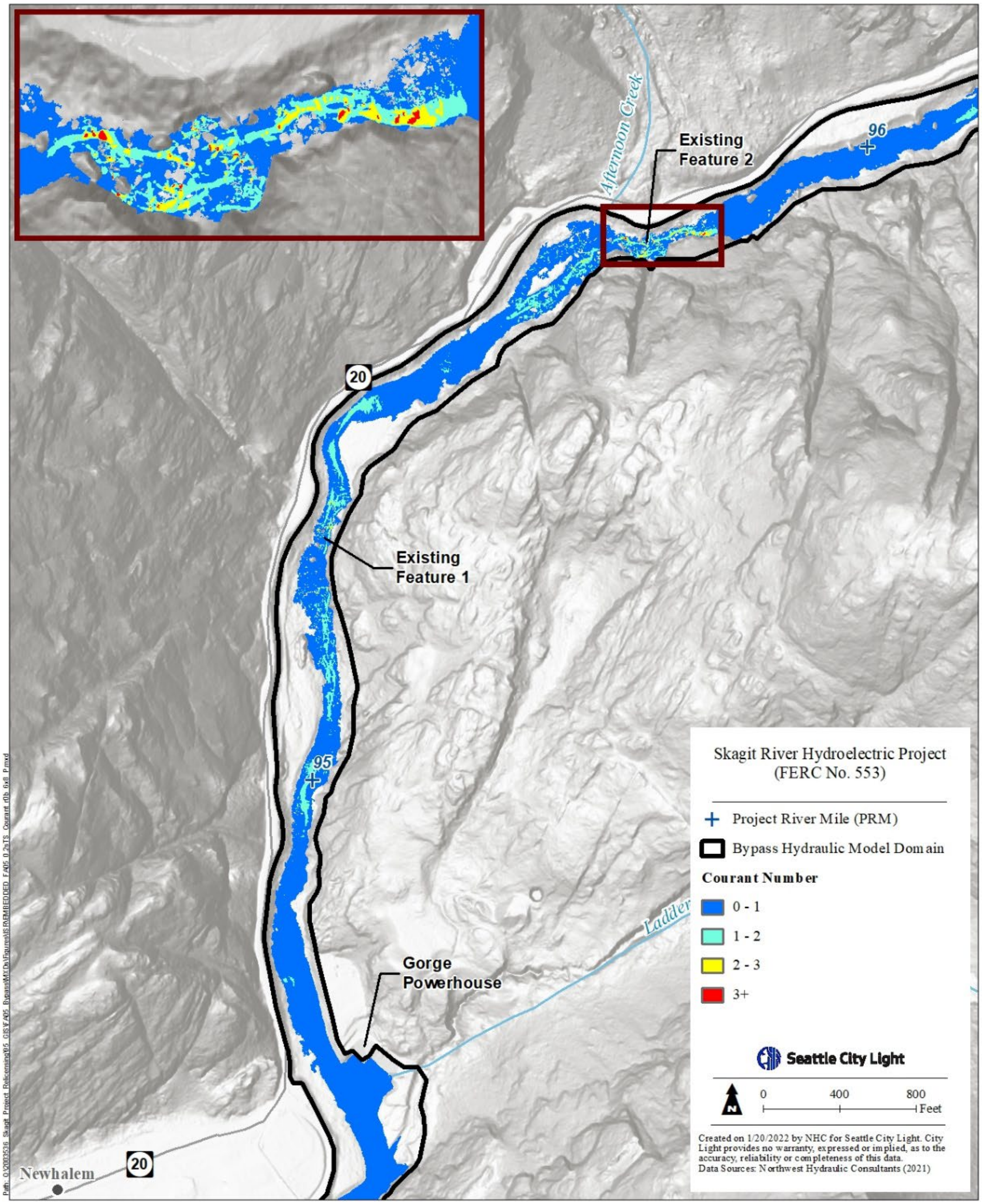

Figure 4.4-6. Courant Numbers for Bypass Hydraulic Model computations with a 1-foot cell size and a 0.2-second timestep.

4.4.3 Turbulence Parameters

HEC-RAS offers the ability to include increasing effects of turbulence in the flow field. Highly turbulent flow characteristics are prominent throughout many sections of the Gorge bypass reach and therefore the impact of increasing turbulence coefficients on Bypass Hydraulic Model results was tested. HEC-RAS provides a range of turbulence coefficients and their qualitative expected mixing intensity (USACE 2021b). Sensitivity testing analyzed the relative impact of using no turbulence input versus the maximum turbulence coefficients that still achieved numerical stability. It should be noted even without turbulence explicitly turned on, the HEC-RAS solution scheme includes numerical diffusion that mimics the effects of turbulence processes to some degree. It was found that as turbulence input is decreased for the Bypass Hydraulic Model, flow patterns develop stronger, more pronounced eddies, and flow paths become narrower and stronger (Figure 4.4-7). HEC-RAS's default turbulence coefficients, representative of moderate mixing intensity, were selected for the base Bypass Hydraulic Model condition carried forward to model calibration. Turbulence sensitivity testing will be used to inform adjustment of turbulence coefficients if warranted during model calibration. Table 4.4-1 provides the range of turbulence coefficient values tested and selected values for the base Bypass Hydraulic Model condition.

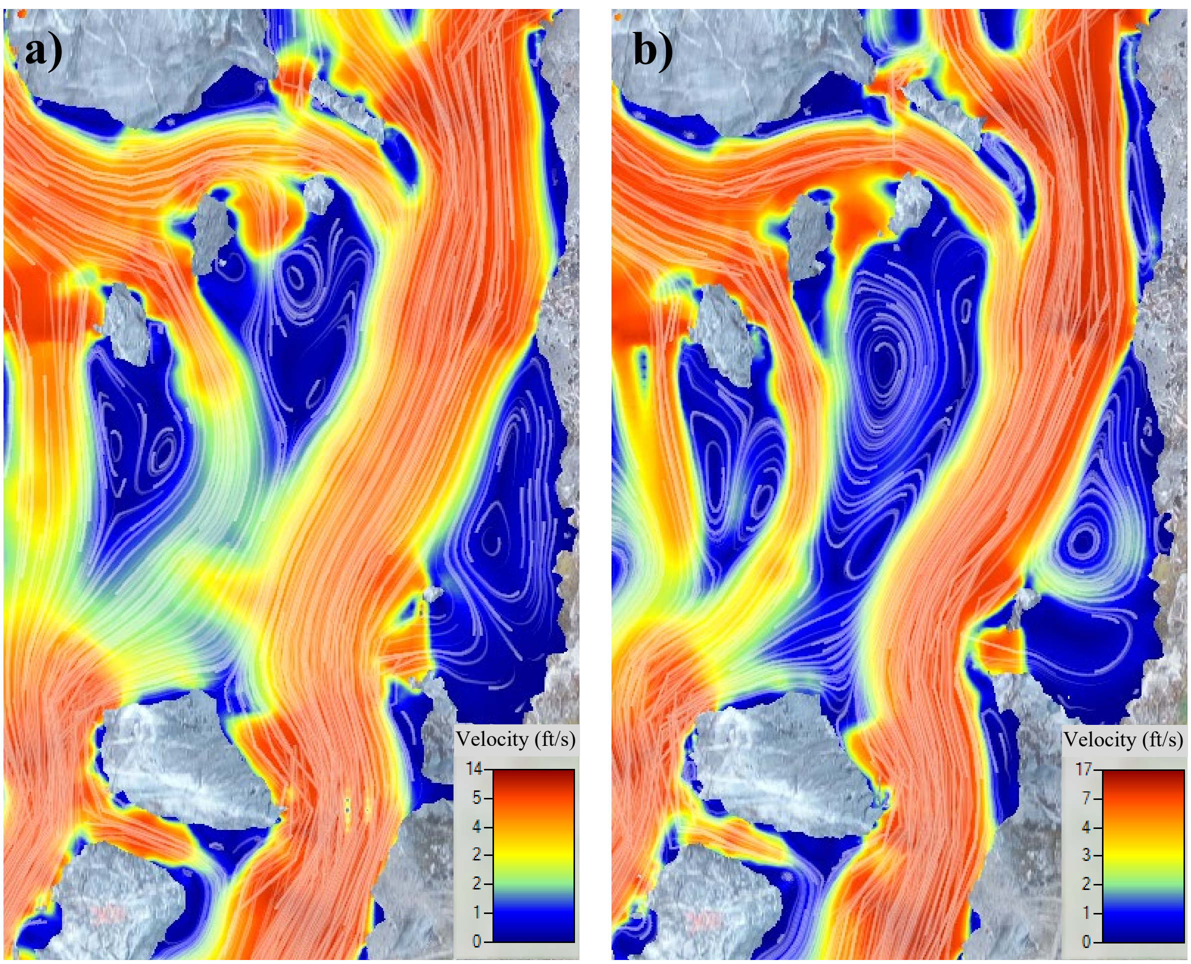

Figure 4.4-7. Computed velocities and flow patterns using a) max allowable turbulence parameters and b) no turbulence input.

Table 4.4-1. Turbulence input sensitivity tests for the Bypass Hydraulic Model.

Turbulence Coefficient	Parameter Values		
	Low[1]	Moderate[2]	Maximum[3]
Longitudinal	0	0.3	0.65
Transverse	0	0.1	0.2
Smagorinsky	0	0.05	0.1

1 Turbulence input omitted.
2 Selected values for base model condition.
3 Maximum values constrained by requirements for model stability.

4.4.4 Hydraulic Roughness

The majority of flow for the range of expected Bypass Hydraulic Model simulation events is confined to the "channel" hydraulic roughness zones. A series of Manning's n values were tested in the channel roughness zones to determine a base condition for initial simulations. Table 4.4-2 provides the Manning's n values used for each sensitivity test. Manning's n valuations based on unvegetated channel coefficients of 0.02 and 0.03 limited specification of other input parameters (cell size, timestep, turbulence) to achieve numerical stability. Even when a stable parameter set was applied, the magnitude of computed velocities was generally much higher than field observations (Figure 4.4-8). Manning's n values based on an unvegetated channel coefficient of 0.05 achieved computed velocities of similar magnitude to field observations without requiring strict limitations to other input parameters, and therefore were selected for the base condition.

Table 4.4-2. Channel roughness sensitivity tests for the Bypass Hydraulic Model.

Hydraulic Roughness Zone	Manning's n Value		
	Test 1	Test 2	Test 3
Channel - Unvegetated	0.02	0.03	0.05
Channel – Light Vegetation	0.03	0.03	0.08
Channel – Medium Vegetation	0.04	0.04	0.12
Channel – Heavy Vegetation	0.05	0.05	0.16

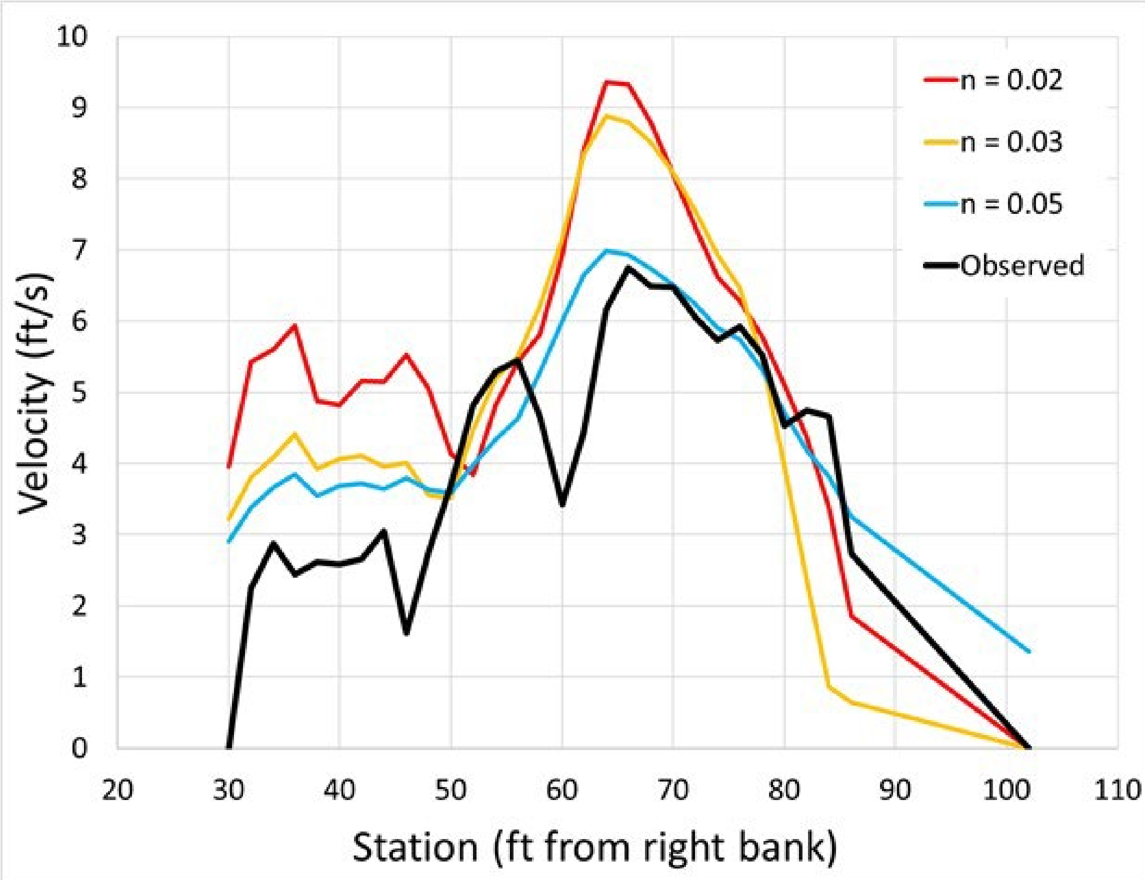

Figure 4.4-8. **Computed versus observed velocities at Transect AA for varied Manning's n values at 1,200 cfs.**

4.5 Bypass Hydraulic Model Calibration (Preliminary)

Calibration is crucial to establishing confidence in the ability of a model to simulate hydraulic characteristics reliably and accurately for a range of flow conditions. Calibration involves the adjustment of model parameters within plausible limits to best match simulated results to field observations. For the Bypass Hydraulic Model, calibration is focused on adjustment to hydraulic roughness zone delineation, Manning's n values, and turbulence coefficients.

The ability of the Bypass Hydraulic Model to accurately predict both depths and velocities, within the constraints of a 2-D depth-averaged model, is critical for analysis of instream flows and fish passage. The following performance indicators (Pasternack 2011) are or will be used to evaluate model simulations for accuracy of results relative to field observations:

- Cross-sectional comparison of depths and velocities at transects. Results from an adequately calibrated model should not show any systematic deviations from field measurements.
- Comparison of water surface elevations along a longitudinal profile derived from UAV orthoimagery. Results from an adequately calibrated model should not show any systematic deviations from field observations.

- Scatter plot analysis of observed versus computed velocity magnitude. Linear regression results for an adequately calibrated model will have (1) a slope with near 1:1 linearity; (2) a y-intercept near zero; and (3) a coefficient of determination (r^2) between 0.6 and 0.8.
- Evaluation of raw deviations between observed and computed depths at transects. Deviations for an adequately calibrated model should be centered near zero.
- Comparison of modeled inundation extents with mapped extents from UAV orthoimagery.

Results from a preliminary calibrated Bypass Hydraulic Model as of November 2021 are presented in Attachment E. Calibration efforts continued through January 2022 and the final calibrated Bypass Hydraulic Model was presented at Workshop 5 on February 1, 2022. A separate model calibration report is under development.

4.5.1 Model Calibration

To date, calibration efforts for the Bypass Hydraulic Model have focused on adjusting roughness zone delineations and Manning's n valuations within the channel while evaluating model simulations versus observations for the July 26, 27, and 29, 2021 controlled releases. Bypass Hydraulic Model performance to date has been evaluated with: (1) cross-sectional comparison of depths and velocities at transects; and (2) comparison of water surface elevations at level loggers. Charts documenting current preliminary calibration results are provided in Attachment E. To achieve the current condition, adjustment to roughness from the base configuration has included: (1) increasing the Manning's n value of unvegetated channel zones to 0.06; and (2) redefining the light vegetation zone upstream of Transect II to a heavy vegetation zone. The following key observations have been noted for this preliminary calibration:

- Computed velocities are generally low, and depths are high relative to field measurements at Transect EE, indicating a need to lower roughness in this region.
- At Transect II, velocities along channel right are high compared to field measurements, while velocities along channel left are low. This indicates a need to increase roughness for vegetated areas along channel right to adjust velocity distribution by shifting more flow left.
- Depths and velocities currently match field measurements at Transect DD well. Located in Afternoon Creek pool, it is expected that model results at this transect will have low sensitivity to roughness and turbulence parameters.
- Distribution of depth and velocity at Transect AA shows a good correlation with field observations, though deviation in velocity can be significant in localized areas. These deviations may be improved by adjusting turbulence coefficients or may warrant revisiting georeferenced field observations to more accurately extract model results where field measurements were taken.
- At Transect GG, computed velocities are low, and depths are high relative to field observations at 50 cfs, indicating that a decrease in roughness may be warranted in this region.
- Computed water surface elevations are generally within about half a foot of level logger measurements at Existing Features 1 and 2. The exceptions to this are computed water surface elevations at level loggers DDL2, DDL4, and DDL5 for the July 29, 2021, flow. The source of these deviations will be further investigated.

Calibration efforts were approximately 50 percent complete as of November 2021. Remaining efforts to achieve a final calibrated condition include:

- Further refinement of hydraulic roughness zones and adjustment to Manning's n values;
- Possible adjustment to turbulence coefficients;
- Evaluation of model results compared to field observations for the late-June 2021 spill;
- Evaluation of model results compared to surface velocities and flow paths derived from UAV orthoimagery for the July 26-29, 2021 controlled releases; and
- Quantification and evaluation of model performance indicators (Pasternack 2011).

4.6 Bypass Habitat Model Development

Habitat model development consists of three components: channel structure, hydraulic simulation, and aquatic HSC. Channel structure includes all fixed-channel features that generally do not change with flow. These features include channel cross-sectional geometry, substrate composition and distribution, and structural cover. Hydraulic variables are those that change with flow, such as water surface elevation, depth, velocities, wetted perimeter, and channel surface area. HSC are numeric representations of preferred depths, velocities, substrate, and cover, for the various life stages of the aquatic species of interest (Bovee et al. 1998). The hydraulic modeling component simulates water depths and velocities under a range of different flow regimes. The aquatic HSC, commonly referred to as HSC curves, contain information on tolerances or preferences of aquatic organisms with respect to the hydraulic and structural characteristics of the stream. They most often are comprised of depth, velocity, and substrate/cover preferences.

4.6.1 Target Species and Life Stages

City Light, in consultation with LPs, selected targets species and life stages to be considered for modeling from a list of species known to be present in the Skagit River mainstem and the Gorge bypass reach. In addition, LPs requested additional species and life stages be added that may not have been collected or observed in the Skagit River mainstem and the Gorge bypass reach but have the potential to be present. A list of target species and life stages considered for instream flow modeling is provided in Table 4.6-1.

Table 4.6-1. Target species and life stages considered for the Upper Skagit (mainstem from Gorge Powerhouse to Sauk River) and the Bypass Instream Flow Models.[1]

Species	Scientific Name	Life Stage			
		Spawning	Adult	Juvenile	Fry
Steelhead	*Oncorhynchus mykiss*	X	X	X	
Chinook Salmon	*Oncorhynchus tshawytscha*	X		X	X
Pink Salmon	*Oncorhynchus gorbuscha*	X			
Chum Salmon	*Oncorhynchus keta*	X			X
Coho Salmon	*Oncorhynchus kisutch*	X		X	X
Sockeye Salmon	*Oncorhynchus nerka*	X			
Rainbow Trout	*Oncorhynchus mykiss*	X	X	X	X
Bull Trout/Dolly Varden	*Salvelinus confluentus/Salvelinus malma*	X		X	X
Sea-Run Bull Trout	*Salvelinus confluentus*	X			
Cutthroat Trout	*Oncorhynchus clarkii*	X	X	X	X
Sea-Run Cutthroat Trout	*Oncorhynchus clarkii*	X			
Mountain Whitefish	*Prosopium williamsoni*	X	X	X	X
Pacific Lamprey	*Entosphenus tridentatus*	X			
Lamprey (generic)	*Lampetra* spp.			X	
Western Brook Lamprey	*Lampetra richardsoni*	X			
Western River Lamprey	*Lampetra ayresii*	X			
White Sturgeon	*Acipenser transmontanus*	X			
Salish Sucker	*Catostomus catostomus*	X		X	

1 Some species and/or life stages selected for habitat modeling consideration may not be present in the mainstem Skagit River, but in collaboration with LPs, have been included to evaluate the amount of potential habitat created under various flow regimes. The habitat model results for these species/life stages may or may not be considered in future instream flow management decisions.

4.6.2 Life Stage Periodicity

The period of year when a species or life stage is present in the study area is an important component of habitat modeling where the model results are used to determine the amount of habitat available over a period with varying flow conditions (often referred to as time series analysis). The periodicity for each of the target species and life stages (Table 4.6-2) was determined in consultation with the LPs. Periodicity was determined primarily from literature resources and professional input from City Light staff and LPs with Skagit-specific field experience. The periodicity information provided in Tables 4.6-1 and 4.6-2 will apply to both the Skagit mainstem and Gorge bypass reach instream flow study areas.

Table 4.6-2. Periodicity for target species and life stages.

Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Steelhead	Adult												
	Spawning												
	Juvenile												
Chinook Salmon	Spawning												
	Fry												
	Juvenile												
Skagit Pink Salmon	Spawning												
Chum Salmon	Spawning												
	Fry												
Coho Salmon	Spawning												
	Fry												
	Juvenile												
Sockeye Salmon	Spawning												
Rainbow Trout	Adult												
	Spawning												
	Fry												
	Juvenile												
Bull Trout	Spawning												
	Fry												
	Juvenile												
Sea-Run Bull Trout	Spawning												
Cutthroat Trout	Adult												
	Spawning												
	Fry												
	Juvenile												

Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sea-run Cutthroat Trout	Spawning												
Mountain Whitefish	Adult												
	Spawning												
	Fry												
	Juvenile												
Pacific Lamprey	Spawning												
Lamprey (generic)	Juvenile												
Western Brook Lamprey	Spawning												
Western River Lamprey	Spawning												
White Sturgeon	Spawning												
Salish Sucker	Spawning												
Salish Sucker	Juvenile												

4.6.3 Habitat Suitability Criteria

Skagit River HSC LP Workshops began in May 2021. After the June and July 2021 Workshops, a recommendation was made to form a smaller technical group of people knowledgeable about HSC and its use in instream flow habitat modeling. In August 2021, the HSC Technical Group was formed and comprised of LPs, City Light, and consultant team members. The HSC Technical Group met a total of 10 times (approximately bi-weekly) from August 2021 through January 2022. The HSC Technical Group's objective was to gather and review available HSC information relevant to the Skagit River and develop a step-wise process to evaluate and ultimately propose recommended HSC curves for each species and life stage being considered for habitat modeling on the Skagit River mainstem and Gorge bypass reach. In addition, the HSC Technical Group evaluated 2021 field validation data collected on the Skagit River as well as additional studies that will be included in WDFW/Ecology’s updated Instream Flow Study Guidelines during 2022.

As a starting point for the HSC curve selection (and in some cases development) process, an HSC library was assembled consisting of curves from City Light’s existing effective spawning habitat (ESH) model, Washington State’s Instream Flow Study Guidelines (Beecher et al. 2016), curves from other west coast region instream flow studies for rivers comparable in size to the Skagit River, and literature from other relevant studies and research.

HSC curves are often referred to by “type” which indicates the basis of the curves (Bovee 1986). Type 1 curves are based on professional judgment with little or no empirical data. Type 2 curves are based on data from locations where target species are observed or collected. Commonly referred to as utilization (or use) curves, Type 2 curves can be biased by a limited range of hydraulic conditions that were available at the time the target species were observed. Type 3 curves are based on data from locations where target species are observed or collected under a variety of conditions to remove environmental bias. Type 3 curves include measurements of “available” habitat (at the time the discrete observation data were collected) which are used to adjust utilization data to become “preference curves.” Type 3 curves tend to be less site-specific than Type 2 curves and can be applied more broadly.

Table 4.6-3 provides a list of species and life stages to be considered for modeling. They are grouped based on the availability and type of existing HSC curves:

- **Group A** includes species and life stages where HSC curves are available from both the Skagit ESH model and WDFW/Ecology Type 3 curves. With the exception of Chum Salmon spawning, field validation studies were conducted in 2021 to collect additional site-specific data (i.e., depth, velocity, substrate, and cover) for Group A species and life stages. These data were used qualitatively to support decisions on HSC curve selection and/or modification. The field validation studies are described in the Habitat Suitability Criteria – 2021 Field Validation Data Summary (HDR 2022b), as attached to the FA-02 Instream Flow Model Development Study Interim Report (City Light 2022a).
- **Group B** originally consisted of two species and life stages where both Skagit-specific Type 2 curves (i.e., based on Skagit River field observation data) and WDFW/Ecology Type 3 curves were available (i.e., Chum spawning and Pink spawning). Early in the HSC evaluation process LPs recommended adding these two species to Group A as there was interest in collecting

additional field observation data during the 2021 field validation study efforts. Moving these two species/life stages into Group A effectively eliminated Group B.

- **Group C** includes species and life stages where HSC curves are not available from the ESH model but are available as WDFW/Ecology Type 3 curves. The Type 3 curves will be used as a default unless field validation studies conducted for Group A provide information that a modification of the WDFW/Ecology Type 3 curves is warranted to better represent site-specific observations on the Skagit River.
- **Group D** HSC curves are not available from either the ESH model, or WDFW/Ecology. For these species and life stages, available HSC curves from other instream flow studies were used as a surrogate and/or consensus curves were developed in collaboration with LPs by modifying available HSC curves. In some cases, literature was available to support development of HSC consensus curves.
- **Group E** consists of the fry life stage for several salmonids. Type 3 HSC curves are not available from WDFW/Ecology, therefore, individual salmonid fry HSC curves from the ESH model will be used for habitat modeling purposes.
- **Group F**, surrogate HSC curves were not available, so consensus curves were developed based on literature review.

Based on WDFW/Ecology policy, the statewide Type 3 curves are preferred unless:

- Enough site-specific, Type 3 data can be found or collected to develop new HSC curves, or
- Enough site-specific Type 3 data can be collected in the field to use as a rationale for adjusting the statewide Type 3 curves, or
- Type 3 curves from another source can be found and determined to be equal to, or more representative than, the statewide Type 3 curves.

HSC curves used in the current ESH model are based on a variety of Type 1 and Type 2 data sources. For example, HSC curves for Steelhead, Chinook, Pink, and Chum spawning life stage are based on hundreds of Skagit-specific field observation data from Crumley and Stober (1984) and considered to be Type 2 curves (attempts to locate detailed field observation data from the studies were unsuccessful). Data collected during the 2021 HSC field validation effort for these four species (spawning life stage) were determined to be insufficient to create new Type 3 curves. However, these data (i.e., observations of redds or fish) were reviewed by the HSC Technical Group and were determined to be consistent with the ESH and statewide HSC curves. Other HSC curves used in the ESH model are based on Type 1 and Type 2 curves from other (non-Skagit) data sources and are considered to be a hybrid of Type 1-2 curves. As a result, in most cases, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves for Skagit River habitat modeling purposes when available.

When WDFW/Ecology Type 3 curves were not available, the HSC Technical Group typically recommended: (1) curves from other surrogate species with statewide Type 3 curves; (2) Type 2 curves from other studies; or (3) developed consensus curves from available and relevant literature.

Depth, velocity, and substrate/cover HSC curves for each species and life stage listed in Table 4.6-3 are provided in Attachment F.

Table 4.6-3. Skagit River target species and life stages.

Species	Life Stage	HSC Group	HSC Status	WDFW/Ecology Guidelines (Beecher et al. 2016) or other reference	
				Substrate	Cover
Steelhead	Spawning	A	WDFW/Ecology Type 3 curves	Table 4	N/A
	Adult holding	D	WDFW/Ecology Type 3 curves for Rainbow Trout adult rearing	Table 3	Table 3
	Juvenile	A	WDFW/Ecology Type 3 curves	Table 3	Table 3
Chinook Salmon	Spawning	A	WDFW/Ecology Type 3 curves	Table 2	N/A
	Juvenile	A	WDFW/Ecology Type 3 curves	Table 3	Table 3
	Fry	E	ESH Model Type 2 curves	ESH Model	N/A
Pink Salmon	Spawning	A	WDFW/Ecology Type 3 curves	Table 2	N/A
Chum Salmon	Spawning	A	WDFW/Ecology Type 3 curves	Table 2	N/A
	Fry	E	ESH Model Type 2 curves	Fraser River (Rempel et al. 2012)	N/A
Coho Salmon	Spawning	C	WDFW/Ecology Type 3 curves	Table 2	N/A
	Juvenile	D	ESH Model Type 2 curves	ESH Model	Table 3
	Fry	E	ESH Model Type 2 curves	ESH Model	N/A
Sockeye Salmon	Spawning	C	WDFW/Ecology Type 3 curves	Table 2	N/A
Rainbow Trout	Spawning	C	WDFW/Ecology Type 3 curves	Table 5	N/A
	Adult rearing			Table 3	Table 3
	Juvenile			Table 3	Table 3
	Fry	E	ESH Model Type 2 curves	ESH Model	N/A
Bull Trout / Dolly Varden	Spawning	C	WDFW/Ecology Type 3 curves	Table 6	N/A
	Juvenile	A	WDFW/Ecology Type 3 curves (updated 2021)	Table 3	Table 3
	Fry	E	ESH Model Type 2 curves	ESH Model	N/A
Sea-Run Bull Trout	Spawning	F	Consensus curves developed	Table 6	N/A

Species	Life Stage	HSC Group	HSC Status	WDFW/Ecology Guidelines (Beecher et al. 2016) or other reference	
				Substrate	Cover
Cutthroat Trout	Spawning	C	WDFW/Ecology Type 3 curves	Table 5	N/A
	Adult	D	WDFW/Ecology Type 3 curves for Cutthroat Trout juvenile	Table 3	Table 3
	Juvenile	C	WDFW/Ecology Type 3 curves (updated 2021)	Table 3	Table 3
	Fry	E	ESH Model Type 2 curves	ESH Model	N/A
Sea-Run Cutthroat Trout	Spawning	D	Consensus curves developed	Table 5	N/A
Mountain Whitefish	Spawning	C	WDFW/Ecology Type 3 curves	Table 7	N/A
	Adult rearing			Table 8	Table 1
	Juvenile			Table 9	Table 1
	Fry	E	ESH Model Type 2 curves	ESH Model	N/A
Pacific Lamprey	Spawning	D	Consensus curves developed	Vadas 2021	N/A
Lamprey (generic)	Juvenile rearing			Vadas 2021	N/A
Western Brook Lamprey	Spawning	F	Consensus curves developed	Vadas 2021	N/A
Western River Lamprey	Spawning			Vadas 2021	N/A
Salish Sucker	Spawning	F	Consensus curves developed	Pearson 2003	N/A
	Juvenile rearing				Pearson 2003
White Sturgeon	Spawning	F	Consensus curves developed	Sacramento River (Gard 1996)	N/A

4.7 Flow-Habitat Analysis

HSC curves and periodicity information in combination with the calibrated hydraulic model will allow for detailed analyses of the amount, timing of availability, and location of suitable habitat under a range of discharges or species and life stages of interest. Bypass Hydraulic Model depth and velocity results will be integrated with habitat data in an Instream Flow Incremental Methodology (IFIM) type analysis to produce flow/habitat relationships for species and life stages of interest. This flow-habitat analysis is awaiting final Bypass Hydraulic Model calibration and HSC.

4.8 Hydraulic Data for Fish Passage Analysis

The calibrated Bypass Hydraulic Model will be run for a range of flows determined in consultation with LPs and Fish Passage Study team fish passage specialists to generate hydraulic data to support fish passage evaluation at Existing Features 1 and 2 conducted as part of the FA-04 Fish Passage Study (City Light 2022b). Additional products to be provided to the FA-04 Fish Passage Study include UAV photos and videos of the Gorge bypass reach, and water level logger records at the Existing Features. These products will be made available to the Fish Passage Study team as processing is completed. The results of the fish passage analysis at Existing Features are presented in the FA-04 Fish Passage Study report (City Light 2022b).

4.9 Consultation

Three consultation workshops were held in the first year of study, through December 2021, to apprise LPs of progress on the study and to solicit feedback and input. In addition to the three workshops, two smaller technical group meetings were held on January 11, 2022 and January 21, 2022 to discuss calibration of the Bypass Hydraulic model. These smaller technical groups were comprised of staff from WDFW, Ecology, and the consultant team. The agencies provided guidance to the final calibrated hydraulic model that was presented during Workshop 5 on February 1, 2022. Further workshops will be held in 2022 during the second year of study.

A series of parallel workshops and smaller technical workgroup meetings was held under the FA-02 Instream Flow Model Development Study (City Light 2022a) with content and discussion relevant to the Bypass Instream Flow Model Development Study. Of particular relevance is the series of workshops and technical workgroup meetings held to address development of HSCs and periodicity data. The resulting preliminary HSC curves and preliminary periodicity table were presented and reviewed during HSC Workshop 5 on February 3, 2022. At HSC Workshop 5, consensus was reached on the majority of the proposed HSC curves (representing 29 species and life stage combinations). Consensus was achieved for the remaining HSC curves (representing 8 species and life stage combinations) via email on February 18, 2022 (Attachment F). A summary of those workshops and workgroup meetings is provided in the FA-02 Instream Flow Model Development Study report (City Light 2022a).

The three workshops held through December 2021 were as follows:

Workshop 1

The primary purpose of Workshop 1 (May 17, 2021) was to discuss and address LP concerns, raised in Workshop 1 of the FA-02 Instream Flow Model Development Study, surrounding the use of numerical hydraulic models for evaluation of fish passage in the Gorge bypass reach (City Light 2022a). The workshop was presented jointly by the Bypass Instream Flow Model Development Study team and the FA-04 Fish Passage Study team. The workshop included:

- Review and discussion of objectives and methodology for fish passage evaluation;
- Discussion of the role of hydraulic modeling in evaluation of fish passage;
- Discussion of concerns raised by LPs regarding the use of the HEC-RAS 2-D model as a fish passage evaluation tool; and
- Discussion of the proposed data collection program to support development of the Bypass Hydraulic Model.

Workshop 2

Workshop 2 was proposed in the RSP to review and discuss proposed updates to biological and habitat metrics. However, following Workshop 1 of the FA-02 Instream Flow Model Development Study (City Light 2022a), it was decided to hold a separate series of workshops and smaller technical working group meetings to specifically address development of HSCs and periodicity data relevant to both the FA-02 Instream Flow Model Development Study and Bypass Instream Flow Model Development Study areas, thus obviating the need for Workshop 2. A summary of the HSC workshops and HSC and periodicity workgroup meetings is provided in the FA-02 Instream Flow Model Development Study report (City Light 2022).

Workshop 3

Workshop 3 (August 26, 2021) provided an update on and discussion of development of the Bypass Hydraulic Model, including:

- Presentation and discussion of the field data collection (details of the data collection program and its results are provided in Attachment B);
- Review and discussion of the development of the Bypass Hydraulic Model terrain dataset; and
- An overview of the approach to Bypass Hydraulic Model development.

Workshop 4

Workshop 4 (November 2, 2021) provided a further study update, including:

- Discussion of uncertainty in the discharge data used for the Bypass Hydraulic Model calibration;
- Update and discussion of Bypass Hydraulic Model development, including the model terrain, geometry, and roughness, and associated model sensitivity tests;
- Presentation and discussion of the approach to Bypass Hydraulic Model calibration and the status of the calibration;
- An update on development of biological and habitat data, including substrate and cover mapping, HSC, and periodicity data; and

- A preview of the planned approach to the integration of Bypass Hydraulic Model outputs and biological/habitat data for instream flow analysis.

The agenda, presentation material, and meeting notes for Workshops 1, 3 and 4 are provided in Attachments G, H, and I respectively.

5.0 PRELIMINARY RESULTS

The Bypass Instream Flow Model Development Study is a two-year study and, as noted previously, calibration of the hydraulic model was ongoing through January 2022 while this study report was being written. As such, there are no final study results to report currently. The following are the outstanding Bypass Instream Flow Model Development Study work products and their expected timelines:

- **Calibrated Bypass Hydraulic Model** – The final Bypass Hydraulic Model calibrated to the depth, velocity and water surface elevation observations described in Section 4.2.2.2 of this study report was presented at Workshop 5 on February 1, 2022.[5] A stand-alone model calibration report is under development and will be available in the spring of 2022.
- **Flow-Habitat Relationships** – The calibrated Bypass Hydraulic Model will be simulated with a suite of flows to generate spatial coverages of depths and velocities from the Gorge Dam plunge pool to the Skagit River at Newhalem USGS gage (USGS #12178000). These will be spatially combined with the substrate and cover layers (Attachment D) and with HSC curves (Attachment F) to generate flow-habitat relationships that will be expressed in map and tabular formats (i.e., Bypass Habitat Model). Development of the Bypass Habitat Model is expected to begin in March 2022.
- **FA-04 Fish Passage Study Support** – The RSP states "The calibrated hydraulic model will be run for a range of flows determined in consultation with LPs and study team fish passage specialists to generate hydraulic data to support the fish passage evaluation. The evaluation of fish passage will be conducted as part of the Fish Passage Study." Application of the Bypass Hydraulic Model to simulate flows for fish passage evaluation will commence in February 2022.

[5] Workshop 5 materials were not available at the time of ISR filing.

6.0 SUMMARY

The Bypass Instream Flow Model Development Study is a two-year study and, as such, data collection is substantially complete, while analysis is ongoing. The only outstanding data collection item is to retrieve the water level loggers in Spring 2022 and to download their recorded values. Data collected after November 2021 may be used to support evaluation of fish passage under the FA-04 Fish Passage Study (City Light 2022b), but is not necessary for, and would not be used in, development of the Bypass Hydraulic Model. Outstanding analysis includes finalizing calibration of the hydraulic model, spatial overlay of the hydraulic and biologic parameters for a suite of discharges (Bypass Habitat Model), and modeling fish passage flows in support of the FA-04 Fish Passage Study.

6.1 Notice of Agreements

The status of June 9, 2021 Notice commitments related to the Bypass Instream Flow Model Development Study is provided in Table 6.1-1.

Table 6.1-1. Status of Bypass Instream Flow Model Development Study modifications identified in the June 9, 2021 Notice.

Study Modifications Identified in the June 9, 2021 Notice: As Written	Status
City Light will provide a planned higher flow event in summer/fall if opportunistic high flow is not available. The study report will assess impacts to fish migration, both beneficial and detrimental, of certain flow regimes.	Complete. A high flow event occurred in late-June/early-July 2021 with a maximum flow of about 7,400 cfs. The hydraulic model will be calibrated to water level data collected in the Existing Features during this event at sustained flows of about 4,800 cfs and 6,200 cfs. The hydraulic model developed as part of this study will be used to support an assessment of fish migration. However, the results of the fish migration assessment will be reported on in the USR for the FA-04 Fish Passage Study.
City Light will clarify the study plan to allow for consideration of additional species [pink salmon (*Oncorhynchus gorbuscha*); chum salmon (*O.keta*); sea-run cutthroat (*O. clarkii clarkii*); Pacific lamprey (*Entosphenus tridentatus*)] for passage analysis.	The additional species have been added to the list of target species to be considered for passage analysis under the FA-04 Fish Passage Study.
City Light and the LPs will be treating these species [Pacific Lamprey, Salish Sucker; Dolly Varden] as present. City Light and the LPs will be selecting species for HSC analysis.	The HSC Tech Group developed/recommended HSC curves for all three requested species. Details are provided below: a) Pacific lamprey (spawning and juvenile rearing life stages) – HSC curves were developed based on literature review of West Fork Hoquiam River, Chehalis River basin and Trapp Creek, Washington and Nicola/coastal Salmon River, British Columbia (Vadas 2021). b) Salish sucker (spawning and juvenile rearing life stages) – HSC curves were developed based on literature review from several sources in Washington State and western

Study Modifications Identified in the June 9, 2021 Notice: As Written	Status
	Canada and are largely based on research performed by Pearson et al. (2003). c) Dolly Varden (spawning, juvenile, and fry) – It is WDFW/Ecology's preference to use statewide Type 3 HSC curves when available. As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves for Bull Trout and Dolly Varden spawning and juvenile life stages (Beecher et al. 2016). HSC curves are not available from WDFW/Ecology for the fry life stage, therefore, the HSC Tech Group recommended using the Type 2 HSC curves from Crumley and Stober (1984) which relied on data from the Arctic Environmental Information and Data Center.
City Light will address downstream and upstream fish passage at the plunge pool to the extent necessary.	The potential for downstream and upstream fish passage at the plunge pool is being considered as part of FA-04 Fish Passage Study implementation.
Address process flows Study Requests specifically: a) Which flows activate channel forming, channel maintenance, and channel flushing flows and upstream (probably covered) and outmigration of fish, and b) Look at magnitude, duration, frequency, seasonality, and timing (rate of change)	The data and analyses being conducted for the GE-04 Skagit River Geomorphology Between Gorge Dam and the Sauk River Study will support identification of flow scenarios to meet these interests and the available data will be discussed at Geomorphology Work Group meetings after the ISR.
City Light and the LPs recognize that there is a need for further dialogue about the use of best professional judgment for decision-making, such as passage flow assessment, and the establishment of objective criteria for evaluating studies as well as implementation of the studies.	Incorporated in the FA-04 Fish Passage Study implementation effort. City Light continues to work with LPs during biweekly Agency Work Sessions in support of this study.

6.2 Next Steps

In November 2021, the Gorge bypass reach experienced high flow due to a significant weather event. A recorded peak discharge of 63,400 cfs at USGS 12181000 (Skagit River at Marblemount, WA) on November 15, and 33,700 cfs at USGS 12178000 (Skagit River at Newhalem, WA) on November 16, 2021 were approximately 40-year and 25-year return interval floods respectively. Spill from Gorge Dam peaked at over 24,000 cfs on November 16, 2021. Localized impacts to channel topography were observed within both existing features but as yet have not been quantified. In the Gorge bypass reach, five of the 12 level logger stilling tubes were ripped from their bolt-anchored positions and four of these were never recovered. Boulders exceeding four tons were observed to have mobilized during the peak spill. Impact assessments of the November flooding on the hydraulic and habitat modeling completed to date are currently being planned for year two of the Bypass Instream Flow Model Development Study and will be reported on in the USR.

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

Several variances from the Bypass Instream Flow Model Development Study were adopted during study implementation as summarized below. These variances were adopted to better meet the study plan objectives by addressing data gaps that became apparent during the study, improving the safety and efficiency of field data collection, and enhancing consultation with LPs:

(1) Terrain refinement: The RSP proposed using the topobathymetric surface developed by QSI from the 2018 LiDAR (QSI 2018) directly to represent the Gorge bypass reach hydraulic model terrain. This surface has a 3-foot terrain resolution. During review of the LiDAR data, it became apparent that a finer resolution terrain was needed in several parts of the Bypass Hydraulic Model domain to provide a more realistic representation of actual conditions and to assure model accuracy. Consequently, City Light leveraged additional information in the raw LiDAR data to refine the model terrain to a 1-foot resolution. The process of developing the refined terrain is described in Attachment A.

(2) Method for acquiring water surface profile data: The RSP proposed acquiring water surface elevation profile data, subject to safety considerations, for each of the controlled releases and for base-flow conditions by manually marking profiles and surveying using conventional survey techniques. Following clarification of the conditions under which UAVs could by flown within the study area, it was decided to acquire water surface elevations profiles by UAV. This method was determined to be more efficient and safer than the method originally proposed. Acquisition and processing of the UAV data is described in Attachment B.

(3) Bypass Hydraulic Model Validation: The RSP states the model will be validated before evaluating alternative Project flow scenarios, without explicitly stating what or how many observations will be reserved for validation. A proposed validation approach of reserving transect observations from the 250 cfs controlled release was proposed at Workshop 4 and subsequently discussed at a small group technical meeting on January 11, 2022 (Section 4.9 of this study report) and the decision was made to forgo a strict validation. The decision to forgo validation was based on a consensus that calibration to the entire data set was more likely to produce favorable results compared to holding data for validation. The Bypass Hydraulic Model does not rely on transect-specific calibration parameters and therefore there is limited benefit in validating model parameters if model performance is adequate for all performance metrics.

(4) Variance in consultation process. The RSP proposed a series of five consultation workshops to apprise LPs of progress on the study and to solicit feedback and input. Following Workshop 1 of the FA-02 Instream Flow Model Development Study, it was decided to establish smaller technical working groups to specifically address development of HSCs and periodicity data for each species and life stage to be modeled. These working groups began meeting monthly from May through July 2021 and increased to approximately bi-weekly from August 2021 through January 2022. The HSC and periodicity subject matter are applicable to both the FA-02 Instream Flow Model Development Study and Bypass Instream Flow Model Development Study areas. Establishment of these technical working groups obviated the need for a combined FA-

02/FA-05 Workshop 2, which was planned for July 2021, and which was intended to discuss proposed updates to relevant biological and habitat metrics.

City Light is not proposing any modifications to the Bypass Instream Flow Model Development Study.

8.0 REFERENCES

Barnes, H.H. 1967. Roughness characteristics of natural channels. U.S. Geological Survey (USGS) Water-Supply Paper 1849.

Beecher, H.A., B.A. Caldwell, and J. Pacheco. 2016. Instream flow study guidelines, technical and habitat suitability issues including fish preference curves. Washington Department of Fish and Wildlife (WDFW) and Washington State Department of Ecology (Ecology). March 9, 2016. 84 pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. U.S. Fish and Wildlife Service Biological Report 86(7): 1 – 235.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Tayler, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey (USGS), Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp.

Crumley, S.C. and Q.J. Stober. 1984. Skagit River Interim Agreement Studies, Volume I Instream Flow Fish Habitat Analysis; Appendices. Final Report for City of Seattle, Department of Lighting, Office of Environmental Affairs, Seattle, WA. FRI-UW-8406. August 1984.

Envirosphere. 1989. Gorge Bypass Reach Fisheries Report. Report prepared for Seattle City Light by Envirosphere Company, Bellevue, Washington.

Gard, M. 1996. Sacramento River White sturgeon spawning criteria. U.S. Fish and Wildlife Service. Ecological Services. Sacramento Field Office. 13 p.

HDR Engineering, Inc. (HDR). 2022a. Upper Skagit River Green LiDAR Classification Technical Memorandum. March 2022.

_____. 2022b. Skagit River Hydroelectric Project FERC No. 553. Habitat Suitability Criteria – 2021 Field Validation Data Summary. March 2022.

Northwest Hydraulic Consultants, Inc. (NHC). 2022a. Gorge Bypass Reach Data Collection for Hydraulic Model Calibration Memorandum. March 2022.

_____. 2022b. Gorge Bypass Reach Discharge Measurement Uncertainty Analysis Memorandum. March 2022.

Pasternack, G.B. 2011. 2D modeling and ecohydraulic analysis. Createspace Independent Publishing Platform, Davis, CA. September 2011.

Pearson, M.P., and M.C. Healy. 2003. Life-history characteristics of the Salish sucker, Catostomus sp., and their implications for management. Copeia 2003: 759-768.

Quantum Spatial Inc. (QSI). 2017. Western Washington 3DEP LiDAR technical data report. Report prepared for U.S. Geological Survey (USGS). September 29, 2017.

_____. 2018. Upper Skagit, Gorge Lake, and Diablo Lake, Washington. Topobathymetric LiDAR and orthoimagery technical data report. Report prepared for Seattle City Light. August 17, 2018.

Rempel, L.L., K. Healey, and F.J.A Lewis. 2012. Lower Fraser River juvenile fish habitat suitability criteria. Can. Tech. Rep. Fish. Aquat. Sci. 2991: ix + 73 pages.

Seattle City Light (City Light). 2021. Revised Study Plan (RSP) for the Skagit River Hydroelectric Project, FERC Project No. 553. April 2021.

_____. 2022a. FA-02 Instream Flow Model Development Study, Interim Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Northwest Hydraulic Consultants, Inc. and HDR Engineering, Inc. March 2022.

_____. 2022b. FA-04 Fish Passage Technical Studies Program, Interim Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by HDR Engineering, Inc. March 2022.

Turnipseed, D.P., and V.B. Sauer.2010. Discharge measurements at gaging stations. (No. 3-A8). U.S. Geological Survey (USGS). 87 p. Also available at https://pubs.usgs.gov/tm.

United States Army Corps of Engineers (USACE). 2021a. HEC-RAS river analysis system version 6.1.0 [Computer Program]. U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center (HEC), Davis, CA. September 2021.

_____. 2021b. HEC-RAS river analysis system. 2D modeling user's manual, version 6.0. Hydrologic Engineering Center. May 2021.

Vadas, R.L. Jr. 2021. Life history and ecology of west-coast lamprey species, with special reference to the habitat needs of Pacific and western river and brook lampreys. Washington Department of Fish and Wildlife (WDFW), Habitat Program. Olympia, WA. 44 pages.

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SKAGIT RIVER GORGE BYPASS REACH HYDRAULIC AND INSTREAM FLOW MODEL DEVELOPMENT STUDY INTERIM REPORT

ATTACHMENT A

UPPER SKAGIT RIVER GREEN LiDAR RECLASSIFICATION MEMORANDUM

Memo

Date:	March 2022
Project:	Skagit River Project FERC Relicensing
To:	Chris Long, Northwest Hydraulic Consultants (NHC)
From:	Kira Lofgren, HDR Inc. (HDR)
Subject:	Upper Skagit River Green LiDAR Classification

1.0 INTRODUCTION

HDR aided NHC in assessing and modifying Light Detection and Ranging (LiDAR) data collected for Seattle City Light (City Light) to support improved hydraulic modeling of the Gorge bypass reach. HDR's intent is to better characterize the Skagit River basin by refining the LiDAR point classification with the intent to improve point density and develop a more detailed ArcGIS terrain. The final product is a high-resolution bare earth digital elevation model (DEM) of the Gorge bypass reach including detailed topographic features in the riverbed.

1.1 LiDAR Data Utilized

Quantum Spatial (QSI) was contracted by City Light to collect topobathymetric LiDAR data and digital imagery in the spring of 2018 for three sites located in the Skagit River corridor: Upper Skagit River, Gorge Lake, and Diablo Lake (QSI 2018). This data collection utilized bathymetric LiDAR (sometimes referred to as Green LiDAR) which provides some penetration into the water column, resulting in combination of bathymetric and topographic dataset. Table 1 provides dataset details specific to this effort.

1.2 LiDAR Assessment

HDR performed an initial assessment of the products delivered to City Light focusing on LiDAR accuracy, density, and classification. LAS files and derivative LiDAR products were reviewed using ESRI ArcPro. A more thorough visual review of the LAS files was performed using Terrasolid's TerraScan Module. HDR also reviewed QSI's Topobathymetric LiDAR and Orthoimagery Technical Data Report (QSI 2018).

QSI followed LAS ASPRS standards including classification of bathymetric bottom, water surface, and water column (Table 2). QSI's workflow for identifying water points consisted of both manual and automated techniques including bathymetric refraction. A combination of bathymetric bottom and ground returns were used to produce the bare earth DEM. The ground and bathymetric bottom classified density of LiDAR data for the Upper Skagit, Gorge Lake and Diablo Lake project was 0.52 points/ft^2 (5.56 points/m^2).

Table 1. Characteristics of LiDAR dataset.

Project Name and Dates	Bathy-metric	Total Acres (US)	Data Resolution and Quality	Original Spatial Reference	Acquisition Dates	Notes
Upper Skagit, Gorge Lake and Diablo Lake, Washington	Y	4,894	Cell Size: 3 ft raster DEM provided by QSI	Projection: Washington State Plane North Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD 88 (GEOID12B) Units: US Survey Feet	4/25/2018 to 4/26/2018	QSI processing report provides analysis of final datasets including LiDAR accuracy and density.

Table 2. American Society for Photogrammetry and Remote Sensing (ASPRS) LAS classification standards applied to the Upper Skagit, Gorge Lake, and Diablo Lake dataset.

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features
2	Ground	Laser returns that are determined to be ground, using automated and manual cleaning algorithms
40	Bathymetric Bottom	Refracted Riegl sensor returns that fall within the water's edge breakline which characterize the submerged topography.
41	Water Surface	Green laser returns that are determined to be water surface points using automated and manual cleaning algorithms.
45	Water Column	Refracted Riegl sensor returns that are determined to be water, using automated and manual cleaning algorithms.

HDR recommended improving upon QSI's already classified ground points. All returns in a point cloud are unclassified to start. Typically, a set of automated processes are used to classify points as ground. These methods do not capture all available ground points. Manually classifying additional ground points in a focused corridor along the river will increase point density and spacing in areas important to improving resolution and accuracy of hydraulic model results. To ensure a reprocessing effort covered an adequate extent for the hydraulic model, NHC identified these extents from analysis of preliminary hydraulic model results and provided HDR with a delineated boundary within which to perform the point reclassification analysis. The reclassification extent includes the channel bottom and, at a minimum, the bank toe below vegetated area. These extents are displayed on Figure 1. Areas delineated as bathymetric bottom would be left as is. Increased ground-point density in the riverbed will allow for the development of a bare earth DEM with one-foot terrain resolution along the riverbed in areas that weren't previously identified as bathymetric bottom to support detailed hydraulic analyses for instream flow and fish passage in the Gorge bypass reach. A sample area was processed and reviewed by NHC and HDR before proceeding with reprocessing.

1.3 LiDAR Data Processing

LiDAR processing broadly utilized three workflows; these are:

(1) Point Cloud Classification – This workflow uses tools specific to Terrasolid products to identify and assign points from default to ground class.

(2) Terrain Surface Creation – This workflow creates ESRI terrain datasets.

(3) Raster DEM Creation – Generating derivative GIS products from the ESRI terrain dataset.

1.3.1 Point Cloud Classification

Ground classification routines do not delineate riverbed topography well. Most automated ground classification methods will pick up small changes in topography but not drastic elevation changes such as boulders. Therefore, HDR manually classified additional default points to ground using the following steps:

- LiDAR points were associated with RGB values using ArcGIS Pro Colorize LAS.
- Areas with bathymetric bottom returns that should not be modified were delineated as polygons. LAS points in these polygons were coded with a unique class to ensure points were not classified as ground. ArcGIS Pro tool Change LAS Class Codes was used to change class from default to an unreserved temporary class (65).
- Default returns were manually classified as ground points using a suite of classification tools available in TerraScan. Terrasolid's TerraScan module is run through OpenRoads Designer which can be formatted for multiple data views allowing the analyst to see both top down and profile views to aid in classification. Figure 2 is an example of the cross-section view.
- Boulders were revisited to ensure ample points were classified as ground.

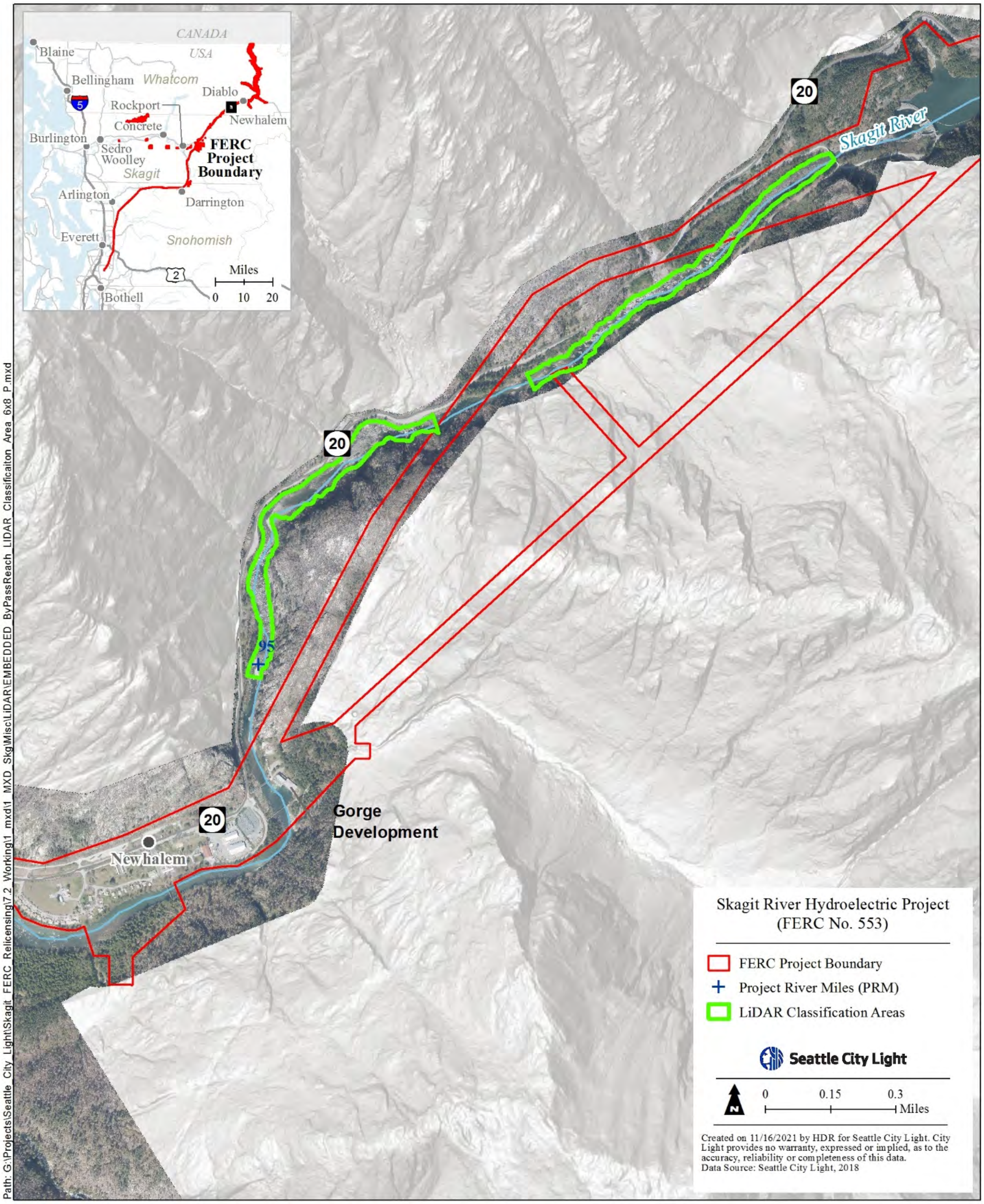


Figure 1. Project footprint and LiDAR classification areas.

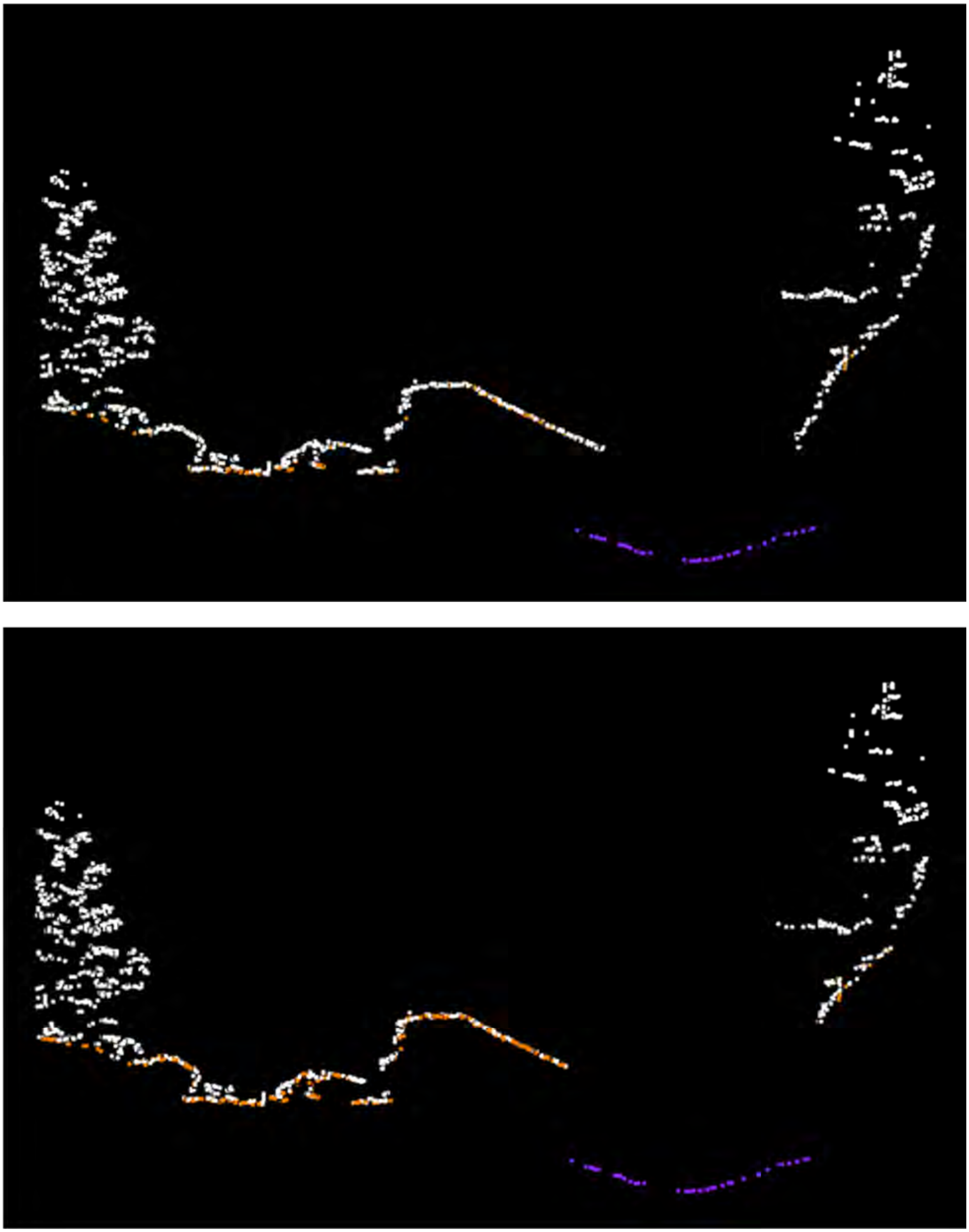


Figure 2. **Cross sections showing default (white), ground (orange) and bathymetric bottom (purple) points before (upper) and after (lower) manual ground classification.**

1.3.2 Terrain Surface Creation

NHC identified areas where the 2018 bathymetric LiDAR survey extent did not cover enough area to accommodate the hydraulic model. The United States Geological Survey's (USGS) Western Washington 3DEP – North AOI (2016) LiDAR dataset (QSI 2017) was utilized to expand coverage where needed. LiDAR data extents and sources are displayed on Figure 3.

LAS files were utilized to produce an ESRI terrain triangulated surface. Digital elevation models (DEMs) were produced from bare earth ground surfaces consisting of only classified ground and bathymetric bottom returns (LAS class 2 and 40). The ESRI terrain was created using the following steps:

- A file Geodatabase was created containing a feature dataset (FDS) set to the FIPS 2926 project coordinate system;
- The 2018 LAS data was filtered by ground and bathymetric bottom returns and converted to ESRI multipoint format in the FDS. The 2016 LAS data was filtered by ground returns and converted to ESRI multipoint format in the FDS;
- Data boundary polygons were loaded into the FDS. Water's edge break lines were provided by QSI but were not granular enough to include in the terrain;
- The blank terrain was created in the FDS;
- Z-tolerance pyramids were created in the terrain. This set requirements for reduced resolution versions of the terrain that can be useful for larger footprint modeling. For instance, watershed-level models frequently use reduced resolution terrains. The Z-tolerance setting was used to control the degree of any potential elevation offsets in the reduced resolution terrains;
- All Feature Classes in the FDS were added to the terrain;
- The terrain was built; and,
- Terrain was reviewed visually for general consistency and through summary statistics for anomalous values.

The terrain datasets provide a flexible environment that can be updated in the future if City Light has a need to integrate newly acquired survey data.

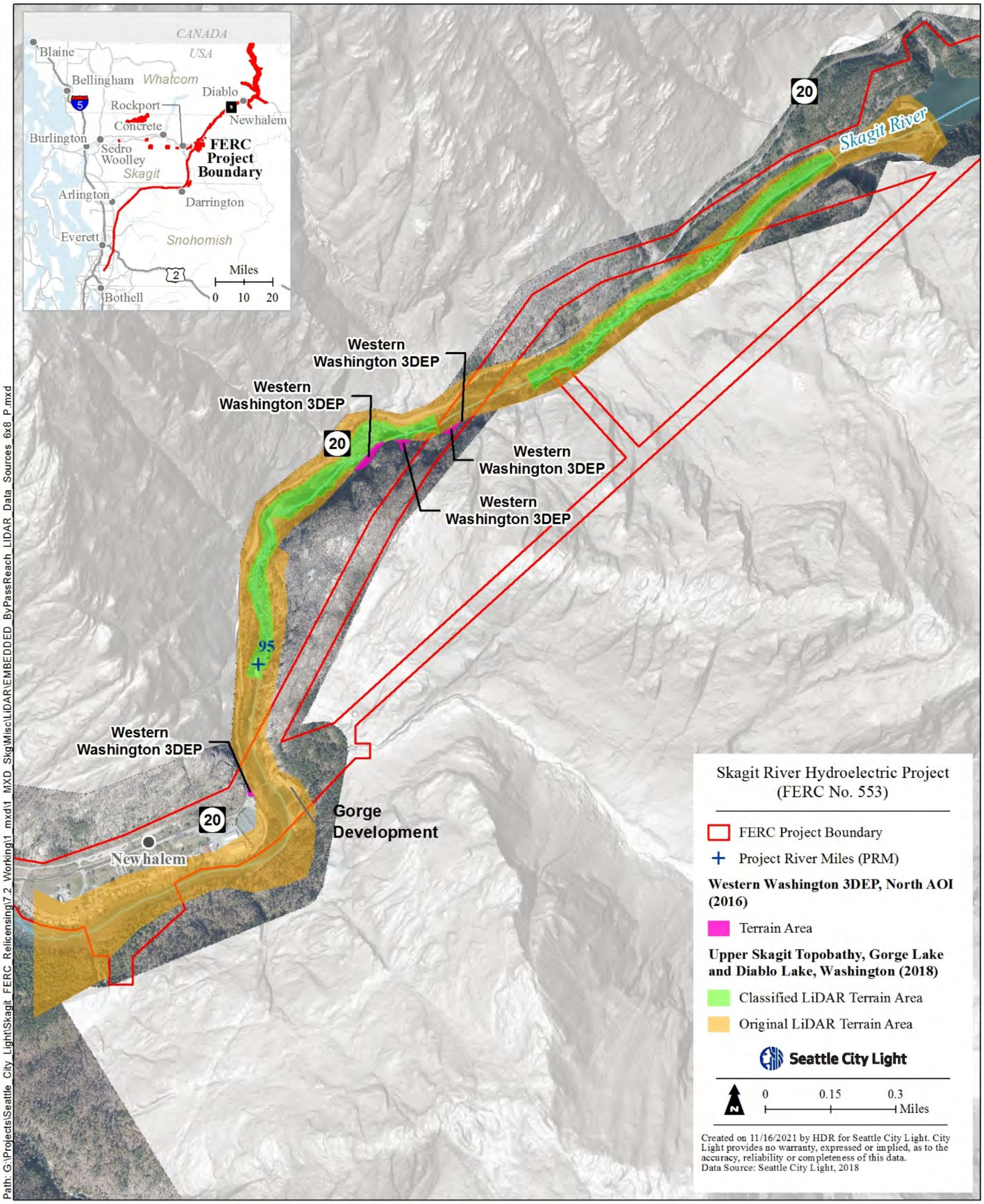


Figure 3. Bare Earth DEM LiDAR data sources.

1.3.3 Raster DEM Creation

Bare earth DEMs were generated utilizing the classified ground and bathymetric bottom LAS data terrain. HDR used the ArcGIS Pro Tool, Terrain to Raster generating a DEM with a 1-foot raster cell resolution. Raster cell resolution was selected to preserve detail in higher ground point density. The higher ground point density supports a raster resolution down to 1 foot in areas of particular relevance for improving the accuracy of hydraulic modeling, but the majority of the dataset does not support a resolution smaller than 3 feet.

The Hillshade dataset is a visualization of the Bare Earth DEM. This visualization uses the ESRI Spatial Analyst hillshade tool utilizing default settings. This provides an easily-interpreted surface for LiDAR data visualization. Figure 4 displays a comparison of the DEM with a 3-foot raster cell resolution provided by QSI as part of the LiDAR deliverables package and the HDR DEM with a 1-foot raster cell resolution.

1.3.4 Modified LiDAR Review

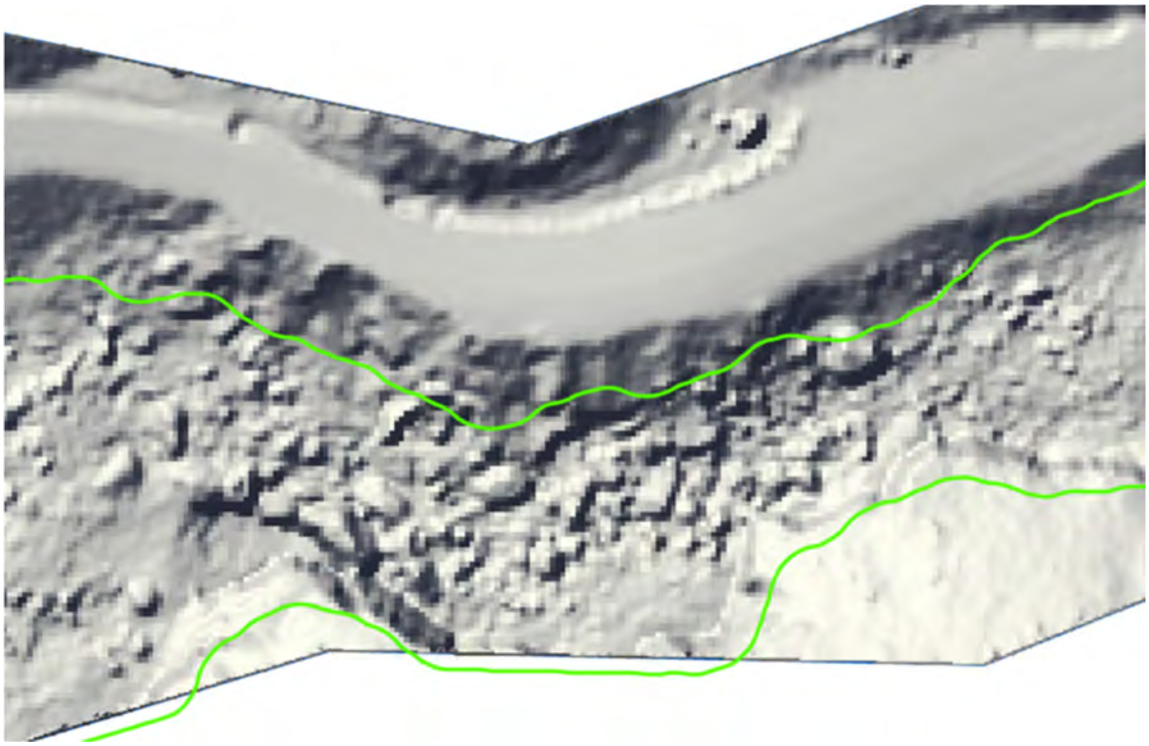
In areas where we focused our efforts, the ground and bathymetric bottom classified density of LiDAR data is 27 points/m^2; a large increase compared to QSI's reported density of 5.56 points/m^2. A standard deviation of 19.65 in the updated dataset reflects the large variance between the densities in comparison to areas covered by riverbed and water. Steep slopes and standing water areas have a low point density. Rocky riverbeds and areas with boulders have a higher density, see Figure 5.

1.3.5 Coordinate System

LAS files were transformed to City Light's preferred coordinate system using ESRI ArcPro LiDAR Tools. No vertical datum shift was required. All LiDAR datasets and derivative products are in:

Projection: Washington State Plane North
Horizontal Datum: NAD83 (HARN)
Vertical Datum: NAVD88 (GEOID12B)
Units: US Survey Feet

Original QSI-produced DEM with a 3-foot raster cell resolution.



HDR-produced DEM with 1-foot raster cell resolution.

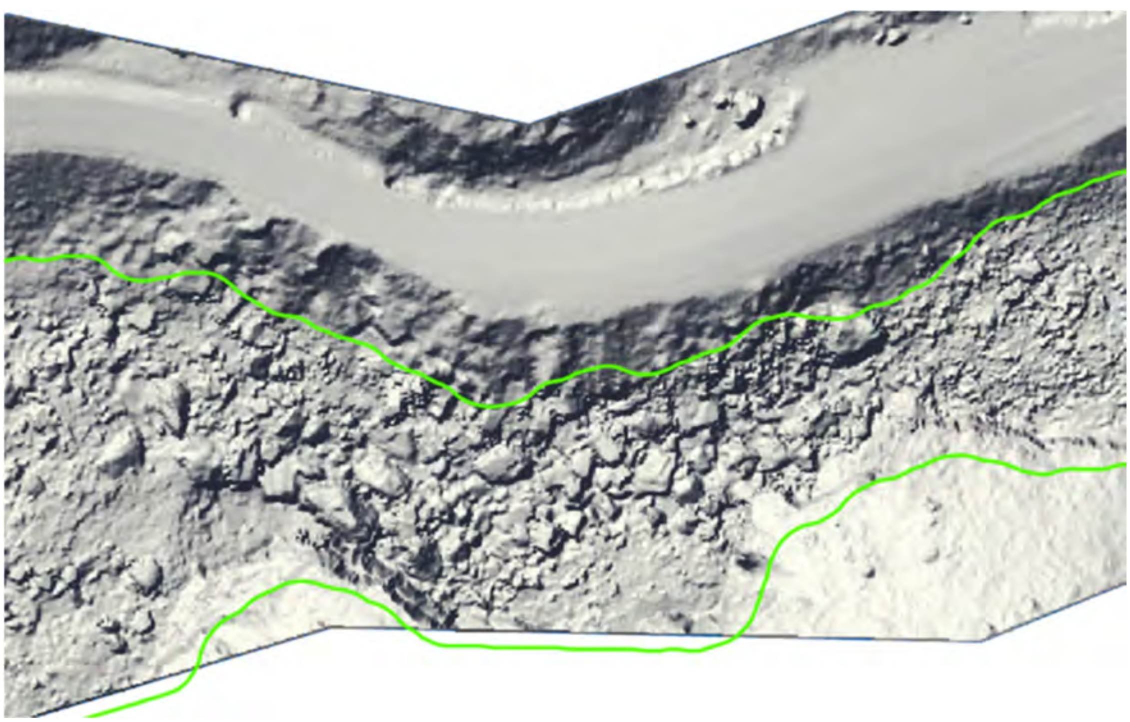


Figure 4. Bare earth DEM hillshade comparison. Green line indicates boundary of additional ground point classification.

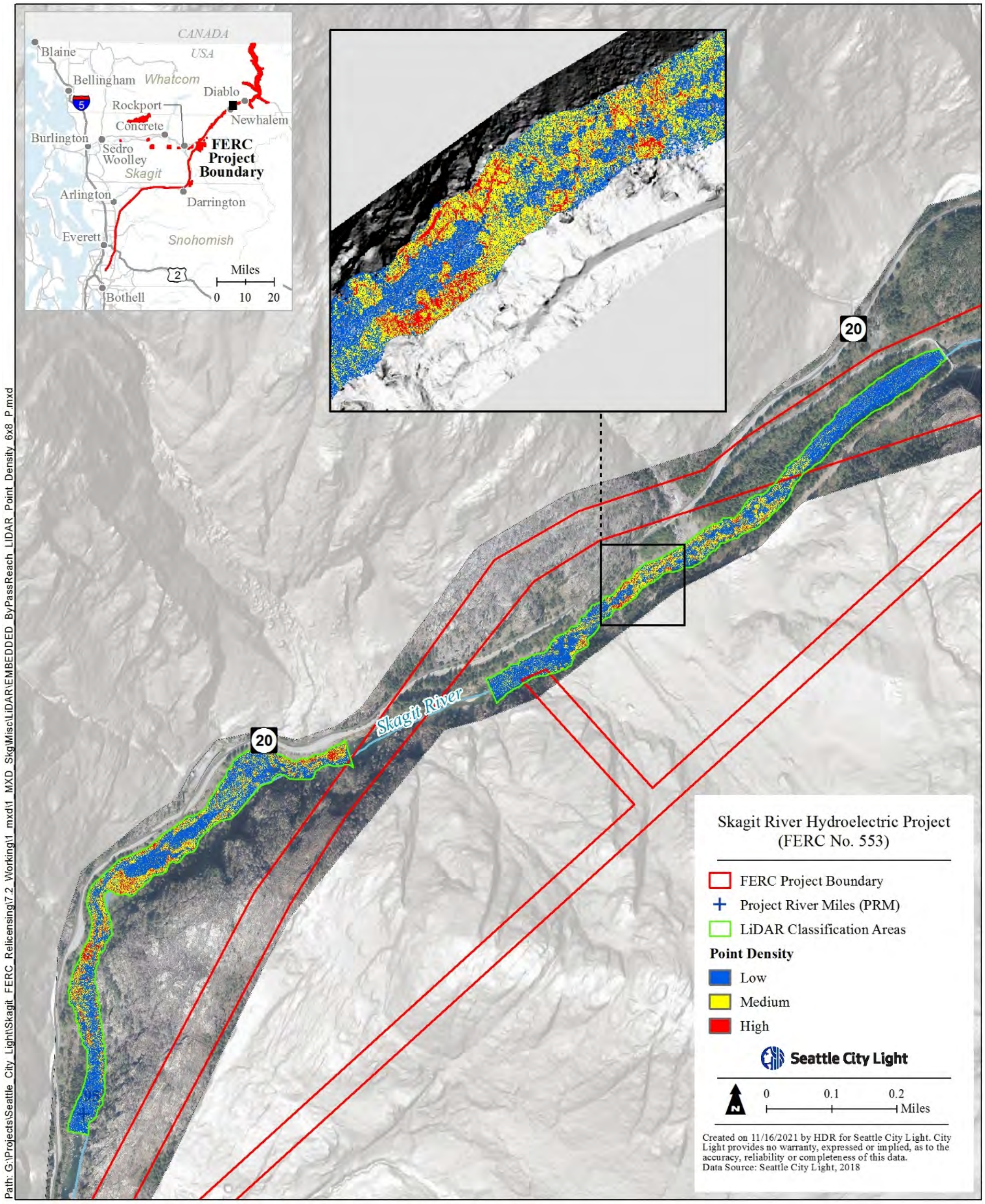


Figure 5. LiDAR point density.

1.3.6 Additional Resources

- APSRS LAS specifications:
  - https://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf
- ESRI Terrain datasets.
  - https://pro.arcgis.com/en/pro-app/help/data/terrain-dataset/terrain-dataset-in-arcgis-pro.htm

1.4 Conclusions

HDR assessed and modified LiDAR data contracted by City Light to support improved hydraulic modeling of the Gorge bypass reach. HDR better characterized the Gorge bypass reach riverbed by refining the LiDAR point classification, thereby improving point density and developing a more detailed terrain. The final product is a high-resolution bare earth DEM of the Gorge bypass reach including detailed topographic features in the riverbed. Note that while the reclassified data more accurately reflects terrain conditions in the riverbed, this did not follow a standard processing workflow and should not be used outside the context of this specific hydraulic modeling effort.

2.0 REFERENCES

Quantum Spatial, Inc. (QSI). 2017. Western Washington 3DEP LiDAR technical data report. Report prepared for USGS. September 29, 2017.

Quantum Spatial, Inc. (QSI). 2018. Upper Skagit, Gorge Lake & Diablo Lake, Washington. Topobathymetric LiDAR & orthoimagery technical data report. Report prepared for Seattle City Light. August 17, 2018.

SKAGIT RIVER GORGE BYPASS REACH HYDRAULIC AND INSTREAM FLOW MODEL DEVELOPMENT STUDY INTERIM REPORT

ATTACHMENT B

GORGE BYPASS REACH DATA COLLECTION FOR HYDRAULIC MODEL CALIBRATION MEMORANDUM

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nhc
northwest hydraulic consultants

MEMORANDUM

To:	**Project File**	Date:	March 2022
		NHC Ref. No.	2003536
From:	Chris Long, PE – NHC		
Re:	**Gorge Bypass Reach Data Collection for Hydraulic Model Calibration**		

1 INTRODUCTION

Northwest Hydraulic Consultants (NHC) collected hydraulic data of the Skagit River between Gorge Dam and Gorge Powerhouse during the period May-July 2021, with some data collection continuing through early-December 2021, for use in calibrating and validating a new hydraulic model (the Bypass Hydraulic Model). The Bypass Hydraulic Model will be used for assessing instream flows and evaluating fish passage among other tasks related to the relicensing of Seattle City Light's (City Light's) Skagit River Hydroelectric Project. Several field efforts occurred prior to controlled flow releases from Gorge Dam during the week of July 26, 2021, at which point a large fieldwork effort commenced to observe hydraulic characteristics at discharges ranging from 50 to 1,200 cfs. This memorandum describes the methods employed and summarizes the data collected.

2 METHODOLOGY

Three categories of data were collected during the controlled releases at the end of July: depth and velocity measurements at established transects, drone imagery flights, and water levels recorded by level logger sensors. In addition to data from the July 26-29, 2021, controlled releases, continuous water level data were obtained from the level logger sensors from late May 2021 through late-September 2021. Although the level loggers continued operating after September 2021, a severe flood in mid-November 2021 destroyed many of the instruments and much of the post-September 2021 data was lost. It is important to note that this data loss does not impact the ability to calibrate and validate the Bypass Hydraulic Model; calibration and validation will depend primarily on data collected during the July 26-29, 2021 controlled releases and during a period of high flow from June 28 – July 3, 2021.

The following sections describe the methods employed to collect the hydraulic information.

2.1 Transect Measurements

Five measurement transects were established in the Gorge bypass reach to record depths and velocities during the July 26-29, 2021, controlled releases from Gorge Dam (Figure 1). Transect locations were selected in consultation with City Light and licensing participants to capture hydraulic characteristics from a variety of geomorphic units. The Gorge bypass reach is not boat accessible and could not be waded at the transect locations for most of the controlled release flows. Therefore, temporary bank-operated cableways were installed at each transect to deploy a raft-mounted SonTek M9 Acoustic Doppler Current Profiler (ADCP) (Figure 2).

nhc

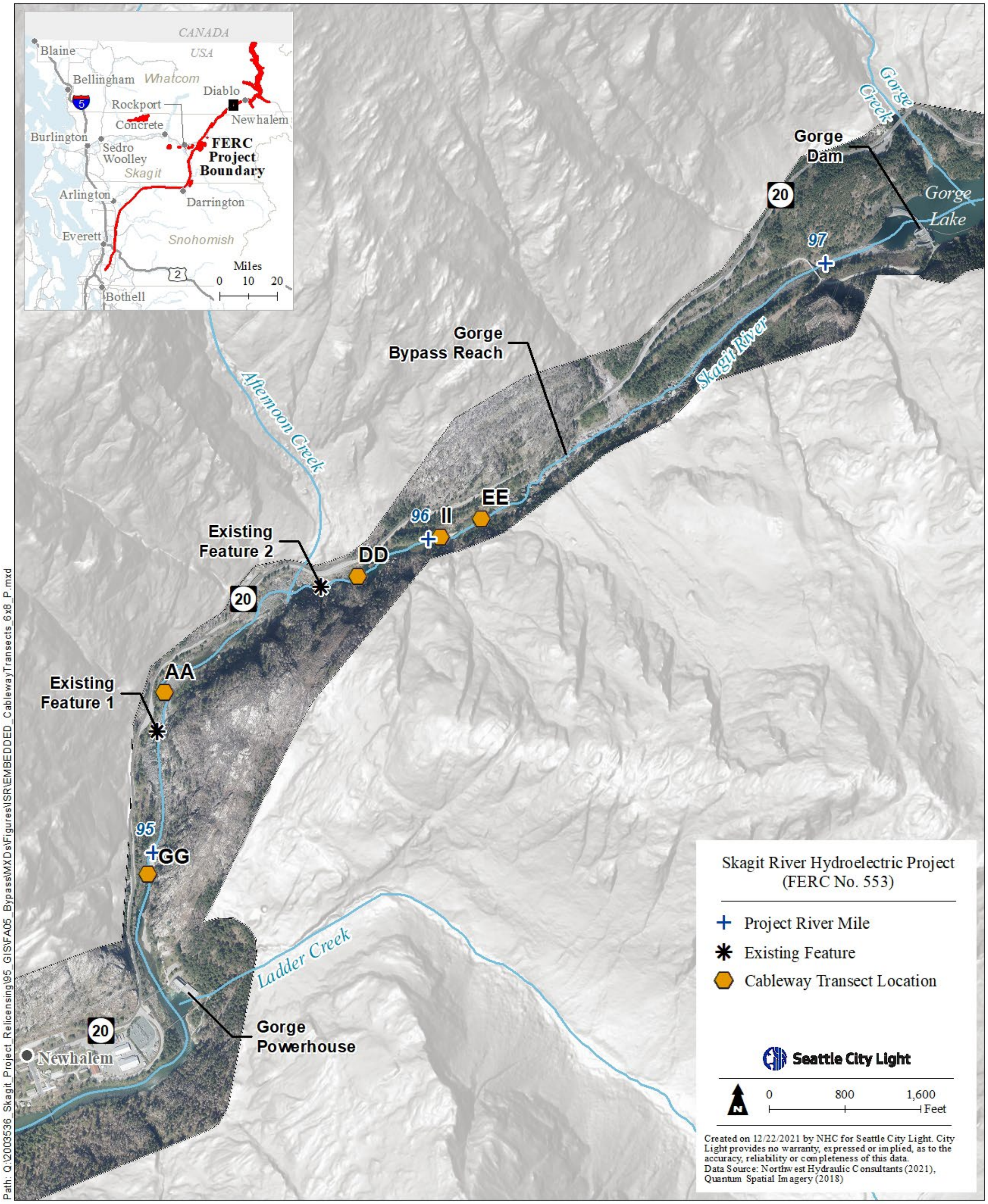

Figure 1. Temporary cableway locations.

Figure 2. Cableway deployment of ADCP at Transect AA on July 26, 2021.

Depth and velocity measurements were recorded at 20-50 stationary positions along each transect, the count depending on wetted channel width. Measurement stations were selected to 1) locate the ADCP where the instrument could be safely operated and perform accurate measurements; and 2) capture less than 5 percent of the total flow between measurement stations. Acoustic signals transmitted by the ADCP record the vertical velocity profile through the water column which is converted to depth-averaged velocity. Velocities were recorded at each station for 40 seconds to average out turbulence fluctuations. Depth and velocity measurements were used to compute discharge at each transect using the USGS mid-section method (Turnipseed and Sauer, 2010). Measurements were collected and processed during the survey with SonTek's RiverSurveyor Stationary LIVE software.

The ADCP's deployment configuration limited instrument operation to depths greater than approximately one foot. When depths along significant portions of a transect were shallower than the ADCP's operable range, field personnel measured depths with a wading rod and velocities with a SonTek FlowTracker2 Acoustic Doppler Velocimeter (ADV) (Figure 3). Wading depths and velocities were recorded and processed with the FlowTracker2's dedicated handheld processor.

Figure 3. ADV operation at Transect EE on July 29, 2021.

High precision RTK GPS is not available throughout much of the Gorge bypass reach, including at all five transects. To geolocate the transects and associated hydraulic measurements, the cableway anchor points were surveyed with a total station relative to nearby National Geodetic Survey (NGS) monuments. A tagline was run along each cableway to record the measurement station distance from the right bank anchor point. Measurement locations were then georeferenced in ArcMap by plotting each measurement station along the surveyed transect (Figure 4). Wherever flow velocities exceeded more than approximately one ft/sec, the ADCP raft drifted downstream of the transect. Photos and video taken of the ADCP deployment at each transect were used to determine any downstream offset relative to the cableway.

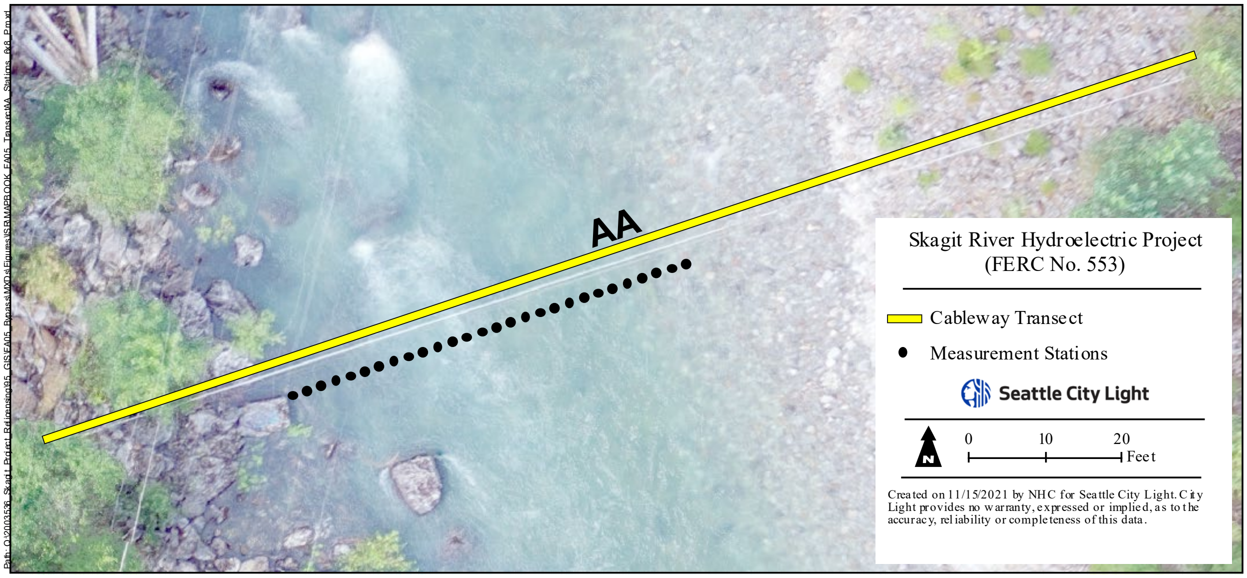

Figure 4. Measurement stations at Transect AA recorded during 1,200 cfs targeted spill. Stations are offset from cableway to account for ADCP drift.

2.2 UAV Imagery

Oblique and nadir (downward facing) photographs and videos were taken with a drone, or unmanned aerial vehicle (UAV), throughout the Gorge bypass reach during the week of the controlled releases. The still photographs were collected to visually document conditions at each controlled release and under baseflow conditions, and for processing through Structure from Motion (SfM), a photogrammetric method to create a three-dimensional model from two-dimensional photographs. Drone-based videos were recorded to support Large Scale Particle Image Velocimetry (LSPIV) analysis, which is a technique for measuring two-dimensional (2-D) surface velocity vectors (magnitude and direction).

2.2.1 Structure from Motion

Structure from Motion (SfM) is a photogrammetric imaging technique for estimating three-dimensional structures (models) from two-dimensional image sequences. The primary inputs for the SfM processing completed in the Gorge bypass reach were overlapping nadir photographs. These photos were taken with a drone at altitude during the controlled releases, primarily to develop orthomosaic images for use during calibration of the Bypass Hydraulic Model; however, they have also been made available to support other Skagit relicensing studies for a variety of applications, including for example, substrate and cover mapping.

UAV Still Photo Collection

Prior to the controlled releases, UAV reconnaissance missions of the Gorge bypass reach were conducted to determine safe flight elevations and flight times to ensure the drone would both avoid obstacles and have sufficient battery life for pre-planned missions. Four pre-planned flight paths were required to achieve the desired coverage of the Gorge bypass reach while complying with FAA safety guidelines and operation restrictions. Note that drone operations were not conducted for approximately 300 feet adjacent the SR 20 tunnel due to the limited field of view and the inability to maintain visual line-of-sight. See Figure 5 for a map of these flight boundaries. The UAV flew a pre-determined gridded path at an altitude of 300 feet above takeoff, as determined in the initial reconnaissance. The drone was programmed to capture photos with 85 percent frontal and side overlap for each flight path (Figure 6), considering the terrain complexity and application in SfM. In consultation with City Light, all drone missions launched and landed within the FERC-designated Project Boundary also shown on Figure 5. The drone was a DJI Mavic2 Pro quadcopter, equipped with a 20-megapixle camera, 4K 10-bit HDR video quality, and a polarizing lens. Prior to dispatching the UAV, 50 surveyed ground control points were marked with high-visibility, temporary chalk that would be easily distinguishable in the photos taken during the controlled releases. The survey points were established utilizing a combination total station survey and RTK GPS where possible, and they were used to georeference the UAV imagery during SfM processing:

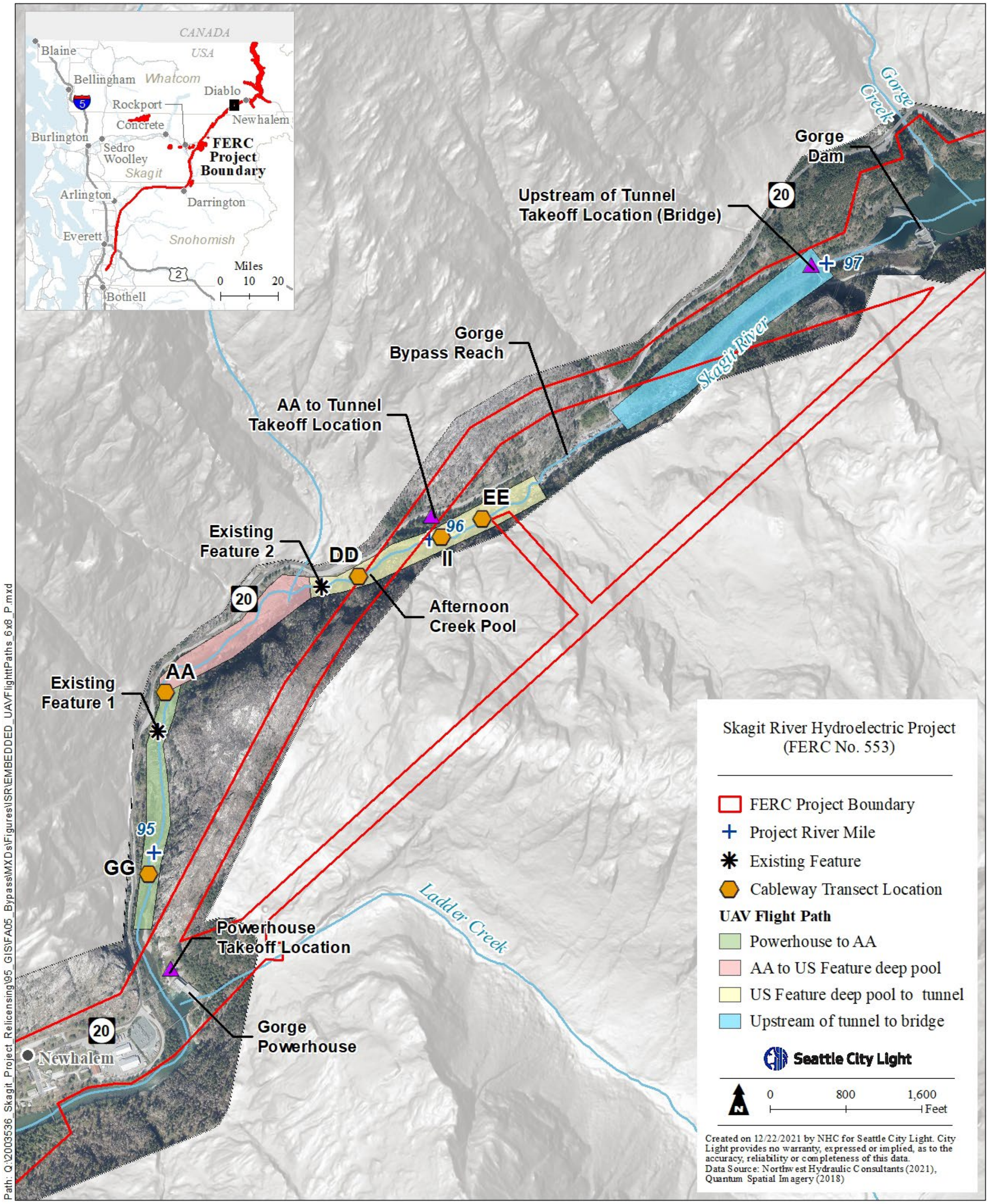

Figure 5. UAV pre-programmed flight plans.

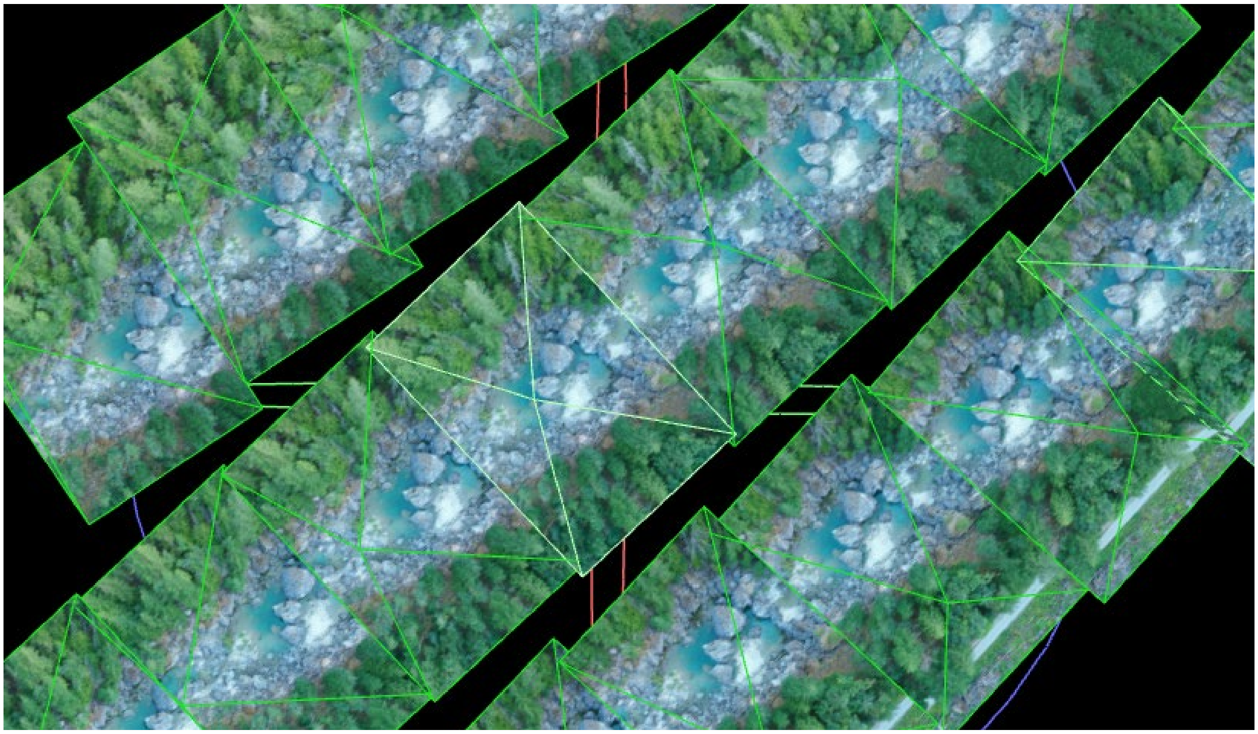

Figure 6. Overlapping nadir photographs of Existing Feature 1 (July 30, 2021).

UAV Still Photo Processing (Structure from Motion)

Approximately 850 UAV-based nadir photos were taken each day of the controlled release week, for a total of almost 4,300 photos covering all four flight paths. The daily photographs were processed through Pix4Dmapper Version 4.3.33, typically applying Standard 3D map settings. Prioritization was given to the photos taken on July 30, 2021, corresponding to no spill from Gorge Dam. These photos supported substrate mapping field efforts and captured the most ground control points. Photos from the remaining days were processed in order from the highest discharge (July 26, 2021) to lowest (July 29, 2021). Photos from these days were used to determine longitudinal water surface elevation profiles to support calibration of the Bypass Hydraulic Model.

2.2.2 Large Scale Particle Image Velocimetry

Large Scale Particle Image Velocimetry (LSPIV) analysis was another field method applied on an experimental basis for measuring two-dimensional (2-D) surface flow velocity vectors (velocity, magnitude, and direction). Given a successful application of LSPIV, these measured velocities could be utilized as a verification of the Bypass Hydraulic Model as well as to provide another perspective of fish passage potential for the FA-04 Fish Passage Technical Studies Program (Fish Passage Study). In summary, the LSPIV method measures the surface flow velocities by video recording the movement of tracer particles seeded onto the flow surface and analyzing the tracer movement in successive video frames (Dermisis and Papanicolaou 2005, Muste et al. 2008). The LSPIV methodology is comprised of two phases, namely: 1) field data collection and 2) field data processing, which are presented in the following Sections.

LSPIV Field Data Collection

The collected field data for the LSPIV method was comprised of video footage recording the movement of tracer particles seeded into the flow. Wood chips were selected as the preferred tracer for these measurements as they closely follow the flow streamlines, offer strong contrast relative to the turbulent white-water surface, and are an ecofriendly, naturally biodegradable material. Approximately 81 cubic feet of wood chips were utilized for the entire LSPIV measurement campaign, which included measurements at Existing Features 1 and 2 during the four controlled releases from July 26-29, 2021. Both Existing Features, shown on Figure 1, are large boulder cascades and were targeted for LSPIV to support fish passage evaluation objectives as part of the FA-04 Fish Passage Study. The wood chips were transported by field personnel to staging areas adjacent to the river channel at the upstream end of both Existing Features (Figure 7). The chips were manually introduced to the flow during each drone video recording. Between eight and ten cubic feet of wood chips were utilized for the 1,200 cfs flow and progressively smaller amounts were used for the smaller discharges.

Figure 7. Staging of wood chips used for flow seeding.

Nadir video footage at Existing Features 1 and 2 were captured with a DJI Mavic 2 Pro drone, which recorded video at 4K resolution, producing 3840 x 2160-pixel video frames at a rate of 30 frames per second (fps). To maximize the velocity vector resolution, the UAV was positioned at the lowest possible altitude (approximately 175 feet) above the water surface, such that the width of the camera field of view (FOV) was marginally larger than the wetted perimeter of the reach. At this altitude, the lengths of the Existing Features were larger than the length of the UAV camera FOV, requiring two sequential FOVs to be captured at each feature (Figure 8). These sequential FOVs were overlapped by about 50 percent to 80 percent to facilitate the juxtaposition of the velocity fields from LSPIV analysis in each FOV. Four ground control points from the still photos taken by the drone were identified in each FOV to determine the scale (i.e., the pixel to physical length ratio) and to juxtapose velocity fields from overlapping FOVs. The duration of captured video footage varied from about five minutes for the 1,200 cfs discharge to about three minutes at the 50 cfs discharge.

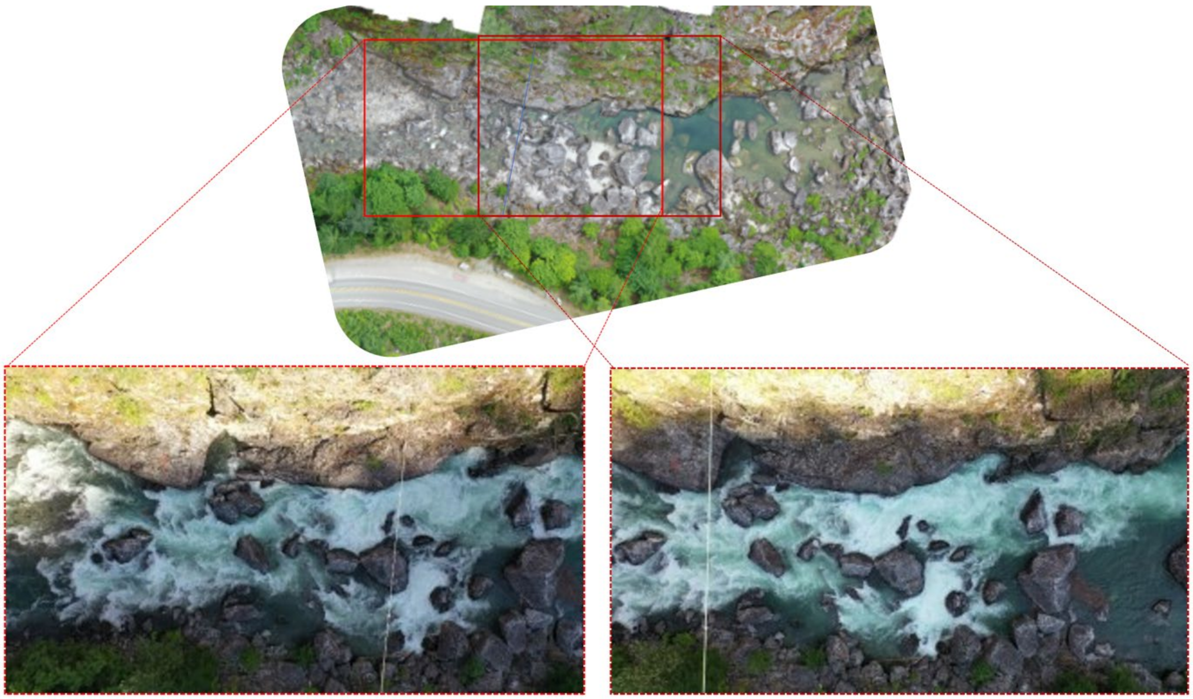

Figure 8. Example of sequential still Fields of View (FOVs) recorded at Existing Feature 1 during the 1,200 cfs spill (July 26, 2021).

LSPIV Field Data Processing

The videos filmed each day at each Existing Feature, including both sequential FOVs captured at each feature, were carefully inspected, and one-minute-long segments from each FOV were isolated and cropped utilizing OpenShot Video Editor software. In principle, the one-minute clips provide sufficiently accurate mean (time-averaged) velocity while minimizing processing time and associated file sizes (Dermisis and Papanicolaou 2005; Muste et al. 2008). LSPIV analysis was performed utilizing RIVeR Version 2.5 software (Patalano et al. 2017). Each 1-minute video clip was imported into RIVeR and separated into 1,800 individual 3840 by 2160-pixel frames (60-second clip captured at 30 fps). The frames were then converted to grayscale to reduce file size and processing times. Dry areas within each frame, such as protruding boulders and riverbanks, were excluded from the analysis by masking these areas within a PIVlab routine (Thielicke and Stamhuis 2014a, 2014b, 2014c) built into RIVeR (Figure 9).

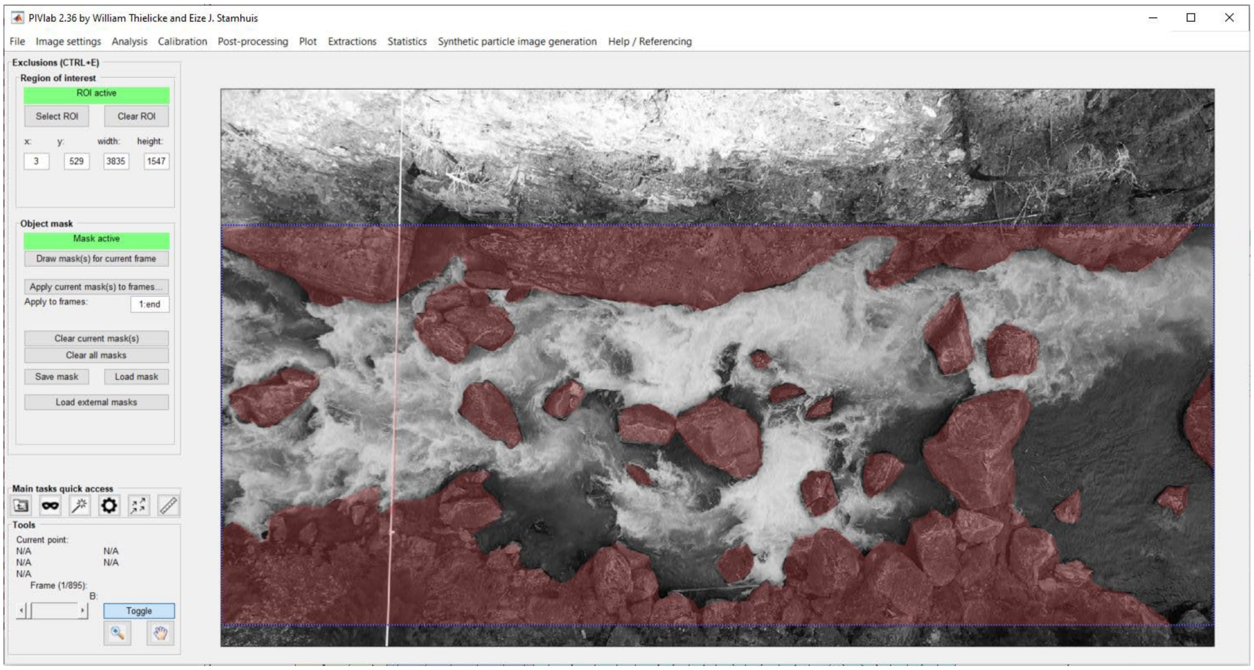

Figure 9. Example of masked areas in the PIVlab environment.

2-D velocity vectors (in pixels per second) were estimated by PIVlab using standard PIV methods (Raffel et al. 1998, Muste et al. 2008, Thielicke and Stamhuis 2014c). PIVlab considers a pair of successive image frames, the first of which is discretized into windows of a specified dimension. These windows are displaced by a given amount in the second image frame. The software then estimates the average displacement from the original window on the first image frame to the displaced window on the second, thus calculating a 2-D velocity vector. The 2-D velocity vector fields were averaged to estimate the mean 2-D velocity vector field (time-averaged across 60 seconds) with an approximately 1.1-foot resolution. Processed velocity fields, still in pixels per second, were imported into RIVeR and georeferenced with respect to the ground control points in each FOV (Figure 10). The instantaneous and mean 2-D velocity vectors were then rectified by RIVeR and converted to physical space units expressed in feet per second.

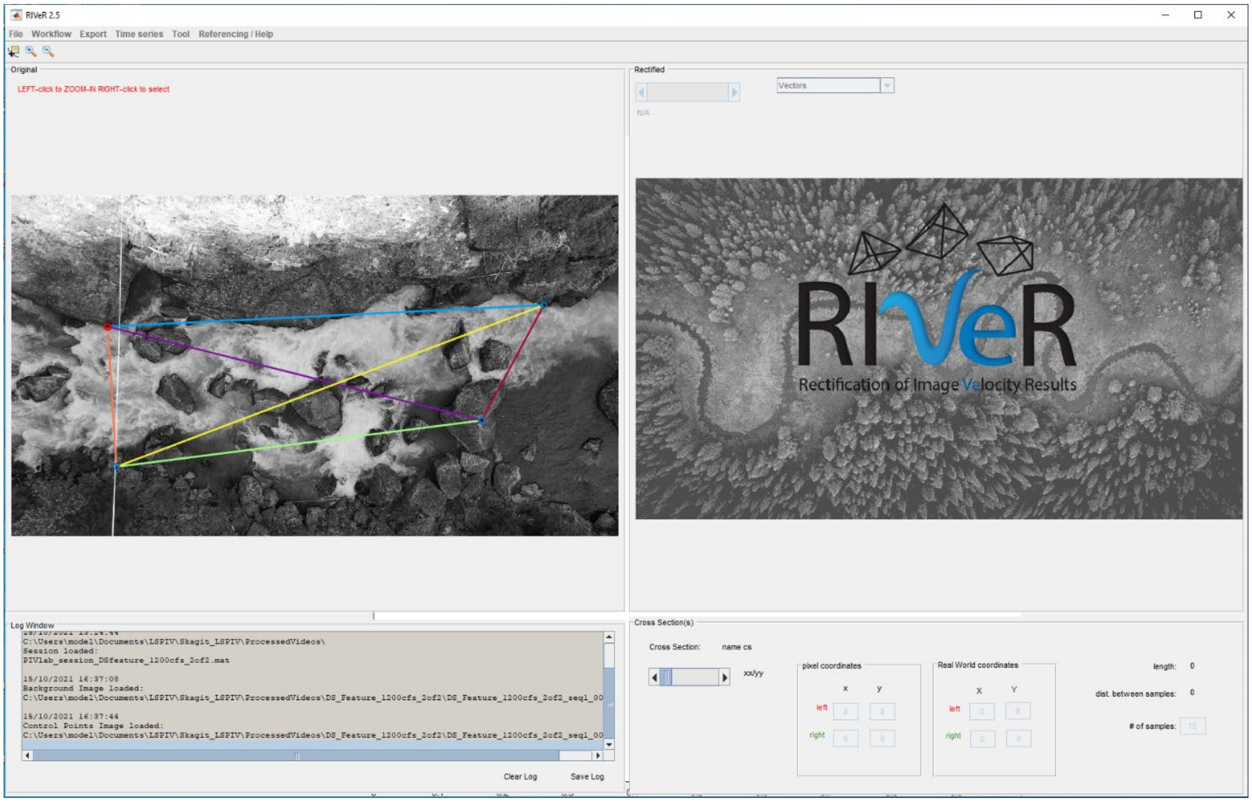

Figure 10. Specification of ground control points for scaling the 2-D velocity vector fields.

2.3 Water Level Logger Data

NHC installed 12 water level loggers at Existing Features 1 and 2 in May 2021 to measure water stage for calibration and validation of the Bypass Hydraulic Model and to support the fish passage assessment as part of the FA-04 Fish Passage Study. Members of both the Fish Passage Study and FA-05 Skagit River Gorge Bypass Reach Hydraulic and Instream Flow Model Development Study (Bypass Instream Flow Model Development) teams visited Existing Features 1 and 2 in spring 2021 to assess site conditions at base flow (no Gorge Dam spill) and at approximately 1,200 cfs. From these visits, the teams determined six locations at each Existing Feature to install water level loggers (Figure 11 and Figure 12). The loggers are numbered DDL1 through DDL6 at the downstream Existing Feature 1, and UUL1 through UUL6 at the upstream Existing Feature 2. The selected locations provide water levels that 1) represent nominally stable pools at each Existing Feature and 2) span the entire length of each Existing Feature, providing a comprehensive, longitudinal water surface profile.

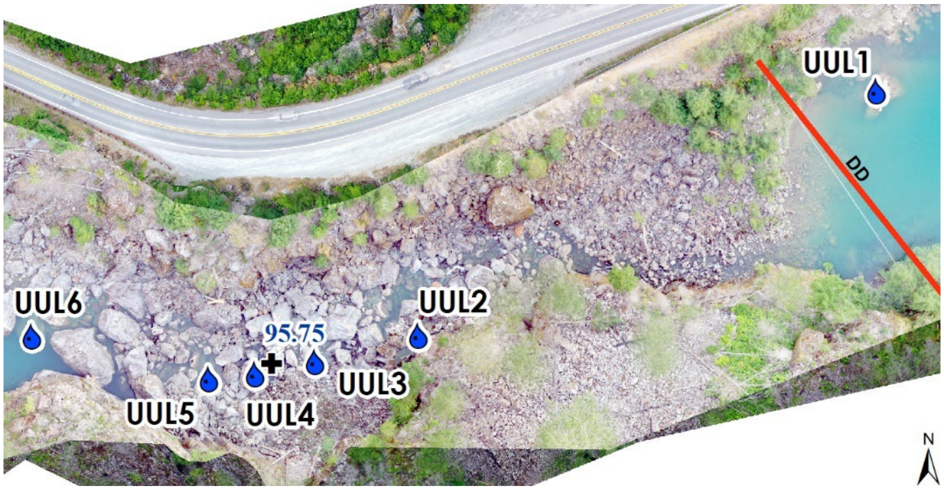

Figure 11. Water level logger locations at Existing Feature 2.

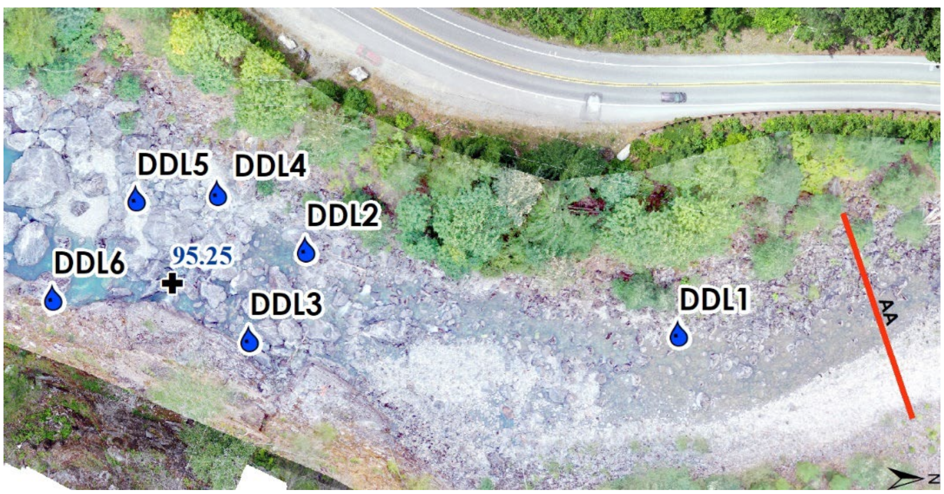

Figure 12. Water level logger locations at Existing Feature 1

Onset HOBO U20 water level loggers were deployed with pressure transducers that can record depths up to 30 feet, with a resolution of .007 feet of water and accuracy within 0.09 psi (maximum error). The loggers record instantaneous pressure and temperature values at a pre-configured interval. To compensate for barometric pressure, one additional U20 level logger was mounted in a vented PVC housing and staged above high-water levels at both Existing Features.

Secure installations in the Gorge bypass reach required careful consideration of channel hydraulics in this high energy environment. Stilling wells were fabricated from 1.5-inch diameter stainless steel conduit to house the pressure transducers and ensure protection against transported cobbles and boulders. The stilling well construction includes an aluminum flat bar to hold the pressure transducer inside, a stopper bolt at the bottom of the tube to stabilize the logger and bar, and a vented cap to equalize pressure. Two metal brackets and anchor bolts were used to secure the pipes against boulders at each install location (Figure 13). Permits to mount the stilling wells were first secured from the National Park Service (NPS) by HDR and SCL.

Figure 13. Mounted stilling well at Existing Feature 2.

Water level data were collected continuously from May 27, 2021 through December 10, 2021. The data were downloaded approximately monthly. The data were initially captured at ten-minute intervals from May 27, 2021, through July 25, 2021, at which time the recording interval was decreased to five-minute, primarily for consistency with the recording interval at the USGS Skagit River at Newhalem stream gage (USGS #12178000). Monthly data downloads were continued through late-September 2021. A data download in October 2021 was not possible because of inability to access the Gorge bypass reach, and extreme flows in mid-November 2021 (maximum reported spill from Gorge Dam of over 24,000 cfs) damaged or destroyed more than half of the data loggers, with consequent loss of much of the post-September 2021 data. A data download in December 2021 retrieved the data from surviving water level loggers through December 10, 2021, at which point the data collection effort was effectively terminated. The surviving data loggers will remain in place until Spring 2022 when improved weather conditions will allow for full removal and decommissioning of the instruments.

Additional measurements were made during each logger download to independently verify the recorded water levels for quality control. The distance from a surveyed reference bolt to the water surface was measured, as shown in Figure 14, to calculate water surface elevation. This water surface elevation was compared to the value determined from the transducer data to check for any drift. Each stilling well contains one reference bolt, either associated with one of the two metal brackets or installed separately on a boulder face nearby. Reference bolt elevations were established by carrying control point elevations set along SR 20 into the Gorge bypass reach with a total station. All resulting water surface elevations reference the North American Vertical Datum of 1988 (NAVD 88). Manual depth measurements were also taken from the stopper bolt at the bottom of the stilling wells for quality control.

Figure 14. Distance to water reading from separate reference bolt at logger DDL3.

3 SUMMARY OF DATA COLLECTED

3.1 Transect Data

Measurements were made at all five transects for targeted flows of 1,200, 500, 250, and 50 cfs during the July 26-29, 2021, controlled releases. Table 1-Table 4 below summarize the depths, velocities, and discharges measured and the instrumentation used at each transect for the controlled releases. Additional discharge measurements were made at the bridge immediately below Gorge Dam, which are also documented in the tables below. Analysis of depth and velocity measurements with RiverSurveyor Stationary LIVE (ADCP) and FlowTracker2 (ADV) software at the five cableway transects shows high quality data was collected with the ADCP and ADV. The number of measurements at each transect provides a complete and detailed representation of hydraulic characteristics across the transect for each controlled release. Measured velocities ranging from near zero to over seven feet/second and depths from near zero to 16 feet were observed. In sum, 644 velocity/depth measurements (587 by ADCP and 57 by ADV) were made to calibrate/validate the Bypass Hydraulic Model. Careful analysis of the computed discharge at each transect reveals an apparent loss of water at Afternoon Creek pool, located immediately upstream of Transect DD (Figure 1). This apparent loss and a detailed discussion of the uncertainty associated with transect discharge measurements is provided in the Gorge Bypass Reach

Discharge Measurement Uncertainty Analysis memorandum (NHC 2022, as attached to the FA-05 Bypass Instream Flow Model Development Study Interim Report [Attachment C]).

Table 1. 1,200 cfs Targeted Spill Transect Measurement Summary

Transect	Depth-Averaged Velocity (ft/s)			Depth (ft)			Discharge (cfs)	Instrument
	Avg	Min	Max	Avg	Min	Max		
Bridge	n/a	n/a	n/a	n/a	n/a	n/a	1165	ADCP
EE	5.36	0.50	7.20	2.4	0.7	3.6	1145	ADCP/ADV
II	1.63	0.11	3.21	6.3	1.9	8.7	1082	ADCP
DD	0.59	0.10	0.93	10.7	2.8	16.0	1045	ADCP
AA	4.30	1.62	6.75	4.3	1.5	6.0	1096	ADCP
GG	1.85	0.93	4.99	7.2	1.9	9.2	1038	ADCP

Table 2. 500 cfs Targeted Spill Transect Measurement Summary

Transect	Depth-Averaged Velocity (ft/s)			Depth (ft)			Discharge (cfs)	Instrument
	Avg	Min	Max	Avg	Min	Max		
Bridge	n/a	n/a	n/a	n/a	n/a	n/a	494	ADCP
EE	3.93	1.90	4.98	2.0	1.5	2.9	491	ADCP
II	1.31	0.01	2.12	5.0	2.2	6.8	514	ADCP
DD	0.31	0.02	0.55	9.5	2.9	14.2	442	ADCP
AA	3.53	0.43	5.77	3.4	1.1	4.3	535	ADCP
GG	1.29	0.31	3.58	6.8	2.4	8.1	438	ADCP

Table 3. 250 cfs Targeted Spill Transect Measurement Summary

Transect	Depth-Averaged Velocity (ft/s)			Depth (ft)			Discharge (cfs)	Instrument
	Avg	Min	Max	Avg	Min	Max		
Bridge	n/a	n/a	n/a	n/a	n/a	n/a	319	ADCP
EE	2.78	0.90	4.46	1.7	0.6	2.7	316	ADV
II	1.08	0.05	1.60	4.6	1.6	6.0	331	ADCP
DD	0.24	0.00	0.34	9.6	2.1	13.4	297	ADCP
AA	2.55	0.82	5.12	3.2	1.5	4.0	306	ADCP
GG	1.67	0.65	3.32	6.3	2.7	7.1	298	ADCP

Table 4. 50 cfs Targeted Spill Transect Measurement Summary

Transect	Depth-Averaged Velocity (ft/s)			Depth (ft)			Discharge (cfs)	Instrument
	Avg	Min	Max	Avg	Min	Max		
Bridge	n/a	n/a	n/a	n/a	n/a	n/a	60	ADCP
EE	1.05	0.00	2.15	1.1	0.0	1.9	56	ADV
II	0.32	0.01	0.55	2.8	0.9	3.9	57	ADCP
DD	0.07	0.05	0.13	8.2	1.5	11.2	58	ADCP
AA	1.47	0.13	2.93	1.9	1.3	2.3	68	ADCP
GG	0.48	0.14	0.97	4.5	1.5	5.4	54	ADCP

3.2 UAV Imagery

The 955 drone-based photos taken on July 30, 2021, of the Gorge bypass reach under base-flow or no-spill conditions were processed in PIX4Dmapper to create a digital model and subsequent orthomosaic images that offer a single high-resolution image of the reaches identified in Figure 5. Figure 15 shows some of the composite orthomosaic image created from the UAV flights between Transect AA and Existing Feature 2, where the UAV-based image has a resolution of 2.4 cm/pixel and the underlying USDA NAIP 2019 ortho image is one meter/pixel. Similar processing was also accomplished for photos taken July 26-29, 2021. Once complete, the following information could be extracted from the orthomosaic imagery for calibration and validation of the Bypass Hydraulic Model and to support other Skagit relicensing studies: 1) characterization of substrate, vegetative cover, and channel characteristics for defining roughness parameters; 2) a water surface elevation profile of the entire reach for each controlled release; and 3) mapping of water surface extents to compare with model output.

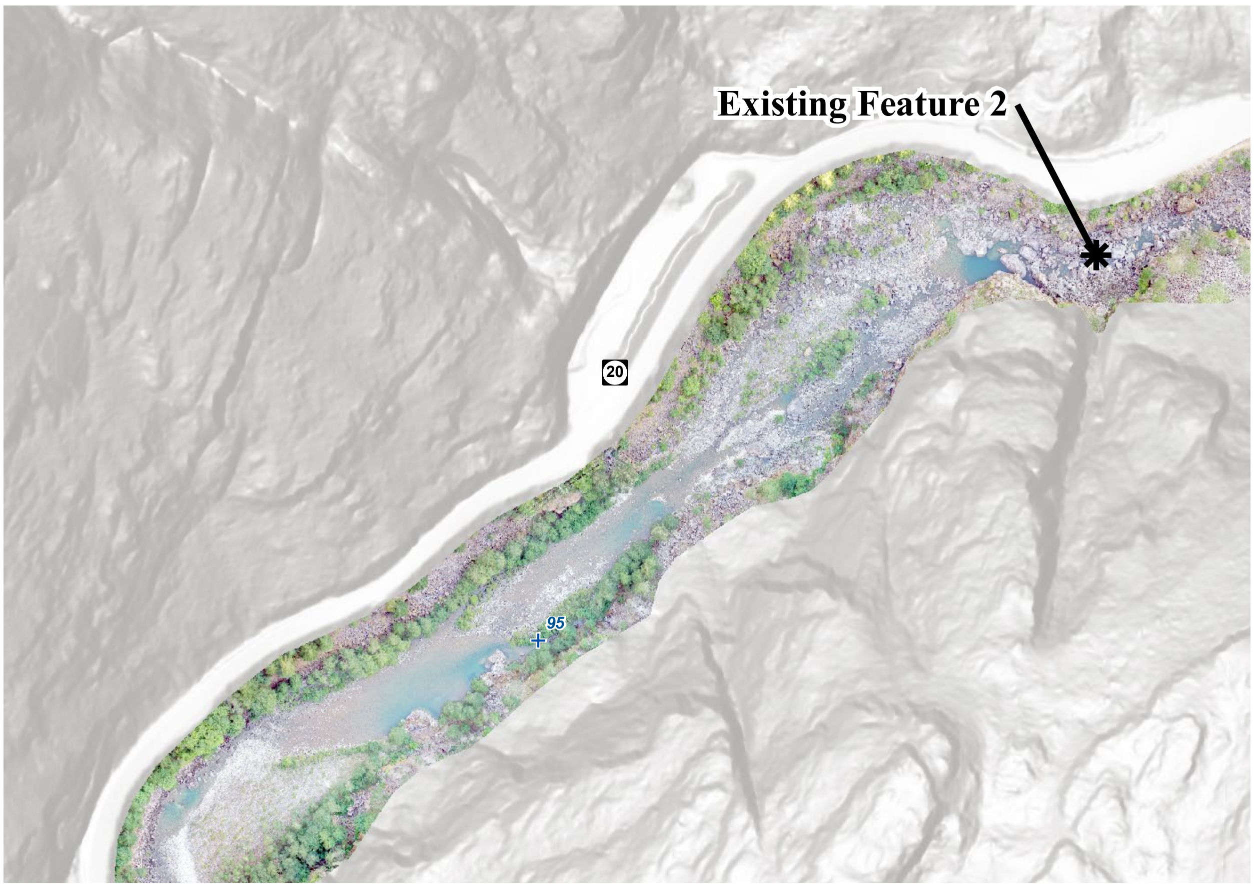

Figure 15. Composite orthomosaic image from July 30, 2021, UAV flights.

3.3 LSPIV

The main outcome of the LSPIV analysis were ~1,800 instantaneous 2-D velocity vector fields, containing the streamwise and transverse velocity components within the camera FOV for the one-minute duration of the analyzed video footage (Figure 16).

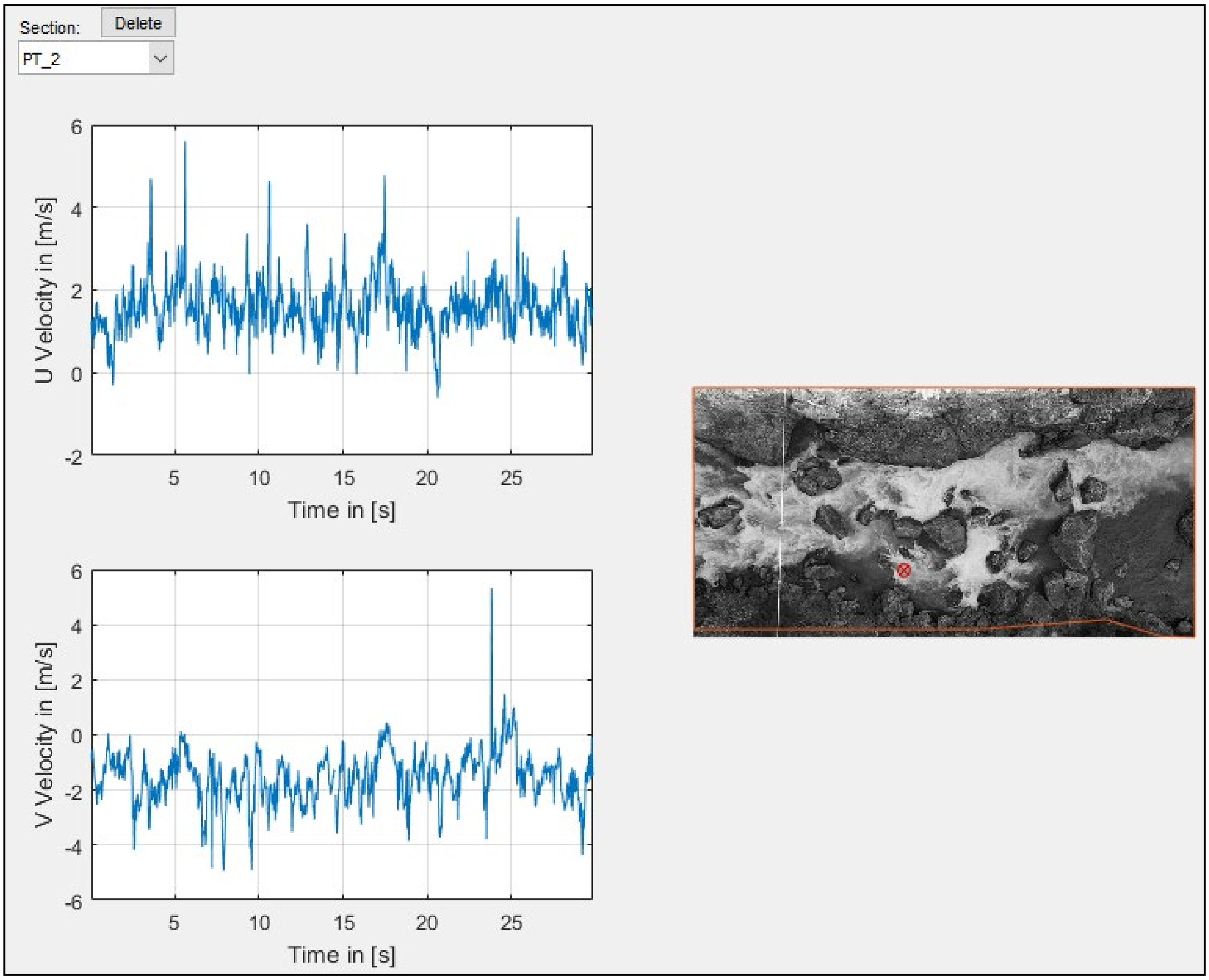

Figure 16. Example of instantaneous streamwise and transverse velocities at a point in the flow field calculated from the LSPIV method.

The 2-D velocity vector fields were averaged to provide the mean (time-averaged) 2-D velocity vector field within the camera FOV (Figure 17). The calculated vector field was also used to provide flow streamlines to facilitate visualization of flow patterns through the measurement domain (Figure 18).

Unfortunately, despite initial promising results, the application of LSPIV in this instance ultimately proved to be unsuccessful. Hydraulic conditions through Existing Features 1 and 2, including turbulent flow, frothy white water, and cascading flow, resulted in a low signal-to-noise ratio over much of the LSPIV measurement domain, with no means of assuring reliable and consistent surface velocity data suitable for the originally intended uses of supporting validation of the Bypass Hydraulic Model and evaluation of fish passage under the FA-04 Fish Passage Study.

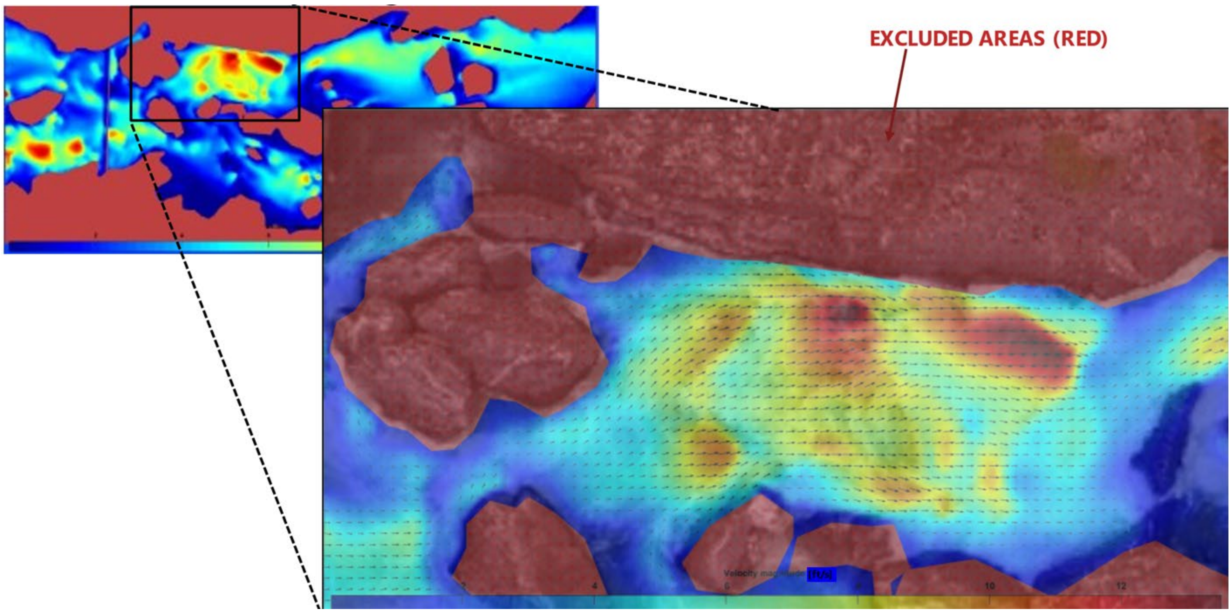

Figure 17. Example of mean 2-D velocity vector field (direction and magnitude) calculated from the LSPIV analysis.

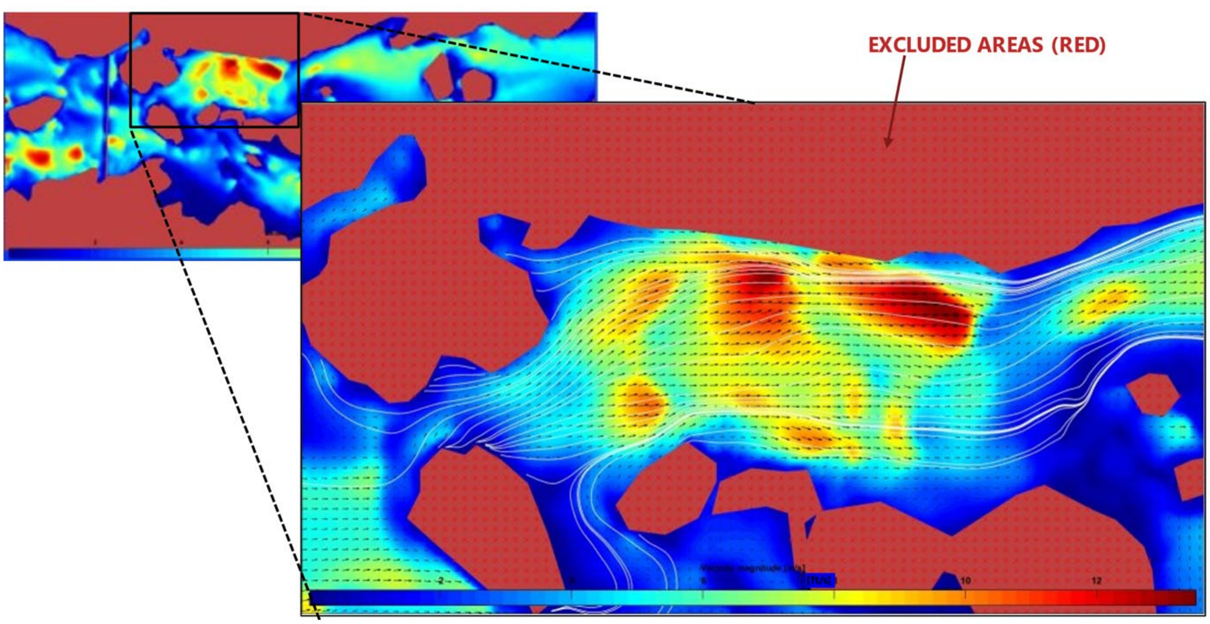

Figure 18. Example flow streamlines calculated from the LSPIV analysis.

3.4 Water Level Logger Data

Water stage data from the full network of level loggers was recorded at Existing Features 1 and 2 for the period May 28 – September 26, 2021, for calibration and validation of the Bypass Hydraulic Model and to support fish passage assessment under the FA-04 Fish Passage Study. The level logger recordings were downloaded monthly through late-September 2021 and were post-processed for quality control. As discussed in more detail in Section 2.3, extreme flows in November 2021 damaged or destroyed more than half of the instruments, with consequent loss of much of the post-September 2021 data. This effectively terminated the data collection program, although water level data through early December 2021 were retrieved from some of the surviving data loggers. Note that the Gorge bypass reach is dry (base-flow conditions) most of the time and that water-level data for those periods have no value for hydraulic model calibration.

The most informative observations for model calibration are those collected during the controlled releases (July 26-29, 2021) and during an unscheduled spill from June 28 to July 3, 2021. The unscheduled spill was associated with an historic heat dome over western Washington which resulted in high snowmelt runoff requiring spill at Gorge Dam. Figure 19 and Figure 20 show the recorded water levels at Existing Features 1 and 2, respectively, during the controlled releases from July 26-29, 2021. Average flow rates determined from NHC's field observations and applied during model calibration, as reported in the Gorge Bypass Reach Discharge Measurement Uncertainty Analysis memorandum (NHC 2022, as attached to the FA-05 Bypass Instream Flow Model Development Study Interim Report [Attachment C]) are displayed on the figures to provide context relating stage and discharge.

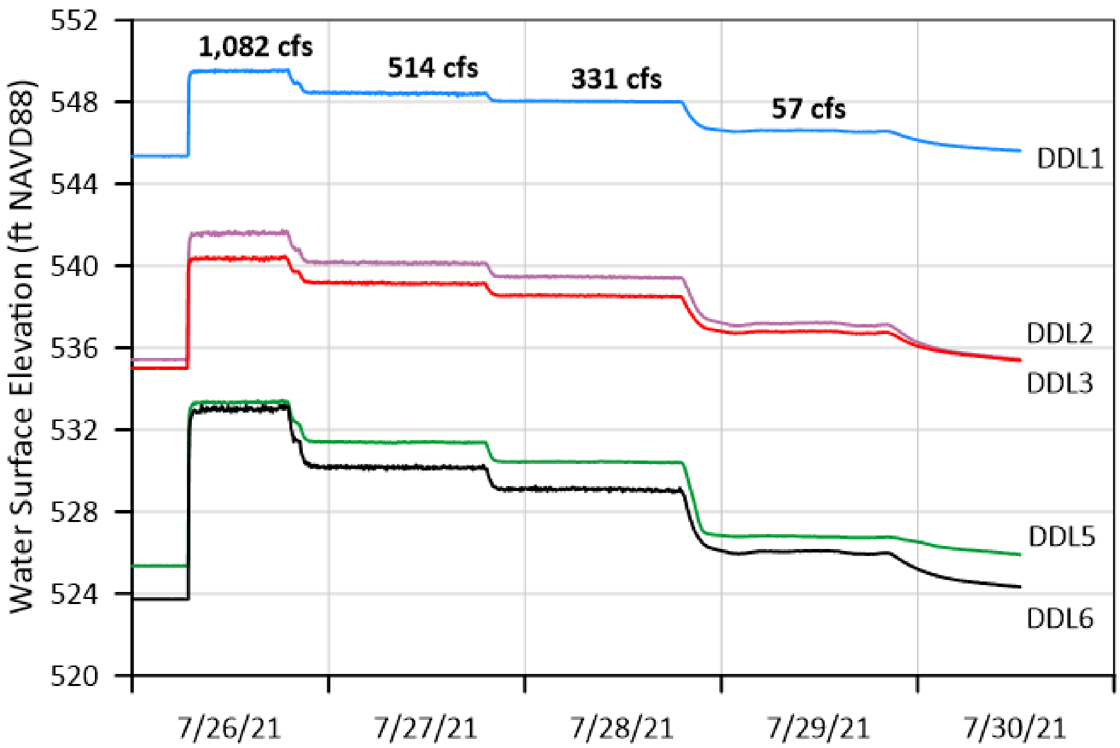

Figure 19. Recorded water levels at Existing Feature 1 during controlled releases from July 26-29, 2021.

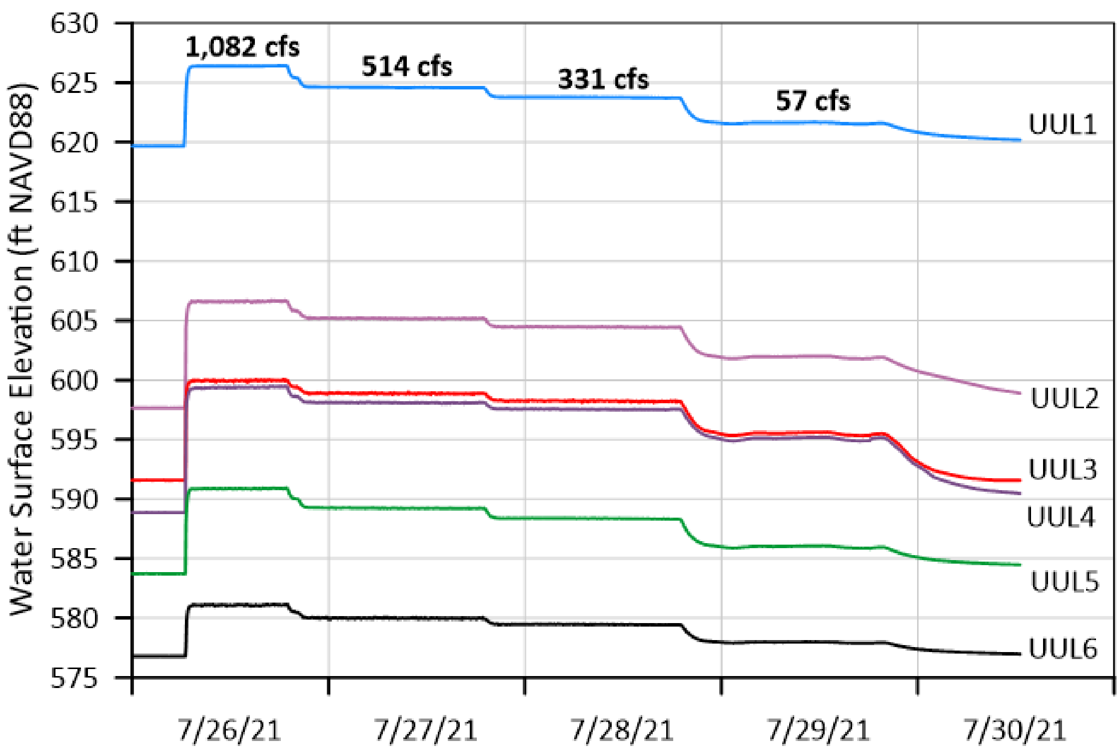

Figure 20. Recorded water levels at Existing Feature 2 during controlled releases from July 26-29, 2021.

Recorded water levels at Existing Features 1 and 2 resulting from spill associated with rapid snowmelt during the extreme heat in late June 2021 are shown in Figure 21 in addition to a graphic of the computed spill. The computed spill is determined with the Gorge Dam Spill Calculator which is a spreadsheet calculation of theoretical spill, given reservoir level and gate opening.

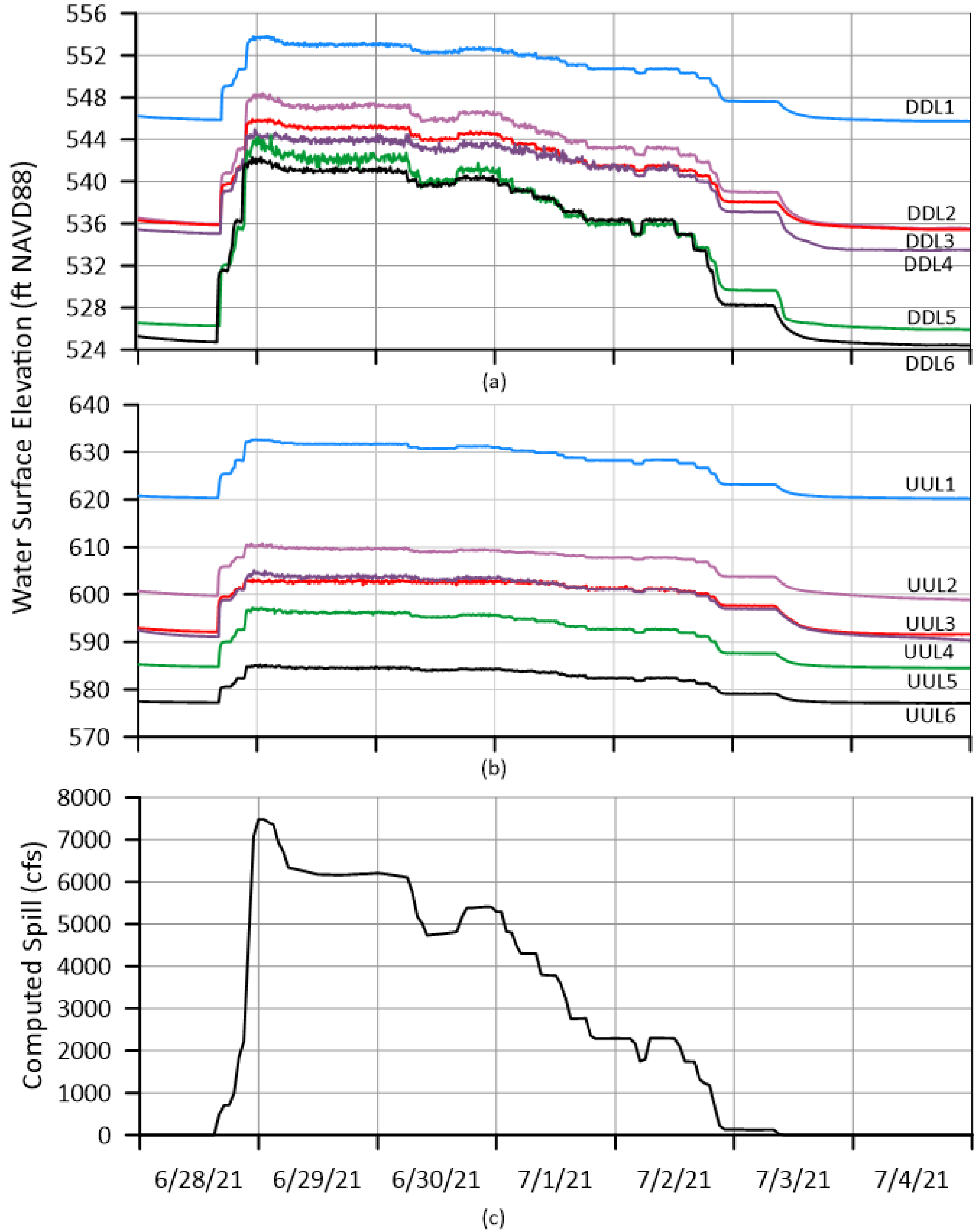

Figure 21. (a) (b) Recorded water levels at Existing Feature 1 and Existing Feature 2 during the unscheduled spill from 28 June to 3 July. (c) Computed spill during the unscheduled release.

4 CONCLUSIONS

Field measurements were conducted of the Skagit River in the Gorge bypass reach for calibrating the Bypass Hydraulic Model and for use in other relicensing studies. Hydraulic characteristics were measured at nominal controlled releases of 1,200, 500, 250, and 50 cfs from Gorge Dam during the week of July 26, 2021. Three categories of data were collected: measurements at established transects, drone-based still photos and videos, and data recorded by water level loggers placed at each of the Existing Features.

Depth and velocity measurements were made using an ADCP and ADV at five established transects and the bridge immediately below Gorge Dam. Analysis of the measurements shows high quality data was collected with excellent coverage along each transect. Measured velocities ranged from near zero at channel margins to over seven feet/sec, and depths up to 16 feet were observed. In sum, 644 velocity/depth measurements (587 by ADCP and 57 by ADV) were made to calibrate/validate the Bypass Hydraulic Model. A discussion of measurement uncertainty and an apparent loss of flow at Afternoon Creek Pool is discussed in Gorge Bypass Reach Discharge Measurement Uncertainty Analysis Technical Memorandum (NHC 2022, as attached to the FA-05 Bypass Instream Flow Model Development Study Interim Report [Attachment C]).

Nearly 4,300 nadir photographs were taken of the Gorge bypass reach between Gorge Dam and Gorge Powerhouse from a drone at altitude. Overlapping photographs from each day were processed through Structure from Motion (SfM) software to produce a 3D model (point cloud) and ultimately a composite orthomosaic of the observed conditions each day. These 3D models and orthomosaics are available to support hydraulic model calibration/validation and to assist other Skagit Project relicensing studies. Video footage at Existing Features 1 and 2 were also recorded at each controlled spill in late July and have been processed in large scale particle image velocimetry software. Resultant velocity vector maps and digital streamlines are available to ground truth the Bypass Hydraulic Model and to support the FA-04 Fish Passage Study.

Twelve water level loggers were installed at Existing Features 1 and 2 in May 2021, and recorded water stage through late-September 2021. Extreme flows in mid-November 2021 destroyed over half of the instruments with consequent loss of much of the post-September 2021 data. This effectively terminated the data collection program, although water level data through early December 2021 were retrieved from some of the surviving data loggers. Data collected during the data collection period included stages for an unplanned spill in late June 2021, where a maximum discharge of ~7,400 cfs was achieved, as well as for the planned controlled releases in late July 2021. Plots of the observed stages track well with spill records, and quality control measurements taken during monthly data downloads reveal little drift and therefore high reliability of records. These records were used to calibrate/validate the Bypass Hydraulic Model.

5 REFERENCES

Dermisis, D.C. and A.N. (Thanos) Papanicolaou. 2005. Determining the 2-D surface velocity field around hydraulic structures with the use of a large scale particle image velocimetry (LSPIV) technique. From American Society of Civil Engineers (ASCE) Impacts of Global Climate Change: World Water and Environmental Resources Congress, 2005. Published online April 26, 2012. DOI: https://doi.org/10.1061/40792(173)404

Muste, M., I. Fujita, and A. Hauet. 2008. Large-scale particle image velocimetry for measurements in riverine environments. Water Resources Research 44.W00D19. DOI: https//doi:10.1029/2008WR006950

Northwest Hydraulic Consultants (NHC). 2022. Gorge bypass reach discharge measurement uncertainty analysis. Technical Memorandum. March 2022.

Patalano, A., C.M. García, and A. Rodríguez, A. 2017. Rectification of Image Velocity Results (RIVeR): A simple and user-friendly toolbox for large scale water surface Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV). Computers and Geosciences 109. 2017: 323–330. DOI: https://doi:10.1016/j.cageo.2017.07.009

Raffel, M., C.E. Willert, and J. Kompenhans. 1998. Particle image velocimetry: a practical guide (Vol. 2). Springer, Berlin: 147-171. DOI: http://dx.doi.org/10.1007/978-3-662-03637-2_6

Thielicke, W. and E.J. Stamhuis. 2014a. PIVlab: Towards User-friendly, affordable and accurate Digital Particle Image Velocimetry for MATLAB. Journal of Open Research Software 2(1): e30,: October 16, 2014. DOI: http://dx.doi.org/10.5334/jors.bl

Thielicke, W. and E.J. Stamhuis. 2014b. PIVlab - Time-Resolved Digital Particle Image Velocimetry Tool for MATLAB (version: 2.36). DOI: http://dx.doi.org/10.6084/m9.figshare.1092508

Thielicke, W. 2014c. The flapping flight of birds: analysis and application. PhD thesis. Rijksuniversiteit Groningen. October 2014. 255p. http://irs.ub.rug.nl/ppn/382783069

Turnipseed, D.P., and V.B Sauer. 2010. Discharge measurements at gaging stations: U.S. Geological Survey (No. 3 A8). 87 p. (Also available at https://pubs.usgs.gov/tm/tm3-a8/)

SKAGIT RIVER GORGE BYPASS REACH HYDRAULIC AND INSTREAM FLOW MODEL DEVELOPMENT STUDY INTERIM REPORT

ATTACHMENT C

GORGE BYPASS REACH DISCHARGE MEASUREMENT UNCERTAINTY ANALYSIS MEMORANDUM

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nhc
northwest hydraulic consultants

MEMORANDUM

To:	**Project File**	Date:	March 2022
		NHC Ref. No.	2003536
From:	Donnie Jones, EIT – NHC Chris Long, PE – NHC		
Re:	**Gorge Bypass Reach Discharge Measurement Uncertainty Analysis**		

1 INTRODUCTION

Northwest Hydraulic Consultants (NHC) collected hydraulic data of the Skagit River between Gorge Dam and Gorge Powerhouse, otherwise known as the Gorge bypass reach, from July 26-30[1], 2021, for use in calibrating and validating a new hydraulic model (the Bypass Hydraulic Model) as part of the FA-05 Skagit River Gorge Bypass Reach Hydraulic and Instream Flow Model Development Study (Bypass Instream Flow Model Development Study). The Bypass Hydraulic Model is being developed to support the Federal Energy Regulatory Commission (FERC) relicensing of the Skagit River Hydroelectric Project (Project) and will be used for assessing instream flows and evaluating fish passage conditions among other FERC relicensing tasks. As requested by licensing participants (LPs) during the FA-05 Study Workshop 3 on August 26, 2021, this memorandum documents NHC's evaluation of uncertainty for measured discharges and subsequent selection of inflows for the hydraulic model representative of discharge in the Gorge bypass reach during the July 26-29, 2021, controlled releases.

2 CONTROLLED RELEASE FLOW MEASUREMENTS

Four controlled flows were released from Gorge Dam from July 26-29, 2021, to allow for field data collection to support calibration of the Bypass Hydraulic Model. During each controlled release, NHC collected discharge measurements at the bridge immediately below Gorge Dam and at five cableway transects (Figure 1). Flow magnitudes of 1,200, 500, 250, and 50 cfs were targeted for the release events on four consecutive days. To release flows of 1,200, 500, and 250 cfs into the bypass reach, one spillway gate on Gorge Dam was raised according to the Project's spillway discharge calculator. At the targeted flow range, this required the 50-foot-tall spillway gate be opened by mere inches. For the targeted release of 50 cfs, both spillway gates were closed, and the log chute was opened to pass flow from Gorge Lake into the Gorge bypass reach.

[1] Data collection from July 26-29 corresponded to controlled flow releases from Gorge Dam, while data collection on July 30 corresponded to base flow conditions (no dam release).

Maintaining a steady flow through the spillway gate and log chute required operators to maintain a constant reservoir elevation throughout each spill event. Sensitivity of the flow releases to fluctuation in reservoir levels and uncertainty in the precise opening of the spillway gate at small gate openings required physical measurements be made to verify the actual discharge released. Detailed discussion of how discharge measurements were made at the bridge and cableway transects is provided in the Gorge Bypass Reach Data Collection for Hydraulic Model Calibration memorandum (NHC 2022, as attached to the FA-05 Bypass Instream Flow Model Development Study Interim Report [Attachment B]). The following sections detail how uncertainty was assessed for each discharge measurement and what discharge values were selected to represent the controlled spill events in the Bypass Hydraulic Model.

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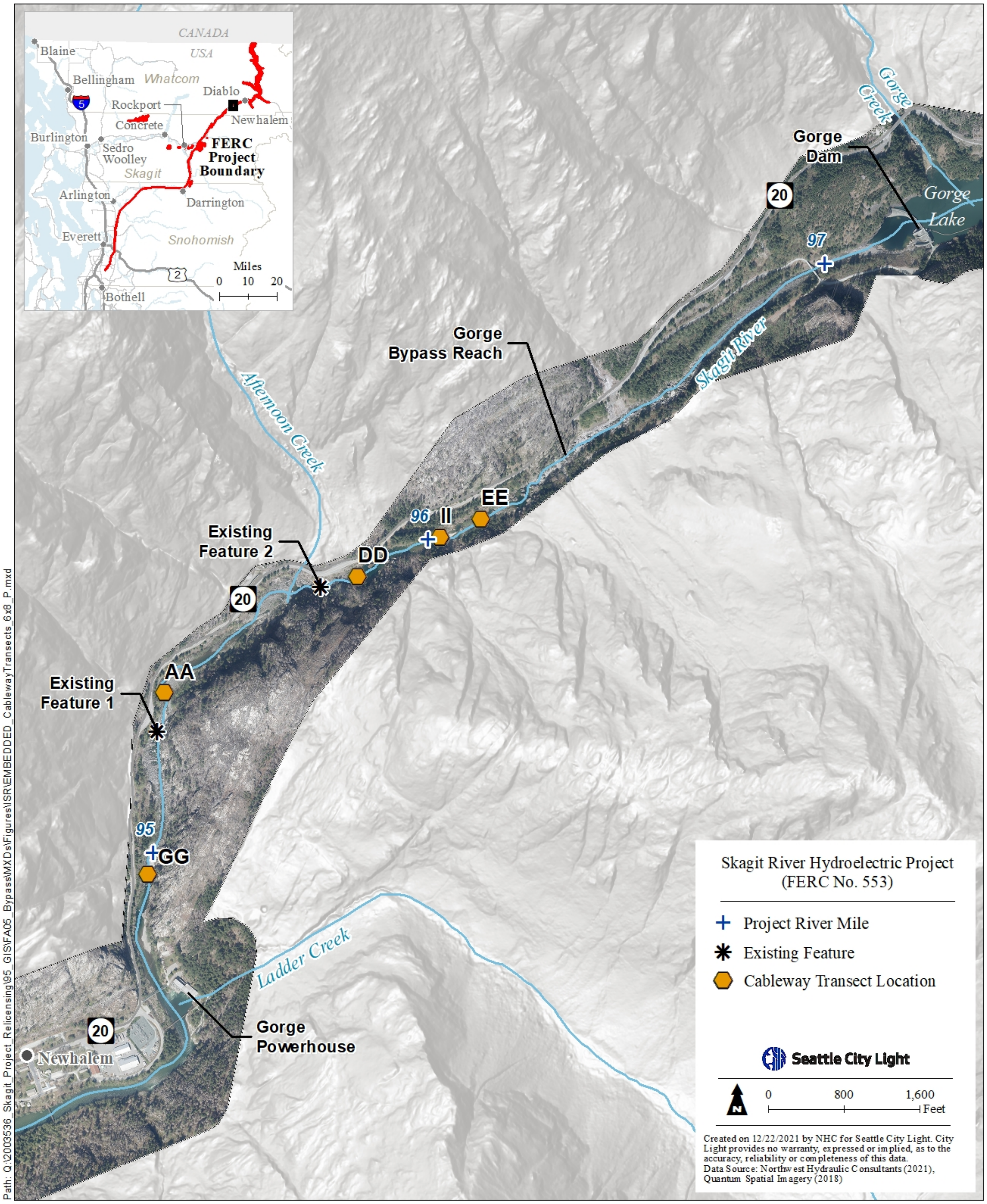


Figure 1. Bridge and cableway transect measurement locations for Bypass Hydraulic Model calibration.

3 MEASUREMENT UNCERTAINTY

The five cableway transect locations were selected in consultation with LPs, primarily Washington State Department of Ecology (Ecology) and Washington Department of Fish and Wildlife (WDFW) after NHC completed an initial reconnaissance of the Gorge bypass reach. The transect locations were selected considering factors such as access, safety, and equipment logistics; however, as the focus of the Bypass Hydraulic Model is assessing instream flows, it was of primary importance to LPs to represent a variety of geomorphic units. Since the transects would be used primarily to calibrate the hydraulic model to observed velocities and depths, selecting locations based on characteristics of an ideal discharge measurement were of lesser importance. Note that an ideal transect for measuring discharge is 1) located along a longitudinally uniform channel, 2) has an even and smooth distribution of velocity, and 3) has a smooth and firm channel bed for measurement of cross-sectional area (Turnipseed and Sauer, 2010). None of the five cableway transects strictly meets these criteria. During each discharge measurement, field staff evaluated both the characteristics of the measurement section and the performance of the data collection process to make a qualitative assessment of confidence in the computed discharge. The following characteristics were found to impact discharge measurement quality at the cableway transects and at the bridge below Gorge Dam:

- Large material and bed features causing abrupt changes in channel elevation relative to flow depth (Bridge; Transects EE and AA);
- Non-uniform channel conditions upstream and/or downstream of measurement cross-section (Transects EE, II, and AA);
- Uneven distribution and rapid changes of velocity along cross-section (Bridge; Transects EE, II, AA, and GG);
- Significant lateral and vertical velocity components (Transects EE and AA);
- Turbulence fluctuations similar in magnitude to time-averaged velocity (Transect DD); and
- Recirculation creating reverse flow (Transect GG).

The preceding field observations were qualitatively assessed to determine the measurement locations that provided the most reliable discharge measurements. Based on the overall poor quality of site conditions at Transect AA, this transect was not used in the discharge assessment. The bridge below Gorge Dam, Transect II, and Transect DD were observed to provide the most reliable discharge measurement conditions, while conditions at Transects EE and GG were deemed acceptable to aid in verification of flows. Note that all velocity and depth measurements are being used to calibrate the hydraulic model; this assessment was focused only on quantifying uncertainty in the computed discharge.

All but one discharge measurement taken at all locations across all four days was made using the USGS mid-section method (Turnipseed and Sauer 2010). The only exception to this was a moving-vessel ADCP measurement (Mueller et al. 2013) at the bridge immediately below Gorge Dam during the 1,200 cfs targeted spill. Unfortunately, the bridge did not provide appropriate conditions to consistently repeat transects during moving-vessel operation. Therefore, this discharge measurement was excluded from this quantitative uncertainty analysis and the mid-section method was used at the bridge for subsequent measurements.

4 UNCERTAINTY QUANTIFICATION

A quantitative assessment of uncertainty for each discharge measurement is provided in Table 1-4. While not used for assessing discharge in the Gorge bypass reach, data from Transect AA is included in these tables for completeness. To quantify total uncertainty, the following individual components were assessed:

- Uncertainty due to 1) changes in depth and velocity between each stationary measurement along a transect and 2) the extent of extrapolated depth and velocity data not directly measured over the entire transect;
- Uncertainty owing to the angle of primary flow direction differing from the cableway angle (not applicable for waded discharge measurements); and
- Uncertainty in estimating the distance to far edge of water from the last measured station. This component is only applicable for cableway measurements made when the channel could not be waded. (The “far edge of water” is on the left bank of the Gorge bypass reach looking downstream and is generally not accessible except under baseflow conditions).

Table 1. 1,200 cfs Targeted Spill Measurement Uncertainty

Transect	Measured Flow (cfs)	Uncertainty (%)				Error Bounds (cfs)	
		Measurement	Flow Angle	Far Edge	Total	Minimum	Maximum
Bridge	1165	14.8	N/A	N/A	14.8	993	1338
EE	1145	3.0	1.2	0.2	4.4	1095	1196
II	1082	2.5	0.4	2.1	5.0	1028	1136
DD	1045	1.9	0.1	1.1	3.1	1013	1077
AA	1096	2.9	0.3	1.9	5.1	1040	1152
GG	1038	6.3	1.5	1.1	8.9	946	1130

Table 2. 500 cfs Targeted Spill Measurement Uncertainty

Transect	Measured Flow (cfs)	Uncertainty (%)				Error Bounds (cfs)	
		Measurement	Flow Angle	Far Edge	Total	Minimum	Maximum
Bridge	494	3.7	1.5	N/A	5.2	469	523
EE	491	3.0	2.3	2.5	7.8	452	529
II	514	2.4	2.1	1.9	6.4	481	547
DD	442	2.3	2.1	0.1	4.5	422	462
AA	535	3.8	0.5	2.5	6.8	499	572
GG	438	2.1	1.6	0.4	4.1	420	455

Table 3. 250 cfs Targeted Spill Measurement Uncertainty

Transect	Measured Flow (cfs)	Uncertainty (%)				Error Bounds (cfs)	
		Measurement	Flow Angle	Far Edge	Total	Minimum	Maximum
Bridge	319	4.5	0.5	N/A	5.0	303	343
EE	316	5.0	N/A	N/A	5.0	300	331
II	331	2.4	0.3	1.4	4.1	318	345
DD	297	2.3	1.7	0.2	4.2	285	310
AA	306	3.2	0.4	3.3	6.9	285	327
GG	298	3.9	0.9	1.9	6.7	279	318

Table 4. 50 cfs Targeted Spill Measurement Uncertainty

Transect	Measured Flow (cfs)	Uncertainty (%)				Error Bounds (cfs)	
		Measurement	Flow Angle	Far Edge	Total	Minimum	Maximum
Bridge	60	4.7	1.7	N/A	6.4	56	63
EE	56	8.1	N/A	N/A	8.1	51	60
II	57	3.7	2.7	0.7	7.1	53	61
DD	58	5.6	0.6	1.1	7.3	54	62
AA	68	7.5	1.4	15.3	24.2	52	85
GG	54	5.9	8.0	2.0	15.9	46	63

The computed discharge from each processed measurement along with error bounds based on computed uncertainty are charted in Figure 2-5.

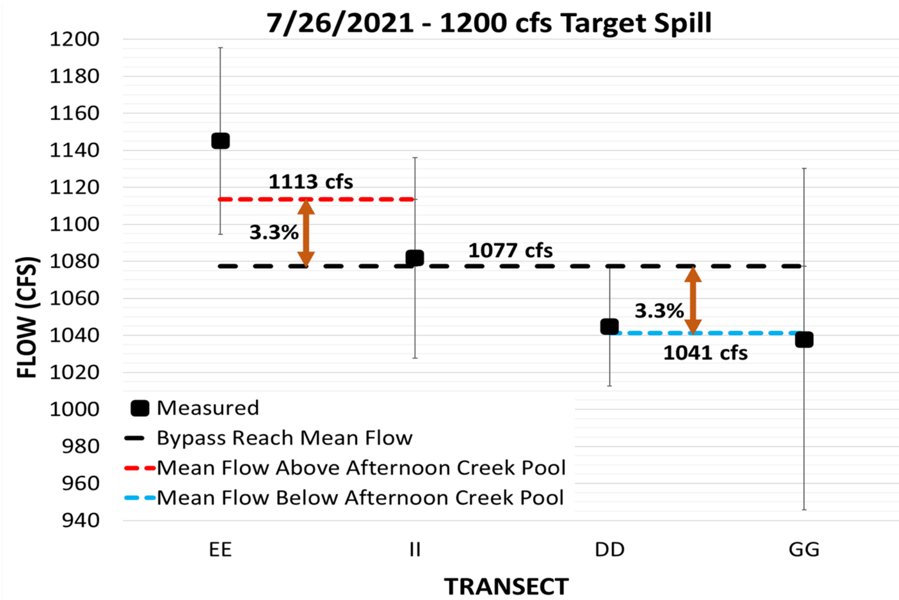


Figure 2. Measured transect flows and computed mean flows during July 26, 2021, controlled spill. Vertical lines indicate error bounds determined from uncertainty analyses.

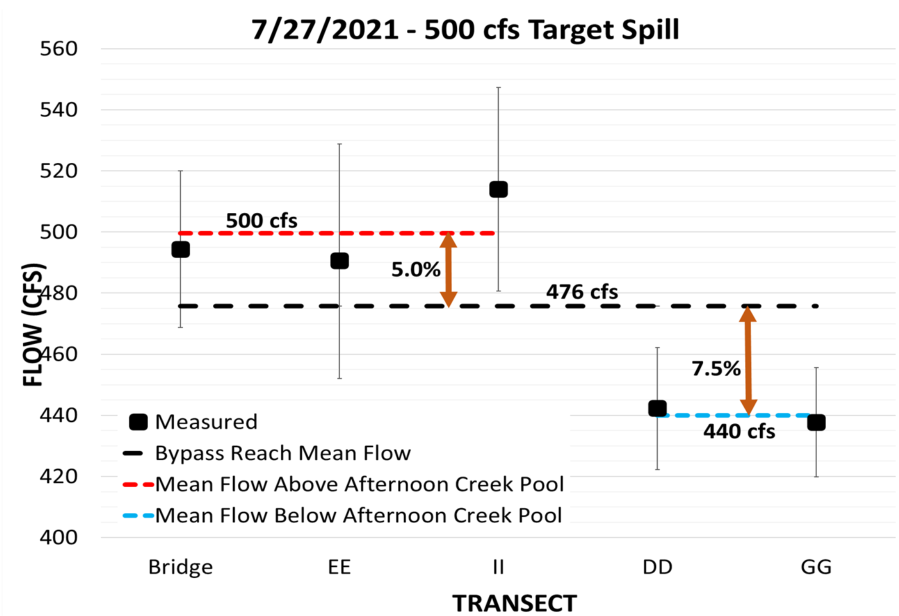


Figure 3. Measured transect flows and computed mean flows during July 27, 2021, controlled spill. Vertical lines indicate error bounds determined from uncertainty analyses.

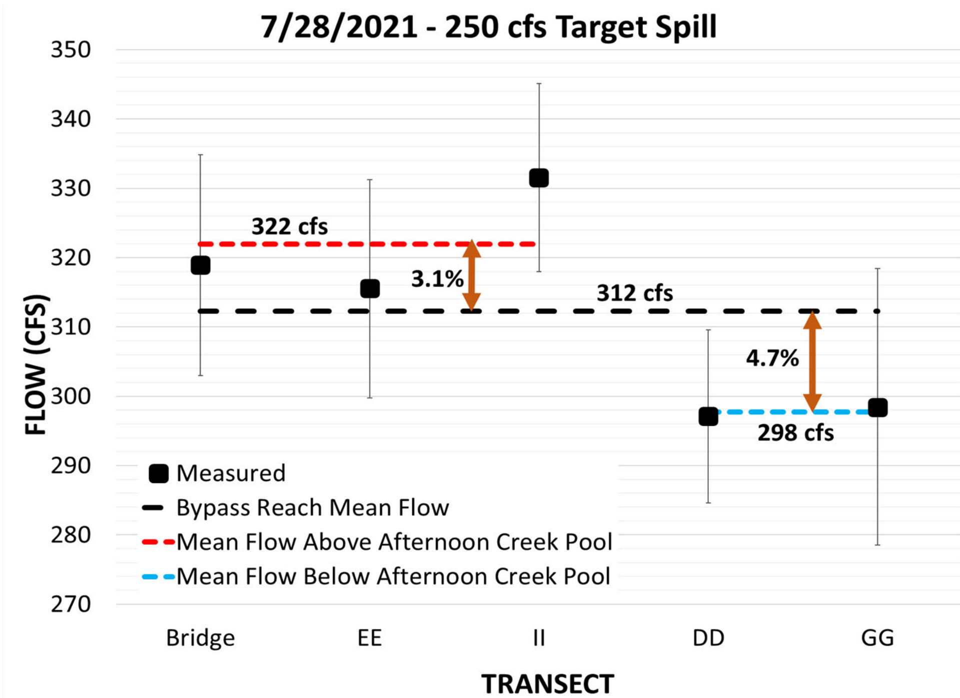


Figure 4. Measured transect flows and computed mean flows during July 28, 2021, controlled spill. Vertical lines indicate error bounds determined from uncertainty analyses.

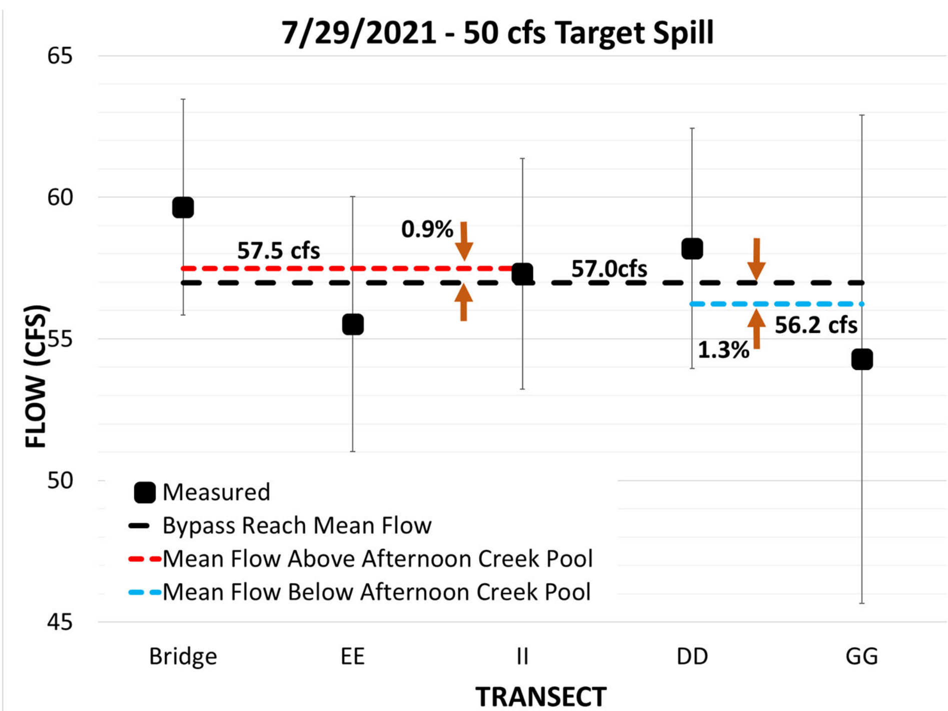


Figure 5. Measured transect flows and computed mean flows during July 29, 2021, controlled spill. Vertical lines indicate error bounds determined from uncertainty analyses.

5 POTENTIAL FLOW LOSS

A significant trend is discernable from the plots in Figure 2-5 where measured flows decrease between Transects II and DD. This was noted at FA-05 Workshop 3 and prompted LPs to request this memorandum. The reach between these transects is characterized by a low gradient (0.7%) and encompasses the largest standing pool in the Gorge bypass reach (Afternoon Creek Pool) which forms behind landslide material otherwise known as Existing Feature 2 (see Figure 1). The decrease in flow within this section amounts to 6.6%, 12.5%, and 7.8% of the mean reach flow for the 1,200 cfs, 500 cfs, and 250 cfs targeted spills, respectively. It is unlikely this trend is solely attributable to a coincidence of random measurement error since it is observed across multiple releases over multiple days. Additionally, the observed mean flow between transects upstream of Afternoon Creek Pool (Bridge, EE and II) falls outside or at the extreme end of the error bounds for measured flows below the pool (DD and GG) and vice versa. During the 50 cfs targeted spill this trend is much less discernable, constituting a 2.2% decrease relative to the mean reach flow.

Within the Gorge bypass reach, large amounts of coarse material are distributed throughout the channel bottom, giving opportunity for water to percolate through. This coarse material includes gravel fill found 200-300 feet deep beneath Gorge Dam; significant deposits of cobble and boulder gravels introduced by landslides, glacial outburst flood deposits, debris flows, small tributary debris cones; and fill from human activities (J. Riedel, personal communication, September 28, 2021; Riedel et al. 2020; Riedel et al. 2006; Riedel 2017). These large material deposits throughout the Gorge bypass reach may provide significant groundwater storage as well as pathways allowing water to flow subsurface. A “mass-movement terrace” (Riedel et al. 2020) and material from the 2004 Afternoon Creek landslide have created large deposits for such groundwater paths to exist near the Afternoon Creek Pool. It’s also important to note that prior to the controlled releases, western Washington experienced a historic “heat dome” in late June with temperatures well over 100 degrees Fahrenheit for a week, and the Gorge bypass reach did not see flow exceeding more than a few cubic feet per second during the month of July. With such extremely dry antecedent conditions, it is possible that significant groundwater storage was available prior to the controlled releases and that this storage was recharged over the course of the week until full, as indicated by the lack of flow loss on July 29, 2021. Further investigation of flow loss is beyond the scope of this study. However, knowledge of the geology of the reach and confidence bounds in the discharge measurements provides a plausible explanation for the apparent loss in observed flow.

6 MODEL CALIBRATION FLOWS

Apparent flow loss at Afternoon Creek Pool during the 1,200, 500, and 250 cfs targeted spills will be accounted for in calibration of the Bypass Hydraulic Model by simulating a mean discharge for measurements made upstream (Bridge, Transects EE and II) and downstream (Transects DD and GG) of the feature. Observed data will be compared to model output from the mean flow corresponding to the location where the observed data were measured. Since discharge measurements during the 50 cfs targeted spill did not indicate discernable flow fluctuations relative to random error, a mean flow was computed from all measurements along the reach for input to the hydraulic model. The following table provides the inflows selected to represent the controlled release events in the hydraulic model.

Table 5. Mean Flows for Bypass Hydraulic Model Calibration

Calibration Simulation	U/S Mean Flow (cfs)*	D/S Mean Flow (cfs)**
July 26, 2021	1113	1041
July 27, 2021	500	440
July 28, 2021	322	298
July 29, 2021	57***	57***

* Mean flow measured upstream of Afternoon Creek Pool (Gorge Dam Bridge, Transects EE and II)
** Mean flow measured downstream of Afternoon Creek Pool (Transects DD and GG)
*** Mean of all discharge measurements

7 REFERENCES

Mueller, D.S., C.R. Wagner, M.S. Rehmel, K.A. Oberg, and Francois Rainville, 2013. Measuring discharge with acoustic Doppler current profilers from a moving boat. (Version 2.0, No. 3-A22). U.S. Geological Survey. December 2013. 95 p. https://dx.doi.org/10.3133/tm3A22

Northwest Hydraulic Consultants (NHC). 2022. Gorge Bypass Reach Data Collection for Hydraulic Model Calibration Memorandum. March 2022.

Riedel, J.L. 2021. Personal communication with NHC. September 28, 2021.

Riedel, J.L. 2017. Deglaciation of the North Cascade Range from the last glacial maximum to the Holocene. Cuadernos de Investigación Geográfica 4: 467-496.

Riedel, J.L, R.A Haugerud, and J.J. Clague. 2007. Geomorphology of a Cordilleran ice sheet drainage network through breached divides in the North Cascades Mountains of Washington and British Columbia. Geomorphology 91: 1-18.

Riedel, J., S. Sarrantonio, K. Ladig, and M. Larrabee. 2020. Skagit River Geomorphology Inventory Report: Part I – Gorge Dam to Sauk River. Report to Seattle City Light. U.S. National Park Service.

Turnipseed, D.P., and V.B. Sauer. 2010. Discharge measurements at gaging stations. (No. 3-8) U.S. Geological Survey. 87 p. (Also available at https://pubs.usgs.gov/tm/tm3-a8/)

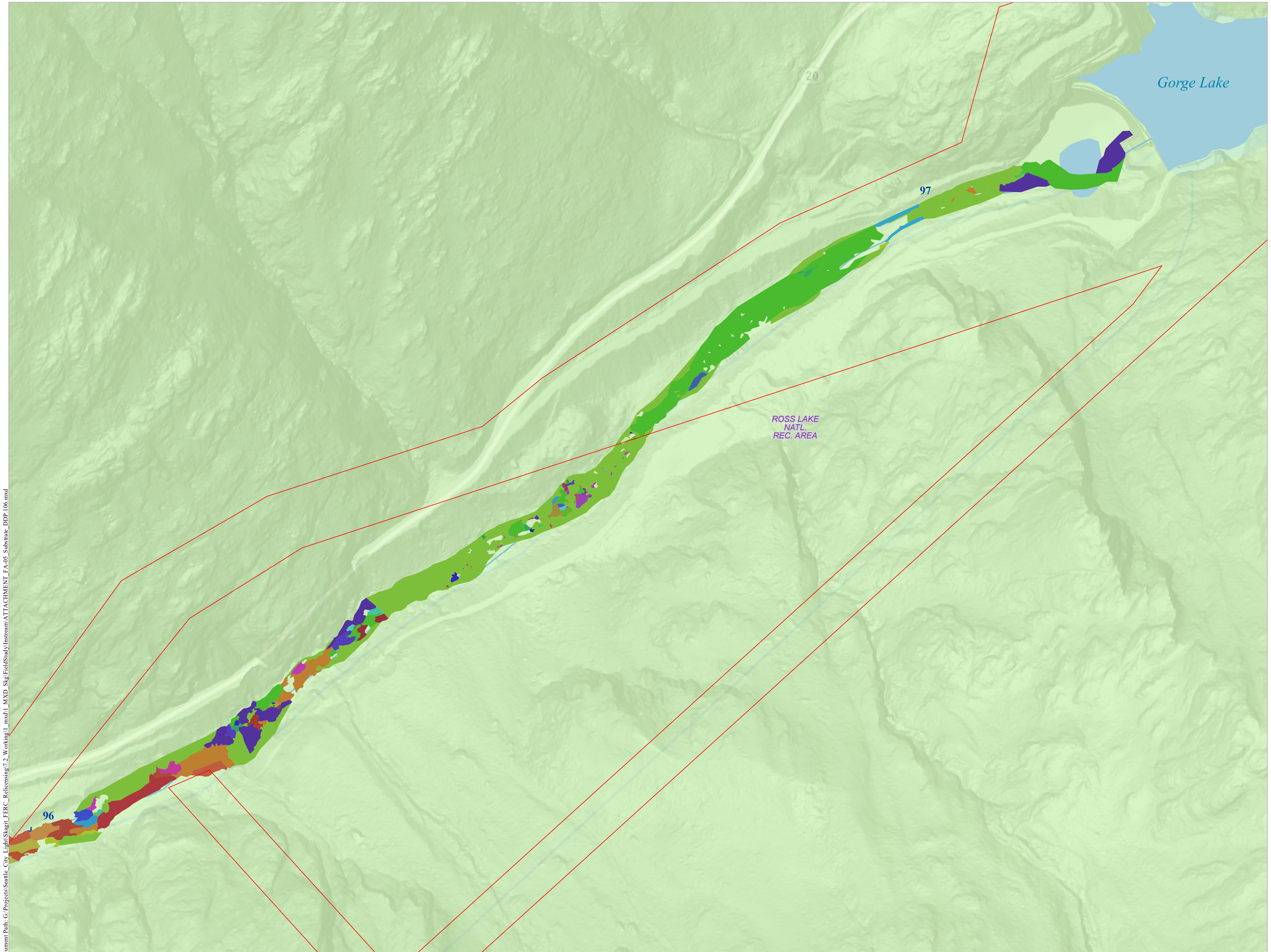
SKAGIT RIVER GORGE BYPASS REACH HYDRAULIC AND INSTREAM FLOW MODEL DEVELOPMENT STUDY INTERIM REPORT

ATTACHMENT D

SUBSTRATE AND COVER MAPBOOKS

The following substrate and cover maps show substrate and cover codes for the Gorge bypass reach per Washington State's Instream Flow Study Guidelines (Beecher et al. 2016). Details on the coding system are provided in Section 4.2.3 of the preceding report text.

With respect to substrate codes, the guidelines stipulate use of dominant and subdominant substrate combinations that result in numerous possible substrate codes. The polygon visual attributes in the following substrate maps and the corresponding legend were selected to highlight the detail resulting from mapping efforts, while also condensing results to a point that is reasonable for an informed review of a large 2-D instream flow study area.



FA-05 BYPASS INSTREAM FLOW MODEL DEVELOPMENT STUDY – SUBSTRATE

FERC Project Boundary

+ Project River Miles (PRM)

Substrate Coding

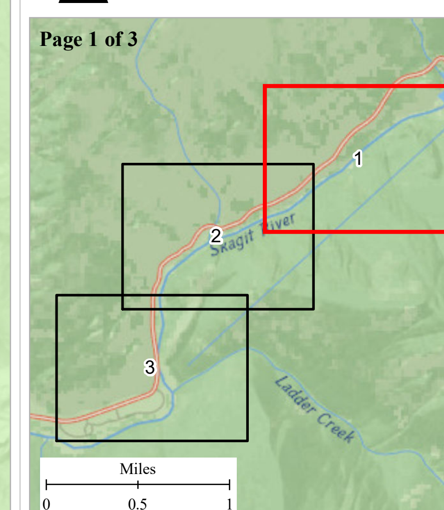
23	54.6	76.7
24.6	54.7	78.6
28.8	54.8	78.7
32.6	56.6	78.8
32.8	56.7	8
34.6	56.8	85.7
34.7	57.7	85.9
34.8	58.6	86
34.9	58.8	86.6
35.7	62	86.8
45	65	87.6
45.5	65.6	87.7
45.6	65.7	87.8
45.7	65.8	87.9
45.8	67.6	88.5
46.6	67.7	89.6
53.6	67.8	89.8
53.7	68.6	9
54	68.7	98.6
	68.8	98.8
	76	98.9

Land Ownership

National Park / National Recreation Area Boundary

N

0 250 500 Feet

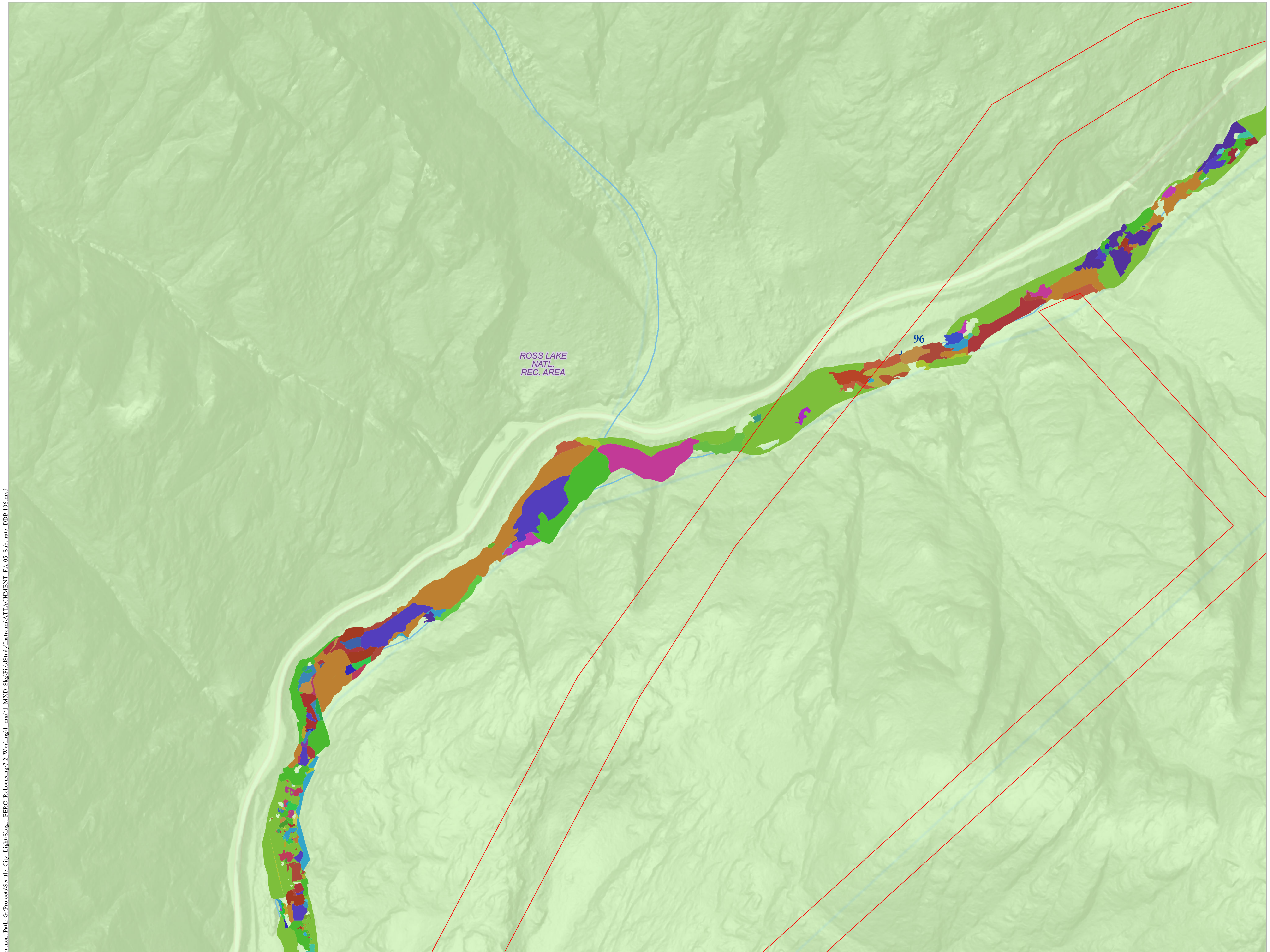


Seattle City Light

SKAGIT RIVER HYDROELECTRIC PROJECT (FERC NO. 553)

Created on 1/19/2022 by HDR for Seattle City Light.
City Light provides no warranty, expressed or implied, as to the accuracy, reliability or completeness of this data.
Data Source: Substrate - HDR.

Document Path: G:\Projects\Seattle_City_Light\Skagit_FERC_Relicensing\7.2_Working\1_mxd\1_MXD_Skg\FieldStudy\Instream\ATTACHMENT_FA-05_Substrate_DDP_106.mxd



FA-05 BYPASS INSTREAM FLOW MODEL DEVELOPMENT STUDY – SUBSTRATE

FERC Project Boundary

+ Project River Miles (PRM)

Substrate Coding

12	57.8	78.9
23	58.7	8
23.8	62	81
28.6	65	82.7
28.8	65.5	85.7
32.9	65.6	85.9
34.6	65.8	86
34.7	67.6	86.6
34.8	67.7	86.7
34.9	67.8	86.8
43.5	67.9	87
43.6	68.6	87.6
45	68.7	87.7
45.7	68.8	87.8
45.8	75	87.9
47.6	76	88.5
54	76.5	89.6
54.6	76.6	89.8
56.6	76.7	9
56.7	76.8	98.6
56.8	76.9	98.8
57.5	78.6	98.9
	78.7	
	78.8	

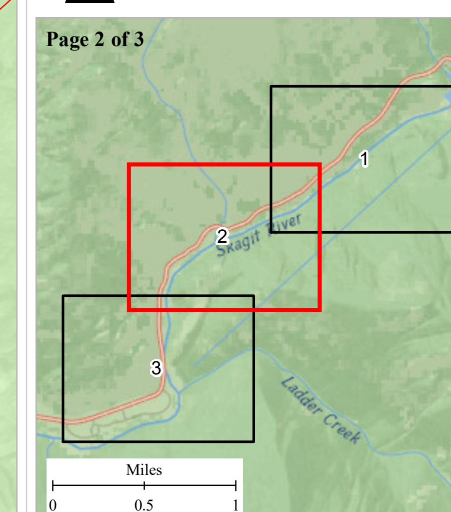
Land Ownership

National Park / National Recreation Area Boundary

N

0 250 500 Feet

Page 2 of 3



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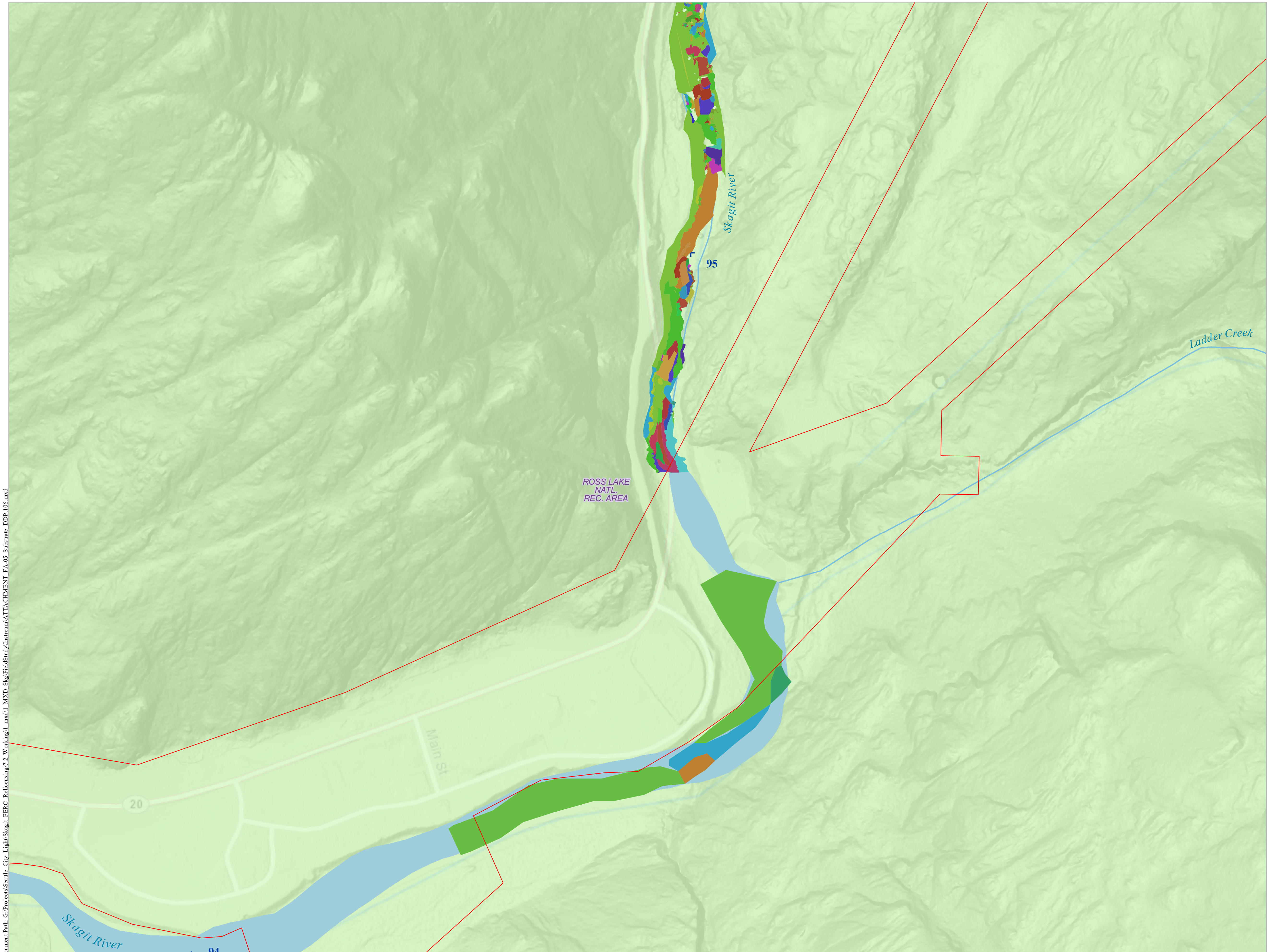


FA-05 BYPASS INSTREAM FLOW MODEL DEVELOPMENT STUDY – SUBSTRATE

FERC Project Boundary

Project River Miles (PRM)

Substrate Coding

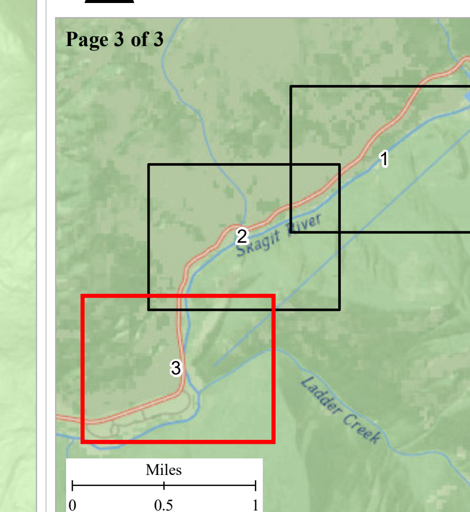
12	62	78.7
23.8	65.5	8
26.8	65.6	81
28.7	65.7	85.7
28.8	65.8	85.9
32.9	67.6	86.6
34.6	67.7	86.7
34.7	67.8	86.8
34.8	67.9	87
34.9	68	87.6
43.6	68.6	87.7
45.7	68.7	87.8
45.8	68.8	87.9
54.6	76	88.5
56.6	76.5	89.6
56.7	76.6	89.9
56.8	76.7	9
58.7	76.8	98.6
	76.9	98.9
	78.6	

Land Ownership

National Park / National Recreation Area Boundary

N

0 250 500 Feet



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FA-05 BYPASS INSTREAM FLOW MODEL DEVELOPMENT STUDY – COVER

FERC Project Boundary
Project River Miles (PRM)

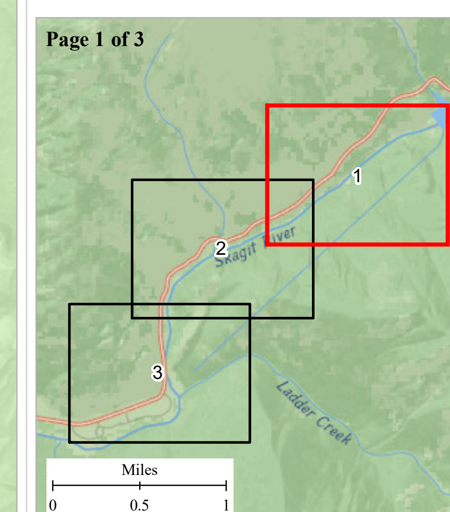
Cover Code

00.2
00.3
00.4
00.5
00.8
00.9

Land Ownership

National Park / National Recreation Area Boundary

0 230 460 Feet



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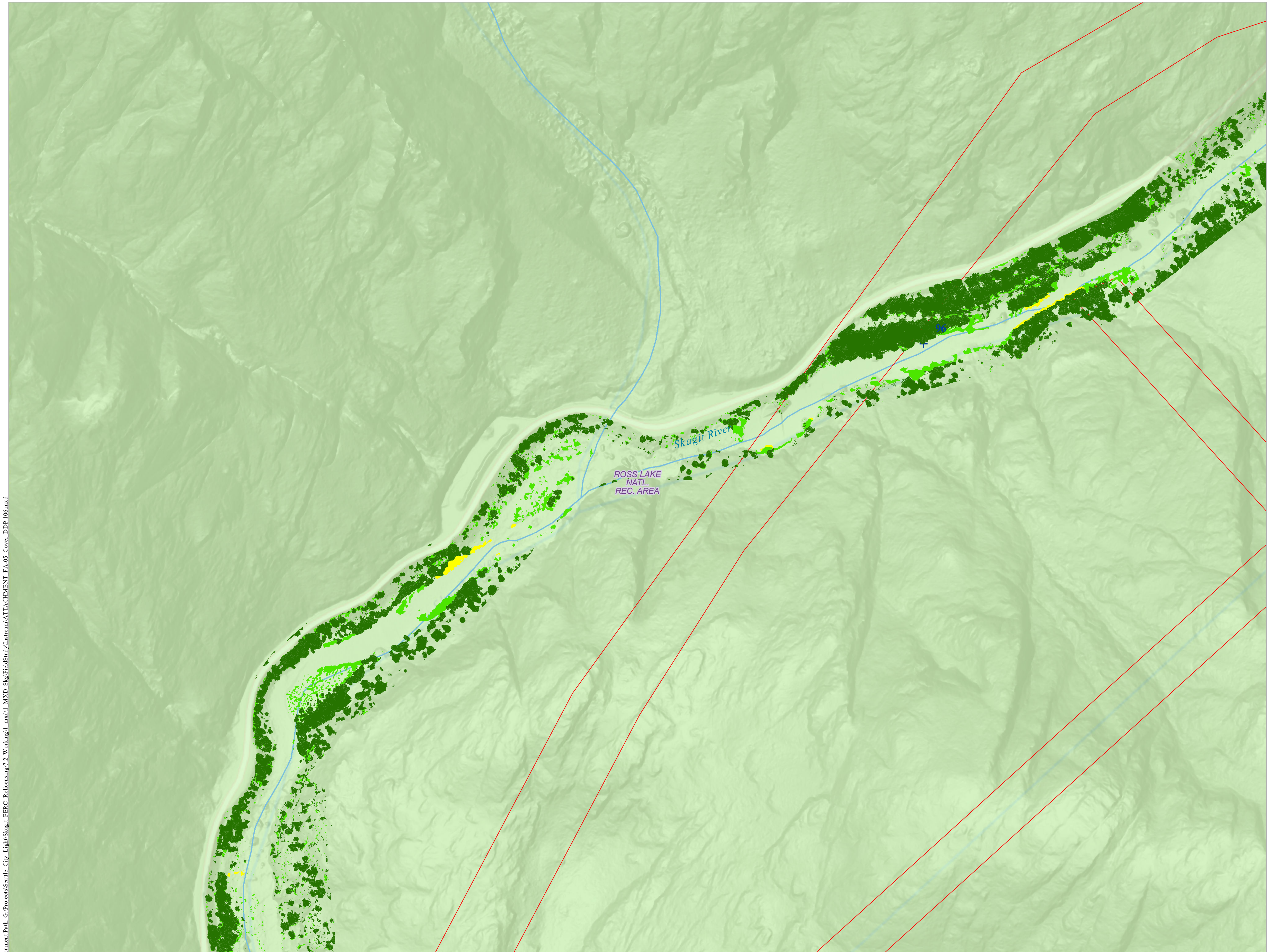


FA-05 BYPASS INSTREAM FLOW MODEL DEVELOPMENT STUDY – COVER

FERC Project Boundary
\+ Project River Miles (PRM)

Cover Code

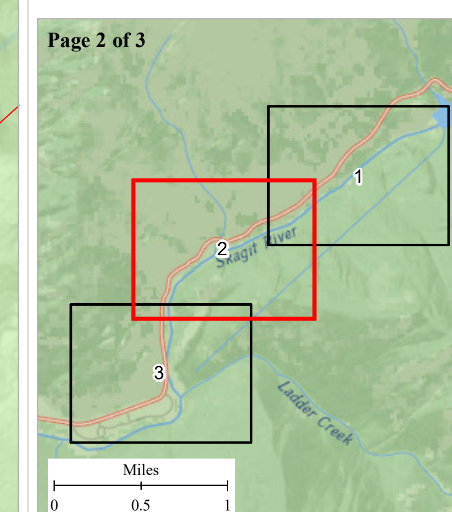
- 00.2
- 00.3
- 00.4
- 00.5
- 00.8
- 00.9

Land Ownership

National Park / National Recreation Area Boundary

N

0 230 460 Feet



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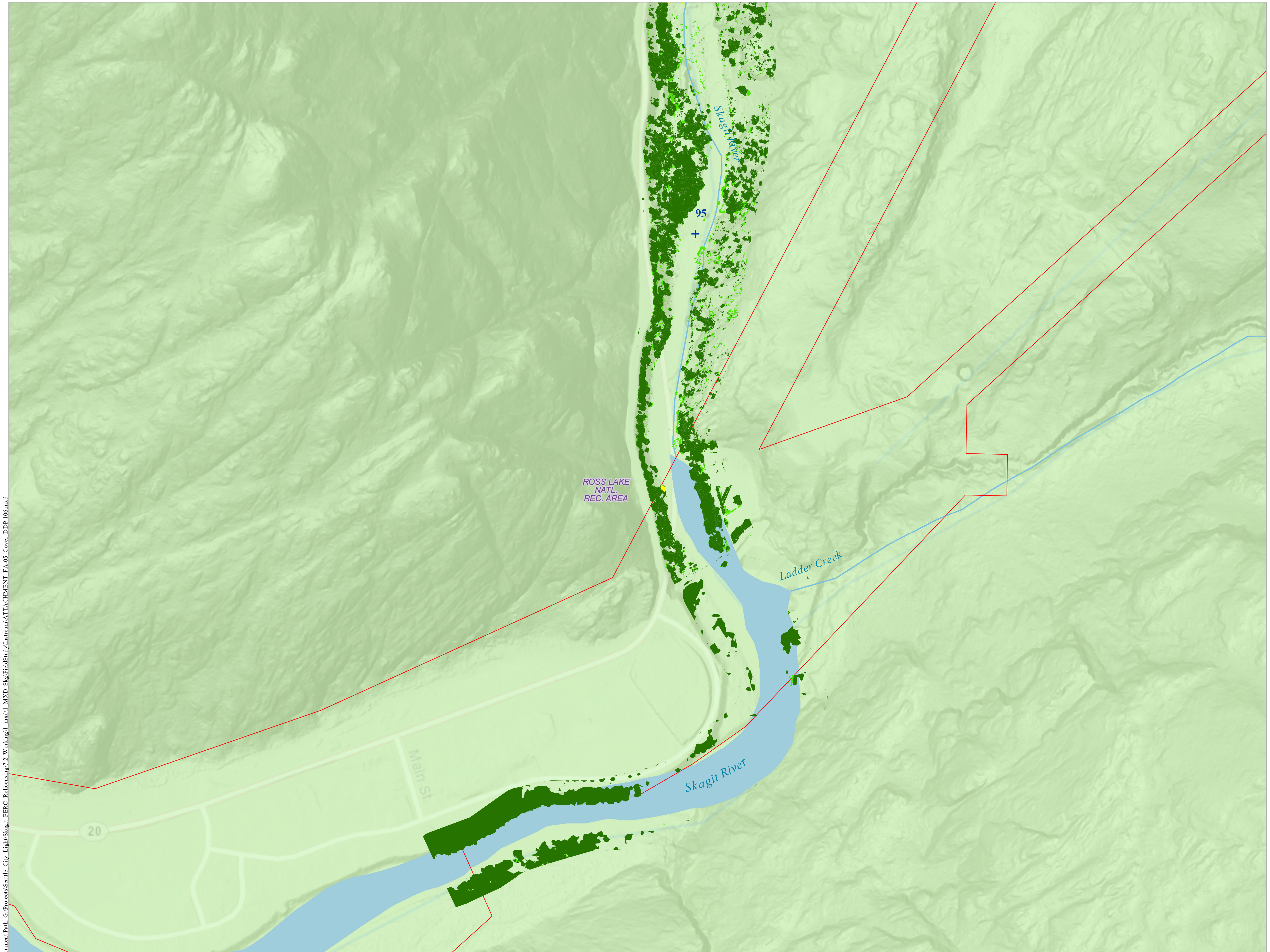


FA-05 BYPASS INSTREAM FLOW MODEL DEVELOPMENT STUDY – COVER

FERC Project Boundary
Project River Miles (PRM)

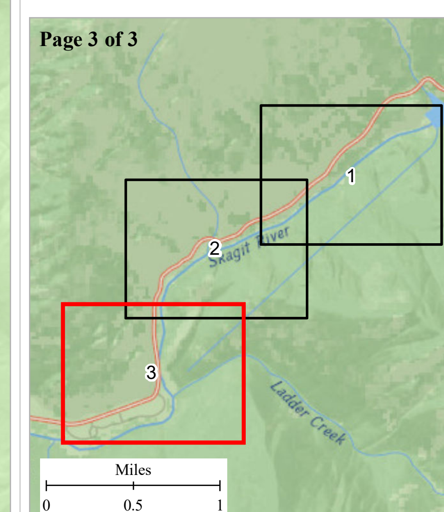
Cover Code

00.2
00.3
00.4
00.5
00.8
00.9

Land Ownership

National Park / National Recreation Area Boundary

0 230 460 Feet



Seattle City Light

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SKAGIT RIVER GORGE BYPASS REACH HYDRAULIC AND INSTREAM FLOW MODEL DEVELOPMENT STUDY INTERIM REPORT

ATTACHMENT E

PRELIMINARY HYDRAULIC MODEL CALIBRATION RESULTS

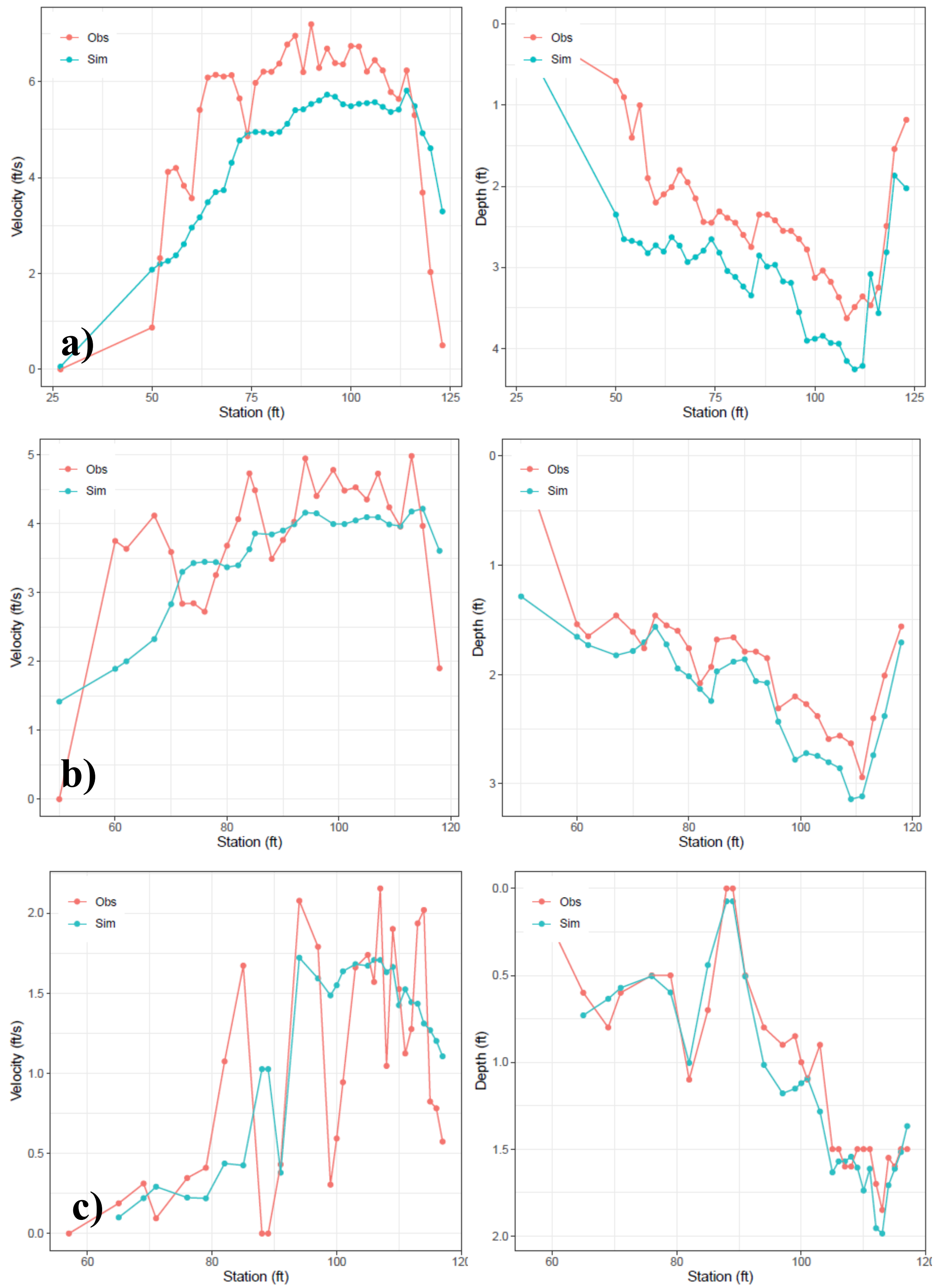


Figure E-1. Preliminary calibration results at Transect EE for a) July 26, b) July 27, and c) July 29, 2021.

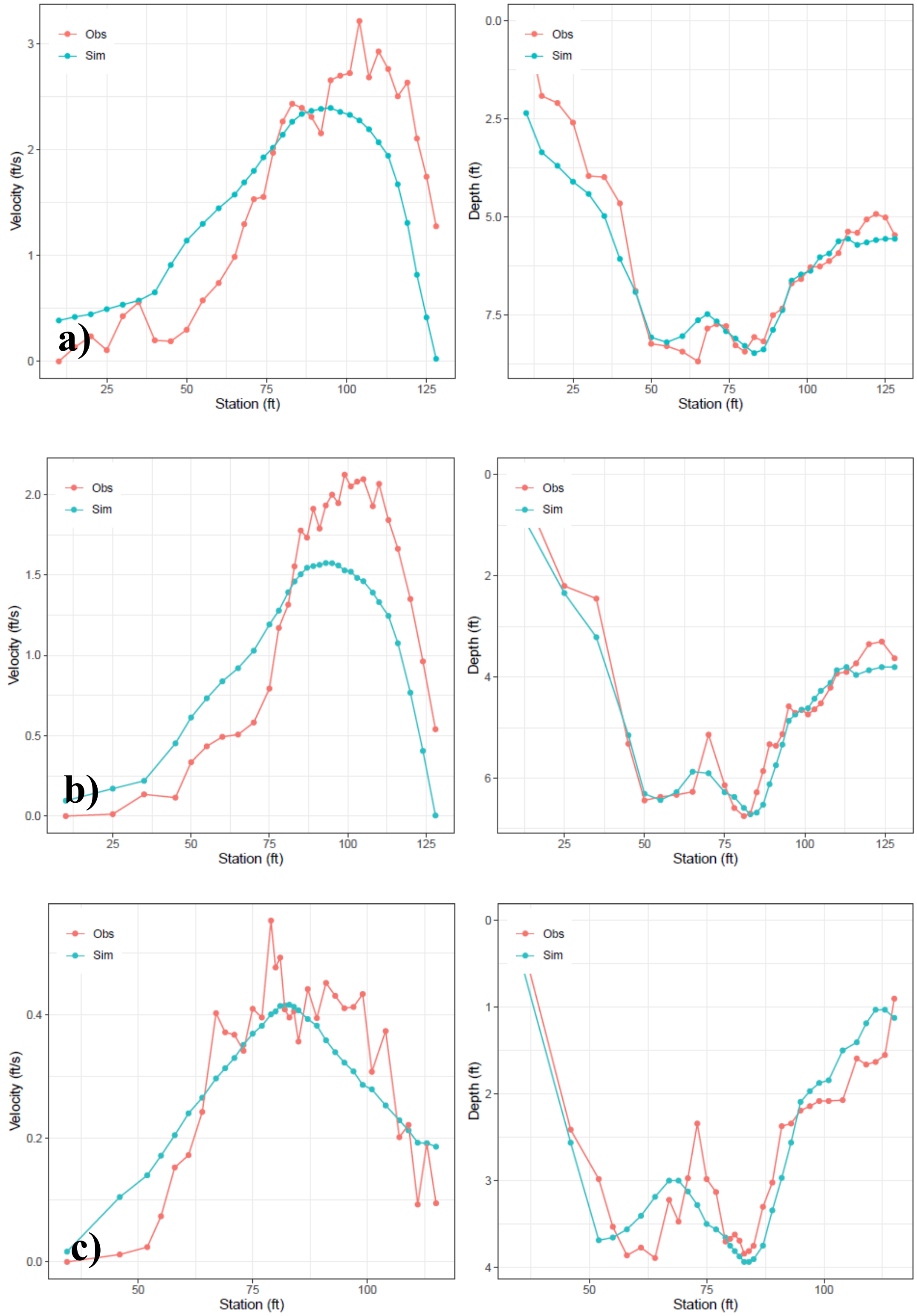


Figure E-2. Preliminary calibration results at Transect II for a) July 26, b) July 27, and c) July 29, 2021.

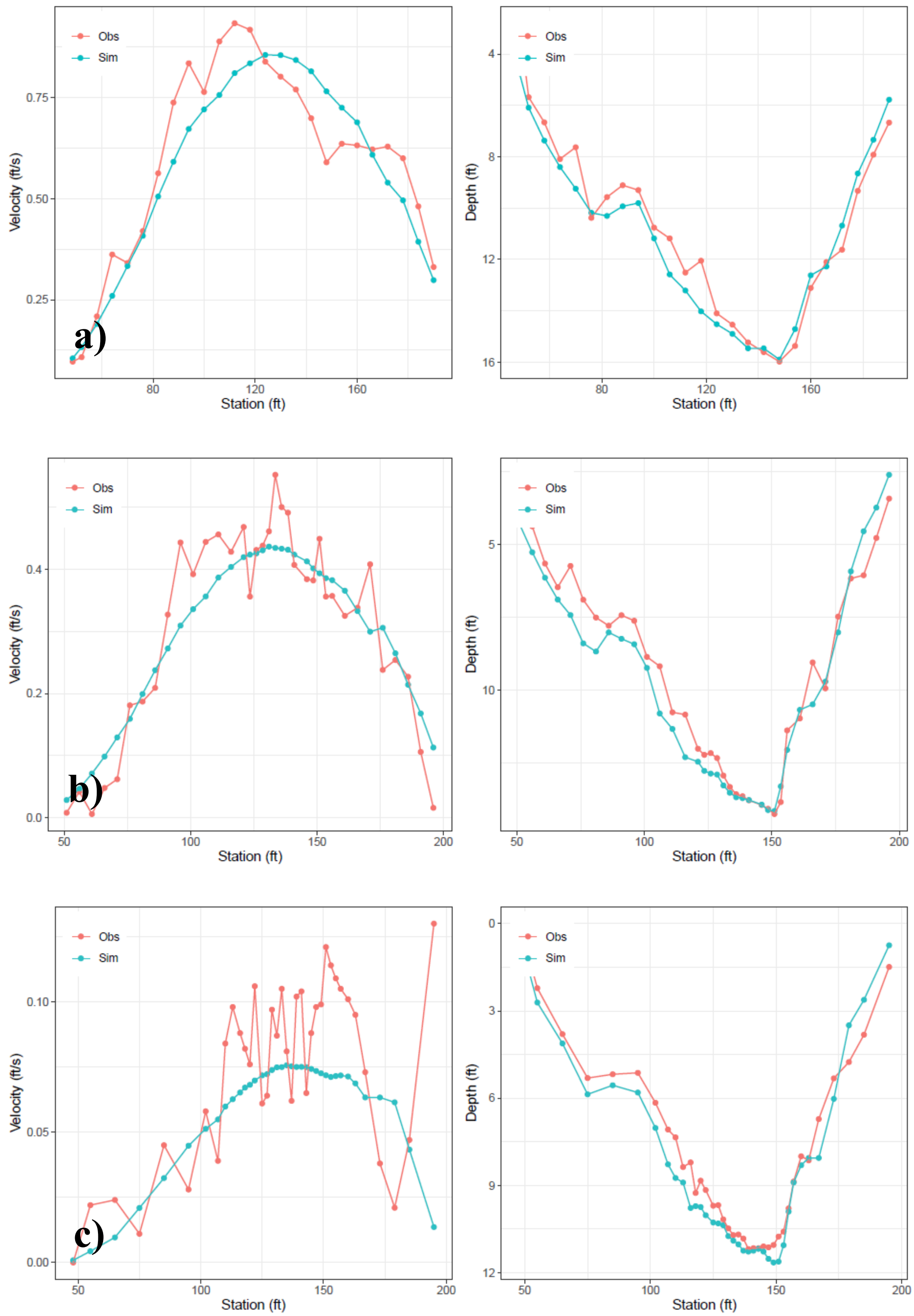


Figure E-3. Preliminary calibration results at Transect DD for a) July 26, b) July 27, and c) July 29, 2021.

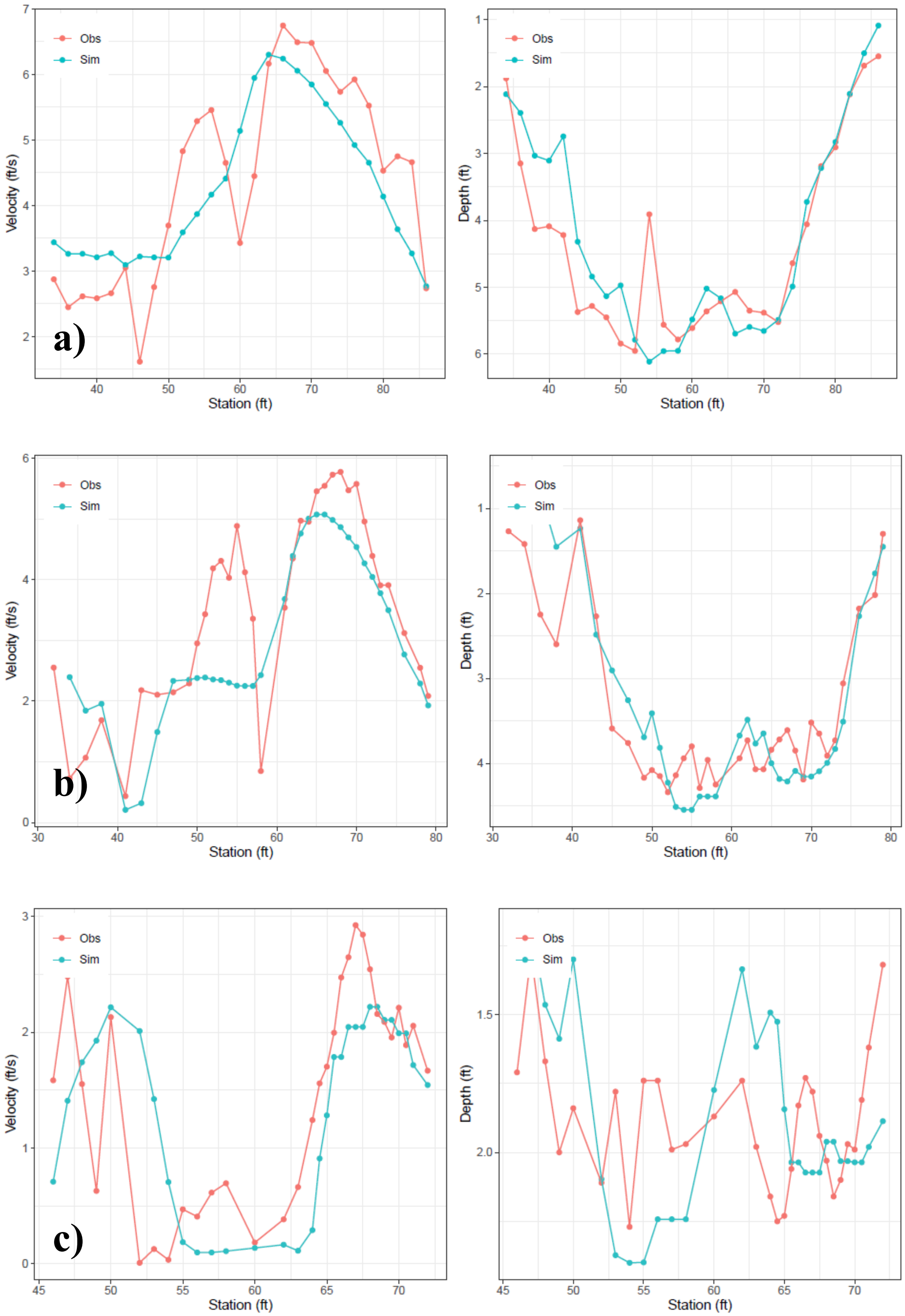


Figure E-4. Preliminary calibration results at Transect AA for a) July 26, b) July 27, and c) July 29, 2021.

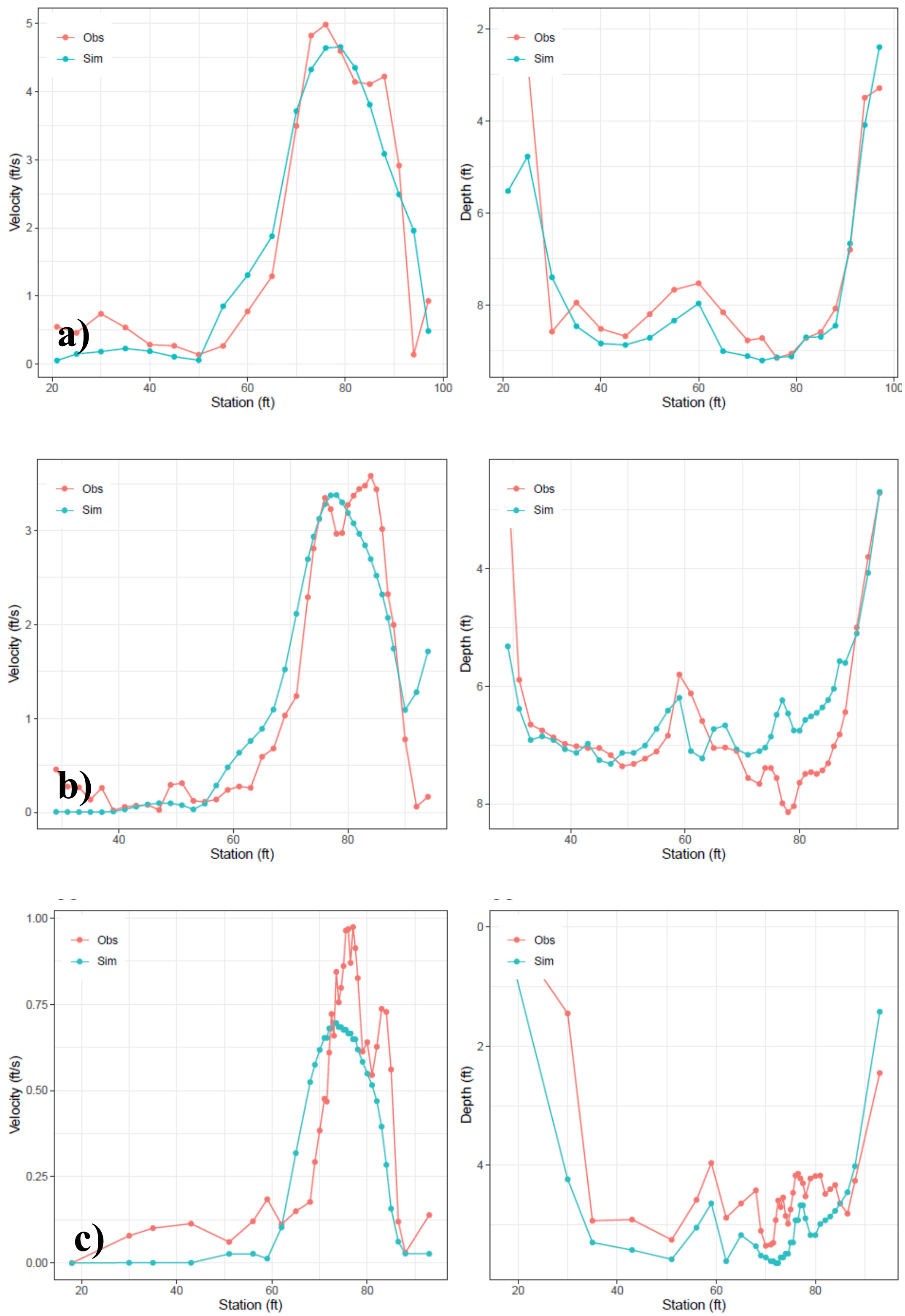


Figure E-5. Preliminary calibration results at Transect GG for a) July 26, b) July 27, and c) July 29, 2021.

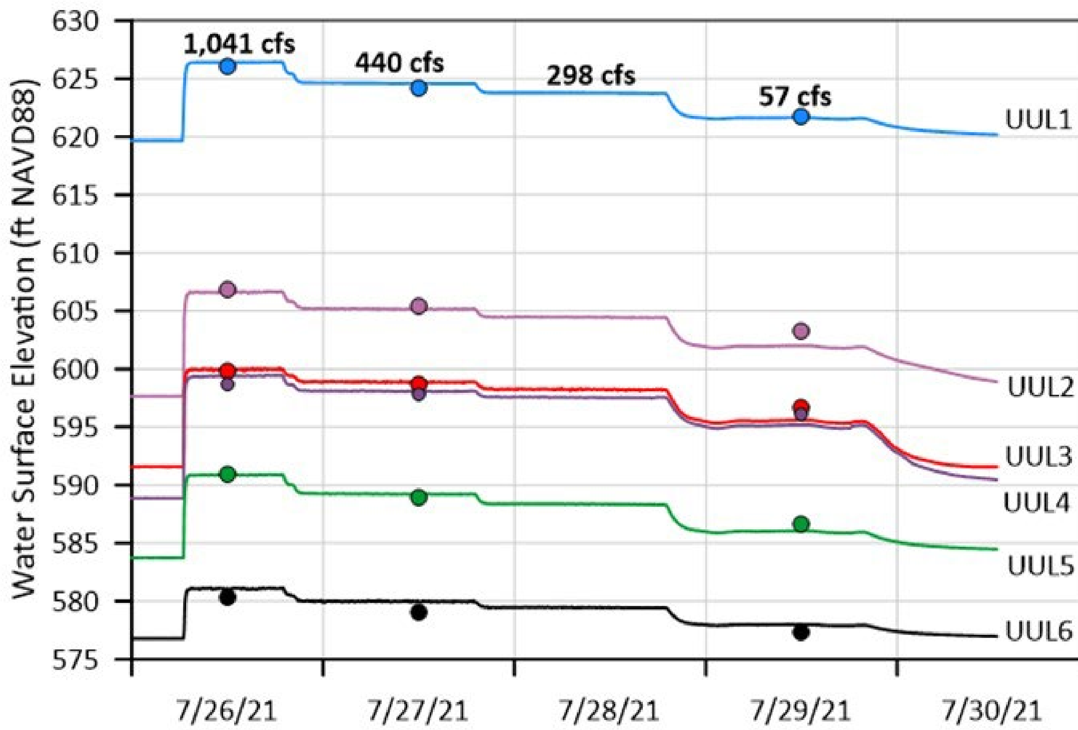


Figure E-6. **Preliminary calibration results at Existing Feature 2.**

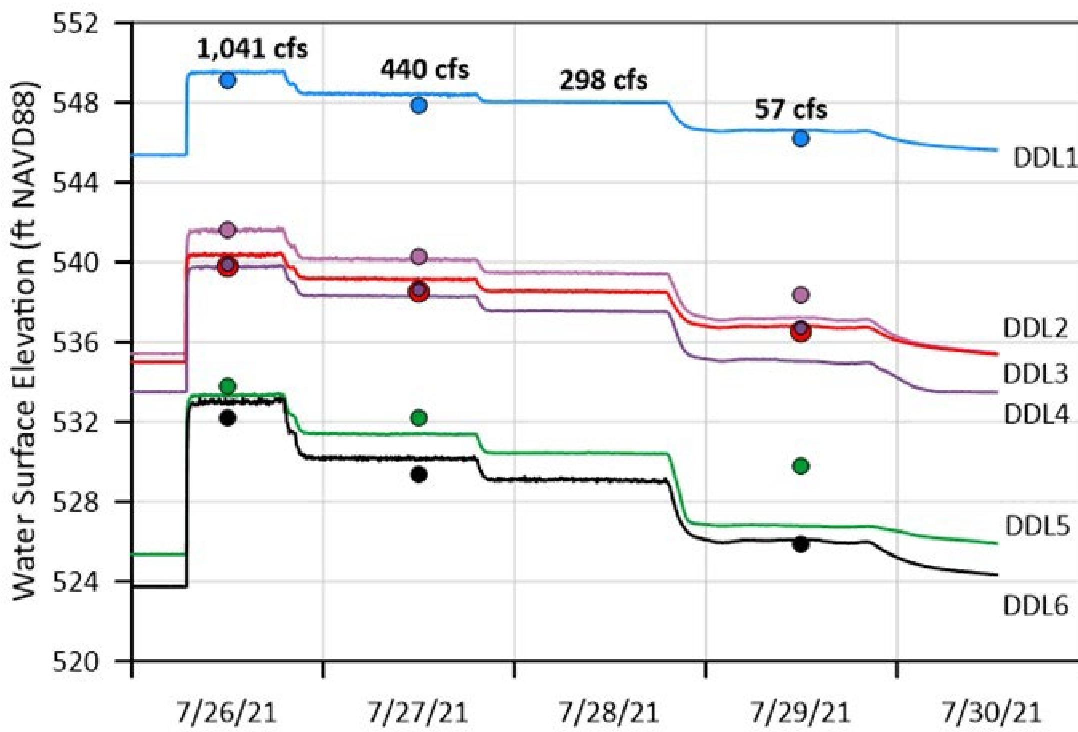


Figure E-7. **Preliminary calibration results at Existing Feature 1.**

SKAGIT RIVER GORGE BYPASS REACH HYDRAULIC AND INSTREAM FLOW MODEL DEVELOPMENT STUDY INTERIM REPORT

ATTACHMENT F

HABITAT SUITABILITY CRITERIA CURVES

Skagit River Habitat Suitability Criteria

HSC Technical Group

Skagit River Habitat Suitability Criteria (HSC) Licensing Participant (LP) Workshops began in May 2021. After the June and July 2021 Workshops, a recommendation was made to form a smaller technical group of people knowledgable about HSC and its use in instream flow habitat modeling. In August 2021, the HSC Technical Group was formed and comprised of LPs, Seattle City Light, and Consultant Team members. The HSC Technical Group met a total of 10 times (approximately bi-weekly) from August 2021 through January 2022. The HSC Technical Group's objective was to gather and review available HSC information relevant to the Skagit River and develop a step-wise process to evaluate and ultimately propose recommended HSC curves for each species and life stage being considered for habitat modeling on the Skagit mainstem and bypass reach. In addition, the HSC Technical Group evaluated 2021 field validation data collected on the Skagit River (see below) as well as additional studies that were included in updated WDFW/Ecology Type 3 HSC curves for Bull Trout juveniles and Cutthroat Trout juveniles.

HSC Background

As a starting point for the HSC curve selection (and in some cases development) process, an HSC library was assembled consisting of curves from City Light's existing effective spawning habitat (ESH) model, Washington State's Instream Flow Study Guidelines (Beecher et al. 2016), curves from other west coast region instream flow studies for rivers comparable in size to the Skagit River, and literature from other relevant studies and research.

HSC curves are often referred to by "type," which indicates the basis of the curves (Bovee 1986). Type 1 curves are based on general life history and professional judgement with little or no empirical data. Type 2 curves are based on data from locations where target species are observed or collected. Commonly referred to as utilization (or use) curves, Type 2 curves can be biased by a limited range of hydraulic conditions that were available at the time the target species were observed. Type 3 curves are based on data from locations where target species are observed or collected under a variety of conditions to remove environmental bias. Type 3 curves include measurements of "available" habitat (at the time the discrete observation data were collected) which are used to adjust utilization data to become "preference curves". Type 3 curves tend to be less site-specific than Type 2 curves and can be applied more broadly.

The HSC List tab provides a list of species and life stages to be considered for modeling. They are grouped based on the availability and type of existing HSC curves as described below.

HSC Groups

Group A includes species and life stages where HSC curves are available from both the Skagit ESH model and WDFW/Ecology Type 3 curves. With the exception of Chum Salmon spawning, field validation studies were conducted in 2021 to collect additional site-specific data (i.e., depth, velocity, substrate, and cover) for Group A species and life stages. These data were used qualitatively to support decisions on HSC curve selection and/or modification.

Group B originally consisted of two species and life stages where both Skagit-specific Type 2 curves (i.e., based on Skagit River field observation data) and WDFW/Ecoloty Type 3 curves were available (i.e., Chum spawning and Pink spawning). Early in the HSC evaluation process the larger LP team recommended adding these two species to Group A as there was interest in collecting additional field observation data during the 2021 field validation study efforts. Moving these two species/life stages into Group A effectively eliminated Group B.

Group C includes species and life stages where HSC curves are not available from the ESH model but are available as WDFW/Ecology Type 3 curves. The Type 3 curves will be used as a default unless field validation studies conducted for Group A provide information that a modification of the WDFW/Ecology Type 3 curves is warranted to better represent site-specific observations on the Skagit River.

Group D HSC curves are not available from either the ESH model, or WDFW/Ecology. For these species and life stages, available HSC curves from other instream flow studies were used as a surrogate and/or consensus curves were developed in collaboration with LPs by modifying available HSC curves. In some cases, literature was available to support development of HSC consensus curves.

Group E consists of the fry life stage for several species. Instead of modeling individual fry species, consensus curves were developed for generic salmonid fry.

Group F surrogate HSC curves were not available, so consensus curves were developed based on literature review.

2021 Field Validation Studies

During the first HSC Workshop on May 12, 2021, LPs discussed and ultimately recommended collecting field validation data (i.e., observatons of fish and/or redds) on the Skagit River to support the HSC evaluation and selection process. Target species and number of observations during the 2021 study period were: spawning life stage [Steelhead (19), Chinook (31), Pink (31), and Chum (NA)] and juvenile life stage [Steelhead (116), Chinook (41), and Bull Trout (4)]. Note due to unseasonably high flows and turbid water conditions during the late-fall/early-winter period, field validation data collection efforts for Chum spawning were not conducted.

HSC Evlauation Process

Based on WDFW/Ecology policy, the statewide Type 3 curves are prefered unless:

a) Enough site-specific, Type 3 data can be found or collected to develop new HSC curves, or
b) Enough site-specific Type 3 data can be collected in the field to use as a rationale for adjusting the statewide Type 3 curves, or
c) Type 3 curves from another source can be found and determined to be equal to, or more representative than, the statewide Type 3 curves.

Skagit River Habitat Suitability Criteria

HSC curves used in the current ESH model are based on a variety of Type 1 and Type 2 data sources. For example, HSC curves for Steelhead, Chinook, Pink, and Chum spawning life stage are based on hundreds of Skagit-specific field observation data from Crumley and Stober 1984, and considered to be Type 2 curves (attempts to locate detailed field observation data from the studies were unsuccessful). Data collected during the 2021 HSC field validation effort for these four species (spawning life stage) were determined to be insufficient to create new Type 3 curves. However, these data (i.e., observations of redds or fish) were reviewed by the HSC Technical Group and were determined to be consistent with the ESH and statewide HSC curves. Other HSC curves used in the ESH model are based on Type 1 and Type 2 curves from other (non-Skagit) data sources and are considered to be a hybrid of Type 1-2 curves. As a result, in most cases, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves for Skagit River habitat modeling purposes when available.

When WDFW/Ecology Type 3 curves were not available, the HSC Technical Group typically recommended a) curves from other surrogate species with statewide Type 3 curves, b) Type 2 curves from other studies, or c) developed consensus curves from available and relevant literature.

Skagit River
Habitat Suitability Criteria (HSC) Summary

<table>
<tr><th rowspan="2">Species</th><th rowspan="2">Life Stage</th><th rowspan="2">HSC Group</th><th rowspan="2">HSC Status</th><th colspan="2">WDFW/Ecology Guidelines (Beecher et al. 2016) or other reference</th></tr>
<tr><th>Substrate</th><th>Cover</th></tr>
<tr><td rowspan="3">Steelhead</td><td>spawning</td><td>A</td><td>WDFW/Ecology Type 3 curves</td><td>Table 4</td><td>N/A</td></tr>
<tr><td>adult holding</td><td>D</td><td>WDFW/Ecology Type 3 curves for RBT adult/rearing</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td>juvenile</td><td>A</td><td>WDFW/Ecology Type 3 curves</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td rowspan="3">Chinook Salmon</td><td>spawning</td><td rowspan="2">A</td><td rowspan="2">WDFW/Ecology Type 3 curves</td><td>Table 2</td><td>N/A</td></tr>
<tr><td>juvenile</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td>fry</td><td>E</td><td>ESH Model Type 2 curves</td><td>ESH Model</td><td>N/A</td></tr>
<tr><td>Pink Salmon</td><td>spawning</td><td>A</td><td>WDFW/Ecology Type 3 curves</td><td>Table 2</td><td>N/A</td></tr>
<tr><td rowspan="2">Chum Salmon</td><td>spawning</td><td>A</td><td>WDFW/Ecology Type 3 curves</td><td>Table 2</td><td>N/A</td></tr>
<tr><td>fry</td><td>E</td><td>Fraser River Type 2 curves</td><td>Fraser River (Rempel et al. 2012)</td><td>N/A</td></tr>
<tr><td rowspan="3">Coho Salmon</td><td>spawning</td><td>C</td><td>WDFW/Ecology Type 3 curves</td><td>Table 2</td><td>N/A</td></tr>
<tr><td>juvenile</td><td>D</td><td>ESH Model Type 2 curves</td><td>ESH Model</td><td>Table 3</td></tr>
<tr><td>fry</td><td>E</td><td>ESH Model Type 2 curves</td><td>ESH Model</td><td>N/A</td></tr>
<tr><td>Sockeye Salmon</td><td>spawning</td><td>C</td><td>WDFW/Ecology Type 3 curves</td><td>Table 2</td><td>N/A</td></tr>
<tr><td rowspan="4">Rainbow Trout</td><td>spawning</td><td rowspan="3">C</td><td rowspan="3">WDFW/Ecology Type 3 curves</td><td>Table 5</td><td>N/A</td></tr>
<tr><td>adult rearing</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td>juvenile</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td>fry</td><td>E</td><td>ESH Model Type 2 curves</td><td>ESH Model</td><td>N/A</td></tr>
<tr><td rowspan="3">Bull Trout/ Dolly Varden</td><td>spawning</td><td>C</td><td rowspan="2">WDFW/Ecology Type 3 curves</td><td>Table 6</td><td>N/A</td></tr>
<tr><td>juvenile</td><td>A</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td>fry</td><td>E</td><td>ESH Model Type 2 curves</td><td>ESH Model</td><td>N/A</td></tr>
<tr><td>Trout</td><td>spawning</td><td>F</td><td>Proposed consensus curves developed</td><td>Table 6</td><td>N/A</td></tr>
<tr><td rowspan="4">Cutthroat Trout</td><td>spawning</td><td>C</td><td>WDFW/Ecology Type 3 curves</td><td>Table 5</td><td>N/A</td></tr>
<tr><td>adult</td><td>D</td><td>Use WDFW/Ecology Type 3 curve for Cutthroat juvenile</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td>juvenile</td><td>C</td><td>WDFW/Ecology Type 3 curves</td><td>Table 3</td><td>Table 3</td></tr>
<tr><td>fry</td><td>E</td><td>ESH Model Type 2 curves</td><td>ESH Model</td><td>N/A</td></tr>
<tr><td>Sea-Run Cutthroat Trout</td><td>spawning</td><td>D</td><td>Proposed consensus curves developed</td><td>Table 5</td><td>N/A</td></tr>
<tr><td rowspan="4">Mountain Whitefish</td><td>spawning</td><td rowspan="3">C</td><td rowspan="3">WDFW/Ecology Type 3 curves</td><td>Table 7</td><td>N/A</td></tr>
<tr><td>adult rearing</td><td>Table 8</td><td>Table 1</td></tr>
<tr><td>juvenile</td><td>Table 9</td><td>Table 1</td></tr>
<tr><td>fry</td><td>E</td><td>ESH Model Type 2 curves</td><td>ESH Model</td><td>N/A</td></tr>
<tr><td rowspan="2">Pacific Lamprey</td><td>spawning</td><td rowspan="2">D</td><td rowspan="2">Proposed consensus curves developed</td><td rowspan="2">Vadas 2021</td><td rowspan="2">N/A</td></tr>
<tr><td>juvenile rearing</td></tr>
</table>

Skagit River Habitat Suitability Criteria (HSC) Summary					
				WDFW/Ecology Guidelines (Beecher et al. 2016) or other reference	
Species	Life Stage	HSC Group	HSC Status	Substrate	Cover
Western Brook Lamprey	spawning	F	Proposed consensus curves developed	Vadas 2021	N/A
Western River Lamprey	spawning	F	Proposed consensus curves developed	Vadas 2021	N/A
Salish Sucker	spawning	F	Proposed consensus curves developed	Pearson 2003	N/A
	juvenile rearing				Pearson 2003
White Sturgeon	spawning	F	Proposed consensus curves developed	Sacramento River (Gard 1996)	N/A

Steelhead

Spawning (Group A)

Steelhead spawning HSC curves from several sources were evaluated including WDFW/Ecology (Type 3; 108 redds), the ESH model (Skagit River-specific Type 2; 305 redds), and the Trinity River (Type 2). It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when available unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. The statewide curves are based on analysis from 6 studies and 108 redds [Rock Creek (WRIA 31), Cedar (2 studies) and Sultan rivers and Chelan Fish Channel (2 studies)] (Beecher et al. 2016). Field validation studies conducted on the Skagit River during 2021 resulted in an additional 19 redd observations. These data were reviewed by the HSC Technical Group and were determined to be consistent with the ESH and statewide HSC curves (i.e., observation data points were generally captured within the defined area under the HSC depth and velocity curves). As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves.

Adult Holding (Group D)

WDFW/Ecology HSC curves for Steelhead adult holding are not available and the ESH model HSC curves are not based on Skagit-specific field observation data (hybrid Type 1-2). As a result, the WDFW/Ecology Type 3 HSC curves for resident Rainbow Trout adult rearing are proposed to represent Steelhead adult. The Rainbow Trout adult rearing curves are based on anlaysis from 15 studies totalling 638 fish observations [mostly streams west of the Cascades, but includes Yakima River, upper Mill Creek (WRIA 32), and Douglas Creek (WRIA 44)] (Beecher et al. 2016).

Juvenile (Group A)

Steelhead juvenile HSC curves from several sources were evaluated including WDFW/Ecology (Type 3; 1,954 fish observations), the ESH model (hybrid Type 1-2), and the Trinity River (Type 2). It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when available unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. The statewide curves are based on analysis from 32 studies and 1,954 fish observatons (from multiple Washington streams of differing sizes and stream types) (Beecher et al. 2016). Field validation studies conducted on the Skagit River during 2021 resulted in an additional 116 fish observations. These data were reviewed by the HSC Technical Group and were determined to be consistent with the ESH and statewide HSC curves (i.e., observation data points were generally captured within the defined area under the HSC depth and velocity curves). As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves.

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for adult and juvenile Steelhead. Therefore, the HSC Technical Group recommended that once depth reaches 3.85 ft (1.0 preference) for adult and 2.65 ft (1.0 preference) for juvenile, it be considered "non-limiting" in the HSC depth curves.

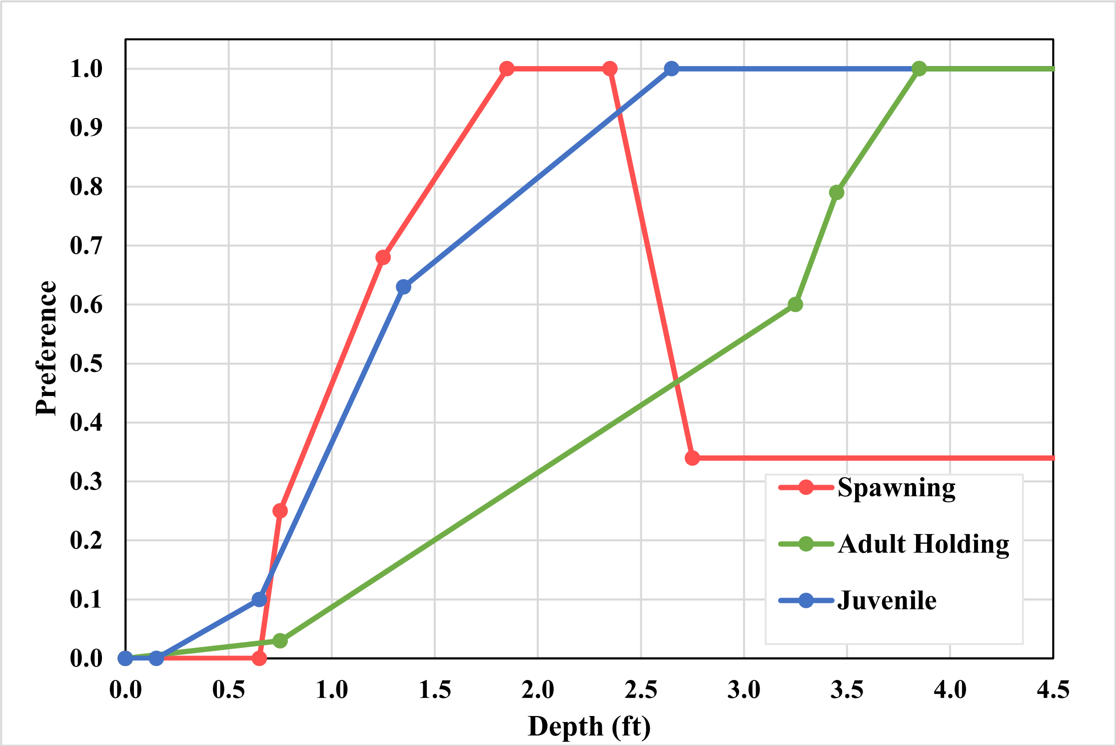
Steelhead

References

WDFW/Ecology: spawning, adult, and juvenile (Beecher et al. 2016)
ESH model: spawning (Crumley and Stober 1984); adult (Bovee 1978); juvenile (Crumley and Stober 1984; Bovee 1978)
Trinity River: spawning, adult, and juvenile (Hampton et al. 1997)
Fraser River: juvenile (Rempel et al. 2012)
Klamath River: juvenile (Hardy and Addley 2001)
McKenzie River: juvenile (Hardin-Davis 1990)

Steelhead

Depth Preference Curves

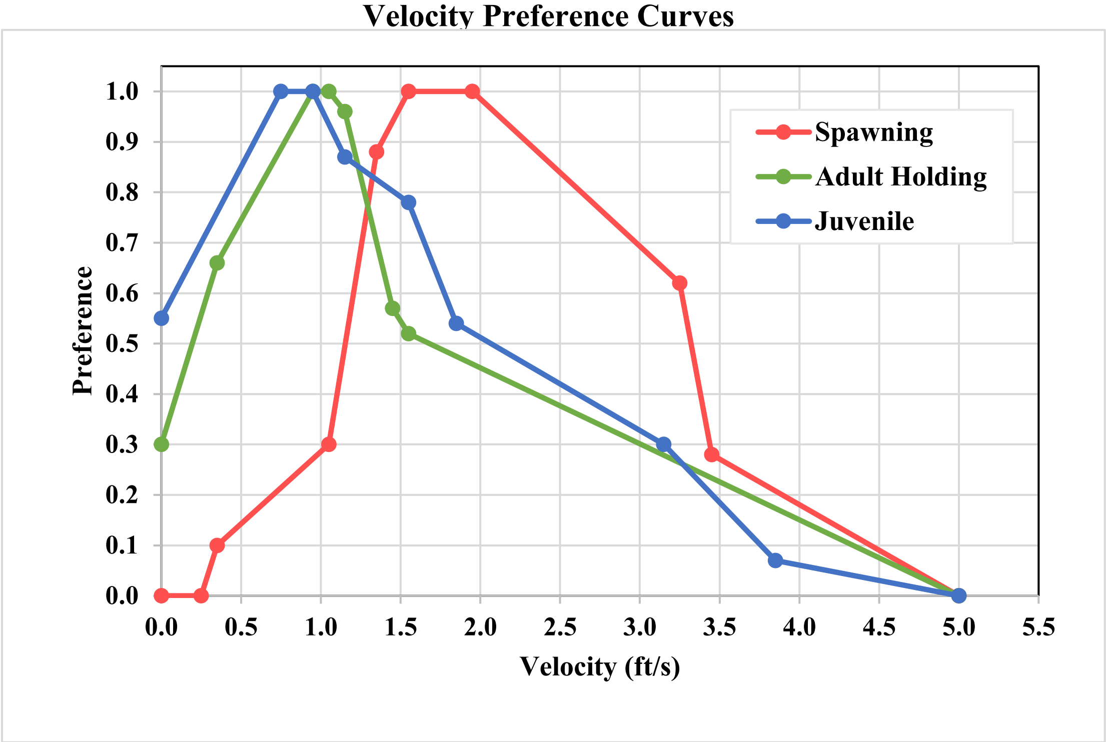


Spawning	
Depth (ft)	Preference
0.00	0.00
0.65	0.00
0.75	0.25
1.25	0.68
1.85	1.00
2.35	1.00
2.75	0.34
99.00	0.34

Adult Holding	
Depth (ft)	Preference
0.00	0.00
0.75	0.03
3.25	0.60
3.45	0.79
3.85	1.00
99.00	1.00

Juvenile	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.65	0.10
1.35	0.63
2.65	1.00
99.00	1.00

Steelhead



Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.25	0.00
0.35	0.10
1.05	0.30
1.35	0.88
1.55	1.00
1.95	1.00
3.25	0.62
3.45	0.28
5.00	0.00

Adult Holding	
Velocity (ft/s)	Preference
0.00	0.30
0.35	0.66
0.95	1.00
1.05	1.00
1.15	0.96
1.45	0.57
1.55	0.52
5.00	0.00

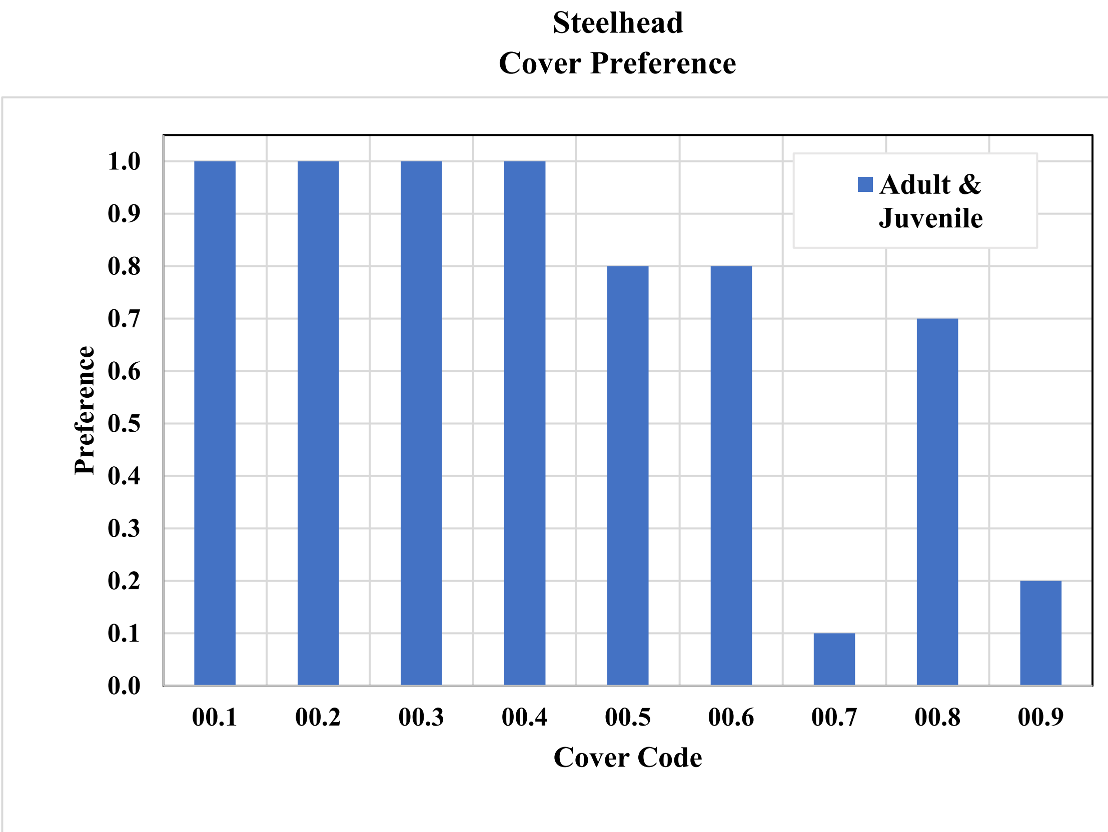
Juvenile	
Velocity (ft/s)	Preference
0.00	0.55
0.75	1.00
0.95	1.00
1.15	0.87
1.55	0.78
1.85	0.54
3.15	0.30
3.85	0.07
5.00	0.00

Steelhead

Substrate Preference Criteria

For Steelhead Spawning Substrate Preference, use Table 4 (Beecher et al. 2016)

For Steelhead Juvenile and Resident Adult Substrate and Cover Preference, use Table 3 (Beecher et al. 2016)



Code	Type of Cover Note: cover codes are not used for spawning life stage	Adult & Juvenile Preference
00.1	Undercut bank	1.00
00.2	Overhanging vegetation near or touching water	1.00
00.3	Rootwad (including parly undercut)	1.00
00.4	Log jam/submerged brush pile	1.00
00.5	Log(s) parallel to bank	0.80
00.6	Aquatic vegetation	0.80
00.7	Short (<1 ft) terrestrial grass	0.10
00.8	Tall (>3 ft) dense grass	0.70
00.9	Vegetation >3 vertical ft above SZF	0.20

Source: Table 3, Beecher et al. 2016

Chinook Salmon

Spawning (Group A)

Chinook spawning HSC curves from several sources were evaluated including WDFW/Ecology (Type 3; 440 redds), the ESH model (Skagit River-specific Type 2; 436 redds), and the Klamath and Trinity rivers (both Type 2). Two sets of WDFW/Ecology Type 3 curves are available; one is recommended for large rivers (examples include the Skagit and Snohomish rivers) and the other is recommended for the Columbia and Snake rivers (Beecher et al. 2016). It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when available unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves for large rivers. Field validation studies conducted on the Skagit River during 2021 resulted in an additional 31 redd observations. These data were reviewed by the HSC Technical Group and were determined to be consistent with both the ESH and statewide HSC curves (i.e., observation data points were generally captured within the defined area under the HSC depth and velocity curves). As a result, the recommended HSC curves for use in the habitat modeling are the large river WDFW/Ecology Type 3 HSC curves.

Juvenile (Group A)

Chinook juvenile HSC curves from several sources were evaluated including WDFW/Ecology (Type 3; 5,615 fish) and the Klamath and Trinity rivers (both Type 2). No curves were available from the ESH model. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when available unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. The statewide curves are based on analysis from 9 studies totaling 5,615 fish observations (Dungeness, Chiwawa, Mad & Similkameen, and Tucannon rivers and Kendall Creek (Beecher et al. 2016). Kendall Creek was a utilization study with 5,055 fish observations (Beecher et al. 2016). Field validation studies conducted on the Skagit River during 2021 resulted in an additional 41 fish observations. These data were reviewed by the HSC Technical Group and were determined to be consistent with the statewide HSC curves (i.e., observation data points were generally captured within the defined area under the HSC depth and velocity curves). As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves.

Fry (Group E)

Type 3 HSC curves are not available from WDFW/Ecology as the salmonid fry life stage is not commonly modeled in instream flow studies. However, habitat results for the fry life stage are of interest on the Skagit River in evaluating the relationship between flow and available habitat along the stream margins/shoreline areas as well as off-channel habitats that may be activated during higher flow events. As a result, the HSC Technical Group recommended using existing Type 2 fry curves when available. For Chinook fry, the HSC Technical Group reviewed existing Type 2 curves used in the ESH model (FRI and WDF) as well as the Trinity River. The velocity curves used in the ESH model are based velocity HSC for Rainbow Trout juvenile which are likely too high for Chinook fry. Therefore, the HSC Technical Group recommended using the Type 2 depth and velocity fry curves from the Trinity River study. Habitat cover preference information was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for juvenile Chinook salmon. Therefore, the HSC Technical Group recommended that once depth reaches 2.45 ft (1.0 preference), it be considered "non-limiting" in the HSC depth curve.

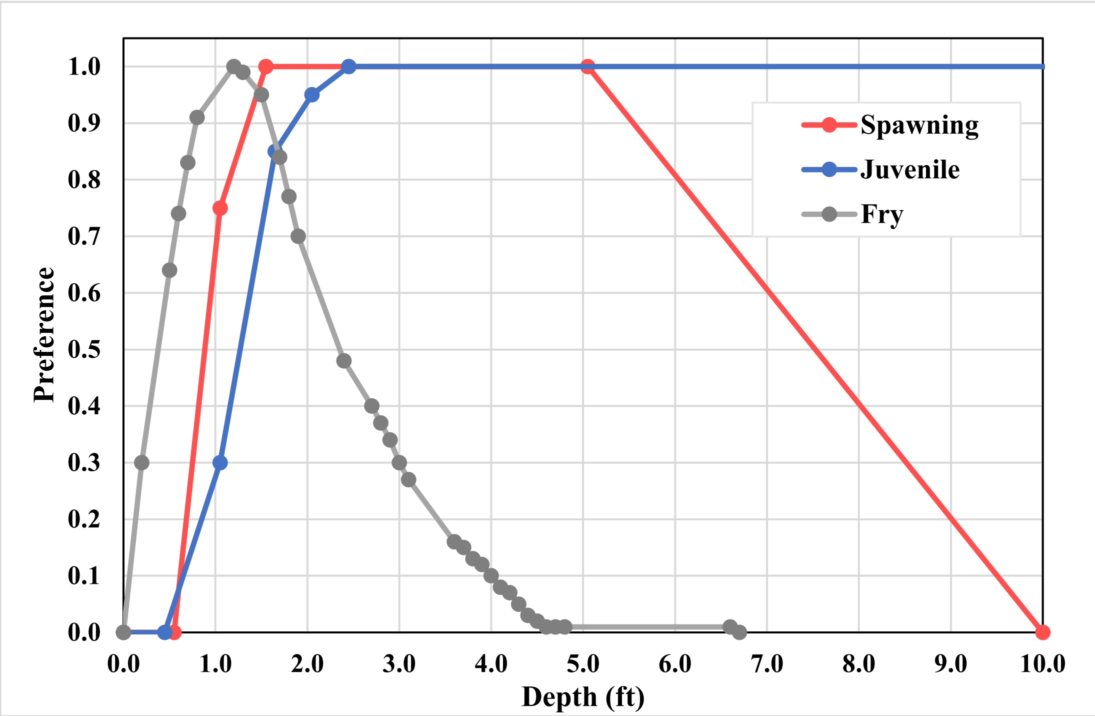
Chinook Salmon

References

WDFW/Ecology: spawning and juvenile (Beecher et al. 2016)
ESH model: spawning and fry (Crumley and Stober 1984; FRI and WDF)
Trinity River: spawning, juvenile, and fry (Hampton et al. 1997)
Klamath River: spawning and juvenile (Hardin et al. 2005; Hardy and Addley 2001)
Fraser River: juvenile (Rempel et al. 2012)

Chinook Salmon

Depth Preference Curves



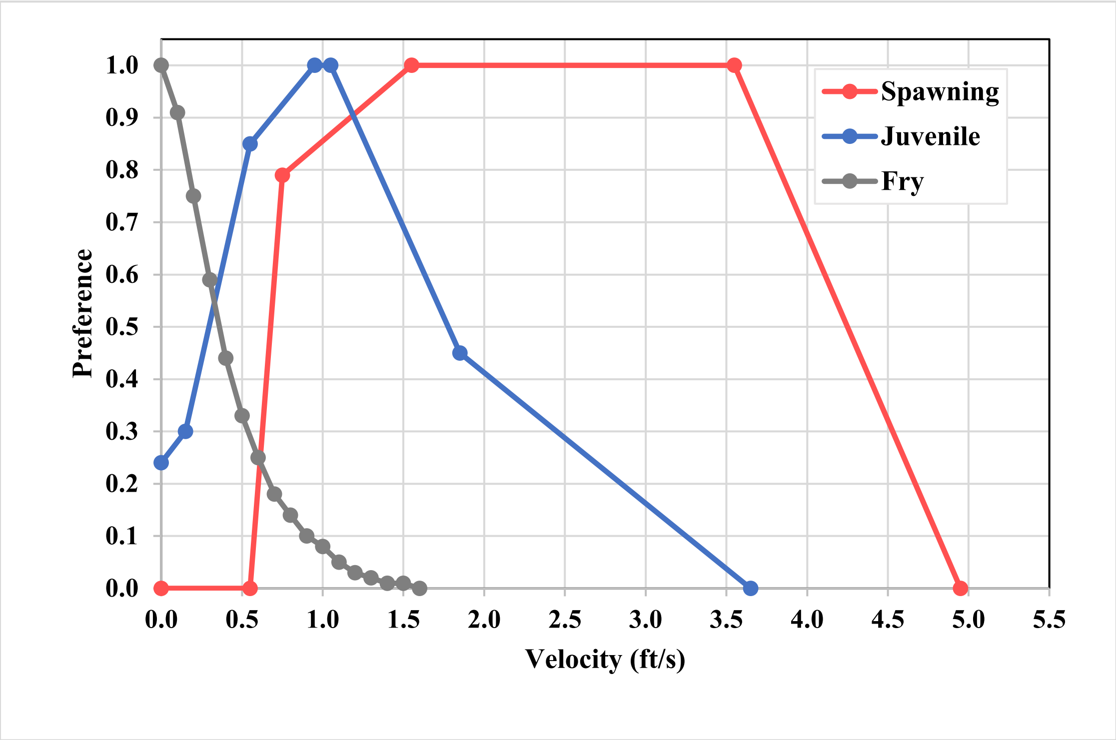
Spawning	
Depth (ft)	Preference
0.00	0.00
0.55	0.00
1.05	0.75
1.55	1.00
5.05	1.00
10.00	0.00

Juvenile	
Depth (ft)	Preference
0.00	0.00
0.45	0.00
1.05	0.30
1.65	0.85
2.05	0.95
2.45	1.00
99.00	1.00

Fry	
Depth (ft)	Preference
0.00	0.00
0.20	0.30
0.50	0.64
0.60	0.74
0.70	0.83
0.80	0.91
1.20	1.00
1.30	0.99
1.50	0.95
1.70	0.84
1.80	0.77
1.90	0.70
2.40	0.48
2.70	0.40
2.80	0.37
2.90	0.34
3.00	0.30
3.10	0.27
3.60	0.16
3.70	0.15
3.80	0.13
3.90	0.12
4.00	0.10
4.10	0.08
4.20	0.07
4.30	0.05
4.40	0.03
4.50	0.02
4.60	0.01
4.70	0.01
4.80	0.01
6.60	0.01
6.70	0.00

Chinook Salmon

Velocity Preference Curves



Fry	
Velocity (ft/s)	Preference
0.00	1.00
0.10	0.91
0.20	0.75
0.30	0.59
0.40	0.44
0.50	0.33
0.60	0.25
0.70	0.18
0.80	0.14
0.90	0.10
1.00	0.08
1.10	0.05
1.20	0.03
1.30	0.02
1.40	0.01
1.50	0.01
1.60	0.00

Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.55	0.00
0.75	0.79
1.55	1.00
3.55	1.00
4.95	0.00

Juvenile	
Velocity (ft/s)	Preference
0.00	0.24
0.15	0.30
0.55	0.85
0.95	1.00
1.05	1.00
1.85	0.45
3.65	0.00

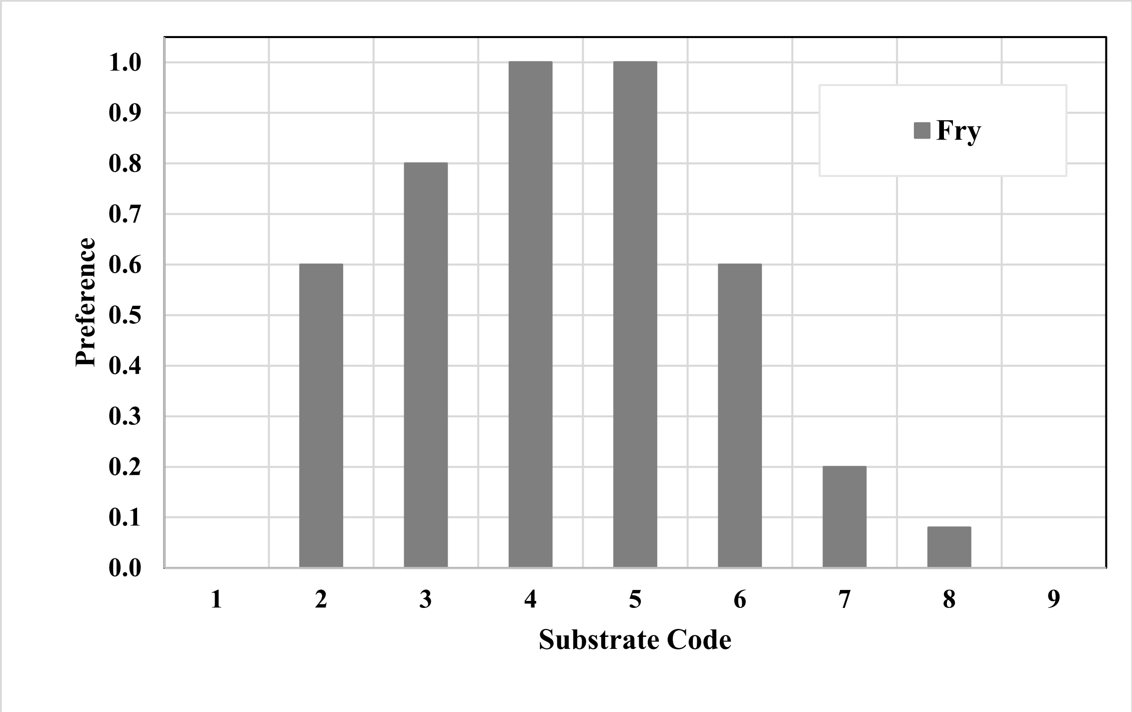
Chinook Salmon

Substrate Preference Criteria

For Chinook Salmon Spawning Substrate Preference, use Table 2 (Beecher et al. 2016)
For Chinook Salmon Juvenile Substrate and Cover Preference, use Table 3 (Beecher et al. 2016)
For Chinook Salmon Fry Substrate Preference, use data from the ESH Model

Chinook Salmon

Substrate Preference

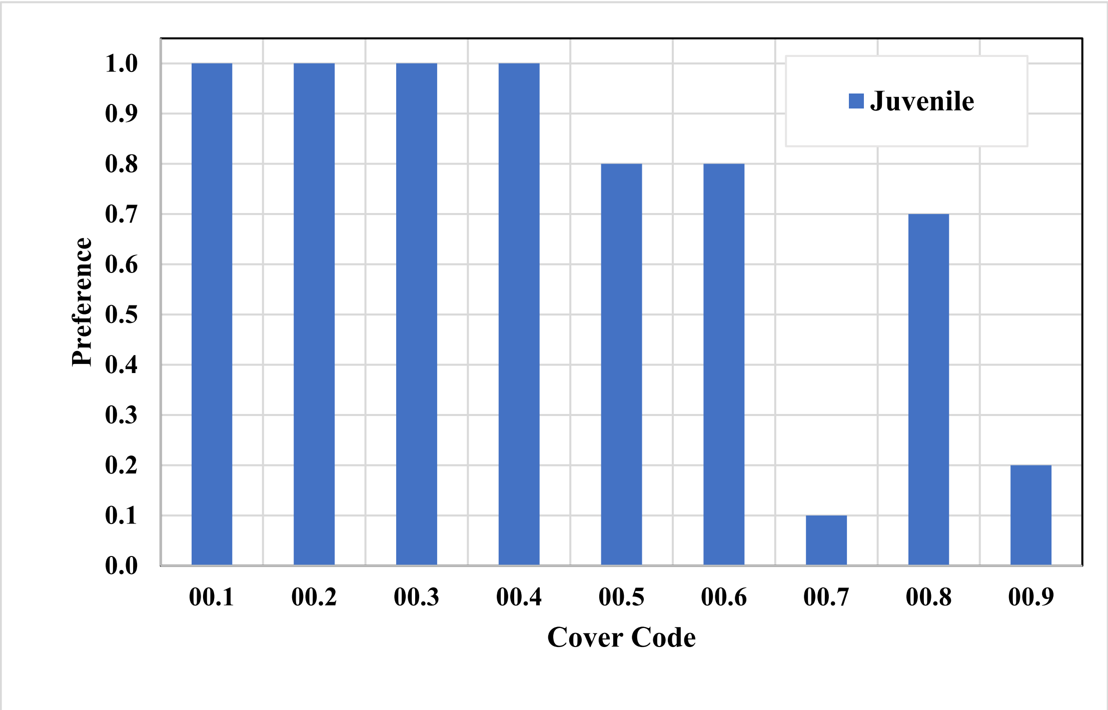


Sustrate Code	Substrate Type	Fry Preference
1	Silt, Clay, or Organic	0.00
2	Sand	0.60
3	Small Gravel (0.1-0.5")	0.80
4	Med Gravel (0.5-1.5")	1.00
5	Large Gravel (1.5-3.0")	1.00
6	Small Cobble (3.0-6.0")	0.60
7	Large Cobble (6.0-12")	0.20
8	Boulder (>12")	0.08
9	Bedrock	0.00

Source: ESH Model

Chinook Salmon

Cover Preference



Code	Type of Cover Note: cover codes are not used for spawning life	Juvenile Preference
00.1	Undercut bank	1.00
00.2	Overhanging vegetation near or touching water	1.00
00.3	Rootwad (including parly undercut)	1.00
00.4	Log jam/submerged brush pile	1.00
00.5	Log(s) parallel to bank	0.80
00.6	Aquatic vegetation	0.80
00.7	Short (<1 ft) terrestrial grass	0.10
00.8	Tall (>3 ft) dense grass	0.70
00.9	Vegetation >3 vertical ft above SZF	0.20

Source: Table 3, Beecher et al. 2016

Pink Salmon

Spawning (Group A)

Pink spawning HSC curves from WDFW/Ecology (Type 3; 104 redds) and the ESH model (Skagit River-specific Type 2; 347 redds) were evaluated by the HSC Technical Group. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when avaiailable unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. Field validation studies conducted on the Skagit River during 2021 resulted in an additional 31 redd observations. These data were reviewed by the HSC Technical Group and were determined to be consistent with both the ESH and statewide HSC curves (i.e., observation data points were generally captured within the defined area under the HSC depth and velocity curves). The statewide curves are based on data from 6 studies and 104 redds [Squire Creek/North Fork Stillaguamish, Dosewallips (3 studies), and Duckabush (2 studies) rivers] (Beecher et al. 2016). As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves.

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for spawning Pink salmon. Therefore, the HSC Technical Group recommended that once depth reaches 1.35 ft (0.30 preference), it be considered "non-limiting" in the HSC depth curve.

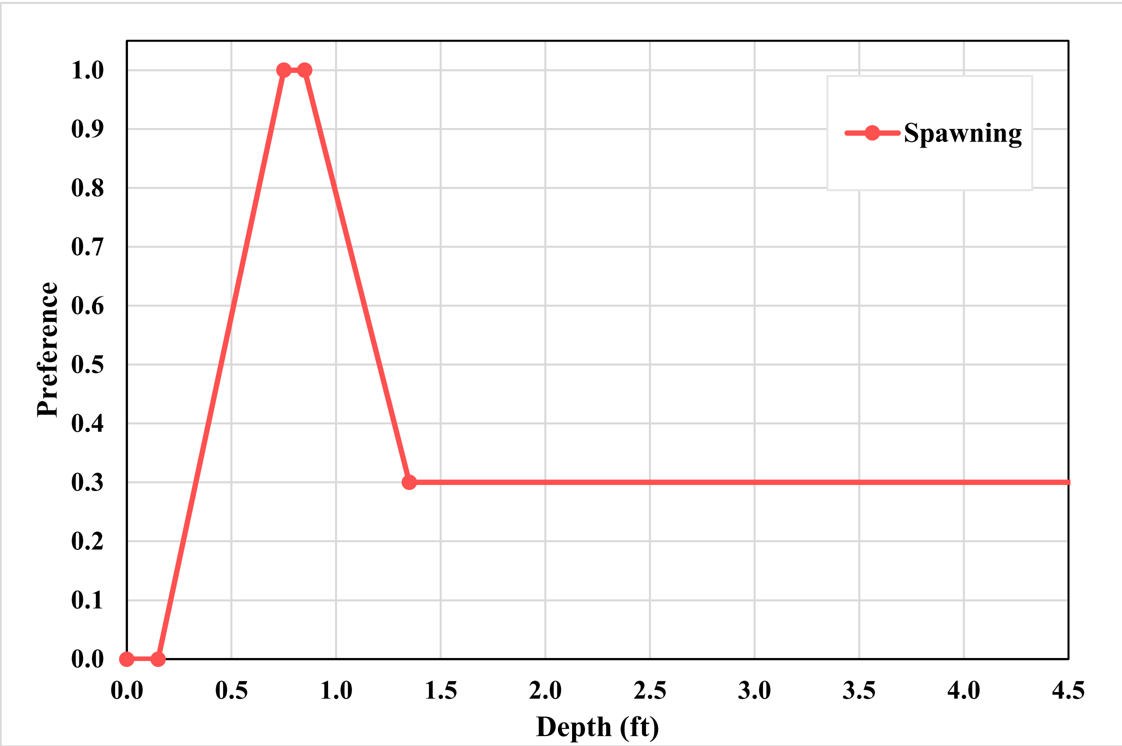
Pink salmon is an "ocean-type" rearing species, therefore, juvenile HSC curves are not recommended for habitat modeling in the Skagit River. However, the HSC Technical Group has developed a set of "generic salmonid fry" HSC curves based on an evaluation of HSC currently used in the ESH model for several salmonid species (see Fry tab in this spreadsheet). The generic salmonid fry HSC curves will be used to evaluate potential fry habitat along stream margins and side-channel areas.

References

WDFW/Ecology: spawning (Beecher et al. 2016)
ESH model: spawning (Crumley and Stober 1984)

Pink Salmon

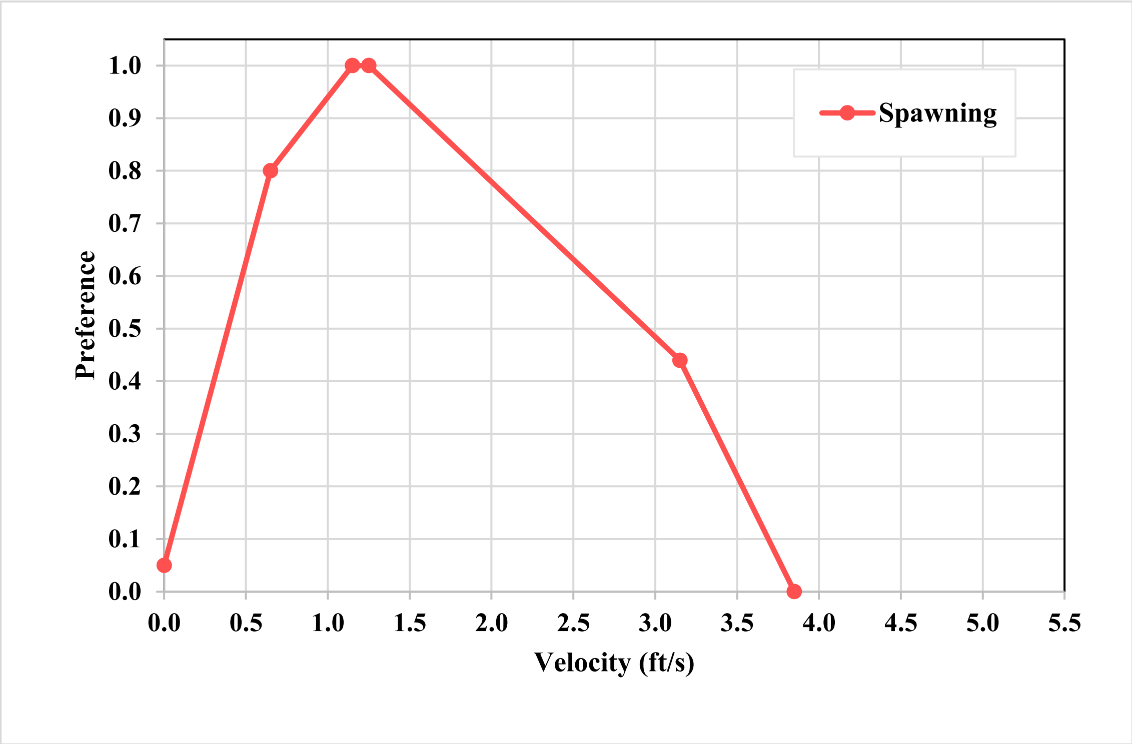
Depth Preference Curves



Spawning	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.75	1.00
0.85	1.00
1.35	0.30
99.00	0.30

Pink Salmon

Velocity Preference Curves



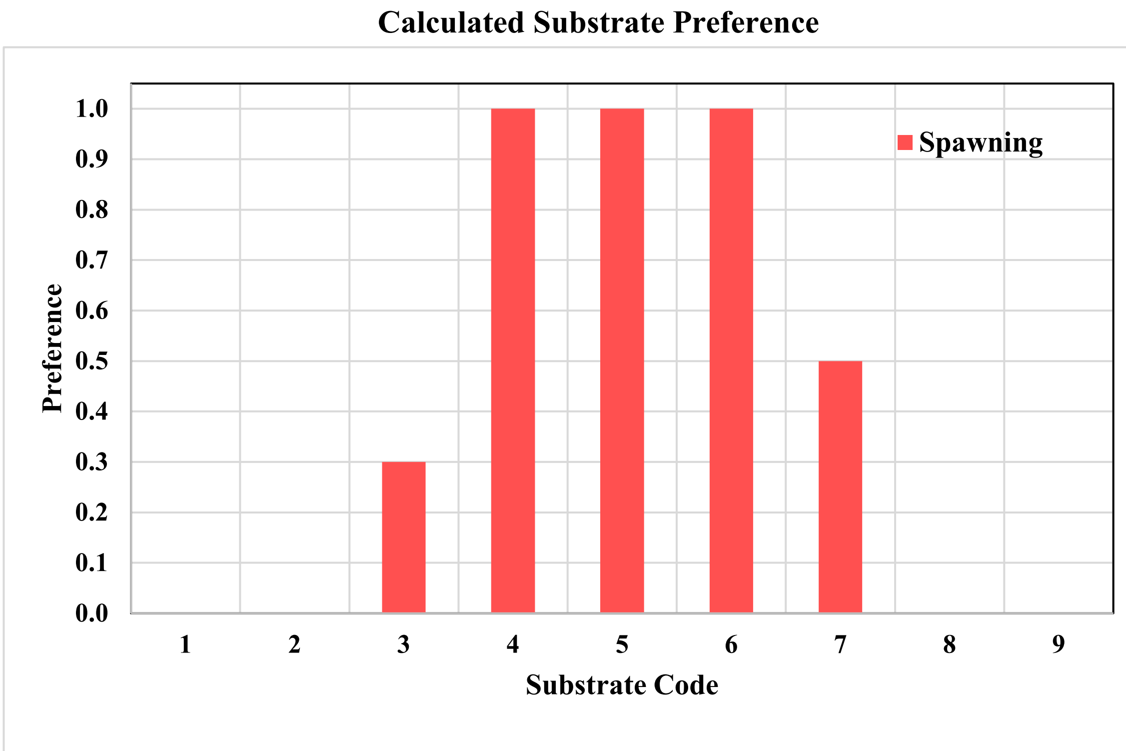
Spawning	
Velocity (ft/s)	Preference
0.00	0.05
0.65	0.80
1.15	1.00
1.25	1.00
3.15	0.44
3.85	0.00

Pink Salmon

Substrate Preference Criteria

For Pink Salmon Spawning Substrate Preference, use Table 2 (Beecher et al. 2016)

Pink Salmon



Sustrate Code	Substrate Type	Spawning Preference
1	Silt, Clay, or Organic	0.0
2	Sand	0.0
3	Small Gravel (0.1-0.5")	0.3
4	Med Gravel (0.5-1.5")	1.0
5	Large Gravel (1.5-3.0")	1.0
6	Small Cobble (3.0-6.0")	1.0
7	Large Cobble (6.0-12")	0.5
8	Boulder (>12")	0.0
9	Bedrock	0.0

Source: Table 12, Beecher et al. 2016

Chum Salmon

Spawning (Group A)

Chum spawning HSC curves from WDFW/Ecology (Type 3; 225 redds) and the ESH model (Skagit River-specific Type 2; 251 redds) were evaluated by the HSC Technical Group. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when avaiailable unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. The statewide curves are based on data from 16 studies and 225 redds [Hill Creek, Kennedy Creek (3 studies), Duckabush (9 studies) and Dosewallips rivers (3 studies)] (Beecher et al. 2016). As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves.

Fry (Group E)

Type 3 curves are not available from WDFW/Ecology or the ESH model for Chum fry. As a result, the proposed HSC curves are based on information from a juvenile fish habitat survey on the Lower Fraser River (Rempel et al. 2012). The authors noted that the HSC curves are consistent with the Type 2 curves proposed by Hale et al. (1985). Habitat cover preference information was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

Additional Notes

The 2021 HSC field validation study included spawning Chum as a target species. However, due to unseasonably high flows on the Skagit River (and poor visibility conditions due to turbidity) during Chum spawning window (i.e., late-fall/early-winter), field observations were not possible.

There is no clear biological evidence that depth becomes a limiting factor for the fry and spawning life stages. Therefore, the HSC Technical Group recommended that once depth reaches 1.31 ft (1.0 preference) for fry and 2.65 ft (0.17 preference) for spawning, it be considered "non-limiting" in the HSC depth curves.

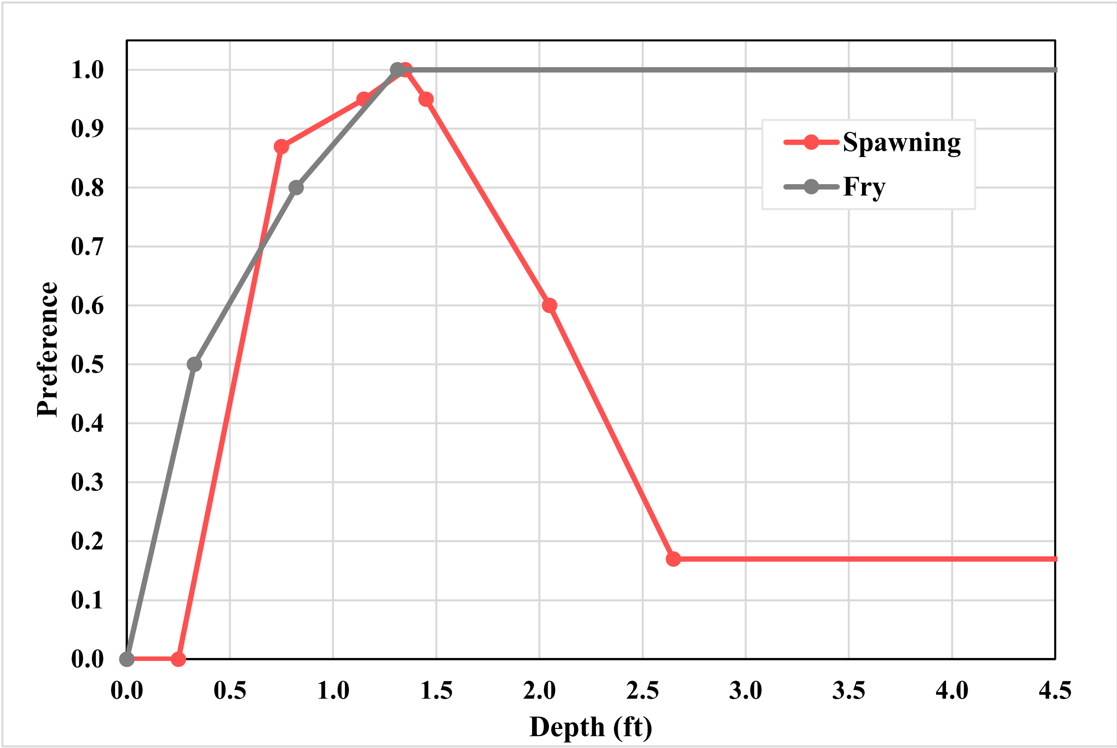
Chum salmon is an "ocean-type" rearing species, therefore, juvenile HSC curves are not recommended for habitat modeling in the Skagit River. However, the HSC Technical Group has developed a set of "generic salmonid fry" HSC curves based on an evaluation of HSC currently used in the ESH model for several salmonid species (see Fry tab in this spreadsheet). The generic salmonid fry HSC curves will be used to evaluate potential fry habitat along stream margins and side-channel areas.

References

WDFW/Ecology: spawning (Beecher et al. 2016)
ESH model: spawning (Crumley and Stober 1984)
Fraser River: spawning and fry (Rempel et al. 2012)

Chum Salmon

Depth Preference Curves

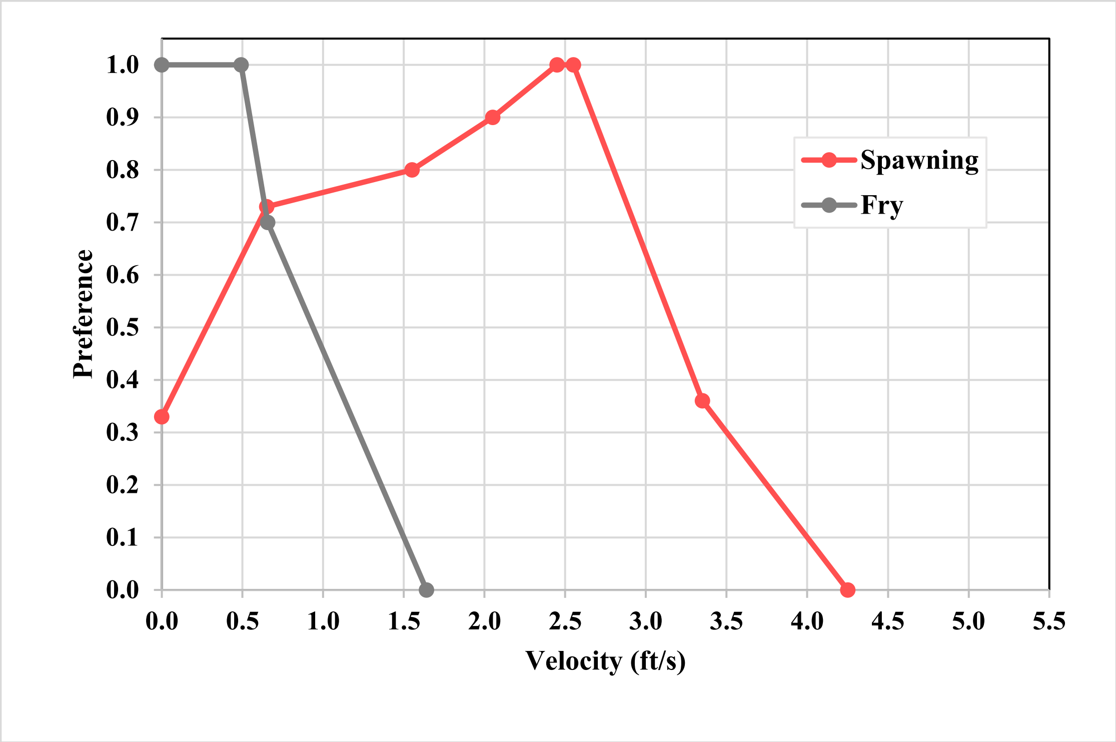


Spawning	
Depth (ft)	Preference
0.00	0.00
0.25	0.00
0.75	0.87
1.15	0.95
1.35	1.00
1.45	0.95
2.05	0.60
2.65	0.17
99.00	0.17

Fry	
Depth (ft)	Preference
0.00	0.00
0.33	0.50
0.82	0.80
1.31	1.00
99.00	1.00

Chum Salmon

Velocity Preference Curves



Spawning	
Velocity (ft/s)	Preference
0.00	0.33
0.65	0.73
1.55	0.80
2.05	0.90
2.45	1.00
2.55	1.00
3.35	0.36
4.25	0.00

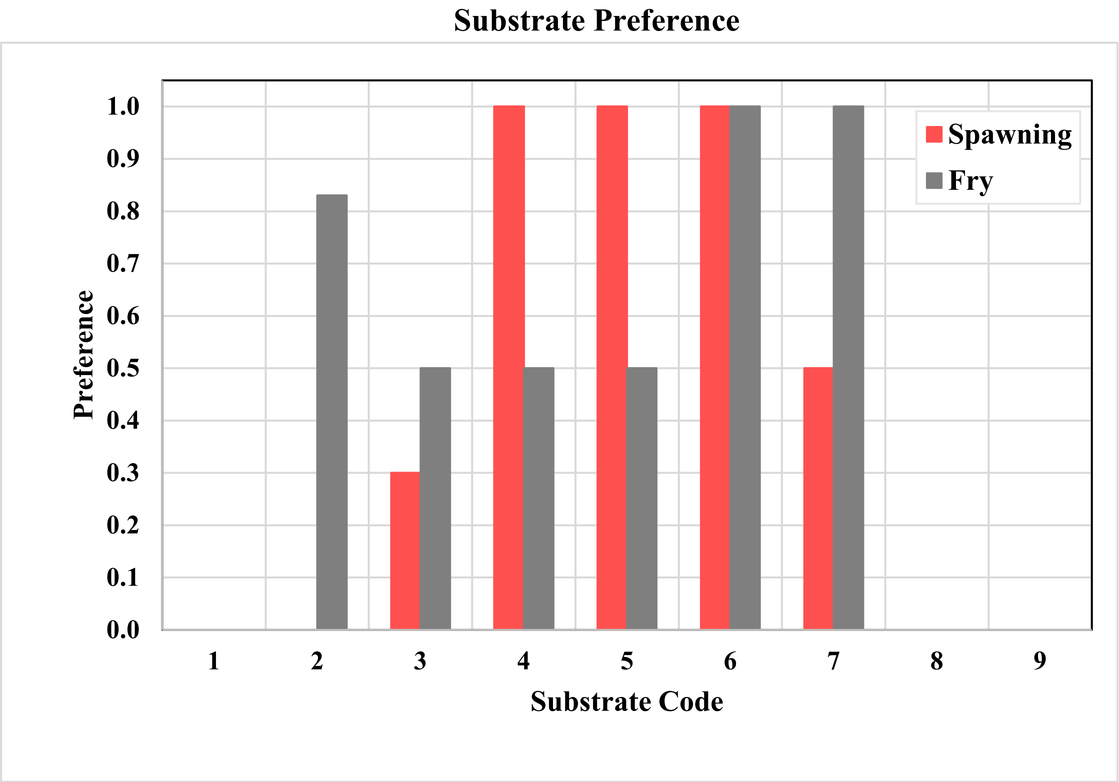
Fry	
Velocity (ft/s)	Preference
0.00	1.00
0.49	1.00
0.66	0.70
1.64	0.00

Chum Salmon

Substrate Preference Criteria

For Chum Salmon Spawning Substrate Preference, use Table 2 (Beecher et al. 2016)
For Chum Salmon Fry Substrate Preference, use Rempel et al. 2012

Chum Salmon



Sustrate Code	Substrate Type	Spawning Preference	Fry Preference
1	Silt, Clay, or Organic	0.0	0.0
2	Sand	0.0	0.8
3	Small Gravel (0.1-0.5")	0.3	0.5
4	Med Gravel (0.5-1.5")	1.0	0.5
5	Large Gravel (1.5-3.0")	1.0	0.5
6	Small Cobble (3.0-6.0")	1.0	1.0
7	Large Cobble (6.0-12")	0.5	1.0
8	Boulder (>12")	0.0	0.0
9	Bedrock	0.0	0.0

Source: Spawning (Table 10, Beecher et al. 2016); Fry (Rempel et al. 2012)

Coho Salmon

Spawning (Group C)

Coho spawning HSC curves from several sources were evaluated including WDFW/Ecology (Type 3; 66 redds), the ESH model (hybrid Type 1-2), and the Trinity River (Type 2). It is WDFW/Ecology's preference to use statewide Type 3 HSC curves when available unless additional site-specific field observation is collected on the Skagit River in sufficient numbers to revisit, and potentially revise, the statewide curves. The statewide HSC curves are based on data from 5 studies and 66 redds (Fletcher Canyon and Irely creeks, and Humptulips and Dewatto rivers). As a result, the proposed habitat modeling approach is to use the existing WDFW/Ecology Type 3 HSC curves.

Juvenile (Group D)

The WDFW/Ecology Instream Flow Study Guidelines are periodically updated with best available data.Versions of the WDFW/Ecology Instream Flow Study Guidelines prior to 2013 provided default Coho juvenile depth and velocity HSC curves developed in earlier studies (Beecher et al. 2002). Subsequent research has shown that the stream flow relating to peak Coho rearing habitat did not resemble the stream flow relating to increased Coho salmon production (Beecher et al. 2010). Based on this, WDFW/Ecology removed the statewide Coho juvenile HSC curves from subsequent versions (Beecher et al. 2013; Beecher et al. 2016).

HSC curves from the ESH model (Type 2) and the Trinity River (Type 2) were evaluated by the HSC Technical Group. While the ESH curves are not based on Skagit-specific field observation data, the HSC Technical Group recommended their use primarily because there is a history of using these curves for Skagit River habitat modeling purposes.

Fry (Group E)

Type 3 HSC curves are not available from WDFW/Ecology as the salmonid fry life stage is not commonly modeled in instream flow studies. However, habitat results for the fry life stage are of interest on the Skagit River in evaluating the relationship between flow and available habitat along the stream margins/shoreline areas as well as off-channel habitats that may be activated during higher flow events. As a result, the HSC Technical Group recommended using existing Type 2 fry curves when available. For Coho fry, the HSC Technical Group reviewed existing Type 2 curves used in the ESH model (Crumley and Stober 1984) as well as the Trinity River with a recommendation to use the ESH model curves for habitat modeling purposes. Habitat cover preference information was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

Additional Notes

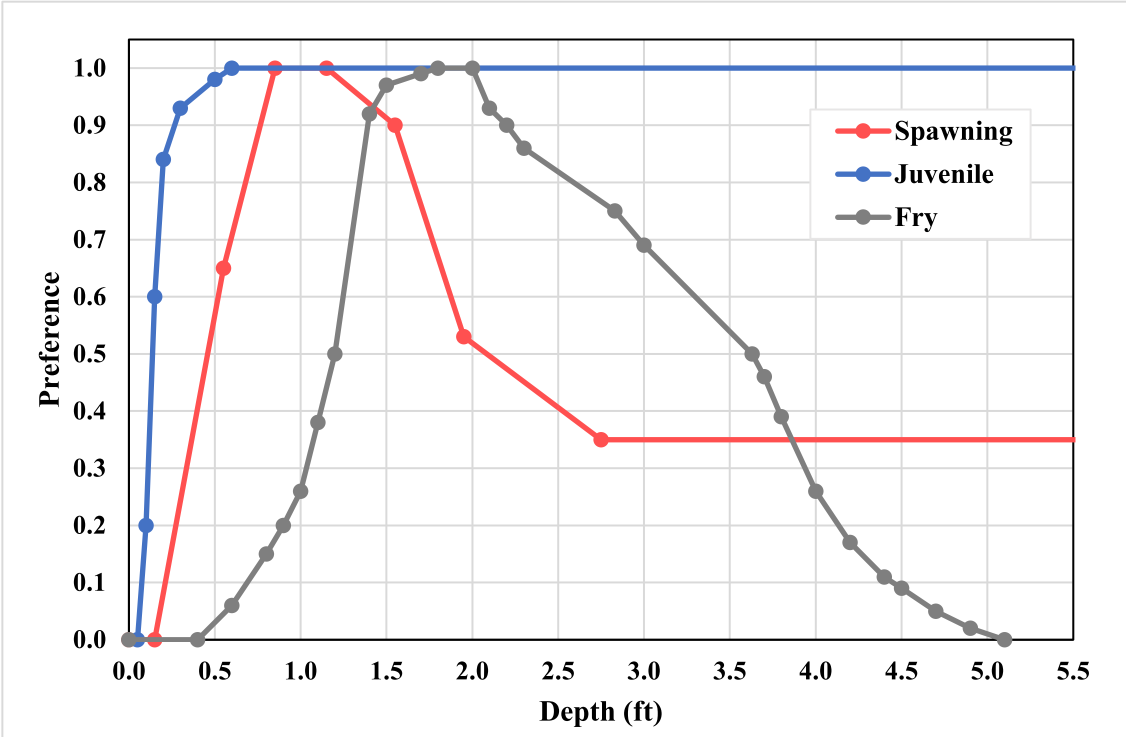
There is no clear biological evidence that depth becomes a limiting factor for spawning and juvenile Coho salmon. Therefore, the HSC Technical Group recommended that once depth reaches 2.75 ft (0.35 preference) for spawning and 2.0 ft (1.0 preference) for juvenile, it be considered "non-limiting" in the HSC depth curves.

References

WDFW/Ecology: spawning (Beecher et al. 2016)
ESH model: spawning, juvenile, and fry (Wampler 1980; Bovee 1978; Crumley and Stober 1984)
Trinity River: spawning, juvenile, and fry (Hampton et al. 1997)

Coho Salmon

Depth Preference Curves



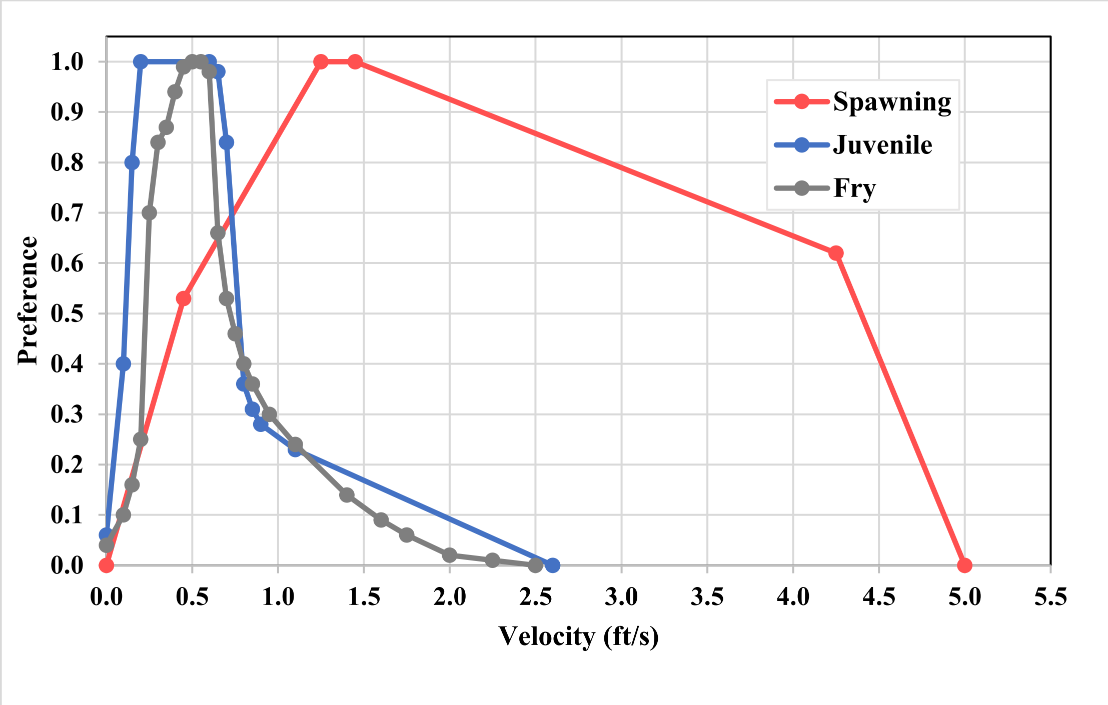
Fry	
Depth (ft)	Preference
0.00	0.00
0.40	0.00
0.60	0.06
0.80	0.15
0.90	0.20
1.00	0.26
1.10	0.38
1.20	0.50
1.40	0.92
1.50	0.97
1.70	0.99
1.80	1.00
2.00	1.00
2.10	0.93
2.20	0.90
2.30	0.86
2.83	0.75
3.00	0.69
3.63	0.50
3.70	0.46
3.80	0.39
4.00	0.26
4.20	0.17
4.40	0.11
4.50	0.09
4.70	0.05
4.90	0.02
5.10	0.00

Spawning	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.55	0.65
0.85	1.00
1.15	1.00
1.55	0.90
1.95	0.53
2.75	0.35
99.00	0.35

Juvenile	
Depth (ft)	Preference
0.05	0.00
0.10	0.20
0.15	0.60
0.20	0.84
0.30	0.93
0.50	0.98
0.60	1.00
99.00	1.00

Coho Salmon

Velocity Preference Curves



Fry	
Velocity (ft/s)	Preference
0.00	0.04
0.10	0.10
0.15	0.16
0.20	0.25
0.25	0.70
0.30	0.84
0.35	0.87
0.40	0.94
0.45	0.99
0.50	1.00
0.55	1.00
0.60	0.98
0.65	0.66
0.70	0.53
0.75	0.46
0.80	0.40
0.85	0.36
0.95	0.30
1.10	0.24
1.40	0.14
1.60	0.09
1.75	0.06
2.00	0.02
2.25	0.01
2.50	0.00

Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.45	0.53
1.25	1.00
1.45	1.00
4.25	0.62
5.00	0.00

Juvenile	
Velocity	Preference
0.00	0.06
0.10	0.40
0.15	0.80
0.20	1.00
0.60	1.00
0.65	0.98
0.70	0.84
0.80	0.36
0.85	0.31
0.90	0.28
1.10	0.23
2.60	0.00

Coho Salmon

Substrate Preference Criteria

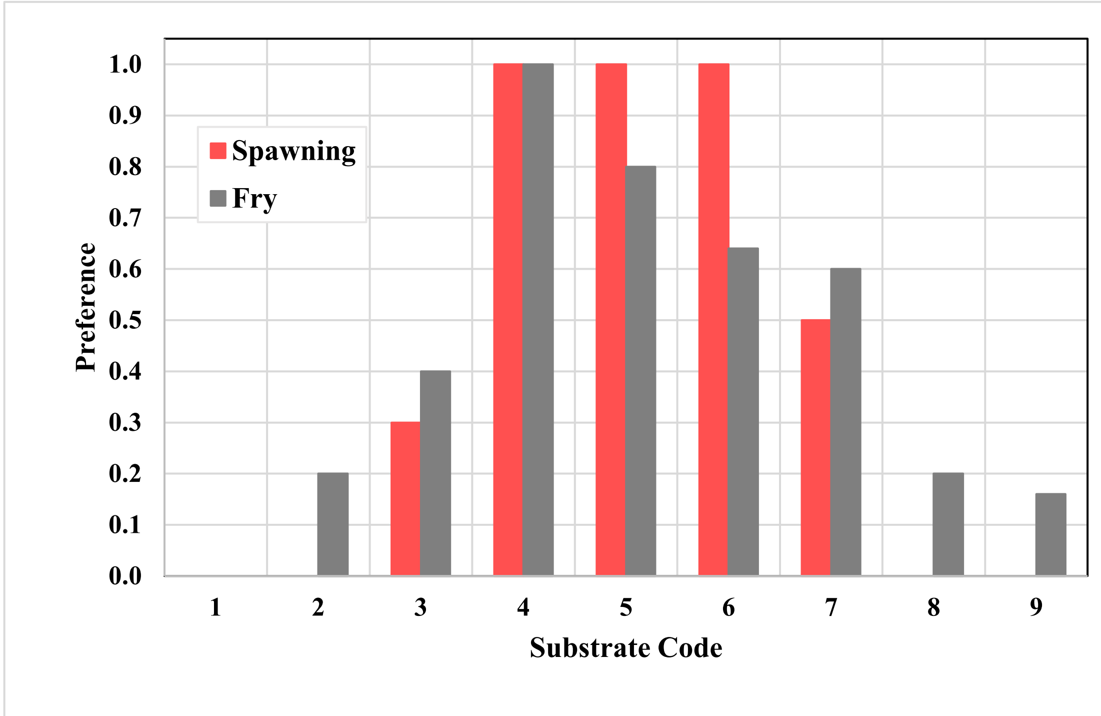
For Coho Salmon Spawning Substrate Preference, use Table 2 (Beecher et al. 2016)

For Coho Salmon Juvenile Substrate and Cover Preference, use Table 3 (Beecher et al. 2016)

For Coho Salmon Fry Substrate Preference, use data from the ESH Model

Coho Salmon

Substrate Preference

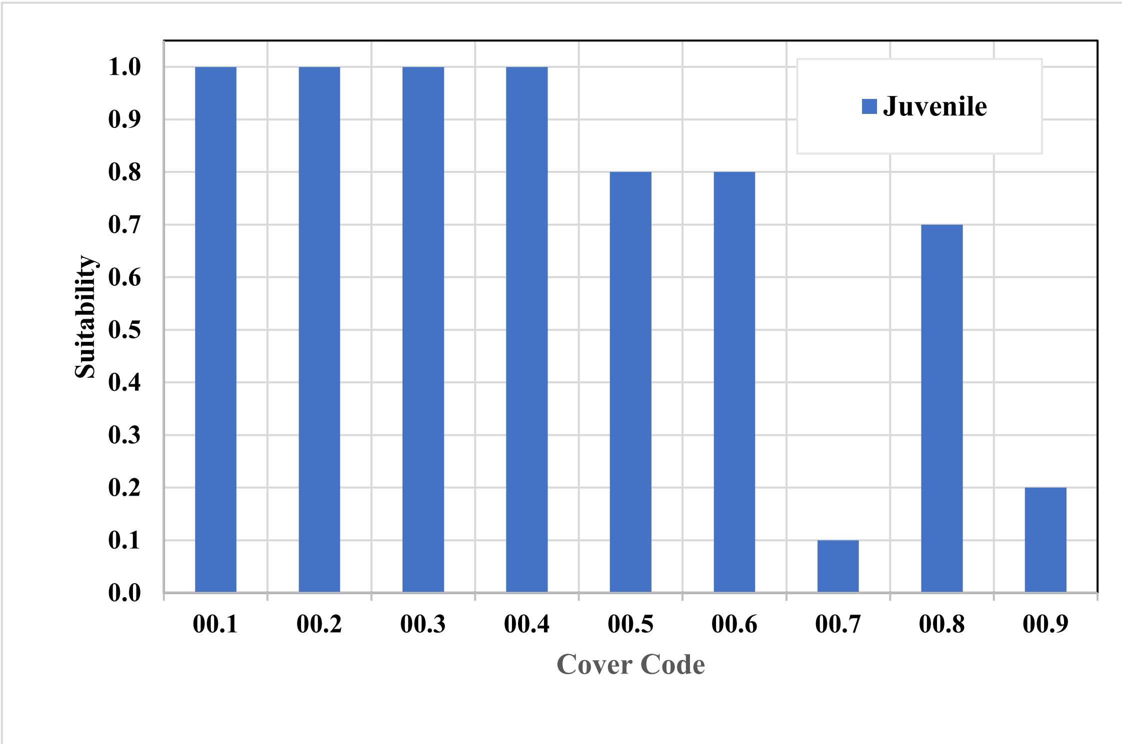


Sustrate Code	Substrate Type	Spawning Preference	Fry Preference
1	Silt, Clay, or Organic	0.0	0.00
2	Sand	0.0	0.20
3	Small Gravel (0.1-0.5")	0.3	0.40
4	Med Gravel (0.5-1.5")	1.0	1.00
5	Large Gravel (1.5-3.0")	1.0	0.80
6	Small Cobble (3.0-6.0")	1.0	0.64
7	Large Cobble (6.0-12")	0.5	0.60
8	Boulder (>12")	0.0	0.20
9	Bedrock	0.0	0.16

Source: Spawning (Table 11, Beecher et al. 2016); Fry (ESH Model)

Coho Salmon

Cover Preference



Code	Type of Cover Note: Cover Codes are not used for Spawning life stage	Juvenile Preference
00.1	Undercut bank	1.00
00.2	Overhanging vegetation near or touching water	1.00
00.3	Rootwad (including parly undercut)	1.00
00.4	Log jam/submerged brush pile	1.00
00.5	Log(s) parallel to bank	0.80
00.6	Aquatic vegetation	0.80
00.7	Short (<1 ft) terrestrial grass	0.10
00.8	Tall (>3 ft) dense grass	0.70
00.9	Vegetation >3 vertical ft above SZF	0.20

Source: Table 3, Beecher et al. 2016

Sockeye Salmon

Spawning (Group C)

For Sockeye spawning, only Type 3 HSC curves from WDFW/Ecology were evaluated by the HSC Technical Group as ESH curves are not available. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when available unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. The statewide curves are based on data from 4 studies and 1,053 redds [Cedar River (3 studies) and Big Creek (Quinault basin)] (Beecher et al. 2016). As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves.

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for spawning Sockeye salmon. Therefore, the HSC Technical Group recommended that once depth reaches 1.55 ft (0.45 preference), it be considered "non-limiting" in the HSC depth curve.

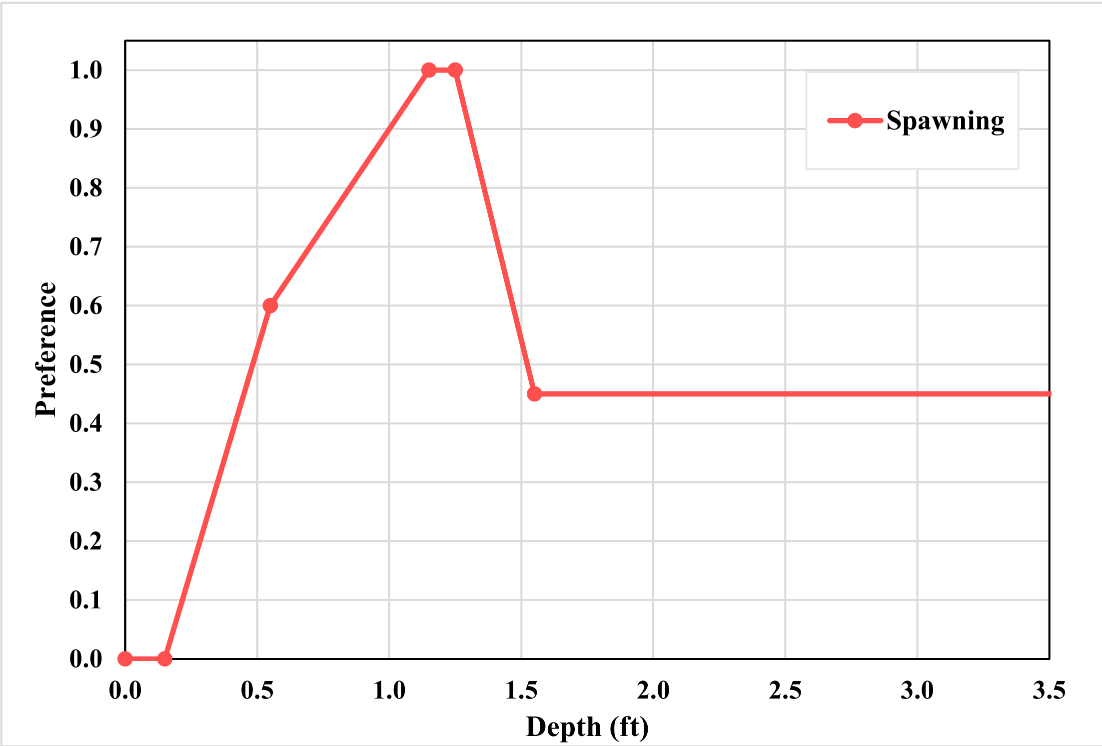
Sockeye salmon is an "ocean-type" rearing species, therefore, juvenile HSC curves are not recommended for habitat modeling in the Skagit River. However, the HSC Technical Group has developed a set of "generic salmonid fry" HSC curves based on an evaluation of HSC currently used in the ESH model for several salmonid species (see Fry tab in this spreadsheet). The generic salmonid fry HSC curves will be used to evaluate potential fry habitat along stream margins and side-channel areas.

References

WDFW/Ecology: spawning (Beecher et al. 2016)
Fraser River: spawning (Rempel et al. 2012)

Sockeye Salmon

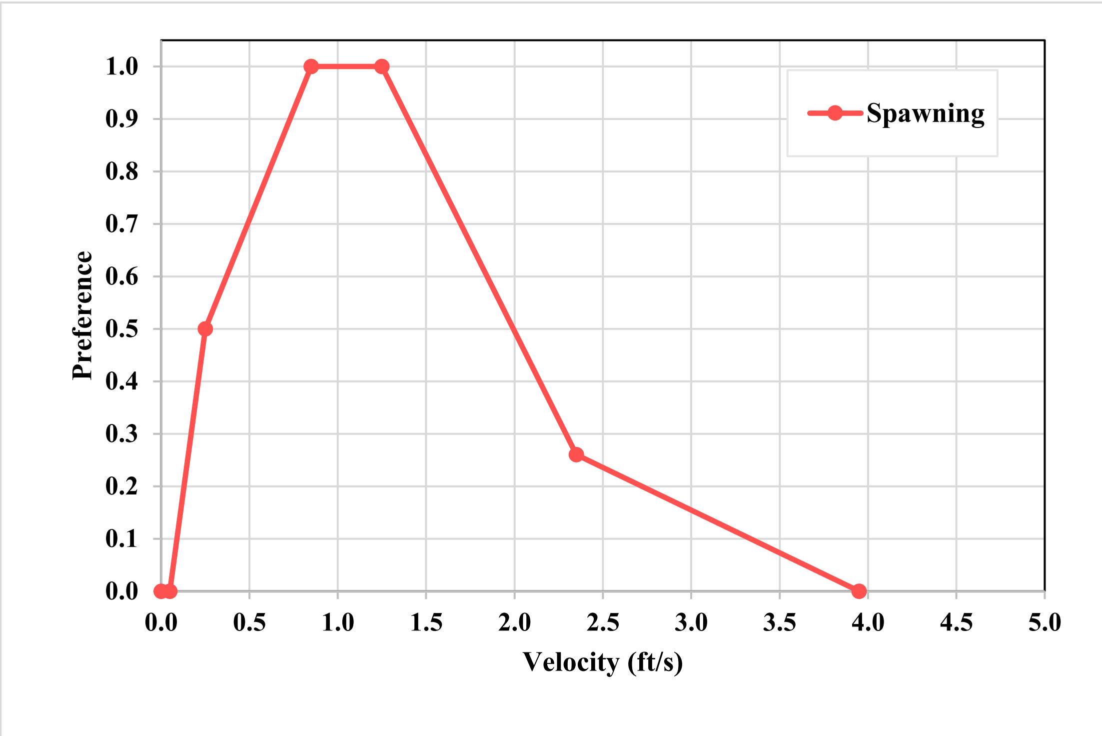
Depth Preference Curves



Spawning	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.55	0.60
1.15	1.00
1.25	1.00
1.55	0.45
99.00	0.45

Sockeye Salmon

Velocity Preference Curves



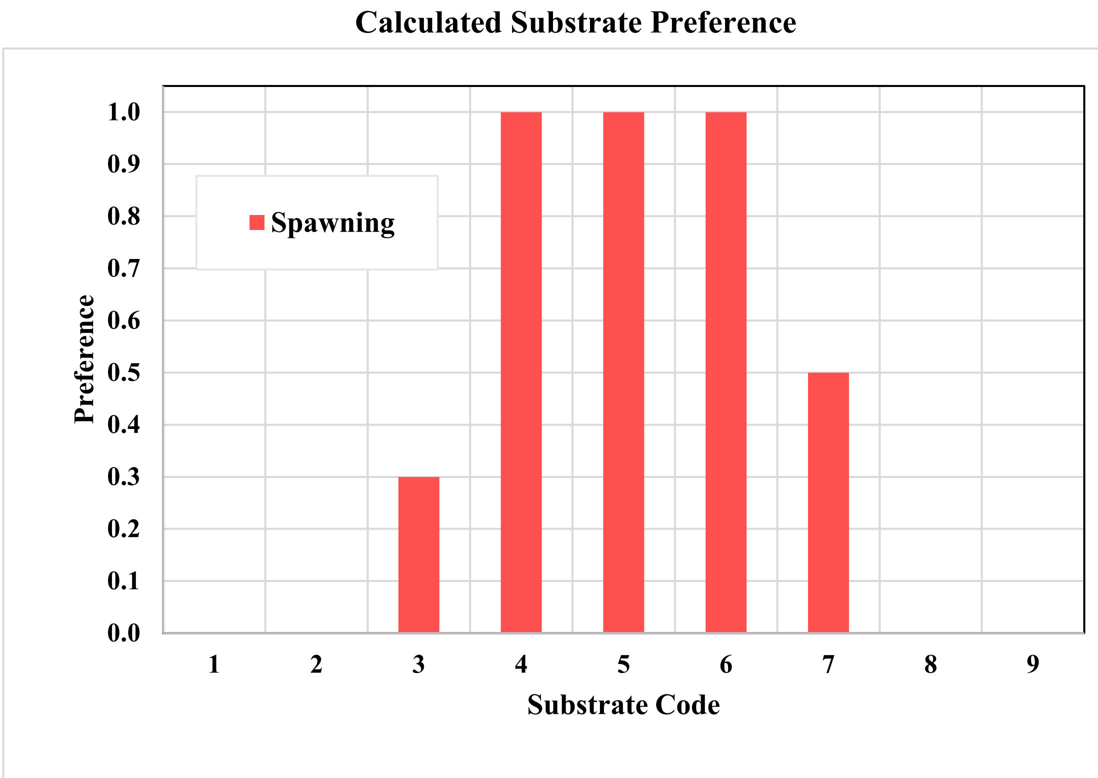
Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.05	0.00
0.25	0.50
0.85	1.00
1.25	1.00
2.35	0.26
3.95	0.00

Sockeye Salmon

Substrate Preference Criteria

For Sockeye Salmon Spawning Substrate Preference, use Table 2 (Beecher et al. 2016)

Sockeye Salmon



Sustrate Code	Substrate Type	Spawning Preference
1	Silt, Clay, or Organic	0.0
2	Sand	0.0
3	Small Gravel (0.1-0.5")	0.3
4	Med Gravel (0.5-1.5")	1.0
5	Large Gravel (1.5-3.0")	1.0
6	Small Cobble (3.0-6.0")	1.0
7	Large Cobble (6.0-12")	0.5
8	Boulder (>12")	0.0
9	Bedrock	0.0

Source: Table 13, Beecher et al. 2016

Rainbow Trout

General Approach

For Rainbow Trout spawning, adult rearing, and juvenile life stages, HSC curves from WDFW/Ecology (Type 3), the ESH model (hybrid Type 1-2), and the Fraser River (Type 2, juvenile only) were evaluated by the HSC Technical Group. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when avaiailable unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves for all three Rainbow Trout life stages. Information specific to each life stage is provided below.

Spawning (Group C)

The WDFW/Ecology Type 3 HSC curves for Rainbow Trout spawning are based on analysis from 2 studies and 27 redds (from the upper Lake and Muller creeks) (Beecher et al. 2016).

Adult Rearing (Group C)

The WDFW/Ecology Type 3 HSC curves for Rainbow Trout adult rearing are based on anlaysis from 15 studies and 638 fish observations [mostly streams west of the Cascades, but includes Yakima River, upper Mill Creek (WRIA 32), and Douglas Creek (WRIA 44)] (Beecher et al. 2016).

Juvenile (Group C)

The WDFW/Ecology Type 3 HSC curves are based on analysis from 32 studies and 1,954 fish observations (from multiple Washington streams of differing sizes and stream types) (Beecher et al. 2016).

Fry (Group E)

Type 3 HSC curves are not available from WDFW/Ecology as the salmonid fry life stage is not commonly modeled in instream flow studies. However, habitat results for the fry life stage are of interest on the Skagit River in evaluating the relationship between flow and available habitat along the stream margins/shoreline areas as well as off-channel habitats that may be activated during higher flow events. As a result, the HSC Technical Group recommended using existing Type 2 fry curves when available. For Rainbow Trout fry, the HSC Technical Group reviewed existing Type 2 curves used in the ESH model (Bovee 1978) as well as the Fraser River with a recommendation to use the ESH model curves for habitat modeling purposes. Habitat cover preference information was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

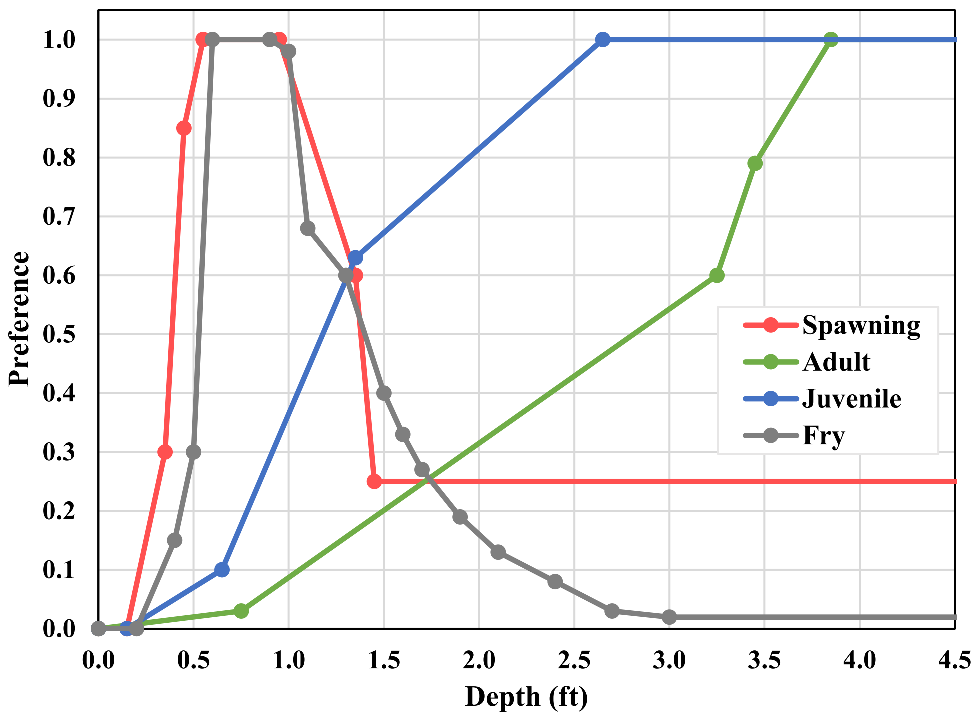
Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for spawning, adult, and juvenile Rainbow Trout. Therefore, the HSC Technical Group recommended that once depth reaches 1.45 ft for spawning (0.25 preference), 3.85 ft (1.0 preference) for adult, and 2.65 ft (1.0 preference) for juvenile, it be considered "non-limiting" in the HSC depth curves.

References

WDFW/Ecology: spawning, adult rearing, and juvenile (Beecher et al. 2016)
ESH model: spawning and fry (Bovee 1978); adult and juvenile (Bovee 1978; Crumley and Stober 1984)
Fraser River: juvenile and fry (Rempel et al. 2012)
Klamath River: spawning, adult, and juvenile (Allen DATE)
McKenzie River: spawning, adult, and juvenile (Hardin-Davis 1990)

Rainbow Trout
Depth Preference Curves



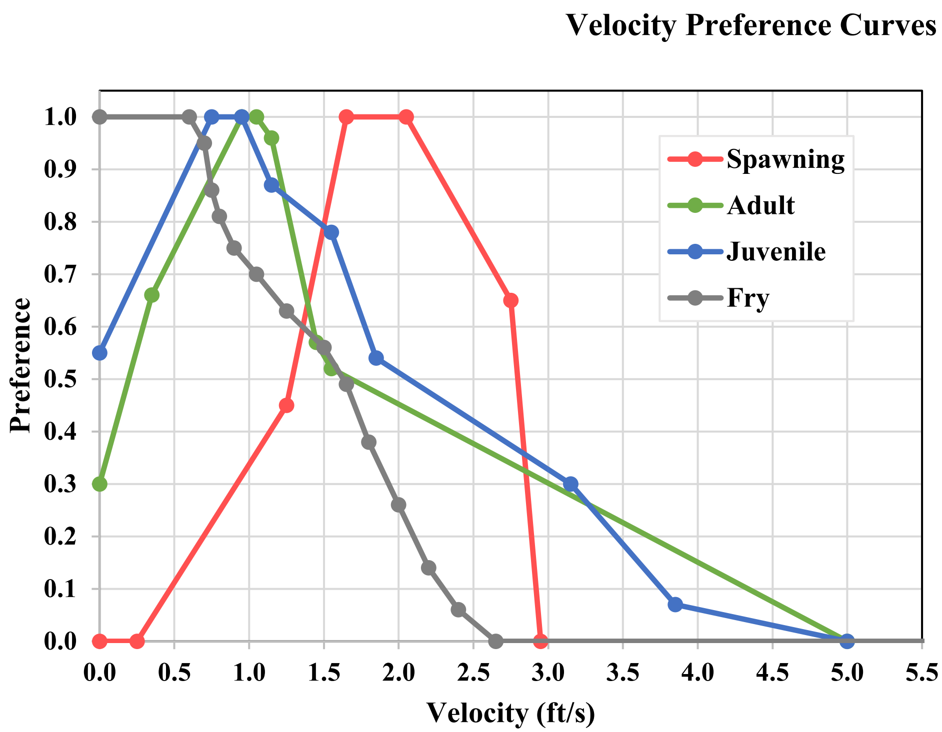
Fry	
Depth (ft)	Preference
0.00	0.00
0.20	0.00
0.40	0.15
0.50	0.30
0.60	1.00
0.90	1.00
1.00	0.98
1.10	0.68
1.30	0.60
1.50	0.40
1.60	0.33
1.70	0.27
1.90	0.19
2.10	0.13
2.40	0.08
2.70	0.03
3.00	0.02
5.00	0.02
6.00	0.02
100.00	0.02

Spawning	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.35	0.30
0.45	0.85
0.55	1.00
0.95	1.00
1.35	0.60
1.45	0.25
99.00	0.25

Adult	
Depth (ft)	Preference
0.00	0.00
0.75	0.03
3.25	0.60
3.45	0.79
3.85	1.00
99.00	1.00

Juvenile	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.65	0.10
1.35	0.63
2.65	1.00
99.00	1.00

Rainbow Trout



Fry	
Velocity (ft/s)	Preference
0.00	1.00
0.60	1.00
0.70	0.95
0.75	0.86
0.80	0.81
0.90	0.75
1.05	0.70
1.25	0.63
1.50	0.56
1.65	0.49
1.80	0.38
2.00	0.26
2.20	0.14
2.40	0.06
2.65	0.00
100.00	0.00

Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.25	0.00
1.25	0.45
1.65	1.00
2.05	1.00
2.75	0.65
2.95	0.00

Adult	
Velocity (ft/s)	Preference
0.00	0.30
0.35	0.66
0.95	1.00
1.05	1.00
1.15	0.96
1.45	0.57
1.55	0.52
5.00	0.00

Juvenile	
Velocity (ft/s)	Preference
0.00	0.55
0.75	1.00
0.95	1.00
1.15	0.87
1.55	0.78
1.85	0.54
3.15	0.30
3.85	0.07
5.00	0.00

Rainbow Trout

Substrate Preference Criteria

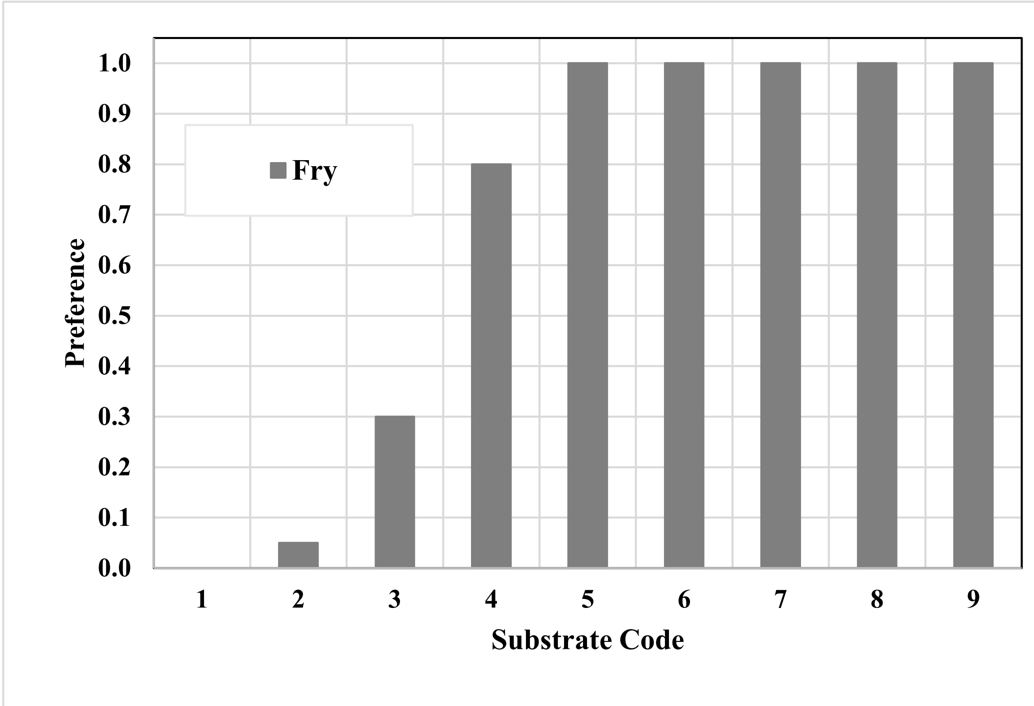
For Rainbow Trout Spawning Substrate Preference, use Table 5 (Beecher et al. 2016)

For Rainbow Trout Adult Rearing and Juvenile Substrate and Cover Preference, use Table 3 (Beecher et al. 2016)

For Rainbow Trout Fry Substrate Preference, use data from the ESH Model

Rainbow Trout

Substrate Preference

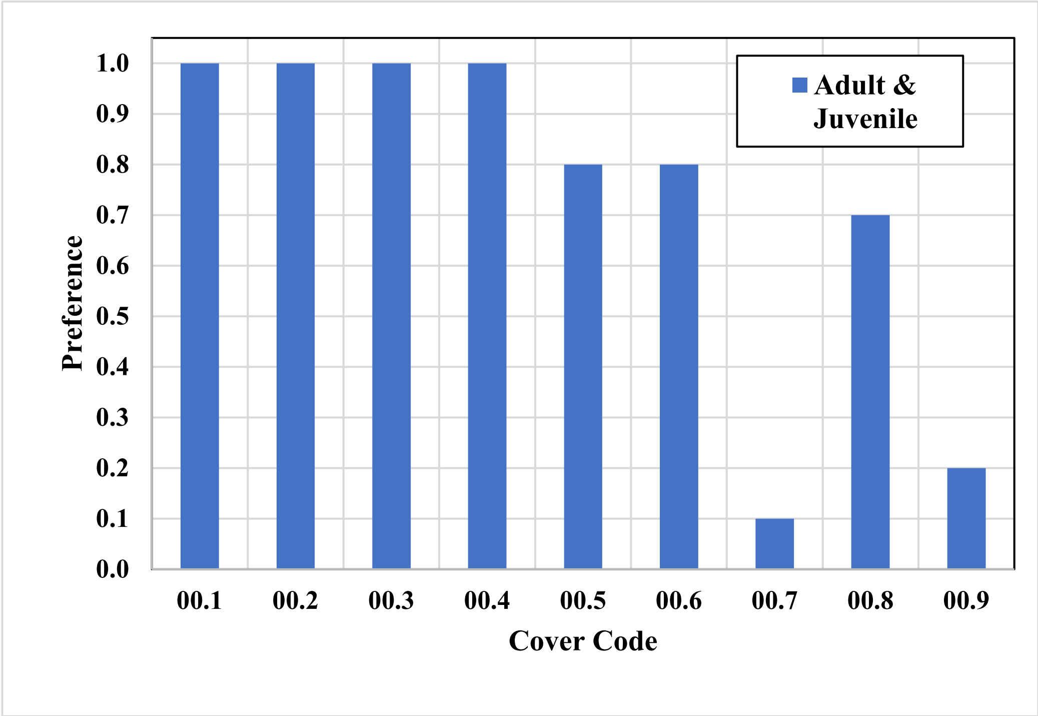


Sustrate Code	Substrate Type	Fry Preference
1	Silt, Clay, or Organic	0.00
2	Sand	0.05
3	Small Gravel (0.1-0.5")	0.30
4	Med Gravel (0.5-1.5")	0.80
5	Large Gravel (1.5-3.0")	1.00
6	Small Cobble (3.0-6.0")	1.00
7	Large Cobble (6.0-12")	1.00
8	Boulder (>12")	1.00
9	Bedrock	1.00

Source: ESH Model

Rainbow Trout

Cover Preference Criteria



Code	Type of Cover Note: Cover Codes are not used for Spawning life stage	Adult & Juvenile Preference
00.1	Undercut bank	1.00
00.2	Overhanging vegetation near or touching water	1.00
00.3	Rootwad (including parly undercut)	1.00
00.4	Log jam/submerged brush pile	1.00
00.5	Log(s) parallel to bank	0.80
00.6	Aquatic vegetation	0.80
00.7	Short (<1 ft) terrestrial grass	0.10
00.8	Tall (>3 ft) dense grass	0.70
00.9	Vegetation >3 vertical ft above SZF	0.20

Source: Table 3, Beecher et al. 2016

Bull Trout and Dolly Varden

General Approach

For Bull Trout and Dolly Varden spawning and juvenile life stages, HSC curves from WDFW/Ecology (Type 3) and the ESH model (hybrid Type 1-2) were evaluated by the HSC Technical Group. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when avaiailable unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves for Bull Trout and Dolly Varden spawning and juvenile life stages. Information specific to each life stage is provided below.

Spawning (Group C)

The WDFW/Ecology Type 3 HSC curves for Bull Trout and Dolly Varden spawning are based on analysis from 8 studies and 122 redds [WRIA 7, WRIA 38, WRIA 45 95), and WRIA 46] (Beecher et al. 2016).

Juvenile (Group A)

The WDFW/Ecology Type 3 HSC curves for Bull Trout and Dolly Varden spawning provided in Beecher et al. 2016 were updated in December 2021 and are now based on anlaysis from 11 studies totalling 127 fish observations [from the Mad, Chiwawa (2 studies), Dungeness, Tucannon, and Kachess rivers; Rock, Early Winters, Phelps, Troublesome, and Box Canyon creeks] (Beecher et al. 2016, Granger 2021). The WDFW/Ecology Instream Flow Guidelines are in the process of being updated and the revised Bull Trout and Dolly Varden juvenile HSC curves will be included in the updated 2022 report. Field validation studies conducted on the Skagit River during 2021 resulted in an additional 4 fish observations (not included in the 2021 update to the HSC curves). Data from these 4 fish observations was reviewed by the HSC Technical Group and were determined to be consistent with both the ESH model and statewide HSC curves (i.e., observation data points were generally captured within the defined area under the HSC depth and velocity curves).

Fry (Group E)

Type 3 HSC curves are not available from WDFW/Ecology as the salmonid fry life stage is not commonly modeled in instream flow studies. However, habitat results for the fry life stage are of interest on the Skagit River in evaluating the relationship between flow and available habitat along the stream margins/shoreline areas as well as off-channel habitats that may be activated during higher flow events. As a result, the HSC Technical Group recommended using existing Type 2 fry curves when available. For Bull Trout and Dolly Varden fry, the HSC Technical Group recommended using the existing Type 2 curves from the ESH model which are based on data from the Arctic Environmental Information and Data Center (1981). Habitat cover preference information was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

Additional Notes

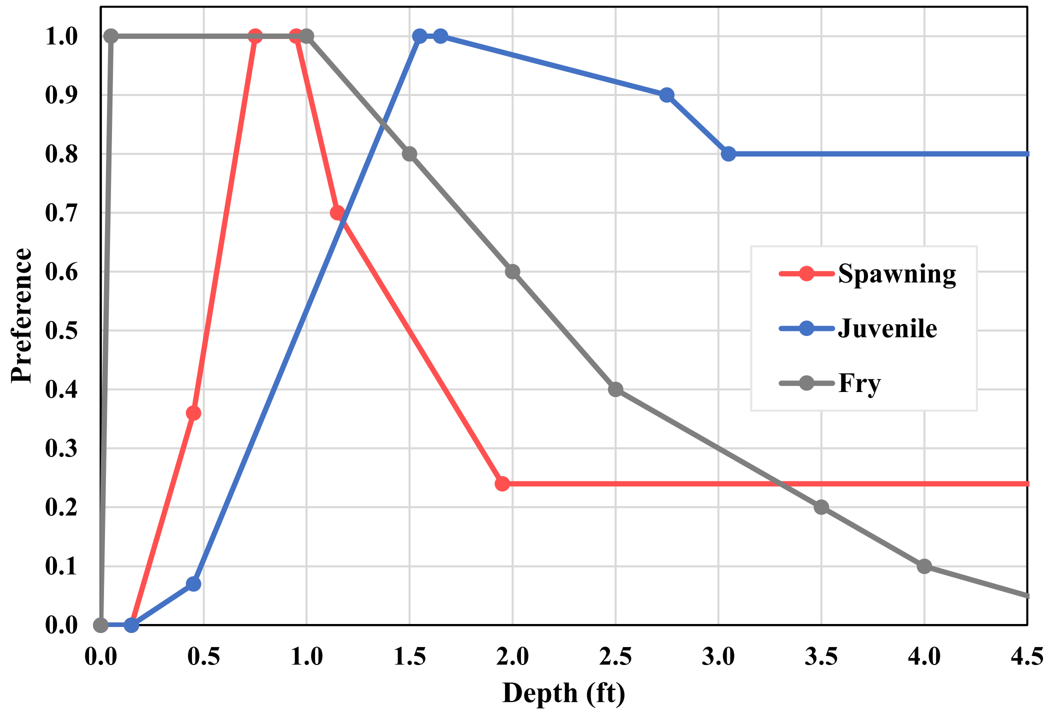
There is no clear biological evidence that depth becomes a limiting factor for spawning and juvenile Bull Trout and Dolly Varden. Therefore, the HSC Technical Group recommended that once depth reaches 1.95 ft (0.24 preference) for spawning and 3.05 ft (0.80 preference) for juvenile, it be considered "non-limiting" in the HSC depth curves.

References

WDFW/Ecology: spawning (Beecher et al. 2016); juvenile (Granger 2021 provisional data)
ESH model: spawning and juvenile (Crumley and Stober 1984); fry (AEIDC 1981)

Bull Trout and Dolly Varden

Depth Preference Curves



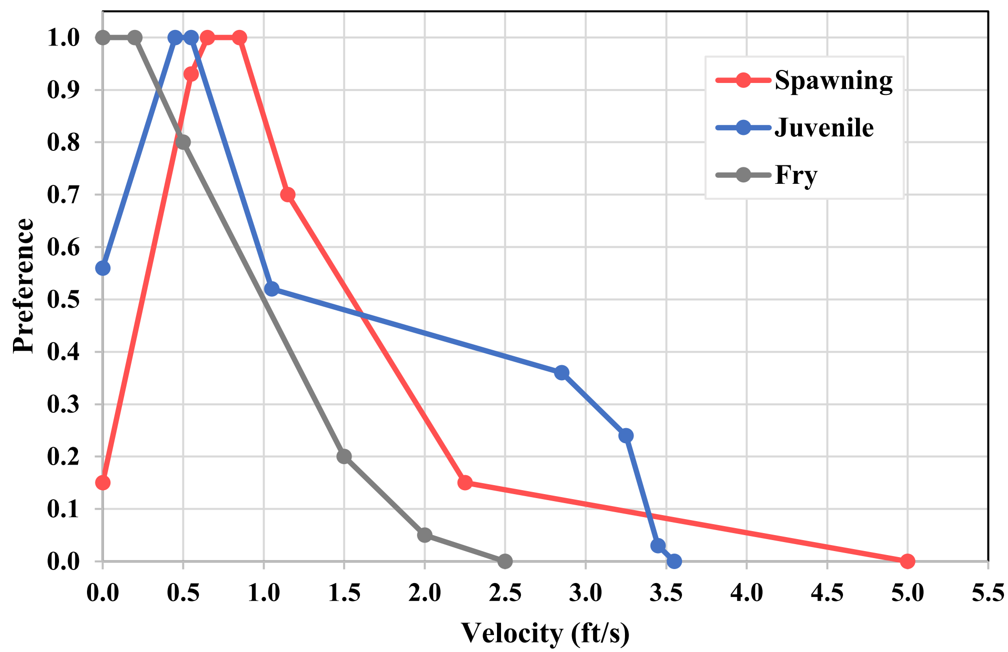
Spawning	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.45	0.36
0.75	1.00
0.95	1.00
1.15	0.70
1.95	0.24
99.00	0.24

Juvenile	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.45	0.07
1.55	1.00
1.65	1.00
2.75	0.90
3.05	0.80
99.00	0.80

Fry	
Depth (ft)	Preference
0.00	0.00
0.05	1.00
1.00	1.00
1.50	0.80
2.00	0.60
2.50	0.40
3.50	0.20
4.00	0.10
5.00	0.00
100.00	0.00

Bull Trout and Dolly Varden

Velocity Preference Curves



Spawning	
Velocity (ft/s)	Preference
0.00	0.15
0.55	0.93
0.65	1.00
0.85	1.00
1.15	0.70
2.25	0.15
5.00	0.00

Juvenile	
Velocity (ft/s)	Preference
0.00	0.56
0.45	1.00
0.55	1.00
1.05	0.52
2.85	0.36
3.25	0.24
3.45	0.03
3.55	0.00

Fry	
Velocity (ft/s)	Preference
0.00	1.00
0.20	1.00
0.50	0.80
1.50	0.20
2.00	0.05
2.50	0.00

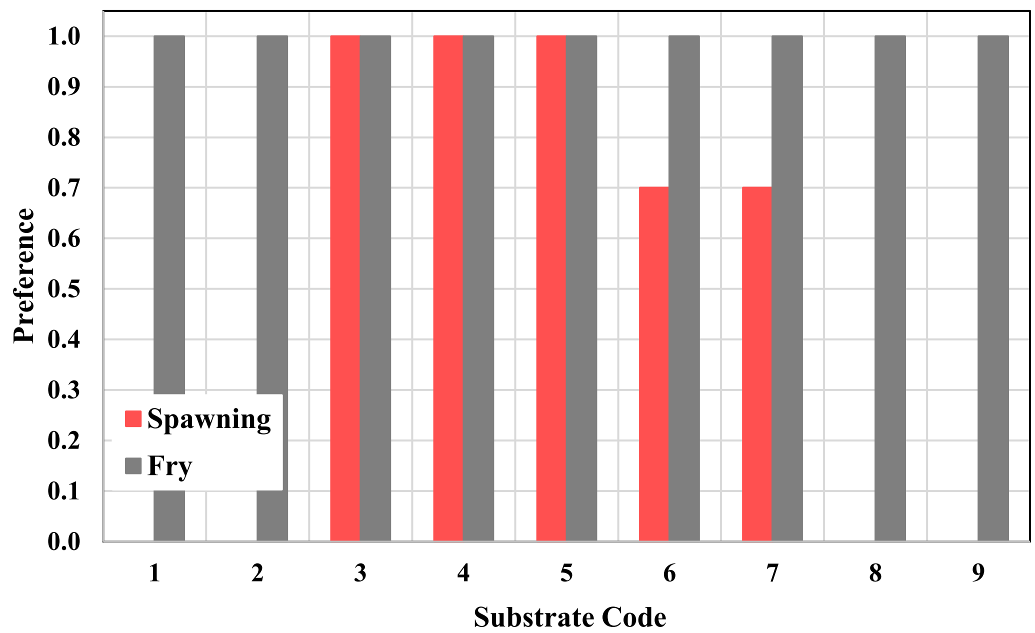
Bull Trout and Dolly Varden

Substrate Preference Criteria

For Bull Trout and Dolly Varden Spawning Substrate Preference, use Table 6 (Beecher et al. 2016)
For Bull Trout and Dolly Varden Juvenile Substrate and Cover Preference, use Table 3 (Beecher et al. 2016)
For Bull Trout and Dolly Varden Fry Substrate Preference, use data from the ESH Model

Bull Trout and Dolly Varden

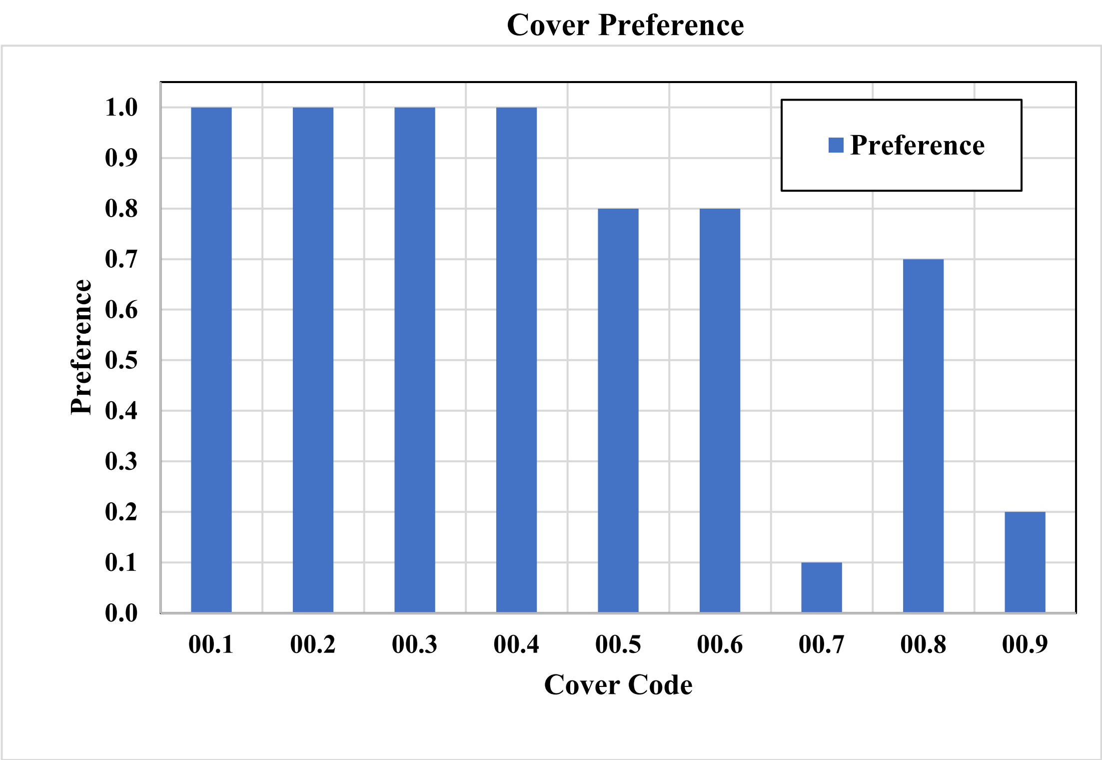
Substrate Preference



Sustrate Code	Substrate Type	Spawning Preference	Fry Preference
1	Silt, Clay, or Organic	0.00	1.00
2	Sand	0.00	1.00
3	Small Gravel (0.1-0.5")	1.00	1.00
4	Med Gravel (0.5-1.5")	1.00	1.00
5	Large Gravel (1.5-3.0")	1.00	1.00
6	Small Cobble (3.0-6.0")	0.70	1.00
7	Large Cobble (6.0-12")	0.70	1.00
8	Boulder (>12")	0.00	1.00
9	Bedrock	0.00	1.00

Source: Spawning (Table 14, Beecher et al. 2016); Fry (ESH Model)

Bull Trout and Dolly Varden



Code	Type of Cover Note: Cover Codes are not used for Spawning life stage	Juvenile Preference
00.1	Undercut bank	1.00
00.2	Overhanging vegetation near or touching water	1.00
00.3	Rootwad (including parly undercut)	1.00
00.4	Log jam/submerged brush pile	1.00
00.5	Log(s) parallel to bank	0.80
00.6	Aquatic vegetation	0.80
00.7	Short (<1 ft) terrestrial grass	0.10
00.8	Tall (>3 ft) dense grass	0.70
00.9	Vegetation >3 vertical ft above SZF	0.20

Source: Table 3, Beecher et al. 2016

Sea-Run Bull Trout

Spawning (Group F)

WDFW/Ecology Type 3 HSC curves are not available and Sea-Run Bull Trout spawning HSC curves are not included in the ESH model. The HSC Technical Group reviewed HSC curves from other studies and developed proposed consensus curves using that information. The other available studies included the Cedar, Yakima, and Wenatchee Rivers in Washington State; the Chowade River, Kemess Creek, and Duncan River in British Columbia; and Smith-Dorrien Creek in Alberta. The general approach was to envelop the depth and velocity HSC curves from the other studies.

Additional Notes

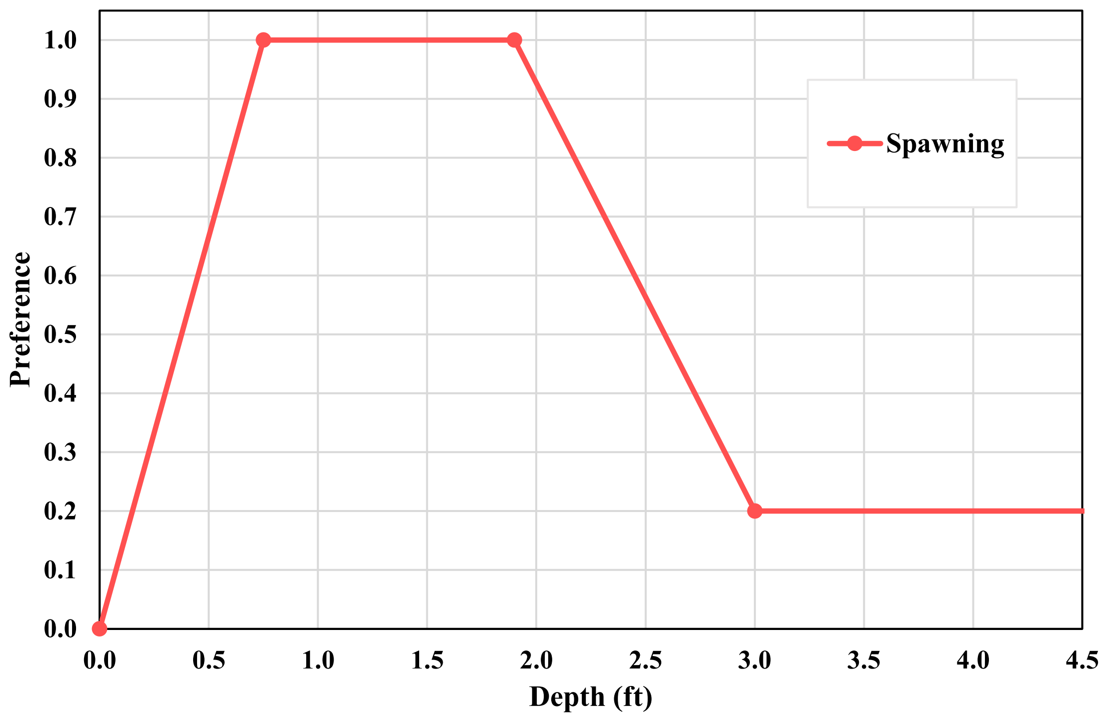
There is no clear biological evidence that depth becomes a limiting factor for spawning Sea-run Bull Trout. Therefore, the HSC Technical Group recommended that once depth reaches 3.0 ft (0.20 preference), it be considered "non-limiting" in the HSC depth curve.

References

Cedar River (Reiser et al. 1997)
Yakima and Wenatchee rivers (Sexauer 1994)
Chowade, British Columbia (Baxter 1995)
Kemess Creek, British Columbia (Bustard and Royea 1995)
Duncan River, British Columbia (O'Brien 1996)
Smith-Dorrien Creek, Alberta (Stelfox and Egan 1995)

Sea-Run Bull Trout

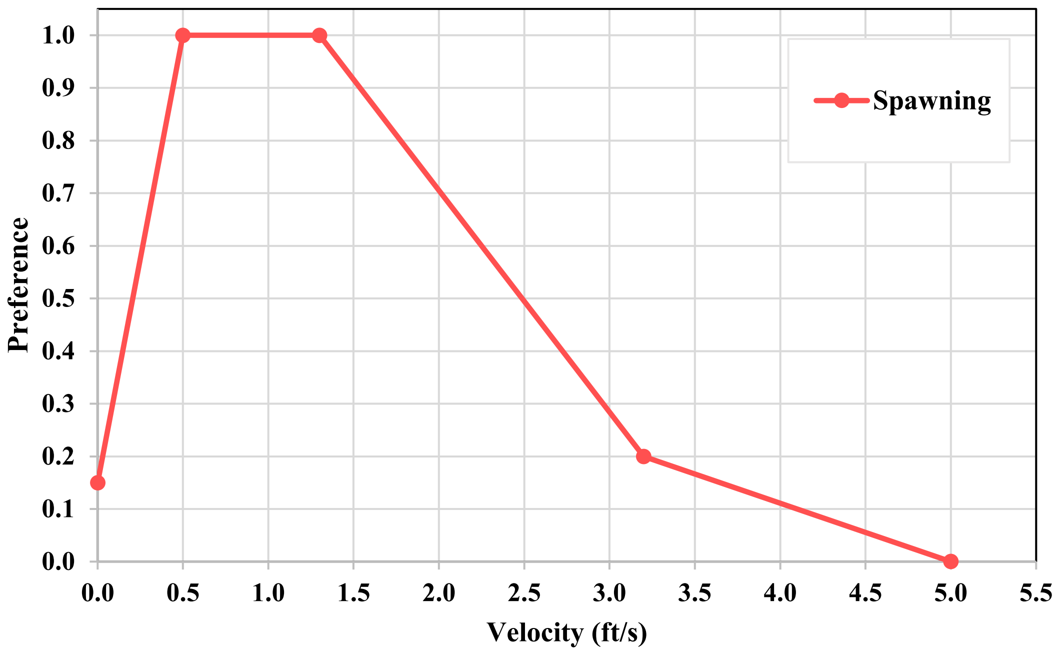
Depth Preference Curves



Spawning	
Depth (ft)	Preference
0.00	0.00
0.75	1.00
1.90	1.00
3.00	0.20
99.00	0.20

Sea-Run Bull Trout

Velocity Preference Curves



Spawning	
Velocity (ft/s)	Preference
0.00	0.15
0.50	1.00
1.30	1.00
3.20	0.20
5.00	0.00

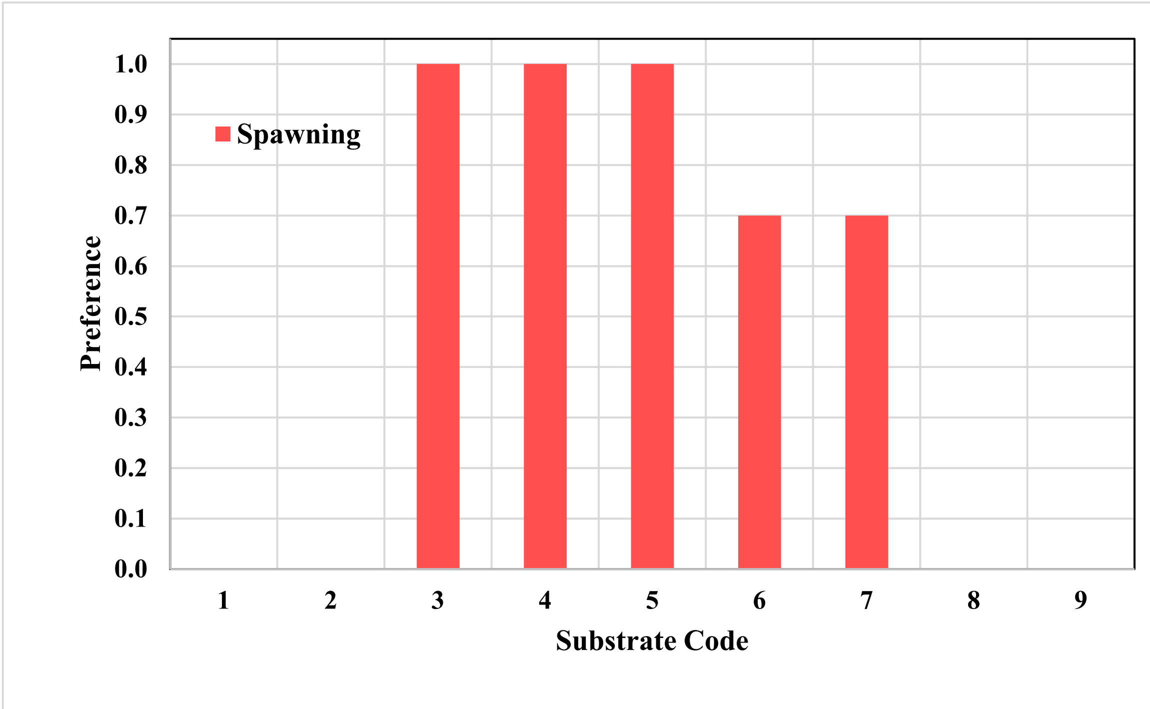
Sea-Run Bull Trout

Substrate Preference Criteria

For Sea-Run Bull Trout Spawning Substrate Preference, use Table 6 (Beecher et al. 2016)

Sea-Run Bull Trout

Calculated Substrate Preference



Sustrate Code	Substrate Type	Spawning Preference
1	Silt, Clay, or Organic	0.0
2	Sand	0.0
3	Small Gravel (0.1-0.5")	1.0
4	Med Gravel (0.5-1.5")	1.0
5	Large Gravel (1.5-3.0")	1.0
6	Small Cobble (3.0-6.0")	0.7
7	Large Cobble (6.0-12")	0.7
8	Boulder (>12")	0.0
9	Bedrock	0.0

Source: Table 14, Beecher et al. 2016

Cutthroat Trout

General Approach

For Cutthroat Trout spawning and juvenile life stages, HSC curves from WDFW/Ecology (Type 3) and the ESH model (hybrid Type 1-2) were evaluated by the HSC Technical Group. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when avaiailable unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves for Cutthroat Trout life stages. Information specific to each life stage is provided below.

Spawning (Group C)

The WDFW/Ecology Type 3 HSC curves for Cutthroat Trout spawning are based on analysis from 7 studies and 123 redds [from the Irely (4 studies) and Skookum (3 studies) creeks] (Beecher et al. 2016).

Adult (Group D)

WDFW/Ecology Type 3 HSC surves are not available for the Cutthroat Trout adult life stage and the ESH model curves are Type 2. Therefore, the HSC Technical Group recommended using the WDFW/Ecology Type 3 HSC curves for Cutthorat Trout juvenile (see below) to also represent the adult life stage.

Juvenile (Group C)

The WDFW/Ecology Type 3 HSC curves for Cutthroat Trout juvenile provided in Beecher et al. 2016 were updated in 2021 and are now based on analysis from 11 studies and 518 fish observations [from the Ohanapecosh and Kachess rivers; Warm, Grade, Martin, Olson, Perry (2 studies), Skookum, Box Canyon, and Mineral creeks] (Beecher et al. 2016, Granger 2021). The WDFW/Ecology Instream Flow Guidelines are in the process of being updated and the revised Cutthroat Trout juvenile HSC curves will be included in the updated 2022 report.

Fry (Group E)

Type 3 HSC curves are not available from WDFW/Ecology as the salmonid fry life stage is not commonly modeled in instream flow studies. However, habitat results for the fry life stage are of interest on the Skagit River in evaluating the relationship between flow and available habitat along the stream margins/shoreline areas as well as off-channel habitats that may be activated during higher flow events. As a result, the HSC Technical Group recommended using existing Type 2 fry curves when available. For Cutthroat Trout fry, the HSC Technical Group recommended using the existing Type 2 curves from the ESH model (Bovee 1978). Habitat cover preference information was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for spawning, adult, and juvenile Cutthroat Trout. Therefore, the HSC Technical Group recommended that once depth reaches 1.55 ft (0.25 preference) for spawning and 4.25 ft (0.50 preference) for adult and juvenile, it be considered "non-limiting" in the HSC depth curve.

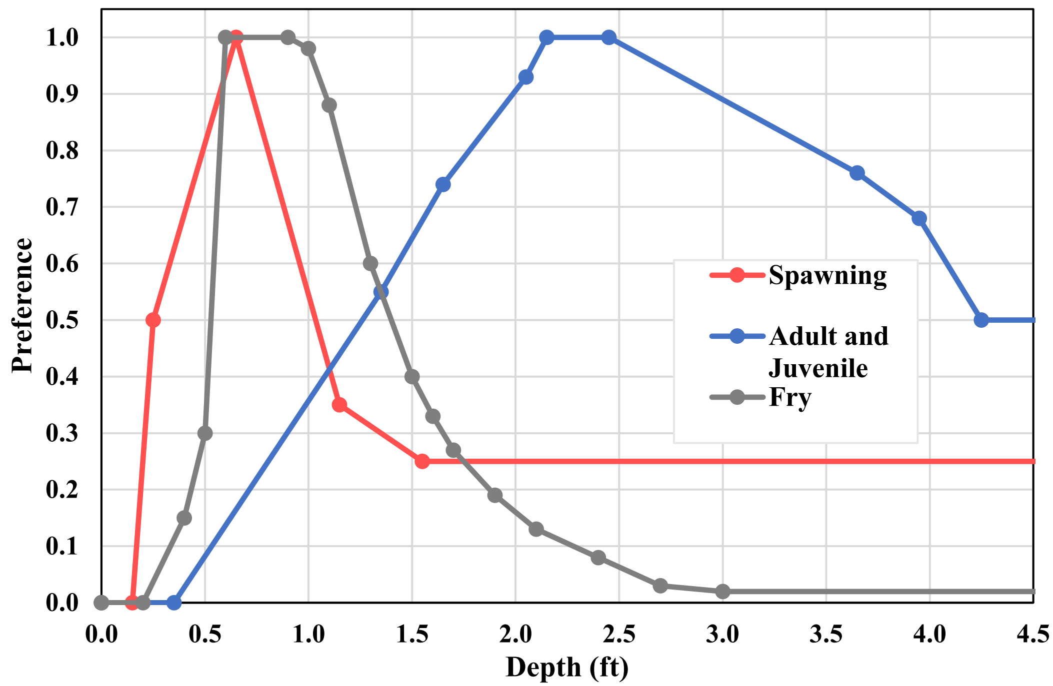
Cutthroat Trout

References

WDFW/Ecology: spawning and adult (Beecher et al. 2016); juvenile (Granger 2021 provisional data)
ESH model: spawning, adult, juvenile, and fry (Bovee 1978; Crumley and Stober 1984)
Additional sources of information:
Hickman and Raleigh 1982; Katopodis and Gervais 2016; Skookum Creek (Losee et al. 2016)

Cutthroat Trout

Depth Preference Curves



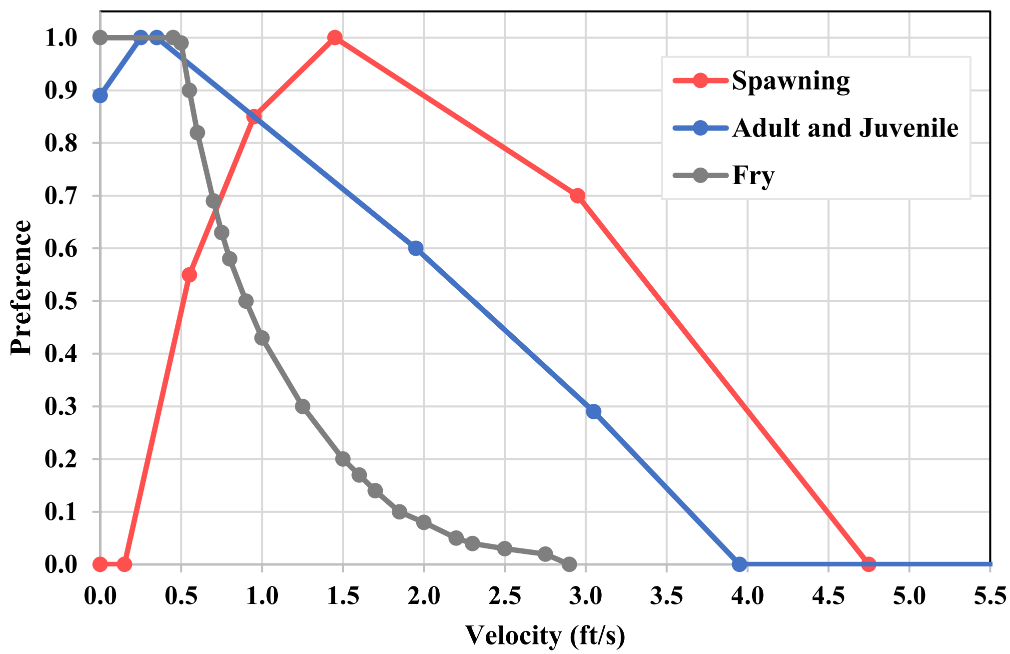
Fry	
Depth (ft)	Preference
0.00	0.00
0.20	0.00
0.40	0.15
0.50	0.30
0.60	1.00
0.90	1.00
1.00	0.98
1.10	0.88
1.30	0.60
1.50	0.40
1.60	0.33
1.70	0.27
1.90	0.19
2.10	0.13
2.40	0.08
2.70	0.03
3.00	0.02
5.00	0.02
6.00	0.02
100.00	0.02

Spawning	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.25	0.50
0.65	1.00
1.15	0.35
1.55	0.25
99.00	0.25

Adult and Juvenile	
Depth (ft)	Preference
0.00	0.00
0.35	0.00
1.35	0.55
1.65	0.74
2.05	0.93
2.15	1.00
2.45	1.00
3.65	0.76
3.95	0.68
4.25	0.50
99.00	0.50

Cutthroat Trout

Velocity Preference Curves



Fry	
Velocity (ft/s)	Preference
0.00	1.00
0.45	1.00
0.50	0.99
0.55	0.90
0.60	0.82
0.70	0.69
0.75	0.63
0.80	0.58
0.90	0.50
1.00	0.43
1.25	0.30
1.50	0.20
1.60	0.17
1.70	0.14
1.85	0.10
2.00	0.08
2.20	0.05
2.30	0.04
2.50	0.03
2.75	0.02
2.90	0.00

Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.15	0.00
0.55	0.55
0.95	0.85
1.45	1.00
2.95	0.70
4.75	0.00

Adult and Juvenile	
Velocity (ft/s)	Preference
0.00	0.89
0.25	1.00
0.35	1.00
1.95	0.60
3.05	0.29
3.95	0.00
99.00	0.00

Cutthroat Trout

Substrate Preference Criteria

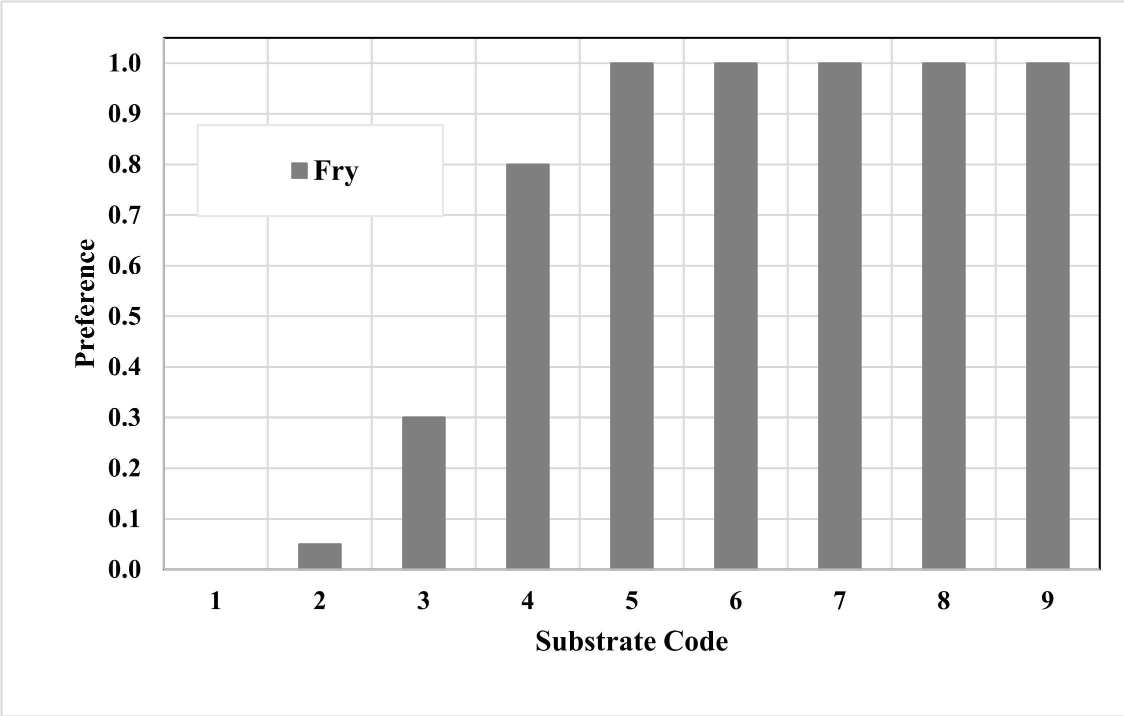
For Cutthroat Trout Spawning Substrate Preference, use Table 5 (Beecher et al. 2016)

For Cutthroat Trout Adult and Juvenile Substrate and Cover Preference, use Table 3 (Beecher et al. 2016)

For Cutthroat Trout Fry Substrate Preference, use data from the ESH Model

Cutthroat Trout

Substrate Preference

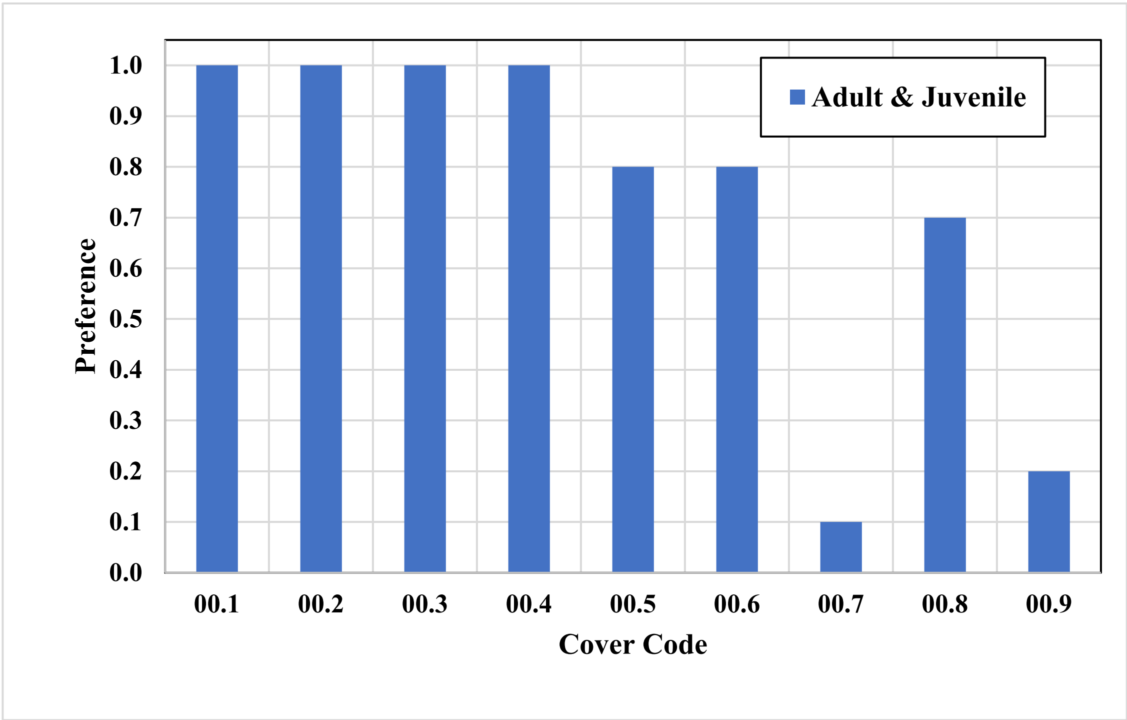


Sustrate Code	Substrate Type	Fry Preference
1	Silt, Clay, or Organic	0.00
2	Sand	0.05
3	Small Gravel (0.1-0.5")	0.30
4	Med Gravel (0.5-1.5")	0.80
5	Large Gravel (1.5-3.0")	1.00
6	Small Cobble (3.0-6.0")	1.00
7	Large Cobble (6.0-12")	1.00
8	Boulder (>12")	1.00
9	Bedrock	1.00

Source: ESH Model

Cutthroat Trout

Cover Preference



Code	Type of Cover Note: Cover Codes are not used for Spawning life stage	Adult & Juvenile Preference
00.1	Undercut bank	1.00
00.2	Overhanging vegetation near or touching water	1.00
00.3	Rootwad (including parly undercut)	1.00
00.4	Log jam/submerged brush pile	1.00
00.5	Log(s) parallel to bank	0.80
00.6	Aquatic vegetation	0.80
00.7	Short (<1 ft) terrestrial grass	0.10
00.8	Tall (>3 ft) dense grass	0.70
00.9	Vegetation >3 vertical ft above SZF	0.20

Source: Table 3, Beecher et al. 2016

Sea-Run Cutthroat Trout

Spawning (Group D)

For Sea-run Cutthroat Trout, HSC curves from several soucres were evaluated by the HSC Technical Group including WDFW/Ecology curves for Cutthroat Trout spawning (Type 3; 66 redds), curves used in the ESH model (hybrid Type 1-2), and Skookum Creek, WA (Losee et al. 2016). While it is WDFW/Ecology's preference to use statewide Type 3 HSC curves when available, for Sea-run Cutthorat Trout, the HSC Technical Group developed proposed consensus curves that basically envelop the WDFW/Ecology Type 3 curve for Cutthroat Trout spawning, but with a little broading of the peak preference range for both the depth and velocity HSC curves.

Additional Notes

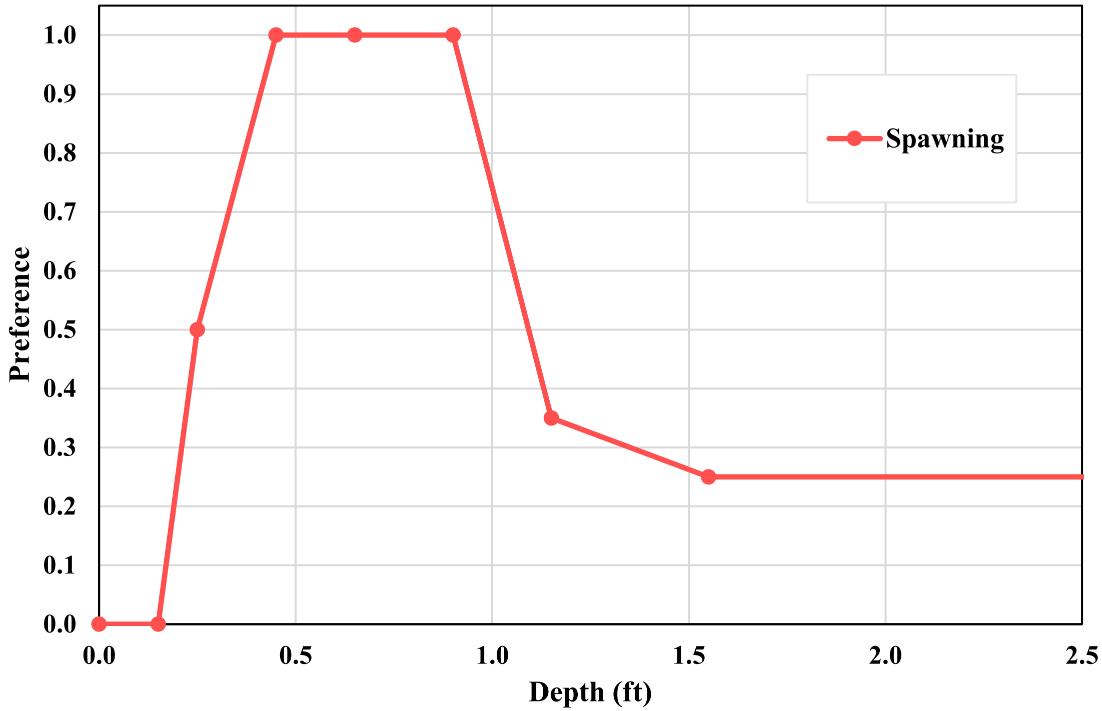
There is no clear biological evidence that depth becomes a limiting factor for spawning Sea-run Cutthroat Trout. Therefore, the HSC Technical Group recommended that once depth reaches 1.55 ft (0.25 preference), it be considered "non-limiting" in the HSC depth curve.

References

WDFW/Ecology: spawning (Beecher et al. 2016)
ESH model: spawning (Crumley and Stober 1984)
Additional sources of information:
Skookum Creek (Losee et al. 2016)
(Hickman and Raleigh 1982)
(Katopodis and Gervais 2016)

Sea-Run Cutthroat Trout

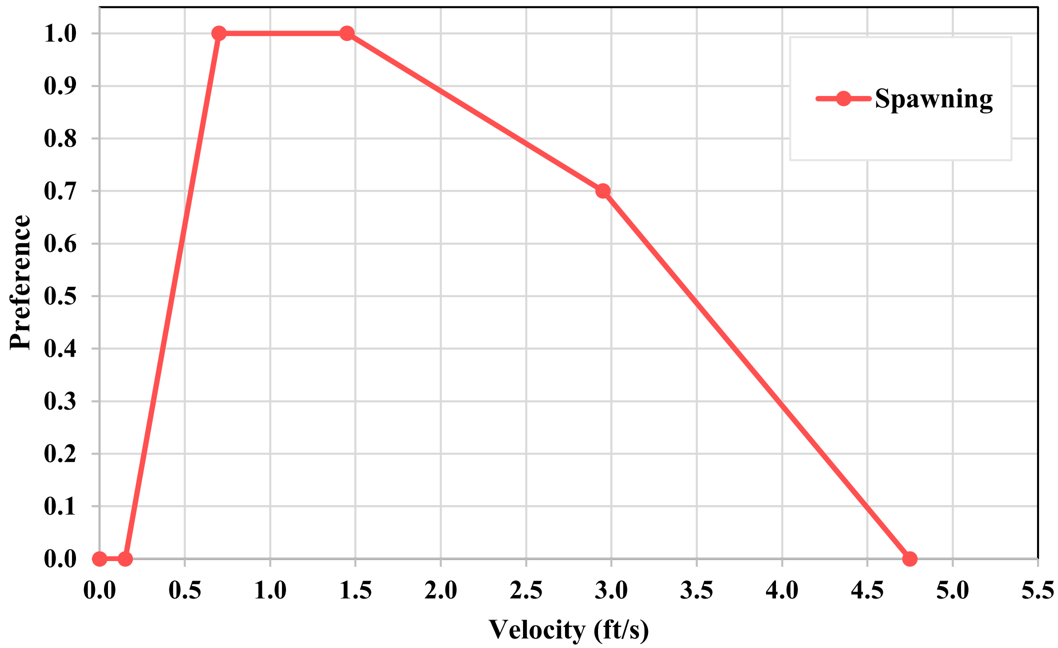
Depth Preference Curves



Spawning	
Depth (ft)	Preference
0.00	0.00
0.15	0.00
0.25	0.50
0.45	1.00
0.65	1.00
0.90	1.00
1.15	0.35
1.55	0.25
99	0.25

Sea-Run Cutthroat Trout

Velocity Preference Curves



Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.15	0.00
0.70	1.00
1.45	1.00
2.95	0.70
4.75	0.00

Substrate Preference Criteria

For Sea-Run Cutthorat Trout Spawning Substrate Preference, use Table 5 (Beecher et al. 2016)

Mountain Whitefish

General Approach

For Mountain Whitefish spawning, adult, and juvenile life stages, HSC curves from WDFW/Ecology (Type 3), the ESH model (hybrid Type 1-2), and the Fraser River (Type 2, juvenile only) were evaluated by the HSC Technical Group. It is WDFW/Ecology's preference to use the statewide Type 3 HSC curves when avaiailable unless additional site-specific field observation data is collected on the Skagit River in sufficient numbers to revisit, and possibly revise, the statewide curves. As a result, the recommended habitat modeling approach is to use the WDFW/Ecology Type 3 HSC curves for all three Mountain Whitefish life stages. Information specific to each life stage is provided below.

Spawning (Group C)

The WDFW/Ecology Type 3 HSC curves for Mountain Whitefish spawning are based on a composite of 8 Canadian studies totalling 3,789 fish observations [from the Oldman, Bow, Sheep, Kananaskis, Red Deer (2), and Highwood rivers] (Beecher et al. 2016).

Adult Rearing (Group C)

The WDFW/Ecology Type 3 HSC curves for Mountain Whitefish adult rearing are based on a composite of 8 Canadian studies totalling 1,616 fish observations [from the Oldman, Bow, Sheep, Kananaskis, Red Deer (2 studies), Highwood, and Fraser rivers] (Beecher et al. 2016).

Juvenile (Group C)

The WDFW/Ecology Type 3 HSC curves for Mountain Whitefish juvenile are based on a composite of 6 Canadian studies totalling 2,306 fish observations (from the Oldman, Bow, Kananaskis, Red Deer, Highwood, and Fraser rivers) (Beecher et al. 2016).

Fry (Group E)

Type 3 HSC curves are not available from WDFW/Ecology as the salmonid fry life stage is not commonly modeled in instream flow studies. However, habitat results for the fry life stage are of interest on the Skagit River in evaluating the relationship between flow and available habitat along the stream margins/shoreline areas as well as off-channel habitats that may be activated during higher flow events. As a result, the HSC Technical Group recommended using existing Type 2 fry curves when available. For Mountain Whitefish fry, the HSC Technical Group reviewed existing Type 2 curves used in the ESH model (Bovee 1978) as well as the Fraser River with a recommendation to use the ESH model curves for habitat modeling purposes. Habitat cover preference information was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

Additional Notes

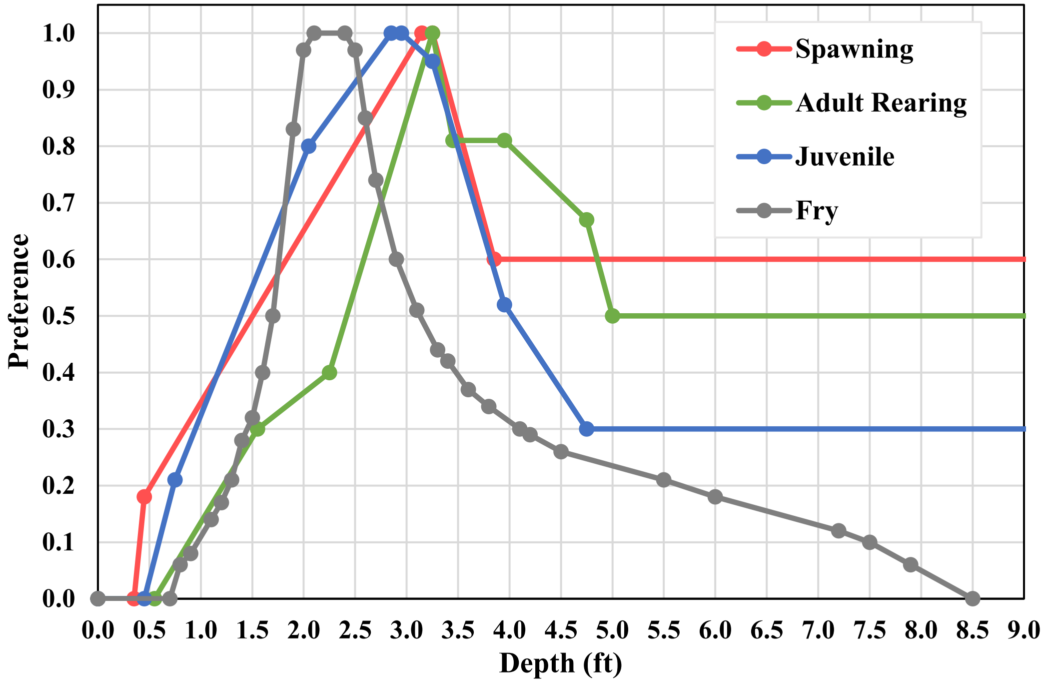
There is no clear biological evidence that depth becomes a limiting factor for spawning, adult rearing, and juvenile Mountain Whitefish. Therefore, the HSC Technical Group recommended that once depth reaches 3.85 ft for spawning (0.60 preference), 5.0 ft (0.50 preference) for adult rearing, and 4.75 ft (0.30 preference) for juvenile, it be considered "non-limiting" in the HSC depth curves.

References

WDFW/Ecology: spawning, adult rearing, and juvenile (Beecher et al. 2016)
ESH model: spawning and fry (Bovee 1978); adult and juvenile (Bovee 1978; Crumley and Stober 1984)
Fraser River: juvenile and fry (Rempel et al. 2012)

Mountain Whitefish

Depth Preference Curves



Spawning	
Depth (ft)	Preference
0.00	0.00
0.35	0.00
0.45	0.18
3.15	1.00
3.25	1.00
3.85	0.60
99.00	0.60

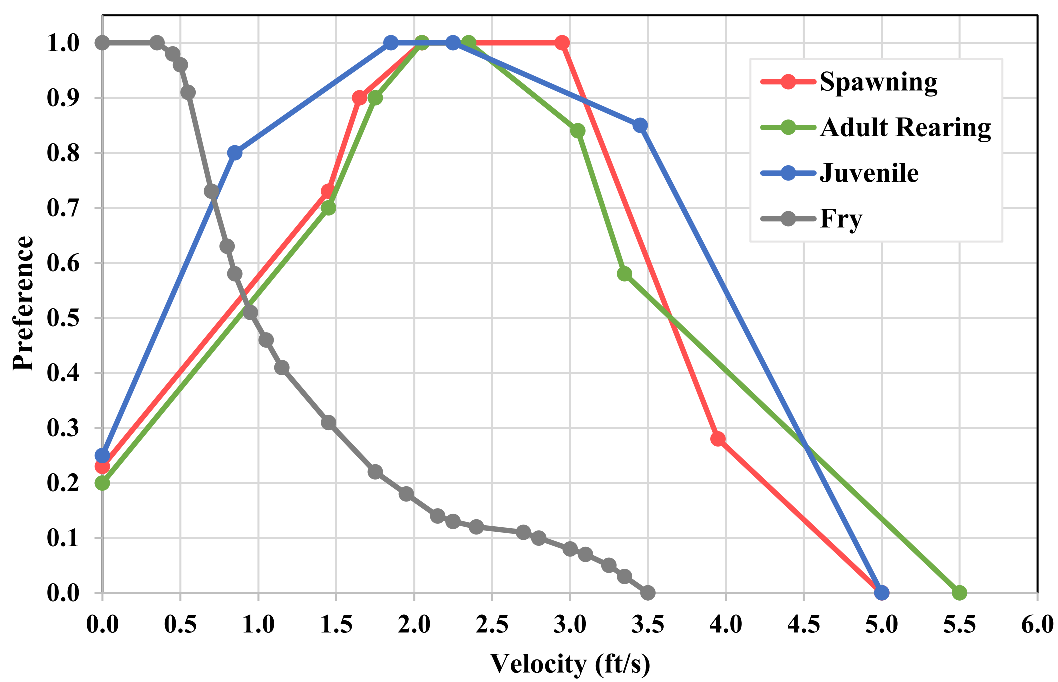
Adult Rearing	
Depth (ft)	Preference
0.00	0.00
0.55	0.00
1.55	0.30
2.25	0.40
3.25	1.00
3.45	0.81
3.95	0.81
4.75	0.67
5.00	0.50
99.00	0.50

Juvenile	
Depth (ft)	Preference
0.00	0.00
0.45	0.00
0.75	0.21
2.05	0.80
2.85	1.00
2.95	1.00
3.25	0.95
3.95	0.52
4.75	0.30
99.00	0.30

Fry	
Depth (ft)	Preference
0.00	0.00
0.70	0.00
0.80	0.06
0.90	0.08
1.10	0.14
1.20	0.17
1.30	0.21
1.40	0.28
1.50	0.32
1.60	0.40
1.70	0.50
1.90	0.83
2.00	0.97
2.10	1.00
2.40	1.00
2.50	0.97
2.60	0.85
2.70	0.74
2.90	0.60
3.10	0.51
3.30	0.44
3.40	0.42
3.60	0.37
3.80	0.34
4.10	0.30
4.20	0.29
4.50	0.26
5.50	0.21
6.00	0.18
7.20	0.12
7.50	0.10
7.90	0.06
8.50	0.00

Mountain Whitefish

Velocity Preference Curves



Spawning	
Velocity (ft/s)	Preference
0.00	0.23
1.45	0.73
1.65	0.90
2.05	1.00
2.95	1.00
3.95	0.28
5.00	0.00

Adult Rearing	
Velocity (ft/s)	Preference
0.00	0.20
1.45	0.70
1.75	0.90
2.05	1.00
2.35	1.00
3.05	0.84
3.35	0.58
5.50	0.00

Juvenile	
Velocity (ft/s)	Preference
0.00	0.25
0.85	0.80
1.85	1.00
2.25	1.00
3.45	0.85
5.00	0.00

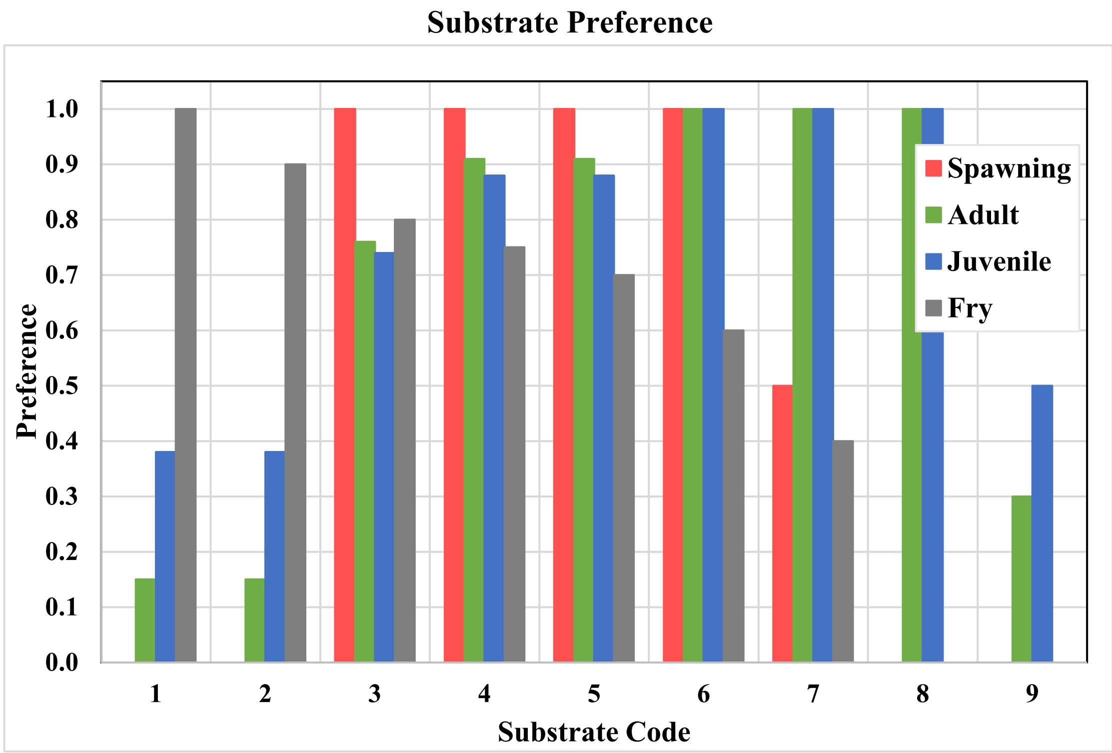
Fry	
Velocity (ft/s)	Preference
0.00	1.00
0.35	1.00
0.45	0.98
0.50	0.96
0.55	0.91
0.70	0.73
0.80	0.63
0.85	0.58
0.95	0.51
1.05	0.46
1.15	0.41
1.45	0.31
1.75	0.22
1.95	0.18
2.15	0.14
2.25	0.13
2.40	0.12
2.70	0.11
2.80	0.10
3.00	0.08
3.10	0.07
3.25	0.05
3.35	0.03
3.50	0.00

Mountain Whitefish

Substrate Preference Criteria

For Mountain Whitefish Spawning Substrate Preference, use Table 7 (Beecher et al. 2016)
For Mountain Whitefish Adult Rearing Substrate Preference, use Table 8 (Beecher et al. 2016)
For Mountain Whitefish Juvenile Substrate Preference, use Table 9 (Beecher et al. 2016)
For Mountain Whitefish Fry Substrate Preference, use data from the ESH Model

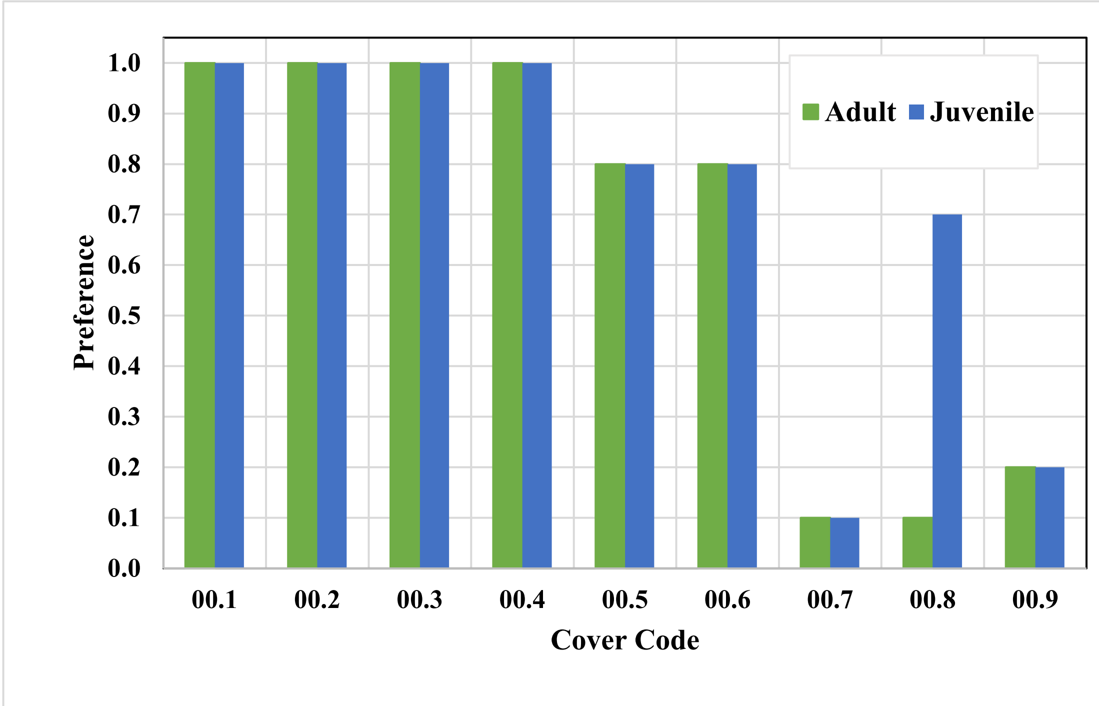
Mountain Whitefish



Sustrate Code	Substrate Type	Spawning	Adult	Juvenile	Fry
1	Silt, Clay, or Organic	0.00	0.15	0.38	1.00
2	Sand	0.00	0.15	0.38	0.90
3	Small Gravel (0.1-0.5")	1.00	0.76	0.74	0.80
4	Med Gravel (0.5-1.5")	1.00	0.91	0.88	0.75
5	Large Gravel (1.5-3.0")	1.00	0.91	0.88	0.70
6	Small Cobble (3.0-6.0")	1.00	1.00	1.00	0.60
7	Large Cobble (6.0-12")	0.50	1.00	1.00	0.40
8	Boulder (>12")	0.00	1.00	1.00	0.00
9	Bedrock	0.00	0.30	0.50	0.00
Source: Beecher et al. 2016		Table 15	Table 16	Table 17	ESH Model

Mountain Whitefish

Cover Preference



Code	Type of Cover Note: Cover Codes are not used for Spawning life stage	Adult Preference	Juvenile Preference
00.1	Undercut bank	1.00	1.00
00.2	Overhanging vegetation near or touching water	1.00	1.00
00.3	Rootwad (including parly undercut)	1.00	1.00
00.4	Log jam/submerged brush pile	1.00	1.00
00.5	Log(s) parallel to bank	0.80	0.80
00.6	Aquatic vegetation	0.80	0.80
00.7	Short (<1 ft) terrestrial grass	0.10	0.10
00.8	Tall (>3 ft) dense grass	0.10	0.70
00.9	Vegetation >3 vertical ft above SZF	0.20	0.20

Source: Table 1, Beecher et al. 2016

Pacific Lamprey

Spawning (Group D)

WDFW/Ecology HSC curves are not available and Pacific Lamprey HSC curves are not included in the ESH model. The HSC Technical Group reviewed HSC curves from other studies and developed proposed consensus curves using that information. The proposed consensus curves envelop depth and velocity preferences from studies on the Lower Merced and Chehalis Rivers and Vadas 2021 literature with a recommended extension of suboptimal preference (i.e., preference = 0.5) depth to 7 ft made by Ralph Lampman (a lamprey research biologist at Yakama Nation Fisheries in Prosser, WA).

Juvenile Rearing (Group D)

WDFW/Ecology HSC curves are not available and Pacific Lamprey HSC curves are not included in the ESH model. The HSC Technical Group reviewed HSC curves from other studies and developed proposed consensus curves using that information. The proposed consensus curves envelop depth and velocity preferences from studies on the Chehalis River (Winkowksi and Kendall 2018) and Vadas 2021 literature. Note due to uncertainty about maximum depth and velocity preferences, both HSC curves have been extended to infinity at a preference of 0.1.

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for spawning and juvenile rearing Pacific Lamprey. Therefore, the HSC Technical Group recommended that once depth reaches 9.0 ft for spawning (0.10 preference) and 5.0 ft (0.10 preference) for juvenile rearing, it be considered "non-limiting" in the HSC depth curves.

Habitat cover preference information for Pacific Lamprey was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

References

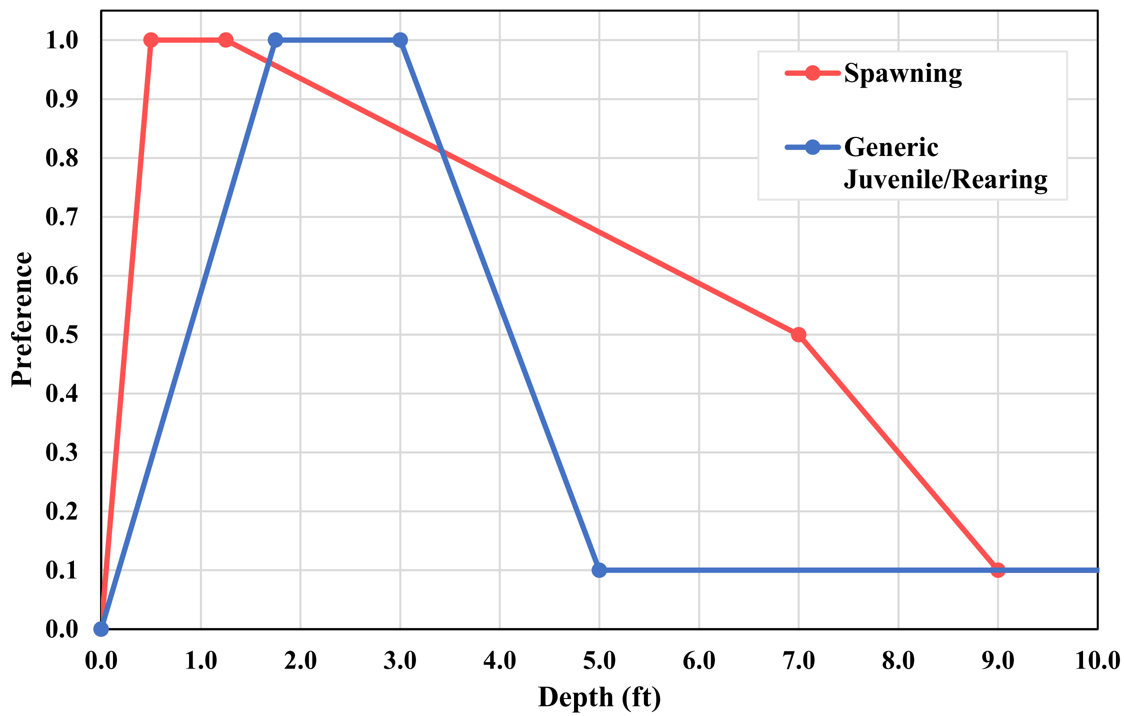
West-coast lamprey species based on literature review of West Fork Hoquiam River, Chehalis River basin and Trapp Creek, Washington and Nichola/coastal Salmon River, British Columbia (Vadas 2000, 2013, and 2021)

Chehalis River, Washington (Winkowski and Kendall 2018)

Additional data source:
Smith River, Oregon (Gunckel et al. 2006)

Pacific Lamprey

Depth Preference Curves

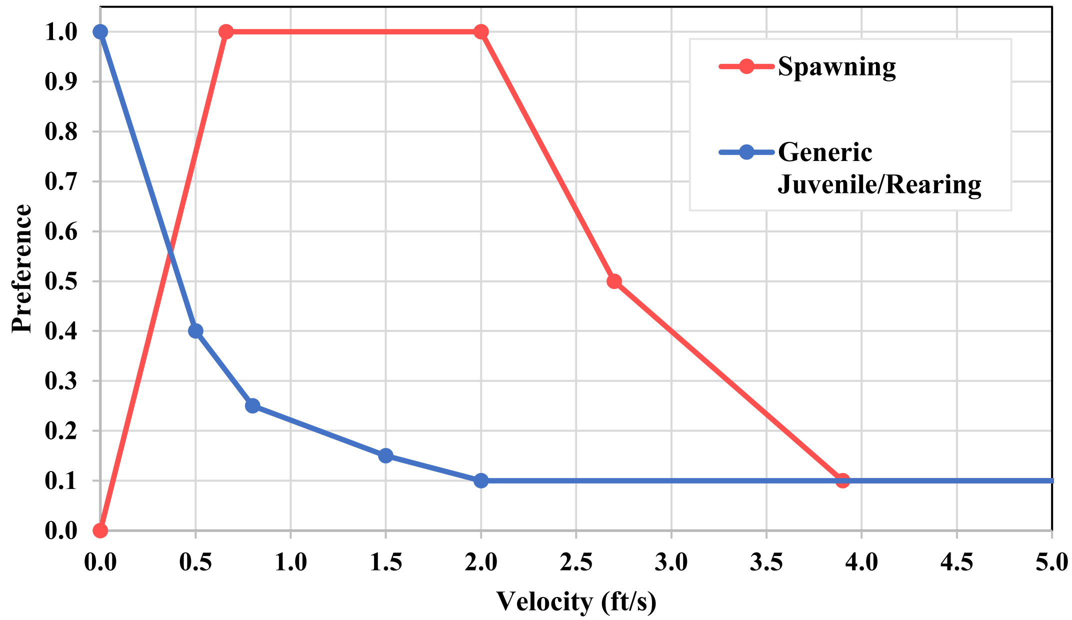


Spawning	
Depth (ft)	Preference
0.00	0.00
0.50	1.00
1.25	1.00
7.00	0.50
9.00	0.10
99.00	0.10

Generic	
Depth (ft)	Preference
0.00	0.00
1.75	1.00
3.00	1.00
5.00	0.10
99.00	0.10

Pacific Lamprey

Velocity Preference Curves

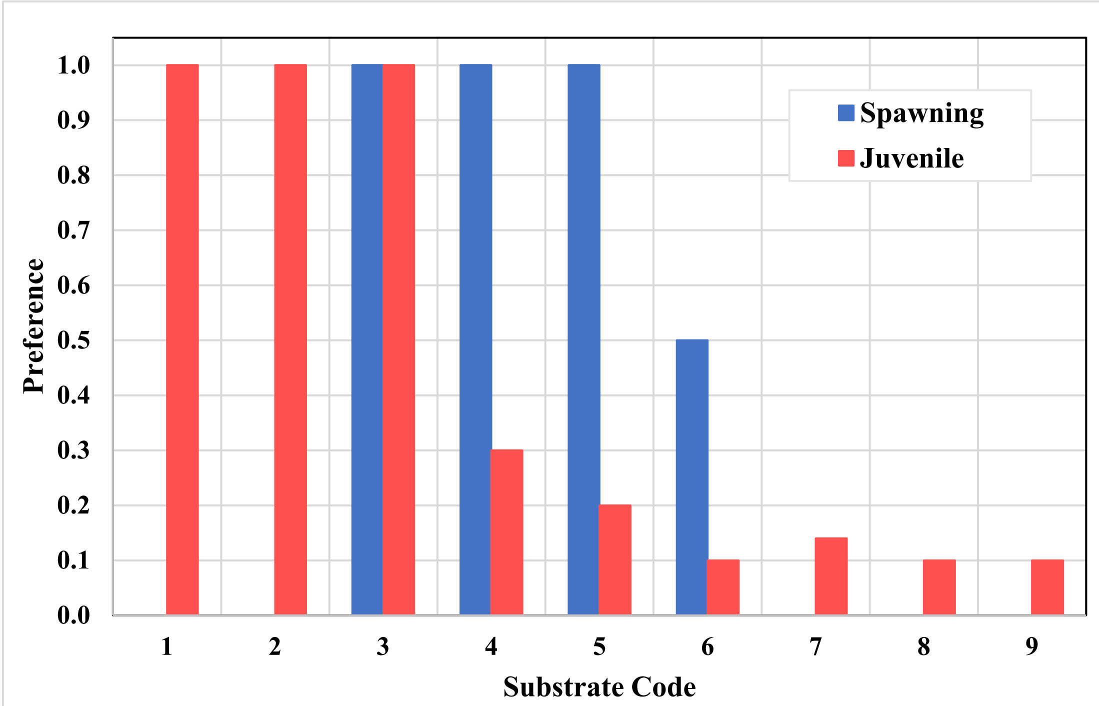


Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.66	1.00
2.00	1.00
2.70	0.50
3.90	0.10
99.00	0.10

Generic	
Velocity (ft/s)	Preference
0.00	1.00
0.50	0.40
0.80	0.25
1.50	0.15
2.00	0.10
99.00	0.10

Pacific Lamprey

Substrate Preference



Sustrate Code	Substrate Type	Spawning Preference	Juvenile Preference
1	Silt, Clay, or Organic	0.0	1.0
2	Sand	0.0	1.0
3	Small Gravel (0.1-0.5")	1.0	1.0
4	Med Gravel (0.5-1.5")	1.0	0.3
5	Large Gravel (1.5-3.0")	1.0	0.2
6	Small Cobble (3.0-6.0")	0.5	0.1
7	Large Cobble (6.0-12")	0.0	0.1
8	Boulder (>12")	0.0	0.1
9	Bedrock	0.0	0.1

Source: Vadas 2021

Western Brook & Western River Lamprey

Western Brook Lamprey Spawning (Group F)

WDFW/Ecology HSC curves are not available and Western Brook Lamprey HSC curves are not included in the ESH model. The HSC Technical Group reviewed HSC curves from other studies and developed proposed consensus curves using that information. The proposed consensus curve is based on research and literature review by Vadas (2000, 2013, and 2021) which includes data from the West Fork Hoquiam River, WA; Nichola/coastal Salmon River, BC; Trapp Creek, WA, and Chehalis River basin, WA.

Western River Lamprey Spawning (Group F)

WDFW/Ecology HSC curves are not available and Western River Lamprey HSC curves are not included in the ESH model. The HSC Technical Group reviewed HSC curves from other studies and developed proposed consensus curves using that information. The proposed consensus curve is based on Vadas 2021 which includes data from the West Fork Hoquiam River, WA; Nichola/coastal Salmon River, BC; Trapp Creek, WA, and Chehalis River basin, WA.

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for spawning Western Brook Lamprey and Western River Lamprey. Therefore, the HSC Technical Group recommended that once depth reaches 1.40 ft for Western Brooke Lamprey (0.10 preference) and 1.80 ft (0.10 preference) for Western River Lamprey, it be considered "non-limiting" in the HSC depth curves.

Habitat cover preference information for Western Brook Lamprey and Western River Lamprey was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

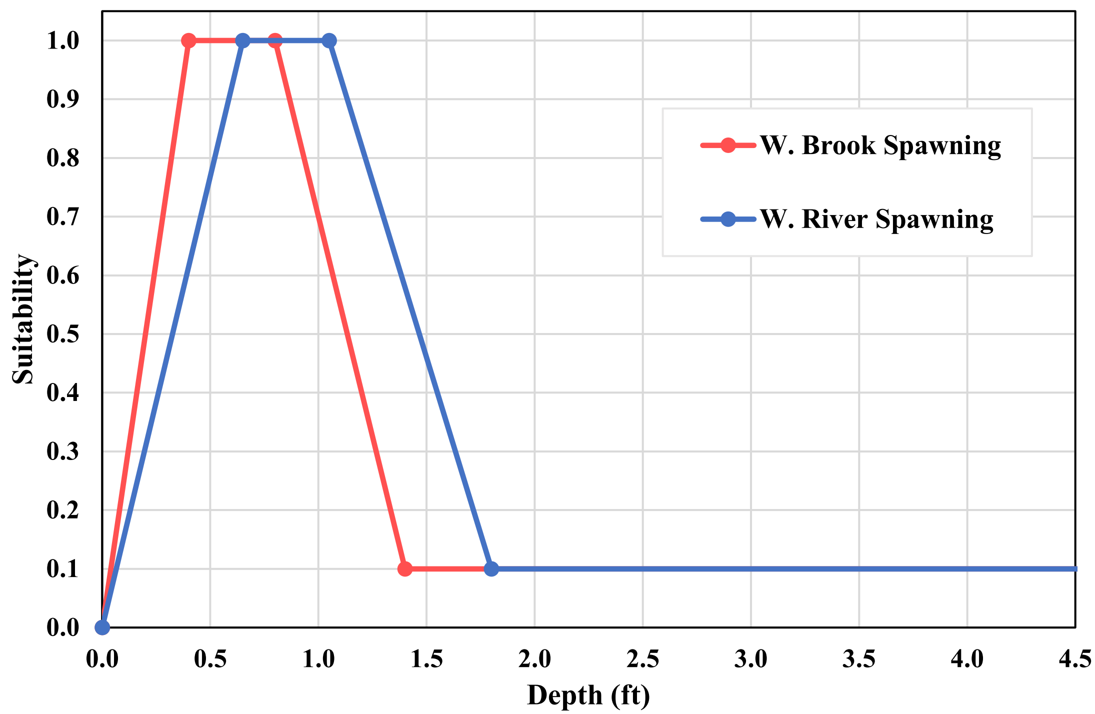
References

West-coast lamprey species based on literature review of West Fork Hoquiam River, Chehalis River basin and Trapp Creek, Washington and Nichola/coastal Salmon River, British Columbia (Vadas 2000, 2013, and 2021)

Additional data source:
(Gunckel et al. 2006)

Western Brook & Western River Lamprey

Depth Preference Curves

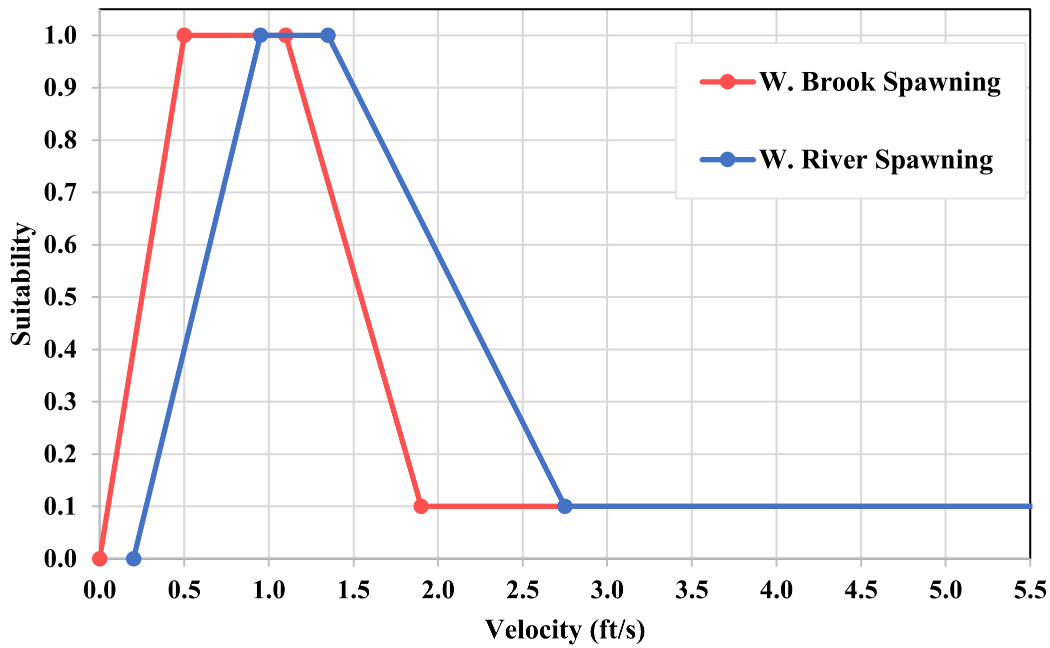


W. Brook Spawning	
Depth (ft)	Preference
0.00	0.00
0.40	1.00
0.80	1.00
1.40	0.10
99.00	0.10

W. River Spawning	
Depth (ft)	Preference
0.00	0.00
0.65	1.00
1.05	1.00
1.80	0.10
99.00	0.10

Western Brook & Western River Lamprey

Velocity Preference Curves

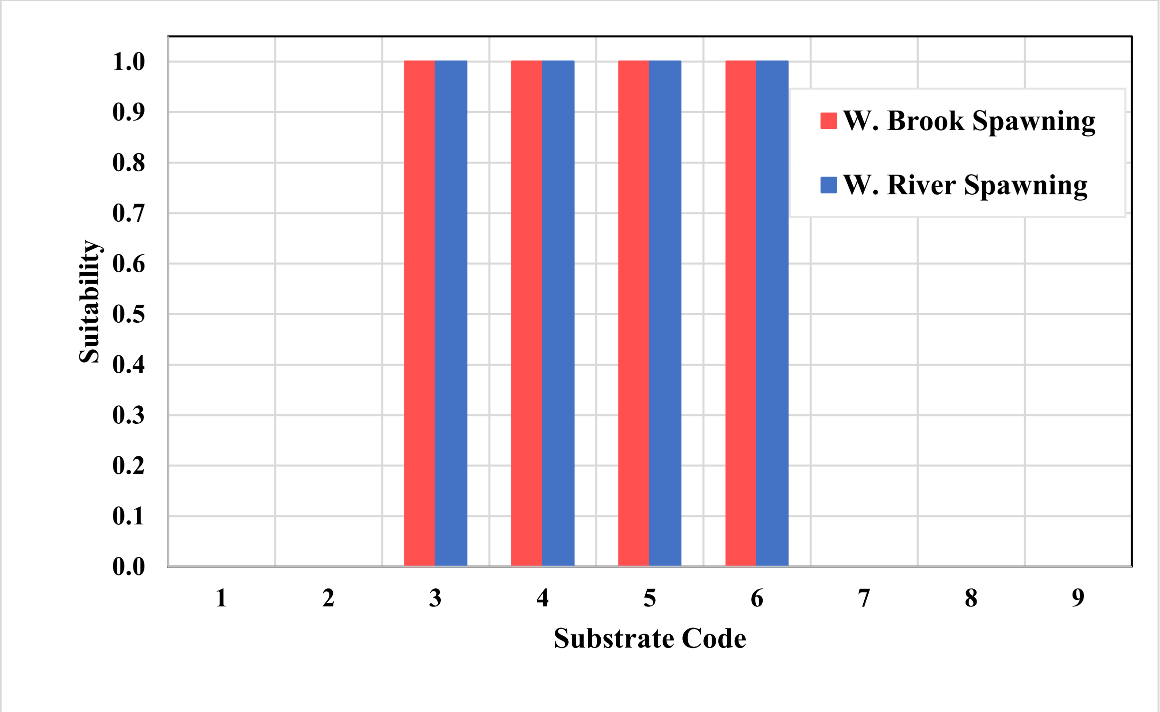


W. Brook Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.50	1.00
1.10	1.00
1.90	0.10
99.00	0.10

W. River Spawning	
Velocity (ft/s)	Preference
0.20	0.00
0.95	1.00
1.35	1.00
2.75	0.10
99.00	0.10

Western Brook & Western River Lamprey

Substrate Preference Criteria



Sustrate Code	Substrate Type	W. Brook Preference	W. River Preference
1	Silt, Clay, or Organic	0.0	0.0
2	Sand	0.0	0.0
3	Small Gravel (0.1-0.5")	1.0	1.0
4	Med Gravel (0.5-1.5")	1.0	1.0
5	Large Gravel (1.5-3.0")	1.0	1.0
6	Small Cobble (3.0-6.0")	1.0	1.0
7	Large Cobble (6.0-12")	0.0	0.0
8	Boulder (>12")	0.0	0.0
9	Bedrock	0.0	0.0

Source: Vadas 2021

Salish Sucker

Spawning (Group F)

WDFW/Ecology HSC curves are not available and Sailish Sucker spawning HSC curves are not included in the ESH model. The HSC Technical Group reviewed literature and HSC data from several sources in Washington State and western Canada (see references cited below). The proposed consensus curves are largely based on research performed by Pearson et al. (2000 and 2003) with a slightly broader peak depth preference that extends an additional 0.5 ft from 2.0 ft to 2.5 ft and a slightly broader peak velocity preference that extends an additional 0.35 ft/s from 1.65 ft/s to 2.0 ft/s.

Juvenile Rearing (Group F)

WDFW/Ecology HSC curves are not available and Sailish Sucker juvenile rearing HSC curves are not included in the ESH model. The HSC Technical Group reviewed literature and HSC data from several sources in Washington State and western Canada (see references cited below). The proposed consensus curves are largely based on research performed by Pearson et al. (2000 and 2003) with a slightly broader peak depth preference range and slightly extended sub-optimal velocity preference range.

Additional Notes

There is no clear biological evidence that depth becomes a limiting factor for juvenile rearing Salish Sucker. Therefore, the HSC Technical Group recommended that once depth reaches 3.0 ft (0.50 preference) for juvenile rearing, it be considered "non-limiting" in the HSC depth curves.

Habitat cover preference information for Sailish Sucker spawning life stage was not available from literature, so this physical attribute will be removed from the habitat modeling process (i.e., habitat model results will be based on depth, velocity, and substrate preferences).

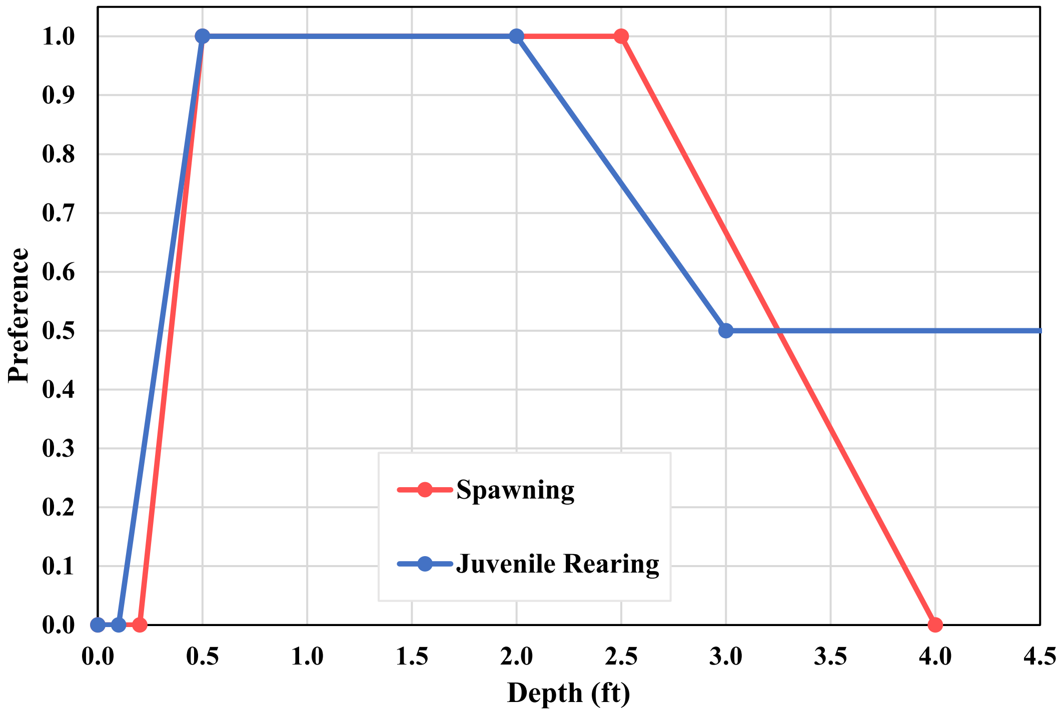
References

Consensus HSC curves: (Pearson et al. 2000 and 2003)

Additional sources of information:
COSEWIC 2012
McPhail 1986
Washington Department of Fish and Wildlife 2015

Salish Sucker

Depth Preference Curves

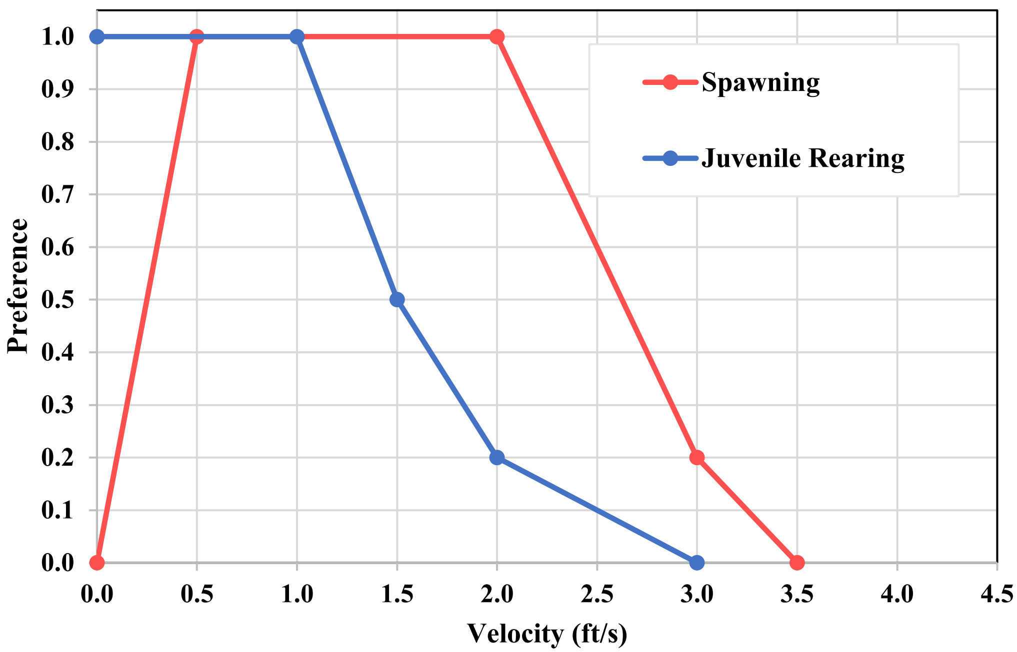


Spawning	
Depth (ft)	Preference
0.00	0.00
0.20	0.00
0.50	1.00
2.50	1.00
4.00	0.00

Juvenile Rearing	
Depth (ft)	Preference
0.00	0.00
0.10	0.00
0.50	1.00
2.00	1.00
3.00	0.50
99.00	0.50

Salish Sucker

Velocity Preference Curves

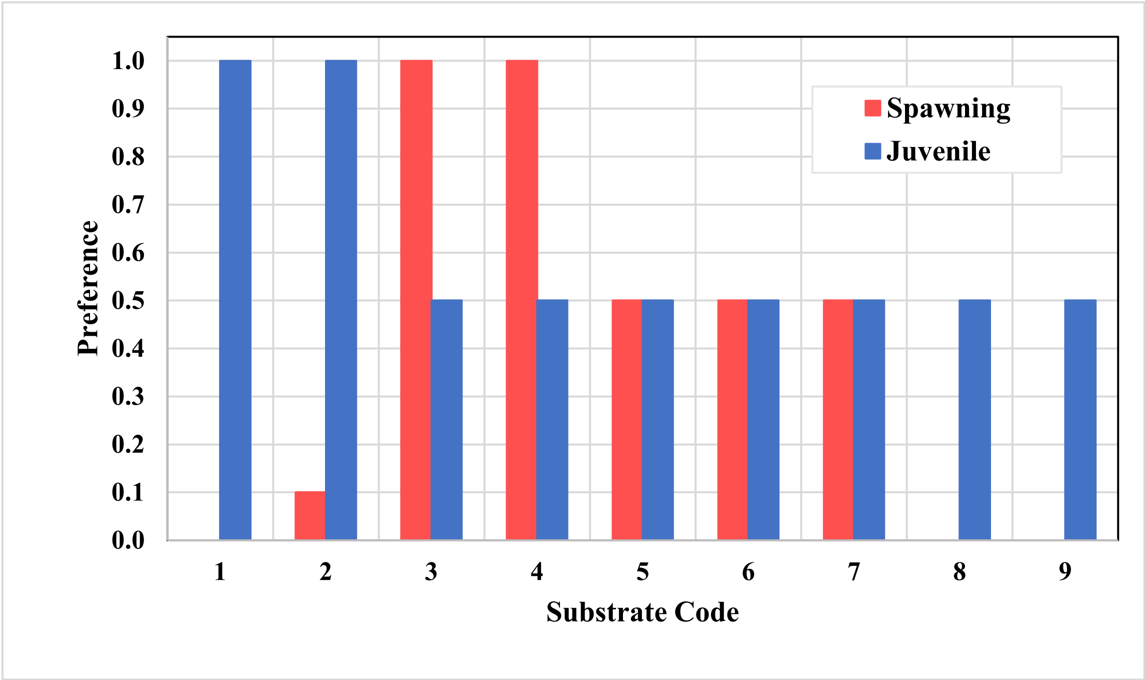


Spawning	
Velocity (ft/s)	Preference
0.00	0.00
0.50	1.00
2.00	1.00
3.00	0.20
3.50	0.00

Juvenile Rearing	
Velocity (ft/s)	Preference
0.00	1.00
1.00	1.00
1.50	0.50
2.00	0.20
3.00	0.00

Salish Sucker

Substrate Preference

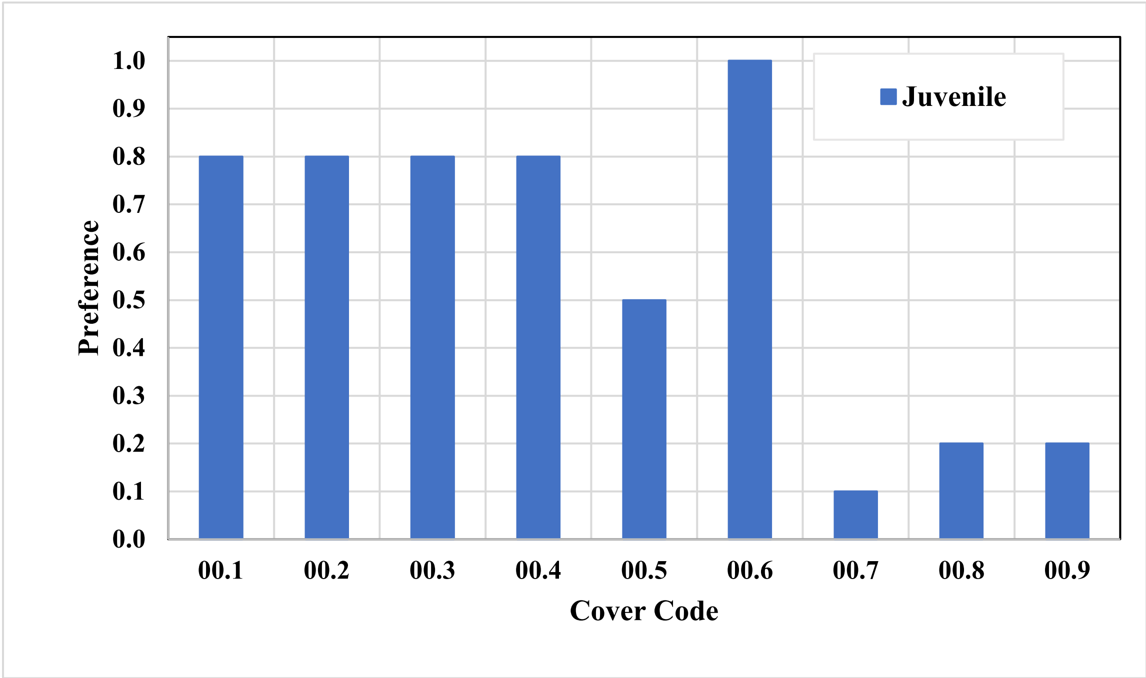


Sustrate Code	Substrate Type	Spawning Preference	Juvenile Preference
1	Silt, Clay, or Organic	0.0	1.0
2	Sand	0.1	1.0
3	Small Gravel (0.1-0.5")	1.0	0.5
4	Med Gravel (0.5-1.5")	1.0	0.5
5	Large Gravel (1.5-3.0")	0.5	0.5
6	Small Cobble (3.0-6.0")	0.5	0.5
7	Large Cobble (6.0-12")	0.5	0.5
8	Boulder (>12")	0.0	0.5
9	Bedrock	0.0	0.5

Source: Pearson et al. 2003

Salish Sucker

Cover Preference



Code	Type of Cover Note: Cover Codes are not used for Spawning	Juvenile Preference
00.1	Undercut bank	0.80
00.2	Overhanging vegetation near or touching	0.80
00.3	Rootwad (including parly undercut)	0.80
00.4	Log jam/submerged brush pile	0.80
00.5	Log(s) parallel to bank	0.50
00.6	Aquatic vegetation	1.00
00.7	Short (<1 ft) terrestrial grass	0.10
00.8	Tall (>3 ft) dense grass	0.20
00.9	Vegetation >3 vertical ft above SZF	0.20

Source: Pearson et al. 2003

White Sturgeon

Spawning (Group F)

WDFW/Ecology HSC curves are not available and White Sturgeon HSC curves are not included in the ESH model. The HSC Technical Group reviewed HSC curves from studies on the Columbia River, WA and Sacramento River, CA. The HSC Technical Group considered the Sacramento River curves to be more representative of the Skagit River as these two rivers are more comparable in size compared to the Columbia River which is much larger; albeit, both sets of HSC curves are similar. As a result, the Sacramento River HSC curves are recommended for habitat modeling.

Additional Notes

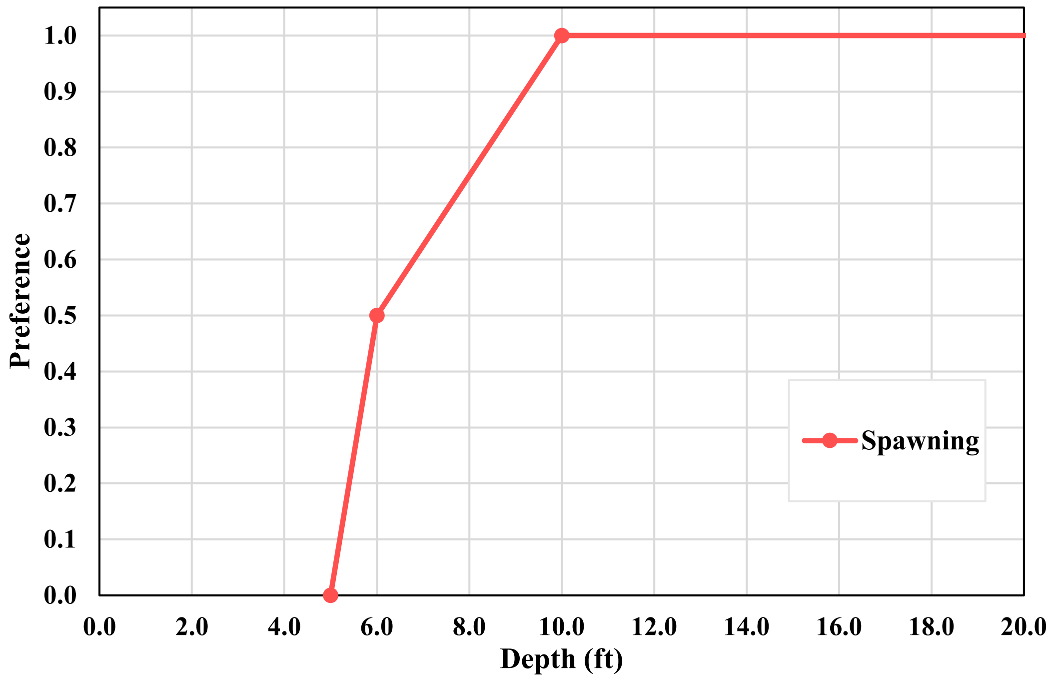
There is no clear biological evidence that depth becomes a limiting factor for spawning White Sturgeon. Therefore, the Sacramento River HSC depth curve is considered to be "non-limiting" once depth reaches 10.0 ft (1.0 preference).

References

Sacramento River: spawning (Gard 1996)

White Sturgeon

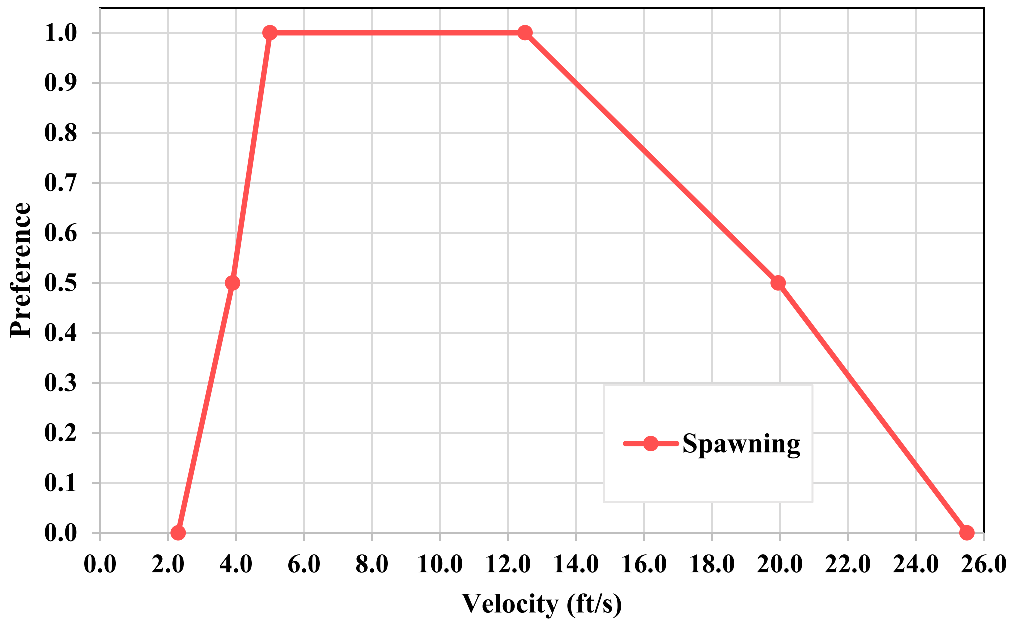
Depth Preference Curves



Spawning	
Depth (ft)	Preference
5.00	0.00
6.00	0.50
10.00	1.00
99.00	1.00

White Sturgeon

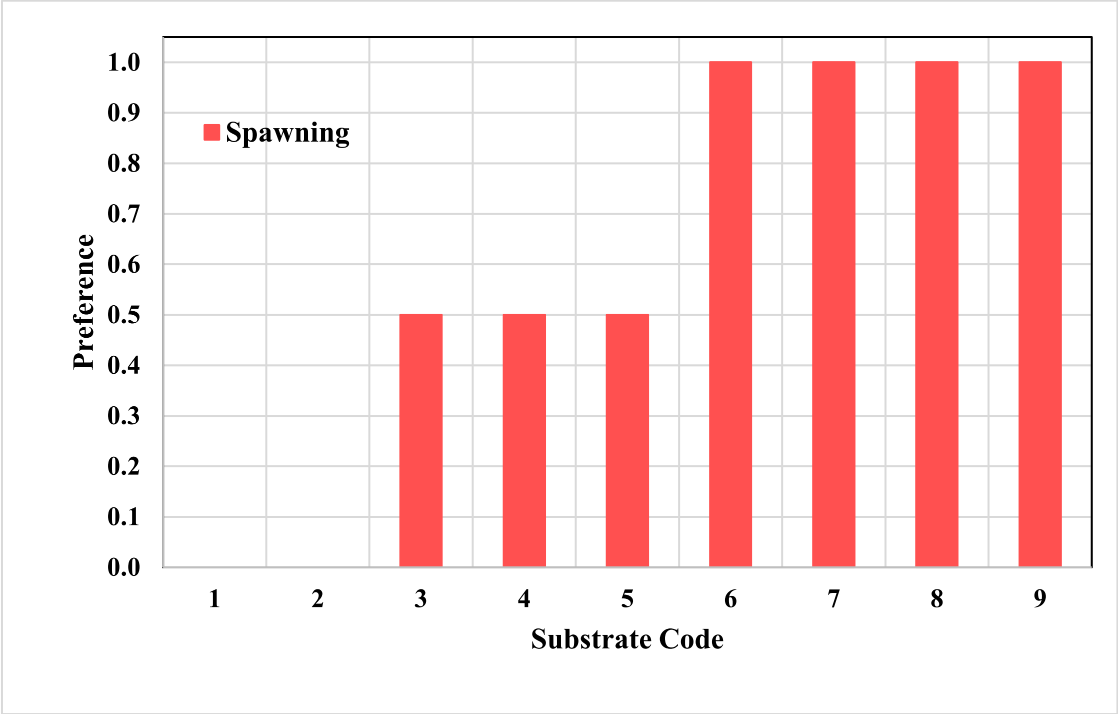
Velocity Preference Curves



Spawning	
Velocity (ft/s)	Preference
2.30	0.00
3.90	0.50
5.00	1.00
12.50	1.00
19.95	0.50
25.50	0.00

White Sturgeon

Substrate Preference Criteria



Sustrate Code	Substrate Type	Spawning Preference
1	Silt, Clay, or Organic	0.0
2	Sand	0.0
3	Small Gravel (0.1-0.5")	0.5
4	Med Gravel (0.5-1.5")	0.5
5	Large Gravel (1.5-3.0")	0.5
6	Small Cobble (3.0-6.0")	1.0
7	Large Cobble (6.0-12")	1.0
8	Boulder (>12")	1.0
9	Bedrock	1.0

Source: Gard 1996

REFERENCE LIST used for Skagit River HSC review and development

1 Baxter, J.S. 1995. Chowade River bull trout studies (1995): habitat and population assessment. Report to Ministry of Environment, Lands and Parks (Fort St John), Fisheries Branch, British Columbia, 108 pages.

2 Beecher, H. A., B. A. Caldwell, and S. B. DeMond. 2002. Evaluation of depth, velocity, substrate, and cover preferences of juvenile coho salmon (Oncorhynchus kisutch) in Washington streams. North American Journal of Fisheries Management 22 (3): 785-795. (Beecher et al. 2002)

3 Beecher, H. A., B. A. Caldwell, S. B. DeMond, D. Seiler, and S. N. Boessow. 2010. An empirical assessment of PHABSIM using long-term monitoring of coho salmon smolt production in Bingham Creek, Washington. NAJFM 30:6, 1529-1543. (Beecher et al. 2010)

Beecher, H. A., B. A. Caldwell, and J. Pacheco. 2013. Instream Flow Study Guidelines. Technical and Habitat Suitability Issues Including Fish Preference Curves. Washington Dept. of Fish and Wildlife and Washing State Dept. of Ecology. Updated April 1, 2013.

4 Beecher, H. A., B. A. Caldwell, and J. Pacheco. 2016. Instream Flow Study Guidelines. Technical and Habitat Suitability Issues Including Fish Preference Curves. Washington Dept. of Fish and Wildlife and Washing State Dept. of Ecology. Updated March 9, 2016.

5 Bovee, K.D. 1978. Probability of use criteria for the family Salmonidae. Instream Flow Information Paper No. 4. U.S. Fish Wildl. Serv. FWS/OBS-78/07.

6 Bovee, K.D. 1986. Development and Evaluation of Habitat Suitability Criteria for Use in the Intream Flow Incremental Methodology. Instream Flow Information Paper No. 21. U.S. Fish Wildl. Serv. FWS/OBS-86/7.

7 Bustard, D. and D. Royea. 1995. Kemess South Gold-Copper Project 1994 Fisheries Study. Report of Dave Bustard and Associates and Hallem Knight Piesold Limited to El Condor resources Limited and St. Phillips Resources Incorporated, Vancouver, British Columbia.

8 COSEWIC 2012. Assessment and update status report on the Salish Sucker *Catostomus* sp. in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 36 pages.

9 Crumley, S.C., and Q.J. Stober 1984. Skagit River interim agreement. Volume 1: Instream flow habitat analysis. Appendices. Final Report for Seattle City Light. 1332 pages.

Additional sources relied upon by Crumley and Stober:

10 AEIDC Arctic Environmental Information and Data Center 1981. An assessment of environmental effects of construction and operation of the Terror Lake hydroelectric facility, Kodiak, Alaska.

11 FRI Fisheries Research Institute, University of Washington. Data only (no

12 WDF Washington State Department of Fisheries. 1977. Salmon spawning groud data report. Progress Report 17. 346 pp.

13 WDF Washington State Department of Fisheries. 1982. Puget Sound salmon spawning groud data report. Water resource inventory areas 1 - 19 for escapement years 1978 - 1981. Progress Report 175. 574 pp.

14 WDF Washington State Department of Fisheries. 1983. Puget Sound salmon spawning groud data report. Water resource inventory areas 1 - 19 for escapement years 1982 - 1983. Progress Report 194. 157 pp.

15 WDG Washington State Game Department. 1980. Steelhead program progress report. April 1, 1980 - June 30, 1980. Cooperative agreement numbers 14-16-0001-5776FS, 14-16-0001-6345IFC between the United States Fish and Wildlife Service and the Washington State Game Department. 217 pp.

16 Gard, M. 1996. Sacramento River White sturgeon spawning criteria. USFWS. Ecological Services. Sacramento Field Office. 13 p.

REFERENCE LIST used for Skagit River HSC review and development

17 Granger, R. 2021. Updated HSC curves for Bull Trout and Dolly Varden juvenile and Cutthroat Trout juvenile. Personnal communication (email). Received 12/28/2021.

18 Gunckel, S, Jones, K., and Jacobs, S. 2006. Spawning distribution and habitat use of adult Pacific and western brook lampreys in Smith River, Oregon.

19 Hampton, M., T.R. Payne, and J. Thomas 1997. Microhabitat suitability for anadromous salmonids of the Trinity River, California. USFWS, Coastal California Fish and Wildlife Office.

20 Hardin, T.S., Grost, R.T., Ward, M.B., and Smith, G.E., 2005, Habitat suitability criteria for anadromous salmonids in the Klamath River, Iron Gate Dam to Scott River, California: California Department of Fish and Game, Stream Evaluation Report No. 05–1, 75 pages.

21 Hardin-Davis, Inc., Hosey & Associates Engineering Co., Clearwater Biostudies, Inc. 1990. Habitat suitability criteria for salmonids of the McKenzie River. Prepared for the Eugene Water and Electric Board.

22 Hardy, T.B., and C. Addley. 2001. Evaluation of interim instream flow needs in the Klamath River Phase 2 Report. US Department of Interior.

23 Hickman, T., and R. F. Raleigh. 1982. Habitat suitability index models: Cutthroat trout. USDI Fish and Wildlife Service. FWS/OBS-82/10.5. 38 pages.

24 Katopodis, C. and R. Gervais. 2016. Fish swimming performance database and analyses. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/002. vi + 550 pages.

25 Losee, J. P., L. Phillips, and B. Young. 2016. Spawn timing and redd morphology of anadromous Coastal Cutthroat Trout, Oncorhynchus clarkii clarkia, in a tributary of South Puget Sound Washington. North American Journal of Fisheries Management 36:375–384.

26 McPhail, J. D., and Baxter 1996. A review of bull trout (Salvelinus confluentus) life history and habitat use in relation to compensation and improvement opportunities (Fisheries Management Report 104.

27 McPhail, J.D. 1986. COSEWIC status report on the Salish Sucker *Catostomus* sp. in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 29 pages.

28 O'Brien, D. S. 1996. Findings of the 1995 Duncan bull trout radiotelemetry project. Report submitted to Columbia Basin Fish and Wildlife Compensation Program, Nelson, British Columbia, 107 p.

29 Pearson, M. P., in L. M. Darling, editor. 2000. Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., 15 - 19 Feb.,1999. Volume Two. B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. and University College of the Cariboo, Kamloops, B.C. pages 619-624.

30 Pearson, M.P., and M.C. Healy. 2003. Life-history characteristics of the Salish sucker, Catostomus sp., and their implications for management. Copeia 2003: 759-768.

31 Rempel, L.L., Healey, K. and Lewis, F.J.A. 2012. Lower Fraser River juvenile fish habitat suitability criteria. Can. Tech. Rep. Fish. Aquat. Sci. 2991: ix + 73 pages.

32 Reiser, D.W., E. Connor, K. Binkley, D. Paige, and K. Lynch. 1997. Evaluation of spawning habitat used by bull trout in the Cedar River watershed, Washington. Pages 331-338 In: Mackay, W.C., M.K. Brewin, and M. Monita (eds.). Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

33 Sexauer, H.A. 1994 Life history aspects of bull trout *Salvelinus confluentus* in the eastern Cascades, Washington. M.S. Thesis. Central Washington University, Ellensburg, WA.

REFERENCE LIST used for Skagit River HSC review and development

34 Stelfox, J.D., and K.L. Egan. 1995. Bull trout investigations in the Smith-Dorrien Creek/Lower Kananaskis Lake System. Alberta Environmental Protection, Natural Resource Service. Fisheries Management Division, Calgary, Alberta 148 pages.

35 Vadas, R.L. Jr. 2021. Life history and ecology of west-coast lamprey species, with special reference to the habitat needs of Pacific and western river and brook lampreys. Washington Department of Fish and Wildlife, Habitat Program. Olympia, WA. 44 pages.

36 Vadas, R.L. Jr. 2013. Development of habitat-suitability models for west-coast lamprey species, with special reference to Pacific and western brook lampreys.

37 Vadas, R.L. Jr. 2000. Instream-flow needs for anadromous salmonids and lamprey on the Pacific coast, with special reference to the Pacific Southwest. Environmental Monitoring and Assessment 64: 331-358.

38 Wampler, P. 1980. Instream Flow Requirements of the Lower North Fork, South Fork and Mainstem Skokomish River.

39 Washington Department of Fish and Wildlife 2015. State Wildlife Action Plan Update. Appendix A-4, pages 107-108.

40 Winkowski, M., and Kendall, M. 2018. Validation of habitat preferences for select native freshwater fishes in the Chehalis River, Washington State. Washington Department of Fish and Wildlife. Olympia, WA. 30 pages.

TABLE 1. Generic Cover/Substrate Codes and Preference Value[1] (Beecher et al. 2016)

Code	Type of Cover Note: Cover Codes are not used for Spawning	Salmon & Trout Rearing	Whitefish Rearing	
		Juvenile & Resident Adult	Juvenile	Adult
00.1	Undercut bank	1.00	1.00	1.00
00.2	Overhanging vegetation near or touching water2	1.00	1.00	1.00
00.3	Rootwad (including parly 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	0.80	0.80	0.80
00.6	Aquatic vegetation	0.80	0.80	0.80
00.7	Short (<1 ft) terrestrial grass	0.10	0.10	0.10
00.8	Tall (>3 ft) dense grass[3]	0.70	0.70	0.10
00.9	Vegetation >3 vertical ft above SZF	0.20	0.20	0.20

Code	Type of Substrate	Spawning					Salmon & Trout Rearing	Whitefish Rearing	
		Salmon	Steelhead[4]	Resident Trout	Native Char[5]	Whitefish	Juvenile & Resident Adult	Juvenile	Adult
1	Silt, clay, or organic	0.00	0.00	0.00	0.00	0.00	0.10	0.38	0.15
2	Sand	0.00	0.00	0.00	0.00	0.00	0.10	0.38	0.15
3	Sm Gravel (0.1 - 0.5")	0.30	0.50	0.80	1.00	1.00	0.10	0.74	0.76
4	Med Gravel (0.5 - 1.5")	1.00	1.00	1.00	1.00	1.00	0.30	0.88	0.91
5	Lrg Gravel (1.5 - 3")	1.00	1.00	0.80	1.00	1.00	0.30	0.88	0.91
6	Sm Cobble (3 - 6")	1.00	1.00	0.50	0.70	1.00	0.50	1.00	1.00
7	Lrg Cobble (6 - 12")	0.50	0.30	0.00	0.70	0.50	0.70	1.00	1.00
8	Boulder (>12")	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00
9	Bedrock	0.00	0.00	0.00	0.00	0.00	0.30	0.50	0.30

Notes:

1. This table reflects average values for the listed species. Site specific preferences would supersede this table.
2. This includes low tree branches (<3 vertical ft. above water surface elevation at stage of zero flow (SZF)) and bushes overhanging the bank-full water's edge.
3. This category refers to stout, almost bushy type grasses such as reed canary grass up to the bank-full water's edge.
4. This category includes intermountain and coastal cutthroat (*Oncorhynchus clarki*).
5. This category includes Bull Trout (*Salvelinus confluentus*) and Dolly Varden (*S. malma*).

TABLE 2. Generic Salmon Spawning Substrate Preference[1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
00.0	Cover codes are not factors for spawning habitat		
00.1			
00.2			
00.3			
00.4			
00.5			
00.6			
00.7			
00.8			
00.9			
11.9[2]	0.00	0.00	0.00
13.9	0.00	0.30	0.00*
17.9	0.00	0.30	0.00*
18.5	0.00	0.00	0.00
21.5	0.00	0.00	0.00
23.9	0.00	0.30	0.00*
27.9	0.00	0.50	0.00*
28.5	0.00	0.00	0.00
29.9	0.00	0.00	0.00
31.5	0.30	0.00	0.00*
31.7	0.30	0.00	0.00*
31.8	0.30	0.00	0.24
31.9	0.30	0.00	0.27
32.5	0.30	0.00	0.00*
32.7	0.30	0.00	0.00*
32.8	0.30	0.00	0.24
32.9	0.30	0.00	0.27
33.9	0.30	0.30	0.30
34.5	0.30	1.00	0.65
34.9	0.30	1.00	0.37
35.5	0.30	1.00	0.65
35.9	0.30	1.00	0.37
36.5	0.30	1.00	0.65
36.9	0.30	1.00	0.37
37.5	0.30	0.50	0.40
37.9	0.30	0.50	0.32
38.5	0.30	0.00	0.15
38.9	0.30	0.00	0.27
39.5	0.30	0.00	0.00*
39.9	0.30	0.00	0.00*
41.5	1.00	0.00	0.00*
41.7	1.00	0.00	0.00*
41.8	1.00	0.00	0.80
41.9	1.00	0.00	0.90
42.5	1.00	0.00	0.00*
42.7	1.00	0.00	0.00*
42.8	1.00	0.00	0.80
42.9	1.00	0.00	0.90
43.5	1.00	0.30	0.65
43.9	1.00	0.30	0.93
44.9	1.00	1.00	1.00
46.9	1.00	1.00	1.00
47.5	1.00	0.50	0.75
47.9	1.00	0.50	0.95
48.5	1.00	0.00	0.5
48.9	1.00	0.00	0.9
49.5	1.00	0.00	0.00*
49.9	1.00	0.00	0.00*
51.5	1.00	0.00	0.00*
51.7	1.00	0.00	0.00*
51.8	1.00	0.00	0.80
51.9	1.00	0.00	0.90
52.5	1.00	0.00	0.00*
52.7	1.00	0.00	0.00*
52.8	1.00	0.00	0.80
52.9	1.00	0.00	0.90
53.5	1.00	0.30	0.65
53.9	1.00	0.30	0.93
54.5	1.00	1.00	1.00
56.9	1.00	1.00	1.00
57.5	1.00	0.50	0.75
57.9	1.00	0.50	0.95
58.5	1.00	0.00	0.5
58.9	1.00	0.00	0.9
59.5	1.00	0.00	0.00*
59.9	1.00	0.00	0.00*

[1] Assume straight line between codes. Values are derived from RP equation (see pg. 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 24).
* Asterisk indicated deviation from the RP formula.

Table 2 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
61.5	1.00	0.00	0.00*
61.7	1.00	0.00	0.00*
61.8	1.00	0.00	0.80
61.9	1.00	0.00	0.90
62.5	1.00	0.00	0.00*
62.7	1.00	0.00	0.00*
62.8	1.00	0.00	0.80
62.9	1.00	0.00	0.90
63.5	1.00	0.30	0.65
63.9	1.00	0.30	0.93
64.5	1.00	1.00	1.00
66.9	1.00	1.00	1.00
67.5	1.00	0.50	0.75
67.9	1.00	0.50	0.95
68.5	1.00	0.00	0.50
68.9	1.00	0.00	0.90
69.5	1.00	0.00	0.00*
71.7	0.50	0.00	0.00*
71.8	0.50	0.00	0.40
71.9	0.50	0.00	0.45
72.5	0.50	0.00	0.00*
72.7	0.50	0.00	0.00*
72.8	0.50	0.00	0.40
72.9	0.50	0.00	0.45
73.5	0.50	0.30	0.40
73.9	0.50	0.30	0.48
74.5	0.50	1.00	0.75
74.9	0.50	1.00	0.55
75.5	0.50	1.00	0.75
75.9	0.50	1.00	0.55
76.5	0.50	1.00	0.75
76.9	0.50	1.00	0.55
77.9	0.50	0.50	0.50
78.5	0.50	0.00	0.25
78.9	0.50	0.00	0.45
79.5	0.50	0.00	0.00*
79.9	0.50	0.00	0.00*
81.5	0.00	0.00	0.00
82.9	0.00	0.00	0.00
83.5	0.00	0.30	0.00*
87.9	0.00	0.50	0.00*
88.9	0.00	0.00	0.00
92.9	0.00	0.00	0.00
93.5	0.00	0.30	0.00*
97.9	0.00	0.50	0.00*
98.5	0.00	0.00	0.00
99.9	0.00	0.00	0.00

TABLE 3. Generic Juvenile & Resident Adult Salmon and Trout Cover/Substrate Preference[1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
00.1	a & b values are not used to determine cover preference		1.00
00.2			1.00
00.3			1.00
00.4			1.00
00.5			0.80
00.6			0.80
00.7			0.10
00.8			0.70
00.9			0.20
11.9[2]	0.10	0.10	0.10
13.9	0.10	0.10	0.10
14.5	0.10	0.30	0.20
14.9	0.10	0.30	0.12
15.5	0.10	0.30	0.20
15.9	0.10	0.30	0.12
16.5	0.10	0.50	0.30
16.9	0.10	0.50	0.14
17.5	0.10	0.70	0.40
17.9	0.10	0.70	0.16
18.5	0.10	1.00	1.00*
18.9	0.10	1.00	1.00*
19.5	0.10	0.30	0.20
19.9	0.10	0.30	0.12
21.5	0.10	0.10	0.10
23.9	0.10	0.10	0.10
24.5	0.10	0.30	0.20
24.9	0.10	0.30	0.12
25.5	0.10	0.30	0.20
25.9	0.10	0.30	0.12
26.5	0.10	0.50	0.30
26.9	0.10	0.50	0.14
27.5	0.10	0.70	0.40
27.9	0.10	0.70	0.16
28.5	0.10	1.00	1.00*
28.9	0.10	1.00	1.00*
29.5	0.10	0.30	0.20
29.9	0.10	0.30	0.12
31.5	0.10	0.10	0.10
33.9	0.10	0.10	0.10
34.5	0.10	0.30	0.20
34.9	0.10	0.30	0.12
35.5	0.10	0.30	0.20
35.9	0.10	0.30	0.12
36.5	0.10	0.50	0.30
36.9	0.10	0.50	0.14
37.5	0.10	0.70	0.40
37.9	0.10	0.70	0.16
38.5	0.10	1.00	1.00*
38.9	0.10	1.00	1.00*
39.5	0.10	0.30	0.20
39.9	0.10	0.30	0.12
41.5	0.30	0.10	0.20
41.9	0.30	0.10	0.28
42.5	0.30	0.10	0.20
42.9	0.30	0.10	0.28
43.5	0.30	0.10	0.20
43.9	0.30	0.10	0.28
44.9	0.30	0.30	0.30
45.9	0.30	0.30	0.30
46.5	0.30	0.50	0.40
46.9	0.30	0.50	0.32
47.5	0.30	0.70	0.50
47.9	0.30	0.70	0.34
48.5	0.30	1.00	1.00*
48.9	0.30	1.00	1.00*
49.5	0.30	0.30	0.30
49.9	0.30	0.30	0.30
51.5	0.30	0.10	0.20
51.9	0.30	0.10	0.28
52.5	0.30	0.10	0.20
52.9	0.30	0.10	0.28
53.5	0.30	0.10	0.20
53.9	0.30	0.10	0.28
54.5	0.30	0.30	0.30
55.9	0.30	0.30	0.30
56.5	0.30	0.50	0.40
56.9	0.30	0.50	0.32
57.5	0.30	0.70	0.50
57.9	0.30	0.70	0.34

[1] Assume straight line between codes. Values are derived from RP equation (see pg 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 24).

* Asterisk indicated deviation from the RP formula.

Table 3 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
58.5	0.30	1.00	1.00*
58.9	0.30	1.00	1.00*
59.5	0.30	0.30	0.30
59.9	0.30	0.30	0.30
61.5	0.50	0.10	0.30
61.9	0.50	0.10	0.46
62.5	0.50	0.10	0.30
62.9	0.50	0.10	0.46
63.5	0.50	0.10	0.30
63.9	0.50	0.10	0.46
64.5	0.50	0.30	0.40
64.9	0.50	0.30	0.48
65.5	0.50	0.30	0.40
65.9	0.50	0.30	0.48
66.9	0.50	0.50	0.50
67.5	0.50	0.70	0.60
67.9	0.50	0.70	0.52
68.5	0.50	1.00	1.00*
68.9	0.50	1.00	1.00*
69.5	0.50	0.30	0.40
69.9	0.50	0.30	0.48
71.5	0.70	0.10	0.40
71.9	0.70	0.10	0.64
72.5	0.70	0.10	0.40
72.9	0.70	0.10	0.64
73.5	0.70	0.10	0.40
73.9	0.70	0.10	0.64
74.5	0.70	0.30	0.50
74.9	0.70	0.30	0.66
75.5	0.70	0.30	0.50
75.9	0.70	0.30	0.66
76.5	0.70	0.50	0.60
76.9	0.70	0.50	0.68
77.9	0.70	0.70	0.70
78.5	0.70	1.00	1.00*
78.9	0.70	1.00	1.00*
79.5	0.70	0.30	0.50
79.9	0.70	0.30	0.66
81.5	1.00	0.10	1.00*
87.9	1.00	0.70	1.00*
88.9	1.00	1.00	1.00
89.5	1.00	0.30	1.00*
89.9	1.00	0.30	1.00*
91.5	0.30	0.10	0.20
91.9	0.30	0.10	0.28
92.5	0.30	0.10	0.20
92.9	0.30	0.10	0.28
93.5	0.30	0.10	0.20
93.9	0.30	0.10	0.28
94.5	0.30	0.30	0.30
95.9	0.30	0.30	0.30
96.5	0.30	0.50	0.40
96.9	0.30	0.50	0.32
97.5	0.30	0.70	0.50
97.9	0.30	0.70	0.34
98.5	0.30	1.00	1.00*
98.9	0.30	1.00	1.00*
99.9	0.30	0.30	0.30

TABLE 4. Steelhead (Oncorhynchus mykiss) Spawning Substrate Preference[1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
00.0	Cover codes are not factors for spawning habitat		
00.1			
00.2			
00.3			
00.4			
00.5			
00.6			
00.7			
00.8			
00.9			
11.9[2]	0.00	0.00	0.00
13.9	0.00	0.50	0.00*
14.5	0.00	1.00	0.00*
16.9	0.00	1.00	0.00*
17.5	0.00	0.30	0.00*
17.9	0.00	0.30	0.00*
18.5	0.00	0.00	0.00
21.5	0.00	0.00	0.00
23.9	0.00	0.50	0.00*
27.9	0.00	0.30	0.00*
28.5	0.00	0.00	0.00
29.9	0.00	0.00	0.00
31.5	0.50	0.00	0.00*
31.7	0.50	0.00	0.00*
31.8	0.50	0.00	0.40
31.9	0.50	0.00	0.45
32.5	0.50	0.00	0.00*
32.7	0.50	0.00	0.00*
32.8	0.50	0.00	0.40
32.9	0.50	0.00	0.45
33.9	0.50	0.50	0.50
34.5	0.50	1.00	0.75
34.9	0.50	1.00	0.55
35.5	0.50	1.00	0.75
35.9	0.50	1.00	0.55
36.5	0.50	1.00	0.75
36.9	0.50	1.00	0.55
37.5	0.50	0.30	0.40
37.9	0.50	0.30	0.48
38.5	0.50	0.00	0.00*
38.9	0.50	0.00	0.00*
39.5	0.50	0.00	0.00*
39.9	0.50	0.00	0.00*
41.5	1.00	0.00	0.00*
41.7	1.00	0.00	0.00*
41.8	1.00	0.00	0.80
41.9	1.00	0.00	0.90
42.5	1.00	0.00	0.00*
42.7	1.00	0.00	0.00*
42.8	1.00	0.00	0.80
42.9	1.00	0.00	0.90
43.5	1.00	0.50	0.75
43.9	1.00	0.50	0.95
44.9	1.00	1.00	1.00
46.9	1.00	1.00	1.00
47.5	1.00	0.30	0.65
47.9	1.00	0.30	0.93
48.5	1.00	0.00	0.00*
48.9	1.00	0.00	0.00*
49.5	1.00	0.00	0.00*
49.9	1.00	0.00	0.00*
51.5	1.00	0.00	0.00*
51.7	1.00	0.00	0.00*
51.8	1.00	0.00	0.80
51.9	1.00	0.00	0.90
52.5	1.00	0.00	0.00*
52.7	1.00	0.00	0.00*
52.8	1.00	0.00	0.80
52.9	1.00	0.00	0.90
53.5	1.00	0.50	0.75
53.9	1.00	0.50	0.95
54.5	1.00	1.00	1.00
56.9	1.00	1.00	1.00
57.5	1.00	0.30	0.65
57.9	1.00	0.30	0.93

[1] Assume straight line between codes. Values are derived from RP equation (see pg 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 24).
* Asterisk indicated deviation from the RP formula.

Table 4 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
58.5	1.00	0.00	0.00*
58.9	1.00	0.00	0.00*
59.5	1.00	0.00	0.00*
59.9	1.00	0.00	0.00*
61.5	1.00	0.00	0.00*
61.7	1.00	0.00	0.00*
61.8	1.00	0.00	0.80
61.9	1.00	0.00	0.90
62.5	1.00	0.00	0.00*
62.7	1.00	0.00	0.00*
62.8	1.00	0.00	0.80
62.9	1.00	0.00	0.90
63.5	1.00	0.50	0.75
63.9	1.00	0.50	0.95
64.5	1.00	1.00	1.00
66.9	1.00	1.00	1.00
67.5	1.00	0.30	0.65
67.9	1.00	0.30	0.93
68.5	1.00	0.00	0.00*
68.9	1.00	0.00	0.00*
69.5	1.00	0.00	0.00*
69.9	1.00	0.00	0.00*
71.5	0.30	0.00	0.00*
71.7	0.30	0.00	0.00*
71.8	0.30	0.00	0.24
71.9	0.30	0.00	0.27
72.5	0.30	0.00	0.00*
72.7	0.30	0.00	0.00*
72.8	0.30	0.00	0.24
72.9	0.30	0.00	0.27
73.5	0.30	0.50	0.40
73.9	0.30	0.50	0.32
74.5	0.30	1.00	0.65
74.9	0.30	1.00	0.37
75.5	0.30	1.00	0.65
75.9	0.30	1.00	0.37
76.5	0.30	1.00	0.65
76.9	0.30	1.00	0.37
77.9	0.30	0.30	0.30
78.5	0.30	0.00	0.00*
78.9	0.30	0.00	0.00*
79.5	0.30	0.00	0.00*
79.9	0.30	0.00	0.00*
81.5	0.00	0.00	0.00*
82.9	0.00	0.00	0.00*
83.5	0.00	0.50	0.00*
83.9	0.00	0.50	0.00*
84.5	0.00	1.00	0.00*
86.9	0.00	1.00	0.00*
87.5	0.00	0.30	0.00*
87.9	0.00	0.30	0.00*
88.5	0.00	0.00	0.00
92.9	0.00	0.00	0.00
93.5	0.00	0.50	0.00*
93.9	0.00	0.50	0.00*
94.5	0.00	1.00	0.00*
96.9	0.00	1.00	0.00*
97.5	0.00	0.30	0.00*
97.9	0.00	0.30	0.00*
98.5	0.00	0.00	0.00
99.9	0.00	0.00	0.00

TABLE 5. Generic Trout Spawning Substrate Preference[1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
00.1	Cover codes are not factors for spawning habitat		
00.2			
00.3			
00.4			
00.5			
00.6			
00.7			
00.8			
00.9			
11.9[2]	0.00	0.00	0.00
13.9	0.00	0.80	0.00*
14.5	0.00	1.00	0.00*
14.9	0.00	1.00	0.00*
15.5	0.00	0.80	0.00*
15.9	0.00	0.80	0.00*
16.5	0.00	0.50	0.00*
16.9	0.00	0.50	0.00*
17.5	0.00	0.00	0.00
21.5	0.00	0.00	0.00
23.9	0.00	0.80	0.00*
24.5	0.00	1.00	0.00*
24.9	0.00	1.00	0.00*
25.5	0.00	0.80	0.00*
25.9	0.00	0.80	0.00*
26.5	0.00	0.50	0.00*
26.9	0.00	0.50	0.00*
27.5	0.00	0.00	0.00
29.9	0.00	0.00	0.00
31.5	0.80	0.00	0.00*
31.7	0.80	0.00	0.00*
31.8	0.80	0.00	0.64
31.9	0.80	0.00	0.72
32.5	0.80	0.00	0.00*
32.7	0.80	0.00	0.00*
32.8	0.80	0.00	0.64
32.9	0.80	0.00	0.72
33.9	0.80	0.80	0.80
34.5	0.80	1.00	0.90
34.9	0.80	1.00	0.82
35.5	0.80	0.80	0.80
35.9	0.80	0.80	0.80
36.5	0.80	0.50	0.65
36.9	0.80	0.50	0.77
37.5	0.80	0.00	0.00*
37.9	0.80	0.00	0.00*
38.5	0.80	0.00	0.00*
38.9	0.80	0.00	0.00*
39.5	0.80	0.00	0.00*
39.9	0.80	0.00	0.00*
41.5	1.00	0.00	0.00*
41.7	1.00	0.00	0.00*
41.8	1.00	0.00	0.80
41.9	1.00	0.00	0.90
42.5	1.00	0.00	0.00*
42.7	1.00	0.00	0.00*
42.8	1.00	0.00	0.80
42.9	1.00	0.00	0.90
43.5	1.00	0.80	0.90
43.9	1.00	0.80	0.98
44.9	1.00	1.00	1.00
45.5	1.00	0.80	0.90
45.9	1.00	0.80	0.98
46.5	1.00	0.50	0.75
46.9	1.00	0.50	0.95
47.5	1.00	0.00	0.00*
47.9	1.00	0.00	0.00*
48.5	1.00	0.00	0.00*
48.9	1.00	0.00	0.00*
49.5	1.00	0.00	0.00*
49.9	1.00	0.00	0.00*
51.5	0.80	0.00	0.00*
51.7	0.80	0.00	0.00*
51.8	0.80	0.00	0.64
51.9	0.80	0.00	0.72
52.5	0.80	0.00	0.00*
52.7	0.80	0.00	0.00*
52.8	0.80	0.00	0.64
52.9	0.80	0.00	0.72
53.5	0.80	0.80	0.80
53.9	0.80	0.80	0.80

[1] Assume straight line between codes. Values are derived from RP equation (see pg 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 24).

* Asterisk indicated deviation from the RP formula.

TABLE 5 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
54.5	0.80	1.00	0.90
54.9	0.80	1.00	0.82
55.9	0.80	0.80	0.80
56.5	0.80	0.50	0.65
56.9	0.80	0.50	0.77
57.5	0.80	0.00	0.00*
57.9	0.80	0.00	0.00*
58.5	0.80	0.00	0.00*
58.9	0.80	0.00	0.00*
59.5	0.80	0.00	0.00*
59.9	0.80	0.00	0.00*
61.5	0.50	0.00	0.00*
61.7	0.50	0.00	0.00*
61.8	0.50	0.00	0.40
61.9	0.50	0.00	0.45
62.5	0.50	0.00	0.00*
62.7	0.50	0.00	0.00*
62.8	0.50	0.00	0.40
62.9	0.50	0.00	0.45
63.5	0.50	0.80	0.65
63.9	0.50	0.80	0.53
64.5	0.50	1.00	0.75
64.9	0.50	1.00	0.55
65.5	0.50	0.80	0.65
65.9	0.50	0.80	0.53
66.9	0.50	0.50	0.50
67.5	0.50	0.00	0.00*
67.9	0.50	0.00	0.00*
68.5	0.50	0.00	0.00*
68.9	0.50	0.00	0.00*
69.5	0.50	0.00	0.00*
69.9	0.50	0.00	0.00*
71.5	0.00	0.00	0.00
72.9	0.00	0.00	0.00
73.5	0.00	0.80	0.00*
73.9	0.00	0.80	0.00*
74.5	0.00	1.00	0.00*
74.9	0.00	1.00	0.00*
75.5	0.00	0.80	0.00*
75.9	0.00	0.80	0.00*
76.5	0.00	0.50	0.00*
76.9	0.00	0.50	0.00*
77.9	0.00	0.00	0.00
82.9	0.00	0.00	0.00
83.5	0.00	0.80	0.00*
83.9	0.00	0.80	0.00*
84.5	0.00	1.00	0.00*
84.9	0.00	1.00	0.00*
85.5	0.00	0.80	0.00*
85.9	0.00	0.80	0.00*
86.5	0.00	0.50	0.00*
86.9	0.00	0.50	0.00*
87.5	0.00	0.00	0.00
92.9	0.00	0.00	0.00
93.5	0.00	0.80	0.00*
93.9	0.00	0.80	0.00*
94.5	0.00	1.00	0.00*
94.9	0.00	1.00	0.00*
95.5	0.00	0.80	0.00*
95.9	0.00	0.80	0.00*
96.5	0.00	0.50	0.00*
96.9	0.00	0.50	0.00*
97.5	0.00	0.00	0.00
99.9	0.00	0.00	0.00

TABLE 6. Bull Trout (Salvelinus confluentus) and Dolly Varden (S. malma) Spawning Substrate Preference[1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
00.1	Cover codes are not factors for spawning habitat		
00.2			
00.3			
00.4			
00.5			
00.6			
00.7			
00.8			
00.9			
11.9[2]	0.00	0.00	0.00
31.7	1.00	0.00	0.00*
31.8	1.00	0.00	0.80
31.9	1.00	0.00	0.90
32.5	1.00	0.00	0.00*
32.7	1.00	0.00	0.00*
32.8	1.00	0.00	0.80
32.9	1.00	0.00	0.90
33.9	1.00	1.00	1.00
35.9	1.00	1.00	1.00
36.5	1.00	0.70	0.85
36.9	1.00	0.70	0.97
37.5	1.00	0.70	0.85
37.9	1.00	0.70	0.97
38.5	1.00	0.00	0.50
38.9	1.00	0.00	0.90
39.5	1.00	0.00	0.00*
41.7	1.00	0.00	0.00*
41.8	1.00	0.00	0.80
41.9	1.00	0.00	0.90
42.5	1.00	0.00	0.00*
42.7	1.00	0.00	0.00*
42.8	1.00	0.00	0.80
42.9	1.00	0.00	0.90
43.5	1.00	1.00	1.00
45.9	1.00	1.00	1.00
46.5	1.00	0.70	0.85
46.9	1.00	0.70	0.97
47.5	1.00	0.70	0.85
47.9	1.00	0.70	0.97
48.5	1.00	0.00	0.50
48.9	1.00	0.00	0.90
49.5	1.00	0.00	0.00*
51.7	1.00	0.00	0.00*
51.8	1.00	0.00	0.80
51.9	1.00	0.00	0.90
52.5	1.00	0.00	0.00*
52.7	1.00	0.00	0.00*
52.8	1.00	0.00	0.80
52.9	1.00	0.00	0.90
53.5	1.00	1.00	1.00
55.9	1.00	1.00	1.00
56.5	1.00	0.70	0.85
56.9	1.00	0.70	0.97
57.5	1.00	0.70	0.85
57.9	1.00	0.70	0.97
58.5	1.00	0.70	0.85
58.9	1.00	0.70	0.97
59.5	1.00	0.00	0.00*
61.7	0.70	0.00	0.00*
61.8	0.70	0.00	0.56
61.9	0.70	0.00	0.63
62.5	0.70	0.00	0.00*
62.7	0.70	0.00	0.00*
62.8	0.70	0.00	0.56
62.9	0.70	0.00	0.63
63.5	0.70	1.00	0.85
63.9	0.70	1.00	0.73
64.5	0.70	1.00	0.85
64.9	0.70	1.00	0.73
65.5	0.70	1.00	0.85
65.9	0.70	1.00	0.73
66.9	0.70	0.70	0.70
67.9	0.70	0.70	0.70
68.5	0.70	0.00	0.35
68.9	0.70	0.00	0.63
69.5	0.70	0.00	0.00*

[1] Assume straight line between codes. Values are derived from RP equation (see pg 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 20).

* Asterisk indicated deviation form RP formula.

Table 6 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
71.7	0.70	0.00	0.00*
71.8	0.70	0.00	0.56
71.9	0.70	0.00	0.63
72.5	0.70	0.00	0.00*
72.7	0.70	0.00	0.00*
72.8	0.70	0.00	0.56
72.9	0.70	0.00	0.63
73.5	0.70	1.00	0.85
73.9	0.70	1.00	0.73
74.5	0.70	1.00	0.85
74.9	0.70	1.00	0.73
75.5	0.70	1.00	0.85
75.9	0.70	1.00	0.73
76.5	0.70	0.70	0.70
76.9	0.70	0.70	0.70
77.9	0.70	0.70	0.70
78.5	0.70	0.00	0.35
78.9	0.70	0.00	0.63
79.5	0.70	0.00	0.00*
82.9	0.00	0.00	0.00*
83.5	0.00	1.00	0.50
83.9	0.00	1.00	0.10
84.5	0.00	1.00	0.50
84.9	0.00	1.00	0.10
85.5	0.00	1.00	0.50
85.9	0.00	1.00	0.10
86.5	0.00	0.70	0.35
86.9	0.00	0.70	0.07
87.5	0.00	0.70	0.35
87.9	0.00	0.70	0.07
88.9	0.00	0.00	0.00
93.5	0.00	0.00	0.00*
97.9	0.00	1.00	0.00*
99.9	0.00	0.00	0.00

TABLE 7. Mountain Whitefish (*Prosopium williamsoni*) Spawning Substrate Preference[1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
00.1	Cover codes are not factors for spawning habitat		
00.2			
00.3			
00.4			
00.5			
00.6			
00.7			
00.8			
00.9			
11.9[2]	0.0	0.0	0.0
21.9	0.00	0.00	0.00
31.5	1.00	0.00	0.50
31.9	1.00	0.00	0.90
32.5	1.00	0.00	0.50
32.9	1.00	0.00	0.90
33.9	1.00	1.00	1.00
36.9	1.00	1.00	1.00
37.5	1.00	0.50	0.75
37.9	1.00	0.50	0.95
38.5	1.00	0.00	0.50
38.9	1.00	0.00	0.90
39.5	1.00	0.00	0.50
39.9	1.00	0.00	0.90
41.5	1.00	0.00	0.50
41.9	1.00	0.00	0.90
42.5	1.00	0.00	0.50
42.9	1.00	0.00	0.90
43.5	1.00	1.00	1.00
46.9	1.00	1.00	1.00
47.5	1.00	0.50	0.75
47.9	1.00	0.50	0.95
48.5	1.00	0.00	0.50
48.9	1.00	0.00	0.90
49.5	1.00	0.00	0.50
49.9	1.00	0.00	0.90
51.5	1.00	0.00	0.50
51.9	1.00	0.00	0.90
52.5	1.00	0.00	0.50
52.9	1.00	0.00	0.90
53.5	1.00	1.00	1.00
56.9	1.00	1.00	1.00
57.5	1.00	0.50	0.75
57.9	1.00	0.50	0.95
58.5	1.00	0.00	0.50
58.9	1.00	0.00	0.90
59.5	1.00	0.00	0.50
59.9	1.00	0.00	0.90
61.5	1.00	0.00	0.50
61.9	1.00	0.00	0.90
62.5	1.00	0.00	0.50
62.9	1.00	0.00	0.90
63.5	1.00	1.00	1.00
66.9	1.00	1.00	1.00
67.5	1.00	0.50	0.75
67.9	1.00	0.50	0.95
68.5	1.00	0.00	0.50
68.9	1.00	0.00	0.90
69.5	1.00	0.00	0.50
69.9	1.00	0.00	0.90
71.5	0.50	0.00	0.25
71.9	0.50	0.00	0.45
72.5	0.50	0.00	0.25
72.9	0.50	0.00	0.45
73.5	0.50	1.00	0.75
73.9	0.50	1.00	0.55
74.5	0.50	1.00	0.75
74.9	0.50	1.00	0.55
75.5	0.50	1.00	0.75
75.9	0.50	1.00	0.55
76.5	0.50	1.00	0.75
76.9	0.50	1.00	0.55
77.9	0.50	0.50	0.50
78.5	0.50	0.00	0.25
78.9	0.50	0.00	0.45
79.5	0.50	0.00	0.25
79.9	0.50	0.00	0.45

[1] Assume straight line between codes. Values are derived from RP equation (see pg 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 24).
* Asterisk indicated deviation from the RP formula.

Table 7 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
81.5	0.00	0.00	0.00
82.9	0.00	0.00	0.00
83.5	0.00	1.00	0.50
83.9	0.00	1.00	0.10
84.5	0.00	1.00	0.50
84.9	0.00	1.00	0.10
85.5	0.00	1.00	0.50
85.9	0.00	1.00	0.10
86.5	0.00	1.00	0.50
86.9	0.00	1.00	0.10
87.5	0.00	1.00	0.50
87.9	0.00	1.00	0.10
88.9	0.00	0.00	0.00
92.9	0.00	0.00	0.00
93.5	0.00	1.00	0.50
93.9	0.00	1.00	0.10
94.5	0.00	1.00	0.50
94.9	0.00	1.00	0.10
95.5	0.00	1.00	0.50
95.9	0.00	1.00	0.10
96.5	0.00	1.00	0.50
96.9	0.00	1.00	0.10
97.5	0.00	1.00	0.50
97.9	0.00	1.00	0.10
98.5	0.00	0.00	0.00
99.9	0.00	0.00	0.00

TABLE 8. Mountain Whitefish Adult Rearing Cover/Substrate Preference [1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference	
00.1	a & b values are not used to determine cover preference		1.0	1.00
00.2			1.0	1.00
00.3			1.0	1.00
00.4			1.0	1.00
00.5			0.8	0.80
00.6			0.8	0.80
00.7			0.1	0.10
00.8			0.1	0.70
00.9			0.2	0.20
11.9[2]	0.15	0.15	0.15	
12.9	0.15	0.15	0.15	
13.5	0.15	0.76	0.46	
13.9	0.15	0.76	0.21	
14.5	0.15	0.91	0.53	
14.9	0.15	0.91	0.23	
15.5	0.15	0.91	0.53	
15.9	0.15	0.91	0.23	
16.5	0.15	1.0	0.58	
16.9	0.15	1.0	0.24	
17.5	0.15	1.0	0.58	
17.9	0.15	1.0	0.24	
18.5	0.15	1.0	0.58	
18.9	0.15	1.0	0.24	
19.5	0.15	0.30	0.23	
19.9	0.15	0.30	0.17	
21.5	0.15	0.15	0.15	
22.9	0.15	0.15	0.15	
23.5	0.15	0.76	0.46	
23.9	0.15	0.76	0.21	
24.5	0.15	0.91	0.53	
24.9	0.15	0.91	0.23	
25.5	0.15	0.91	0.53	
25.9	0.15	0.91	0.23	
26.5	0.15	1.00	0.58	
26.9	0.15	1.00	0.24	
27.5	0.15	1.00	0.58	
27.9	0.15	1.00	0.24	
28.5	0.15	1.00	0.58	
28.9	0.15	1.00	0.24	
29.5	0.15	0.30	0.23	
29.9	0.15	0.30	0.17	
31.5	0.76	0.15	0.46	
31.9	0.76	0.15	0.70	
32.5	0.76	0.15	0.46	
32.9	0.76	0.15	0.70	
33.9	0.76	0.76	0.76	
34.5	0.76	0.91	0.84	
34.9	0.76	0.91	0.78	
35.5	0.76	0.91	0.84	
35.9	0.76	0.91	0.78	
36.5	0.76	1.0	0.88	
36.9	0.76	1.0	0.78	
37.5	0.76	1.0	0.88	
37.9	0.76	1.0	0.78	
38.5	0.76	1.0	0.88	
38.9	0.76	1.0	0.78	
39.5	0.76	0.30	0.53	
39.9	0.76	0.30	0.71	
41.5	0.91	0.15	0.53	
41.9	0.91	0.15	0.83	
42.5	0.91	0.15	0.53	
42.9	0.91	0.15	0.83	
43.5	0.91	0.76	0.84	
43.9	0.91	0.76	0.90	
44.9	0.91	0.91	0.91	
45.9	0.91	0.91	0.91	
46.5	0.91	1.0	0.96	
46.9	0.91	1.0	0.92	
47.5	0.91	1.0	0.96	
47.9	0.91	1.0	0.92	
48.5	0.91	1.0	0.96	
48.9	0.91	1.0	0.92	
49.5	0.91	0.30	0.61	
49.9	0.91	0.30	0.85	
51.5	0.91	0.15	0.53	
51.9	0.91	0.15	0.83	
52.5	0.91	0.15	0.53	
52.9	0.91	0.15	0.83	
53.5	0.91	0.76	0.84	
53.9	0.91	0.76	0.90	
54.5	0.91	0.91	0.91	
55.9	0.91	0.91	0.91	
56.5	0.91	1.0	0.96	
56.9	0.91	1.0	0.92	

[1] Assume straight line between codes. Values are derived from RP equation (see pg 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 24).

* Asterisk indicated deviation from the RP formula.

Table 8 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
57.5	0.91	1.0	0.96
57.9	0.91	1.0	0.92
58.5	0.91	1.0	0.96
58.9	0.91	1.0	0.92
59.5	0.91	0.30	0.61
59.9	0.91	0.30	0.85
61.5	1.0	0.15	0.58
61.9	1.0	0.15	0.92
62.5	1.0	0.15	0.58
62.9	1.0	0.15	0.92
63.5	1.0	0.76	0.88
63.9	1.0	0.76	0.98
64.5	1.0	0.91	0.96
64.9	1.0	0.91	0.99
65.5	1.0	0.91	0.96
65.9	1.0	0.91	0.99
66.9	1.0	1.0	1.00
68.9	1.0	1.0	1.00
69.5	1.0	0.30	0.65
69.9	1.0	0.30	0.93
71.5	1.0	0.15	0.58
71.9	1.0	0.15	0.92
72.5	1.0	0.15	0.58
72.9	1.0	0.15	0.92
73.5	1.0	0.76	0.88
73.9	1.0	0.76	0.98
74.5	1.0	0.91	0.96
74.9	1.0	0.91	0.99
75.5	1.0	0.91	0.96
75.9	1.0	0.91	0.99
76.5	1.0	1.0	1.00
78.9	1.0	1.0	1.00
79.5	1.0	0.30	0.65
79.9	1.0	0.30	0.93
81.5	1.0	0.15	0.58
81.9	1.0	0.15	0.92
82.5	1.0	0.15	0.58
82.9	1.0	0.15	0.92
83.5	1.0	0.76	0.88
83.9	1.0	0.76	0.98
84.5	1.0	0.91	0.96
84.9	1.0	0.91	0.99
85.5	1.0	0.91	0.96
85.9	1.0	0.91	0.99
86.5	1.0	1.0	1.00
88.9	1.0	1.0	1.00
89.5	1.0	0.30	0.65
89.9	1.0	0.30	0.93
91.5	0.30	0.15	0.23
91.9	0.30	0.15	0.29
92.5	0.30	0.15	0.23
92.9	0.30	0.15	0.29
93.5	0.30	0.76	0.53
93.9	0.30	0.76	0.35
94.5	0.30	0.91	0.61
94.9	0.30	0.91	0.36
95.5	0.30	0.91	0.61
95.9	0.30	0.91	0.36
96.5	0.30	1.0	0.65
96.9	0.30	1.0	0.37
97.5	0.30	1.0	0.65
97.9	0.30	1.0	0.37
98.5	0.30	1.0	0.65
98.9	0.30	1.0	0.37
99.9	0.30	0.30	0.30

TABLE 9. Mountain Whitefish Juvenile Rearing Cover/Substrate Preference [1]

Code (ab.c)	Preference value a	Preference value b	Recommended Preference	
00.1	a & b values are not used to determine cover preference		1.00	1.00
00.2			1.00	1.00
00.3			1.00	1.00
00.4			1.00	1.00
00.5			0.80	0.80
00.6			0.80	0.80
00.7			0.10	0.10
00.8			0.70	0.70
00.9			0.20	0.20
11.9[2]	0.38	0.38	0.38	
12.9	0.38	0.38	0.38	
13.5	0.38	0.74	0.56	
13.9	0.38	0.74	0.42	
14.5	0.38	0.88	0.63	
14.9	0.38	0.88	0.43	
15.5	0.38	0.88	0.63	
15.9	0.38	0.88	0.43	
16.5	0.38	1.0	0.69	
16.9	0.38	1.0	0.44	
17.5	0.38	1.0	0.69	
17.9	0.38	1.0	0.44	
18.5	0.38	1.0	0.69	
18.9	0.38	1.0	0.44	
19.5	0.38	0.50	0.44	
19.9	0.38	0.50	0.39	
21.5	0.38	0.38	0.38	
22.9	0.38	0.38	0.38	
23.5	0.38	0.74	0.56	
23.9	0.38	0.74	0.42	
24.5	0.38	0.88	0.63	
24.9	0.38	0.88	0.43	
25.5	0.38	0.88	0.63	
25.9	0.38	0.88	0.43	
26.5	0.38	1.0	0.69	
26.9	0.38	1.0	0.44	
27.5	0.38	1.0	0.69	
27.9	0.38	1.0	0.44	
28.5	0.38	1.0	0.69	
28.9	0.38	1.0	0.44	
29.5	0.38	0.50	0.44	
29.9	0.38	0.50	0.39	
31.5	0.74	0.38	0.56	
31.9	0.74	0.38	0.70	
32.5	0.74	0.38	0.56	
32.9	0.74	0.38	0.70	
33.9	0.74	0.74	0.74	
34.5	0.74	0.88	0.81	
34.9	0.74	0.88	0.75	
35.5	0.74	0.88	0.81	
35.9	0.74	0.88	0.75	
36.5	0.74	1.0	0.87	
36.9	0.74	1.0	0.77	
37.5	0.74	1.0	0.87	
37.9	0.74	1.0	0.77	
38.5	0.74	1.0	0.87	
38.9	0.74	1.0	0.77	
39.5	0.74	0.50	0.62	
39.9	0.74	0.50	0.72	
41.5	0.88	0.38	0.63	
41.9	0.88	0.38	0.83	
42.5	0.88	0.38	0.63	
42.9	0.88	0.38	0.83	
43.5	0.88	0.74	0.81	
43.9	0.88	0.74	0.87	
44.9	0.88	0.88	0.88	
45.9	0.88	0.88	0.88	
46.5	0.88	1.0	0.94	
46.9	0.88	1.0	0.89	
47.5	0.88	1.0	0.94	
47.9	0.88	1.0	0.89	
48.5	0.88	1.0	0.94	
48.9	0.88	1.0	0.89	
49.5	0.88	0.50	0.69	
49.9	0.88	0.50	0.84	
51.5	0.88	0.38	0.63	
51.9	0.88	0.38	0.83	
52.5	0.88	0.38	0.63	
52.9	0.88	0.38	0.83	
53.5	0.88	0.74	0.81	
53.9	0.88	0.74	0.87	
54.5	0.88	0.88	0.88	
55.9	0.88	0.88	0.88	
56.5	0.88	1.0	0.94	
56.9	0.88	1.0	0.89	

[1] Assume straight line between codes. Values are derived from RP equation (see pg 23).

[2] Substrate code section begins at 11.9. This is an example of a redundant code (see pg 24).
* Asterisk indicated deviation from the RP formula.

Table 9 Continued

Code (ab.c)	Preference value a	Preference value b	Recommended Preference
57.5	0.88	1.0	0.94
57.9	0.88	1.0	0.89
58.5	0.88	1.0	0.94
58.9	0.88	1.0	0.89
59.5	0.88	0.50	0.69
59.9	0.88	0.50	0.84
61.5	1.0	0.38	0.69
61.9	1.0	0.38	0.94
62.5	1.0	0.38	0.69
62.9	1.0	0.38	0.94
63.5	1.0	0.74	0.87
63.9	1.0	0.74	0.97
64.5	1.0	0.88	0.94
64.9	1.0	0.88	0.99
65.5	1.0	0.88	0.94
65.9	1.0	0.88	0.99
66.9	1.0	1.0	1.00
68.9	1.0	1.0	1.00
69.5	1.0	0.50	0.75
69.9	1.0	0.50	0.95
71.5	1.0	0.38	0.69
71.9	1.0	0.38	0.94
72.5	1.0	0.38	0.69
72.9	1.0	0.38	0.94
73.5	1.0	0.74	0.87
73.9	1.0	0.74	0.97
74.5	1.0	0.88	0.94
74.9	1.0	0.88	0.99
75.5	1.0	0.88	0.94
75.9	1.0	0.88	0.99
76.5	1.0	1.0	1.00
78.9	1.0	1.0	1.00
79.5	1.0	0.5	0.75
79.9	1.0	0.5	0.95
81.5	1.0	0.38	0.69
81.9	1.0	0.38	0.94
82.5	1.0	0.38	0.69
82.9	1.0	0.38	0.94
83.5	1.0	0.74	0.87
83.9	1.0	0.74	0.97
84.5	1.0	0.88	0.94
84.9	1.0	0.88	0.99
85.5	1.0	0.88	0.94
85.9	1.0	0.88	0.99
86.5	1.0	1.0	1.00
88.9	1.0	1.0	1.00
89.5	1.0	0.5	0.75
89.9	1.0	0.5	0.95
91.5	0.50	0.38	0.44
91.9	0.50	0.38	0.49
92.5	0.50	0.38	0.44
92.9	0.50	0.38	0.49
93.5	0.50	0.74	0.62
93.9	0.50	0.74	0.52
94.5	0.50	0.88	0.69
94.9	0.50	0.88	0.54
95.5	0.50	0.88	0.69
95.9	0.50	0.88	0.54
96.5	0.50	1.0	0.75
96.9	0.50	1.0	0.55
97.5	0.50	1.0	0.75
97.9	0.50	1.0	0.55
98.5	0.50	1.0	0.75
98.9	0.50	1.0	0.55
99.9	0.50	0.5	0.50