# FINAL TECHNICAL MEMORANDUM

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| **To:** | Technical Work Group – Eklutna River Project |
| **From:** | Dudley Reiser, Ben Cary, Chiming Huang, Stuart Beck, Audrey Thompson, and Mike Gagner – Kleinschmidt Associates |
| **Cc:** | Samantha Owen – McMillen Jacobs Associates |
| **Date:** | March 24, 2023, **Document No.** 2819278.02 |
| **Re:** | Two-dimensional Modeling and Habitat Suitability Analysis for Reaches 3, 4, 6, and 10 of the Eklutna River – Preliminary Results and Example Flow Analysis |

## 1.0 INTRODUCTION

The Instream Flow Study of the Eklutna River was initiated in 2021 in accordance with Section 3.1 of the May 2021 Final Study Plans (McMillen Jacobs Associates [MJA] 2021). The Year 1 Interim Report (Kleinschmidt Associates [Kleinschmidt] 2022a) was completed in January 2022 and described the methods used and summarized the data and information collected during the first year of the Instream Flow Study, covering the period June 2021 through October 2021.

Subsequent data analysis in 2022 resulted in the completion of three modeling efforts for the Eklutna River including: 1) development of a Hydrologic Engineering Center's River Analysis System (HEC-RAS) one-dimensional (1D) model; 2) development of Physical Habitat Simulation (PHABSIM) models; and 3) barrier analysis for five (named A-E) potential barriers to fish migration within Reach 7. The preliminary results of the PHABSIM and barrier analysis were provided in a Technical Memorandum (Kleinschmidt 2022b) and presented during a Technical Work Group (TWG) meeting on September 28, 2022.

The 1D PHABSIM study sites were located within the following river reaches (R-) of the Eklutna River – R11, R9, R8, R7, and R4 (Figure 1-1). No study sites were established in Reaches 10, 6, 3, 2, and 1 in part due to accessibility issues during release of the high target flow, susceptibility to channel change due to sediment deposition, tidal influence (R3), and complexity of habitats (braiding and multiple channels) within those reaches. These complex areas contain off-channel habitats frequently used by juvenile salmonids for rearing and may also support some spawning habitats. Light Detection and Ranging (LiDAR) based two-dimensional (2D) hydraulic modeling can provide a reasonable characterization of these complex habitats under a wide range of flows and is not as constrained as 1D PHABSIM modeling[1]. As a result, the following four (4) new study sites were identified for 2D HEC-RAS hydraulic modeling in 2022 (MJA 2022):

- Reach 10 to encompass main and side channel complexity in an upper reach of the Eklutna River inaccessible during the 2021 study flow releases;
- Reach 6 to encompass channel characteristics within the canyon reach of the Eklutna River immediately upstream from the confluence with Thunderbird Creek; this reach contained substantial sediment deposits and therefore channel morphologies would have likely changed during the three test flow releases; the reach was likewise inaccessible during the 2021 study flow releases;
- Reach 4 within the section of the Eklutna River between the highway and railroad bridges encompassing the “flooded forest” complex; and
- Reach 3 within a section of the Eklutna River below the railroad bridge containing a braided beaver complex considered as supporting high value juvenile habitats (see Fish Study).

The selection of 2D study sites was made in coordination with the TWG based on results of habitat mapping, review of new 2022 LiDAR, and with consideration of existing sites and transects established for the 1D PHABSIM analysis. These 2D models were then used to evaluate available fish habitat under different flow release scenarios. Two-dimensional modeling study reaches and the 1D instream flow transect locations are show in Figure 1-1 below.

[1] Note that 2D modeling was considered during the early study planning process (MJA 2021), but its potential use was considered most applicable to off-channel and side channel complex habitat areas that provide juvenile salmonid rearing habitat. As a result, the 1D suite of models provided in the Physical Habitat Simulation (PHABSIM) programs, in concert with the 1D HEC-RAS model were the primary set of models applied in the Year 1 Study. The 1D HEC-RAS model was developed for the entire length of the Eklutna River to develop stage/discharge rating curves at PHABSIM transects and also for estimating channel changes due to sediment transport as determined in the Geomorphology/Sediment Transport Study.

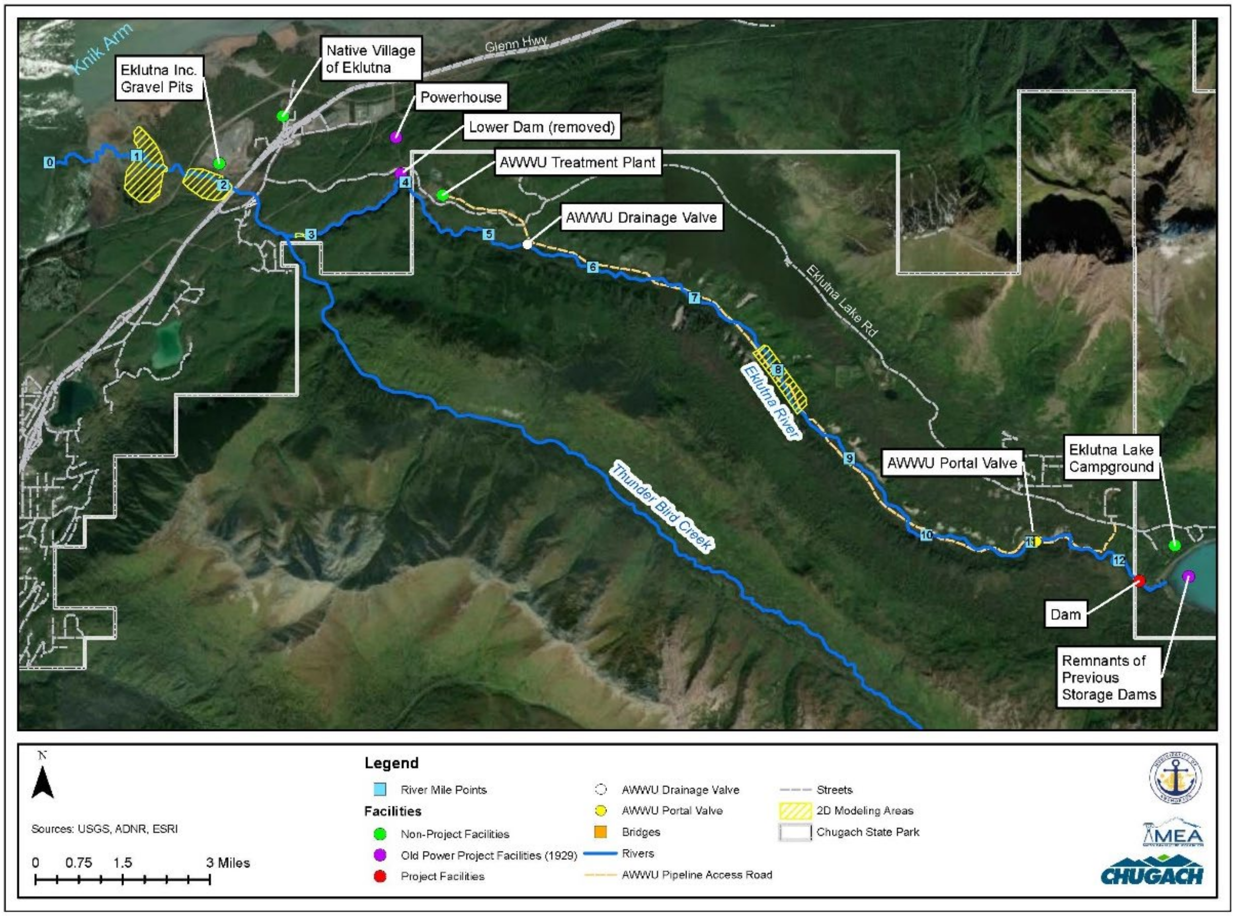



**Figure 1-1 Eklutna Instream Flow Study Area showing reach designations. PHABSIM transects were located in Reaches 11, 9, 8, 7, 5, and 4. Two-dimensional HEC-RAS modeling sections were located in Reaches 10, 6, 4, and 3 and are indicated by areas of yellow cross-hatching. The Reach 6 section is small and located just above the confluence of Thunderbird Creek.**

## 1.1 Purpose and Objective

The purpose of this technical memorandum (TM) is to summarize the development of the 2D HEC-RAS models in R3, R4, R6, and R10, describe the preliminary results, and demonstrate via example how the modeling can be applied in evaluating potential flow release levels and release options (see September 28, 2022 TM [Kleinschmidt 2022b]).

Similar to the PHABSIM analysis (Kleinschmidt 2022b), the overall objective is to demonstrate the reliability and utility of the 2022 LiDAR data and 2D HEC-RAS modeling, and to substantiate its use, along with the PHABSIM and geomorphology/sediment transport models, and the hydro-operations model for deriving and testing flow-release alternatives.

The TM follows a similar process as described in the PHABSIM TM (Kleinschmidt 2022b) and includes descriptions of the 2D HEC-RAS model development and how model outputs were translated into habitat-flow relationships; the derivation of flow options based on habitat results using the same four flow levels (Level 1 – 90%, Level 2 – 70%, Level 3 – 50%, and Level 4 – 30% of maximum habitat flow) as applied in the PHABSIM analysis except now based on 2D model results for only R10 and R6 for juvenile rearing habitats; adjustment of flows based on three flow release location options[2]; and completion of time series analysis. Two separate time series are presented, both strictly based on flow releases into the Eklutna River above Thunderbird Creek. The first, Time Series A, built solely on the 2D modeling results for juvenile rearing habitats in R10, R6, R4, and R3, and the second, Time Series B, an integrated approach that combines 1D and 2D model results that also includes 1D PHABSIM spawning habitats. Details of these specific elements are provided in the sections below.

It should be noted that all the results presented in this TM are based on the habitat-flow relationships developed during 1D and 2D instream flow modeling. It is recognized that there may be limitations of existing or potential-future infrastructure to deliver some of the flows presented.  Such constraints did not factor into any of the results presented but will be discussed in the Engineering Feasibility Report.

### 1.2 Overview of 2D HEC-RAS and Habitat Modeling

The 2D HEC-RAS modeling at each site was conducted using the latest version of the U.S. Army Corps of Engineers (USACE) software (6.3.1) and utilized the new topobathymetric LiDAR collected in May 2022 to derive the terrain surface.

Model setup included development of model geometry using the HEC-RAS Mapper extension, estimation of channel roughness (Manning's n) for each channel and overbank area, and establishment of boundary conditions to define the upstream and downstream limits of the model. Model calibration was first performed by comparison of the LiDAR elevations with surveyed elevations (surveyed on August 2-5, 2022) using a Real-Time Kinematic (RTK)–Global Positioning System (GPS) unit. Spot measurements of water elevation under observed flow conditions were made at surveyed RTK-GPS points and

[2] The three potential flow release locations are: Option A – the existing spill gate just below Eklutna Dam; Option B – from the upper Anchorage Water and Wastewater Utility (AWWU) portal located approximately 6,000 ft below the spill gate; and Option C – from the lower AWWU drainage valve located approximately 3000 ft below the lower extent of Reach 9.

compared with model predictions for that flow. The actual calibration process varied depending on how much flowing water was present at the site, and the hydraulic complexity of the reach.

Once developed, the 2D HEC-RAS models were linked with the Habitat Suitability Criteria (HSC) curves (Kleinschmidt 2022c) and for comparative purposes, applied over the same range of flows (10 cubic feet per second [cfs] to 375 cfs)[3] used in the 1D PHABSIM analysis to define juvenile rearing habitat-flow relationships for two target species (Chinook [*Oncorhynchus tshawytscha*] and Coho [*O. kisutch*] salmon). Sockeye (*O. nerka*) Salmon are also target species, but juvenile rearing typically occurs in lakes, not rivers and streams (see Section 4). As noted in the Year 2 Study Plan, the 2D habitat analysis was focused on juvenile rearing habitat and specifically to determine to what extent gains in habitat could be achieved if side channel and off channel areas could be connected via flow. Spawning habitat was considered but was deemed secondary to rearing habitats since in general, the composited 1D PHABSIM habitat – flow relationships for spawning were more defined than for rearing habitats. This suggested that higher flows may benefit juvenile rearing habitat more than spawning habitat. In addition, because there has been no substrate mapping completed in the four reaches, the computation of spawning habitat would only be based on depth and velocity parameters and would overestimate spawning habitat. Unlike juvenile rearing habitat in which all substrate types are considered suitable, substrate type (size) plays a key role in defining spawning habitat. The 2D models were also used in a companion juvenile habitat analysis to explore flow-habitat connectivity pathways and resulting surface areas of inundation within side channel and off-channel habitats.

[3] The 2D HEC-RAS model is capable of modeling flows greater than 375 cfs and will be used in conjunction with the geomorphic/sediment transport modeling to explore geomorphically-based flow scenarios.

# 2.0 SITE SELECTION AND MODEL EXTENT DETERMINATION

Study reaches were selected for 2D hydraulic model development due to their habitat and hydraulic complexity (Reaches 4 and 3) and accessibility issues during the 2021 test flow releases (Reaches 10 and 6) (Figure 1-1). In general, 2D hydraulic models perform best when the modeled reaches fully contain any split flow paths within the area of interest and have clearly defined inflow and outflow locations. The specific segments of the modeled reaches were adjusted accordingly and contain representative habitat features within each, complete with inflow and outflow features. Nominally, the R3 model was 2,183 ft in length, R4 2,502 ft., R6 1,167 ft, and R10 3,744 ft (Figure 2-1).


**Figure 2-1 Model extents for each of the four reaches. The polygon border in orange represents the extent of the hydraulic model and the polygon in light green is the habitat model extent. Nominally, the models for Reaches 3, 4, 6, and 10 were 2,183 ft., 2,502 ft., 1,167 ft, and 3,744 ft in length, respectively. The line passing the middle of each polygon represents the main water course at low flow.**

# 3.0 TWO-DIMENSIONAL (2D) HEC-RAS HYDRAULIC MODEL DEVELOPMENT

As noted above, the 2D HEC-RAS hydraulic modeling was completed using USACE software (6.3.1) and the topobathymetric LiDAR data collected by NV5 Geospatial in May 2022 supplemented with RTK-GPS survey and flow data collected in August 2022. Those data allowed for comparison of LiDAR based elevations versus ground survey data and revealed that for the purposes of defining hydraulic conditions for habitat analysis, the LiDAR data could be used in 2D hydraulic model development. Therefore, no adjustments were made to the topobathymetric LiDAR data set. The analysis and comparison of the LiDAR data are described below.

## 3.1 2022 Topobathymetric LiDAR Data Collection

In May 2022, NV5 Geospatial was contracted by MJA to collect topobathymetric LiDAR data for the Eklutna River. This data set was the primary source of elevation data of the Eklutna River's floodplain and bathymetric elevations (NV5 Geospatial 2022). The LiDAR (out of channel) portions of this survey had estimated vertical accuracies of 0.101 meters evaluated at a 95% confidence interval. The bathymetric portions of the survey had estimated vertical accuracies of 0.328 meters evaluated at a 95% confidence interval. NV5 Geospatial indicated the differences in vertical accuracy between the out-of-channel and in-channel topography were likely a result of highly turbid and shallow depth stream conditions, combined with the altitude required to safely fly over the river. Based on on-the ground observations during the RTK-GPS data collection effort (Section 3.2), Reaches 4 and 3 exhibited the greatest amount of turbidity. Because of the differences in vertical accuracy, using this bathymetric data as the basis for the 2D hydraulic model introduces some uncertainty into the analysis. However, this uncertainty was reduced through model calibration and sensitivity analysis.

## 3.2 RTK-GPS Survey and Additional Data Collection and Comparison with LiDAR

RTK-GPS surveying and field data collection for the 2D hydraulic modeling were collected at each of the four selected reaches (R10, R6, R4, and R3). The RTK-GPS surveys and data collection efforts occurred from August 2 to August 5, 2022, with one full day spent at each of the four reaches. The objective of the surveys was to collect data useable for development of the 2D model. Because of time limitations, the data collection was prioritized as follows:

- Priority 1 data were required and involved collection of a sufficient number of RTK GPS elevation points in each study reach to evaluate the quality of floodplain and in-channel portions of the topobathymetric LIDAR data in those areas;
- Priority 2 data would be useful in the model development and consisted of the collection of water surface elevations under flow conditions present during the site visit; and
- Priority 3 data were considered optional since they were not directly needed for model development but could provide supplemental information including photos, preliminary roughness estimates, dimensions of key hydraulic features, and main channel substrates.

Figure 3-1 depicts the set-up and RTK-GPS survey data collection process.

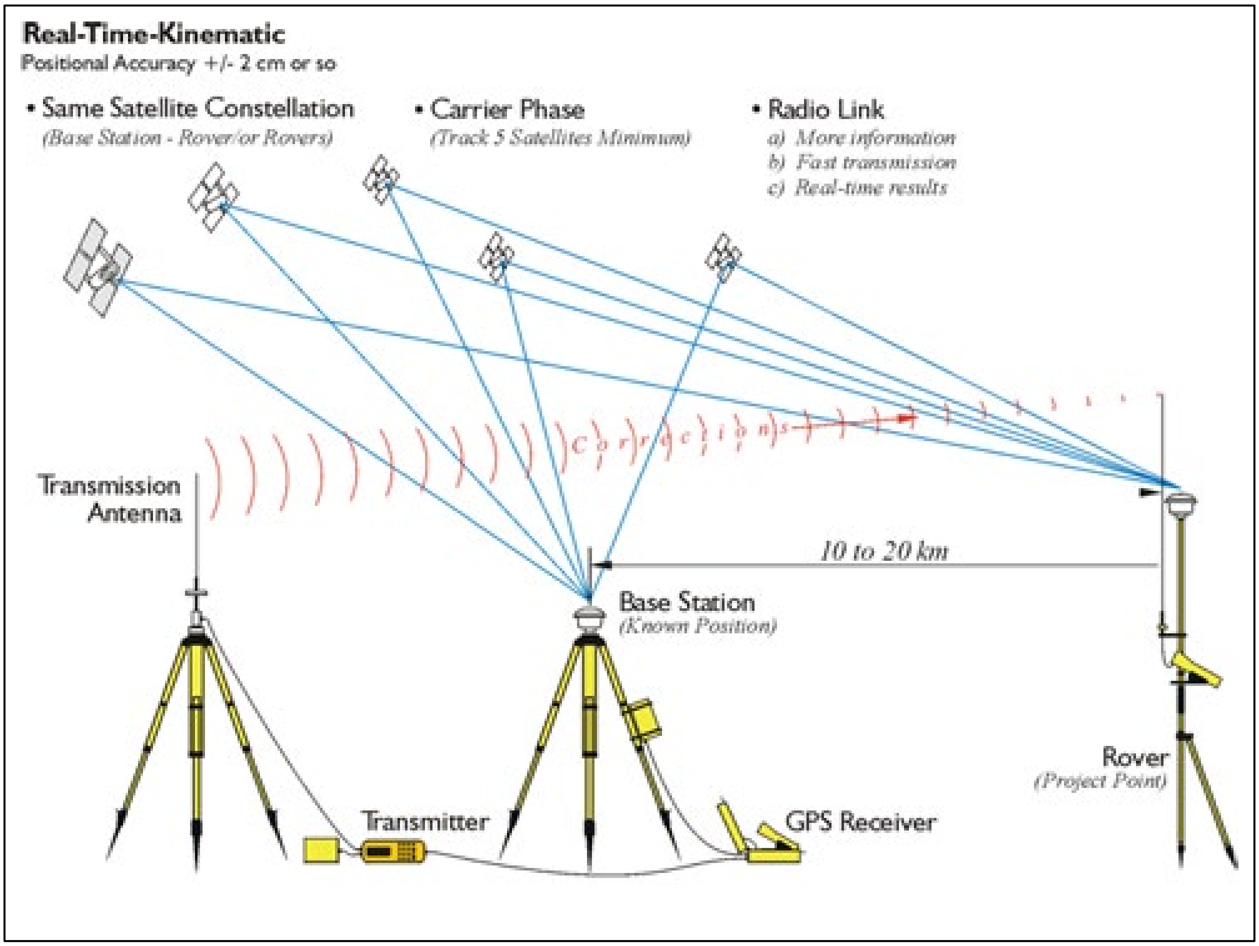



**Figure 3-1 Example field set-up for collecting RTK-GPS Ground elevation points (*Source: GPS for Land Surveyors*) for the Eklutna River.**

The priority 1 data were used to identify areas where the topobathymetric LiDAR data were unable to capture the true channel bottom, while priority 2 data were used for model calibration. Where collected, the priority 3 data were used to improve the model geometry and estimates of available habitat. Substrate data collection was limited and focused on defining Manning's roughness coefficients for use in the 2D model. Time constraints precluded detailed mapping of spawning substrate which would be required for computing 2D derived estimates of spawning habitat. Priority 3 data included channel flow, main channel substrate information, and site photos.

The field survey data and information were subjected to quality assurance/quality control procedures and then used to check the 2022 LiDAR data and calibrate the hydraulic model. Table 3-1 lists the flows measured at each of the four sites as well as the number of ground and water surface elevation measurements taken.

**Table 3-1 RTK-GPS and flow data collection in each of the 2D model sites in Reaches 10, 6, 4, and 3 of the Eklutna River.**

| Reach | Measured Flow(s) (cfs) | Number of Ground/Channel Measurements | Number of Water Surface Measurements |
|---|---|---|---|
| 10 | 0.57 | 148 | 12 |
| 6 | 8.23, 8.55 | 114 | 39 |
| 4 | 61.10, 66.70 | 218 | 53 |
| 3 | 62.4 | 175 | 40 |

Some limited qualitative substrate data within Reaches 10, 6, and 4 were recorded, but only in the main channel portions of the study areas. R3 was a large and widely distributed study area and appeared to have a uniform substrate composition ranging from fine sediments to large gravels and thus, was not mapped. However, the substrate data collected were not sufficient to use in the evaluation of channel and floodplain spawning habitats as described in this technical memorandum. This would require detailed substrate mapping of each of the 2D Study sites which has not been done.

As described in Section 3.1, the LiDAR report provided to Kleinschmidt Associates by NV5 Geospatial noted that in areas with high turbidity, significant vegetation cover, and very shallow depths, the bathymetric elevations have greater uncertainty than the out-of-channel LiDAR elevations.

Kleinschmidt Associates completed a separate analysis of the LiDAR elevation data by comparing the LiDAR elevations to the RTK-GPS survey data that was collected within two months of the LiDAR flight. The comparison revealed that overall, the Root Mean Square Error (RMSE) between the RTK-GPS surveyed elevations and the LiDAR topobathymetry elevations was 0.16 feet and ranged from 0.12 to 0.18 feet. RMSE describes how concentrated data are around the line of best fit between two data sets (low values mean two highly correlated data sets). The RMSE listed for each of the data sets listed in Table 3-2 reveals that there is a high correlation between the RTK-GPS survey elevations and the 2022 topobathymetric LiDAR data. Figure 3-2 highlights the elevation differences of the two data sets. This analysis revealed that the LiDAR and RTK-GPS elevation data are accurate to within roughly 0.2 meters for the whole data set. Reaches 6 and 4 had greater agreement compared to R3 and R10. Reaches 3 and 10 had the greatest amount of vegetative cover while R3 had the most turbidity of the four reaches.

**Table 3-2 Root Mean Square Error (RMSE) for LiDAR vs. RTK-GPS elevation comparison for the four 2D HEC-RAS study reaches of the Eklutna River.**

| Reach | RMSE (ft) |
|---|---|
| 10 | 0.18 |
| 6 | 0.12 |
| 4 | 0.15 |
| 3 | 0.18 |

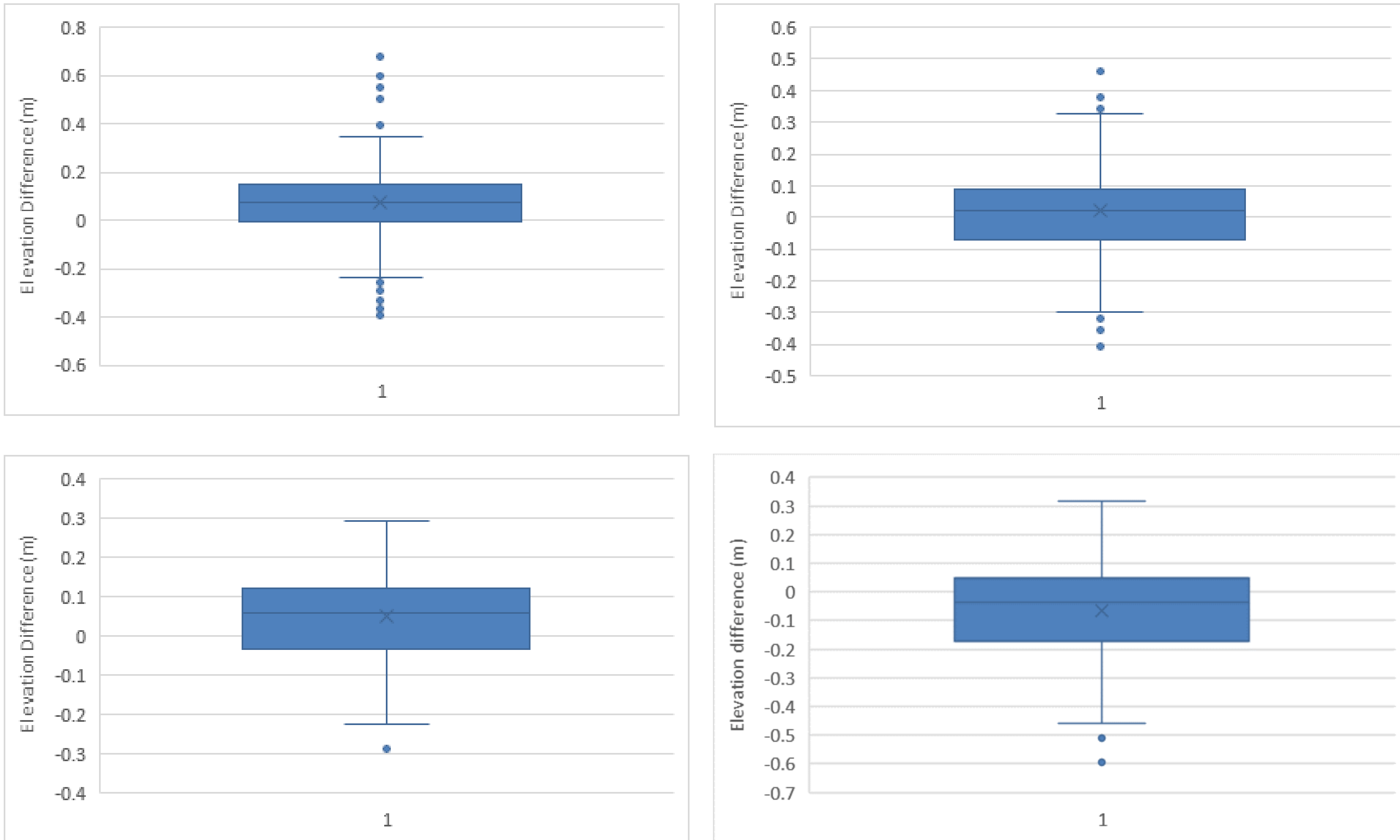



**Figure 3-2 Elevation differences between the LiDAR data and RTK-GPS survey data for the Eklutna River for Reach 4 (upper left), Reach 3 (upper right), Reach 10 (lower left), and Reach 6 (lower right).**

### 3.3 Development of 2D Mesh and Selection of Manning's Roughness Values

HEC-RAS 2D utilizes a grided computation mesh to compute the direction, velocity, and depth of flow within the model domain. Each 2D mesh is made of computational cells that are sized to capture adequate detail within areas of interest. Typically, areas of higher importance or hydraulic conveyance, such as in-channel areas, will be assigned smaller cells than out-of-channel areas to capture greater hydraulic detail. Table 3-3 below summarizes the cell sizes selected for the models in Reaches 10, 6, 4, and 3.

**Table 3-3 Computational cell sizes utilized for the 2D model for Reaches 10, 6, 4, and 3 in the Eklutna River.**

| Reach | Floodplain Cell Size (ft) | Channel Cell Size (ft) | Total Number of Cells |
|---|---|---|---|
| 10 | 25 | 2-3 | 100,275 |
| 6 | 10 | 3 | 6,122 |
| 4 | 25 | 3 | 71,282 |
| 3 | 25 | 3-5 | 30,383 |

Initial Manning's roughness coefficients of each site's channel and floodplain was estimated through on the ground observations, review of site photos and channel substrate maps, and guidance provided in the HEC-RAS 2D User's Manual (USACE 2021). These initial Manning's roughness coefficients of each sites channel and floodplain were based on the flow conditions observed at the time of the calibration data collection. The flow channel roughness values used for each site were adjusted to best match the observed data recorded during the site visit (see Section 3.5 of this report for discussion on the calibration process). Typically, the Manning's roughness coefficients of a streams channel and floodplain are higher at lower flows when the frictional forces on the flow are higher. As flow, and subsequently depth increase, these frictional forces decrease and the Manning's roughness coefficients used to model these higher flows also decrease. These effects are more pronounced in river reaches that are confined to a single channel thread and lessened in reaches that are wide and multi-threaded. For this reason, adjustments to Manning's roughness based on flow were made for the R6 and R10 models, given that these reaches are much more confined then R3 and R4. Table 3-4 summarizes the final roughness values used for each model at the calibration flow level. Table 3-5 and Table 3-6 highlight the adjustments to Manning's roughness based on flow for R6 and R10.

**Table 3-4 Floodplain and Main Channel Manning's "n" roughness values applied to the 2D HEC-RAS hydraulic models developed for Reaches 10, 6, 4, and 3 of the Eklutna River.**

| Reach | Floodplain Description | Floodplain Manning's n Roughness Coefficient | Main Channel Description | Main Channel Manning's "n" Roughness Coefficient |
|---|---|---|---|---|
| 10 | Emergent Herbaceous Forest and Shrubs | 0.085 | Large cobble/boulder bed; cascading pools | 0.055 |
| 6 | Large Cobble/Deciduous Forest | 0.065-0.075 | Gravel/cobble bed | 0.025-0.038 |
| 4 | Shrub/Scrub | 0.07 | Gravel/cobble bed | 0.032 |
| 3 | Woody Wetlands | 0.065 | Incised channel with vegetated banks and small gravel/fine bed | 0.04* |

*Defined channel not present in majority of study area.

**Table 3-5 Adjusted Manning's roughness values for Reach 6 of the Eklutna River.**

| Flow (cfs) | Manning's Roughness | | |
|---|---|---|---|
| | Right Floodplain | Left Floodplain | Channel |
| 8.4 | 0.087 | 0.134 | 0.038 |
| 25 | 0.087 | 0.134 | 0.032 |
| 50 | 0.087 | 0.134 | 0.030 |
| 75 | 0.071 | 0.098 | 0.029 |
| 150 | 0.059 | 0.074 | 0.028 |
| 200 | 0.056 | 0.070 | 0.028 |
| 250 | 0.053 | 0.065 | 0.028 |
| 375 | 0.050 | 0.060 | 0.027 |

**Table 3-6 Adjusted Manning's roughness values for Reach 10 of the Eklutna River.**

| Flow (cfs) | Manning's Roughness | | |
|---|---|---|---|
| | Floodplain | Channel | Roadway |
| 8.4 | 0.147 | 0.055 | 0.050 |
| 25 | 0.147 | 0.049 | 0.050 |
| 50 | 0.147 | 0.046 | 0.050 |
| 75 | 0.147 | 0.044 | 0.050 |
| 150 | 0.147 | 0.042 | 0.050 |
| 200 | 0.085 | 0.042 | 0.042 |
| 250 | 0.071 | 0.041 | 0.039 |
| 375 | 0.060 | 0.040 | 0.036 |

### 3.4 MODEL HYDROLOGY AND BOUNDARY CONDITIONS

Boundary conditions, which allow flow to enter and exit the model domain, were applied to each 2D mesh at the upstream and downstream ends of the model. Flow hydrographs were used to define the upstream model boundaries, and the normal depth or channel slope was used to define the downstream model boundaries. In order to replicate the flows analyzed in the 1D PHABSIM analysis, the flow hydrographs used in the analysis were held constant to achieve a "quasi-steady" state condition within the model domain. This means natural attenuation within the Eklutna River system was not accounted for in this preliminary analysis.

One of the purposes of the 2D HEC-RAS models is to provide hydraulic inputs to the 2D habitat model needed to develop the habitat vs. flow curves described in Section 4.5. For this, each of the reaches was modeled with the flow conditions of 10, 25, 50, 75, 100, 150, 200, 250, 300, and 375 cfs. That range of flows proved sufficient for defining the shapes of the curves in R3 and R4 where, because of adjacent and abundantly available floodplain channels, additional flow equates to additional habitat. However, R6 in particular, and R10 to some extent are confined within a narrower floodplain and therefore opportunities for off-channel connectivity are more limited. To better define the habitat – flow relationships in those reaches, an additional five flows (37 cfs, 62 cfs, 87 cfs, 175 cfs, and 225 cfs) intermediate to those for R3 and R4 were modeled (Table 3-7). Table 3-8 summarizes the flows and normal depth slopes used for each of the four hydraulic models. The selected calibration flow used for Reaches 6 and 4 was an average of the two measured calibration flows recorded during the site visit.

**Table 3-7 Flows used in the 2D habitat modeling for Reaches 3, 4, 6, and 10 of the Eklutna River. Ten flows were sufficient to define the habitat vs. flow relationships in R3 and R4, but an additional five flows were modeled in R6 and R10 to better define the relationships.**

| 2D Habitat Modeled Flow (cfs) | | | |
|---|---|---|---|
| **Reach 3** | **Reach 4** | **Reach 6** | **Reach 10** |
| 10 | 10 | 8.4 | 10 |
| 25 | 25 | 25 | 25 |
| 50 | 50 | 37 | 37 |
| 62.4 | 63.5 | 50 | 50 |
| 75 | 75 | 62 | 62 |
| 100 | 100 | 75 | 75 |
| 150 | 150 | 87 | 87 |
| 200 | 200 | 100 | 100 |
| 250 | 250 | 150 | 150 |
| 300 | 300 | 175 | 175 |
| 375 | 375 | 200 | 200 |
| | | 225 | 225 |
| | | 250 | 250 |
| | | 300 | 300 |
| | | 375 | 375 |

**Table 3-8 Model boundary conditions including calibration flows, and normal depth slope used in defining downstream boundaries for Reaches 10, 6, 4, and 3 of the Eklutna River.**

| Reach | Calibration Flow | Downstream Normal Depth Slope (ft/ft)** |
|---|---|---|
| 10 | 0.57* | 0.01198 |
| 6 | 8.4 | 0.0204 |
| 4 | 63.5 | 0.00743 |
| 3 | 62.4 | 0.00136, 0.00321*** |

* Calibration for Reach 10 was not conducted given how small the measured flow (0.57 cfs) was compared to the modeled habitat flow range (10-375 cfs).

** Normal depth was estimated based on the slope of the terrain through the boundary of the model.

*** Reach 3 contained two distinct outlets for flow and thus, had two normal depth boundary conditions.

### 3.5 MODEL CALIBRATION

Calibration flows were measured for all four study reaches as described above in Section 3.4. However, the measured flow in Reach 10 (0.57 cfs) was too low to use in model calibration given the range of modeled flows (10-375 cfs). Model calibration data was limited to the flows present in the noted reaches at the time of data collection (August 2-5, 2022).

For the other three reaches, Manning's "n" values were adjusted to best replicate the observed water surface elevations measured during the RTK-GPS survey. For this preliminary analysis, Manning's roughness was determined to be the primary calibration parameter as the other hydraulic model parameters were assumed to be known (flow, ground elevations, bathymetry). The base and adjusted Manning's n values are shown in Table 3-9 below.

**Table 3-9 Manning's calibration used for the Eklutna River 2D HEC-RAS hydraulic model.**

| Reach | Base Main Channel Manning's n Roughness Coefficient | Adjusted Main Channel Manning's n Roughness Coefficient |
|---|---|---|
| 10 | 0.055 | 0.055** |
| 6 | 0.045 | 0.025-0.038 |
| 4 | 0.045 | 0.032 |
| 3 | 0.045* | 0.04* |

*Defined channel not observed in majority of study area.
*Not calibrated.

The final calibrated model reported average differences between measured and modeled water surface elevations of -0.35, -0.23, and -0.12 feet for Reaches 6, 4, and 3, respectively. These differences between modeled and measured water surface elevations are adequate for a 2D model of this size. Figure 3-3 shows the correlation between measured and modeled water surface elevations for the three reaches. These figures highlight the strong correlation between the predicted and measured water surface elevations in the three calibrated models.

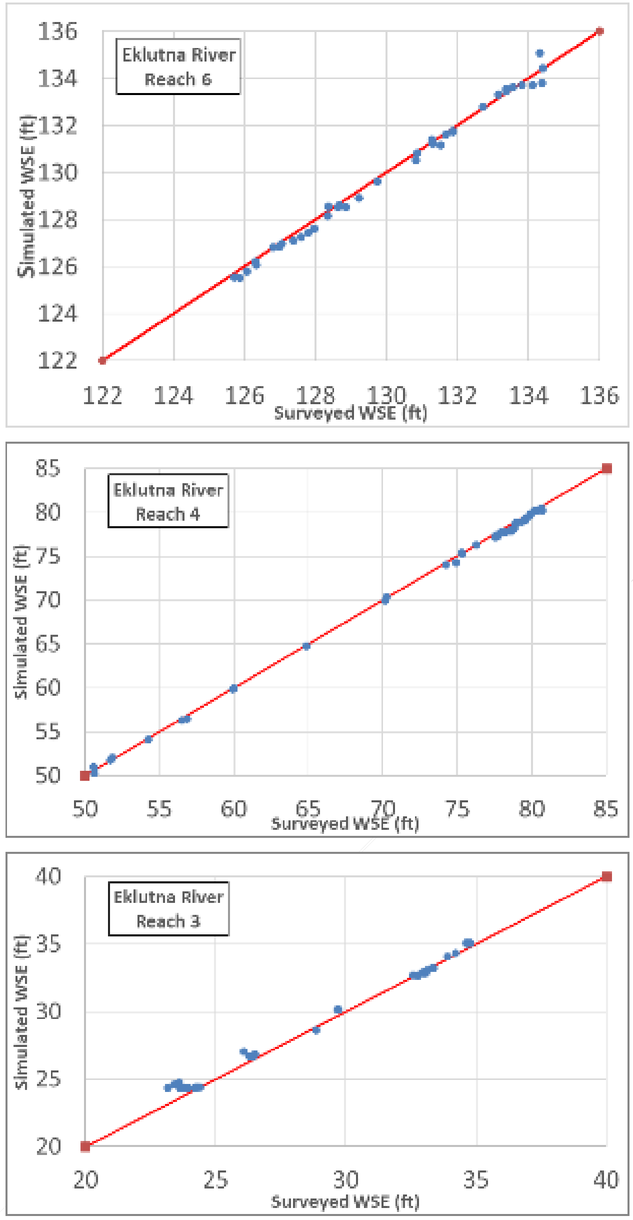



**Figure 3-3 Reach 6 (top), Reach 4 (middle), and Reach 3 (bottom) water surface elevation calibrations for the 2D HEC-RAS model for the Eklutna River.**

Based on the analysis of the LiDAR data (Section 3.0), the areas with thicker vegetation canopy and high turbidity levels exhibited greater discrepancy between the LiDAR surface and the RTK-GPS survey points. This conclusion is further supported by the calibration of the hydraulic models, which revealed that the models for reaches with thicker vegetation canopy and high turbidity levels (Reaches 4 and 3) did not calibrate as well as the Reach 6 model which had minimal vegetated canopy and low turbidity.

## 3.6 INTERPRETING MODEL RESULTS

The results produced by this hydraulic model represent the depth, velocity, and inundation extents related to specific flow levels within the Eklutna River. Additional sources of flow within the modeled areas such as groundwater, rainfall/runoff, tidal, or snowmelt are not accounted for. This means the areas of inundation, or "wetted areas", are only shown if they are hydraulically connected to the Eklutna River under the modeled flow levels in the Eklutna River. If the model results indicate that a portion of the channel or floodplain is dry, those areas may still be inundated as a result of other hydrologic sources.

As an example, Reach 3 has numerous ponds that are inundated year-round regardless of the flow level in the Eklutna River (Figure 3-4). The source of the water that keeps these ponds full is unknown and not accounted for in the model. The 2D model results for Reach 3 suggest that these ponds are not hydraulically connected to the Eklutna River (dry). However, since these ponds are known to hold water (Figure 3-4), it is possible that some hydraulic connections to the Eklutna River and its floodplain do exist, and/or other sources of inflow (i.e., rainfall/runoff, snowmelt, groundwater exfiltration, etc.) are occurring. The aerial images captured in Figure 3-4 would suggest that the ponds to the south (clear, darker water), are not connected to the Eklutna River floodplain (light turbid water).

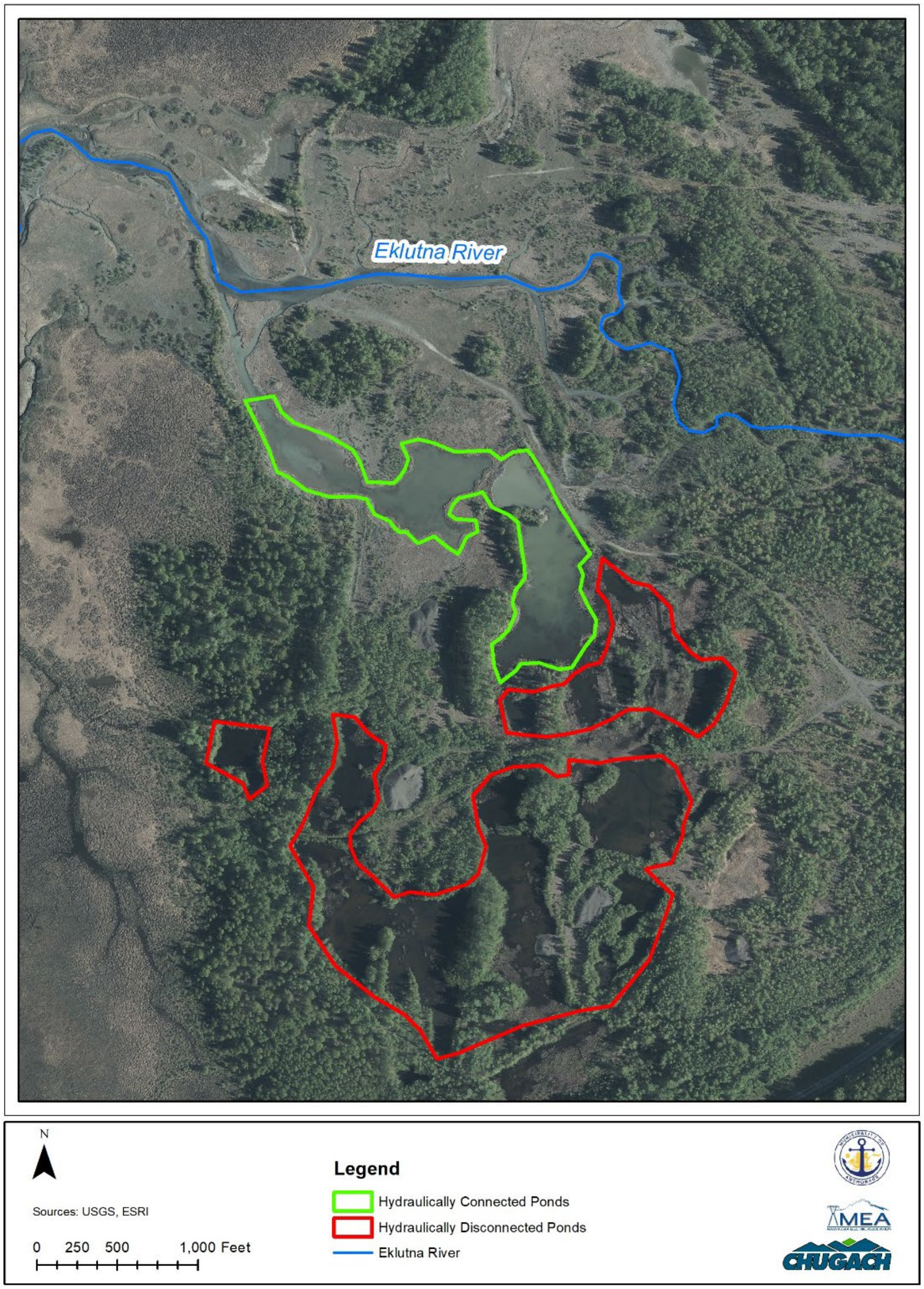



**Figure 3-4 Off Channel Ponds located in Reach 3 of the Eklutna River. Some of these ponds may become physically connected to the river via surface flows, while others may remain disconnected with water levels influenced by groundwater from other sources or hyporheic underflow from the river.**

# 4.0 2D HABITAT ANALYSIS

The 2D habitat analysis used outputs from the 2D HEC-RAS model for the Eklutna River combined with a python program built within the Quantum Geographic Information System (QGIS), an open-source mapping software that provides services similar to ArcGIS. The program read in the simulated velocity and depth from the hydraulic modeling results and merged the HSC preference curves to calculate weighted usable habitat area for the fish species (Chinook and Coho salmon) and life stages (juvenile rearing) of interest. Figure 4-1 illustrates the general steps of the modeling process applied in the 2D analysis, with details described below.

## 4.1 LINKAGE WITH THE 2D HEC-RAS MODEL

The 2D habitat modeling used the hydraulics pertinent to the cells defined in the 2D HEC-RAS hydraulic model. Mesh cell sizes varied within the terrain model with larger cells applied in the broad off-channel and floodplain areas (~10 ft to 25 ft) and smaller cells in the main channels (~2 ft to 5 ft.) to capture the more complex habitat features. Figure 4-2 through Figure 4-5 illustrate the mesh cell sizes applied in the 2D HEC-RAS and 2D habitat modeling. A cell was considered either wet or dry in the habitat model, but only the wet cells were included in the habitat calculations. Different flows will have different water surface elevations (WSEs) and for one flow, there may be dry cells in one location while cells in other locations may be wetted. Table 4-1 summarizes the number of cells in each of the four reaches (R3, R4, R6, and R10) used for both hydraulic simulation and habitat modeling, the latter which are notably less than those for hydraulic simulation. These differences are because of the shorter modeling extents used in the habitat model (Table 4-2; Figure 2-1) which excluded the less developed hydraulic transition zones near the upstream and downstream boundaries.

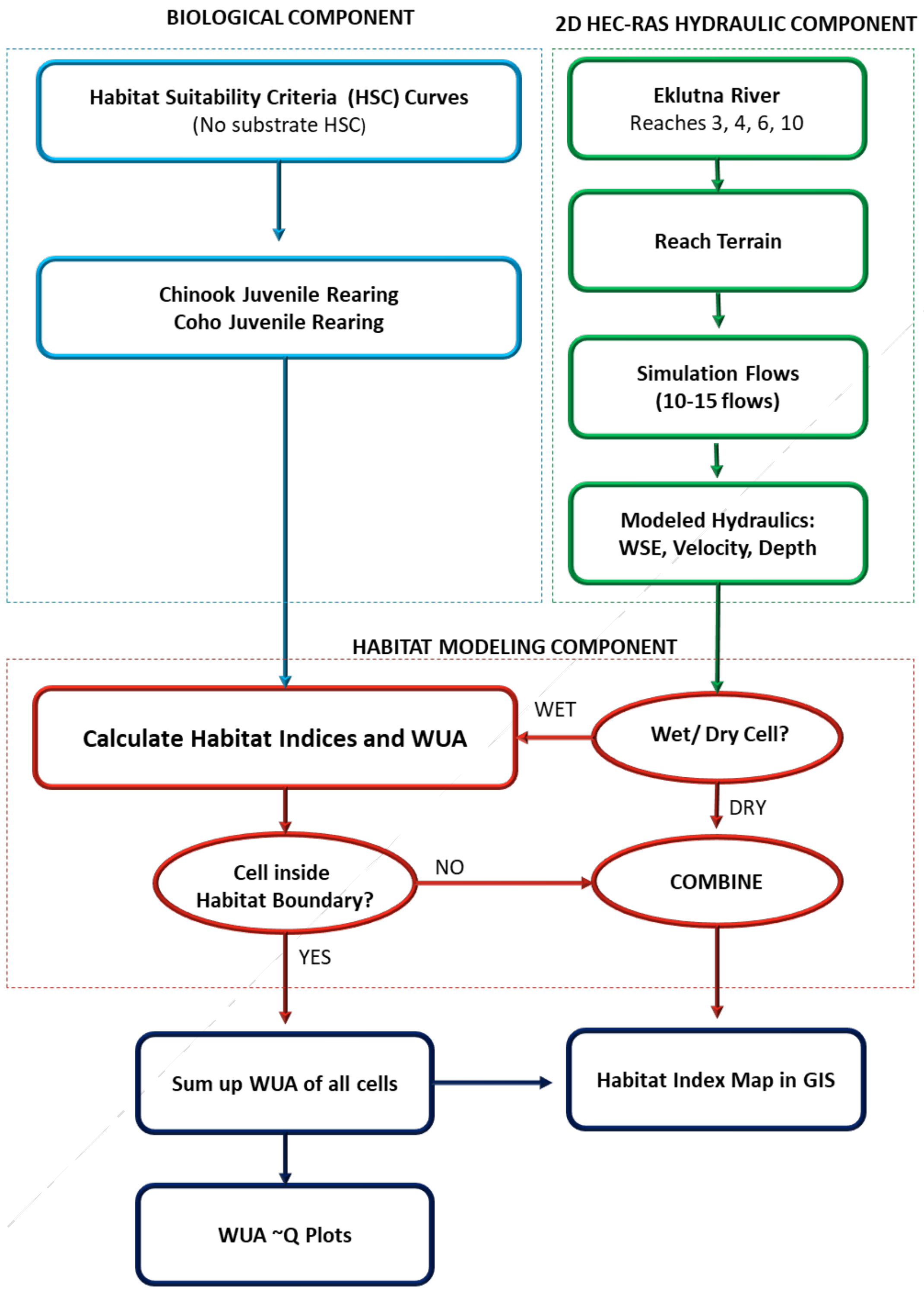



**Figure 4-1 Flow chart depicting components of the Eklutna River 2D HEC-RAS hydraulic and habitat modeling analysis. The biological components are shown on the left and the 2D HEC-RAS modeling components shown on the right.**

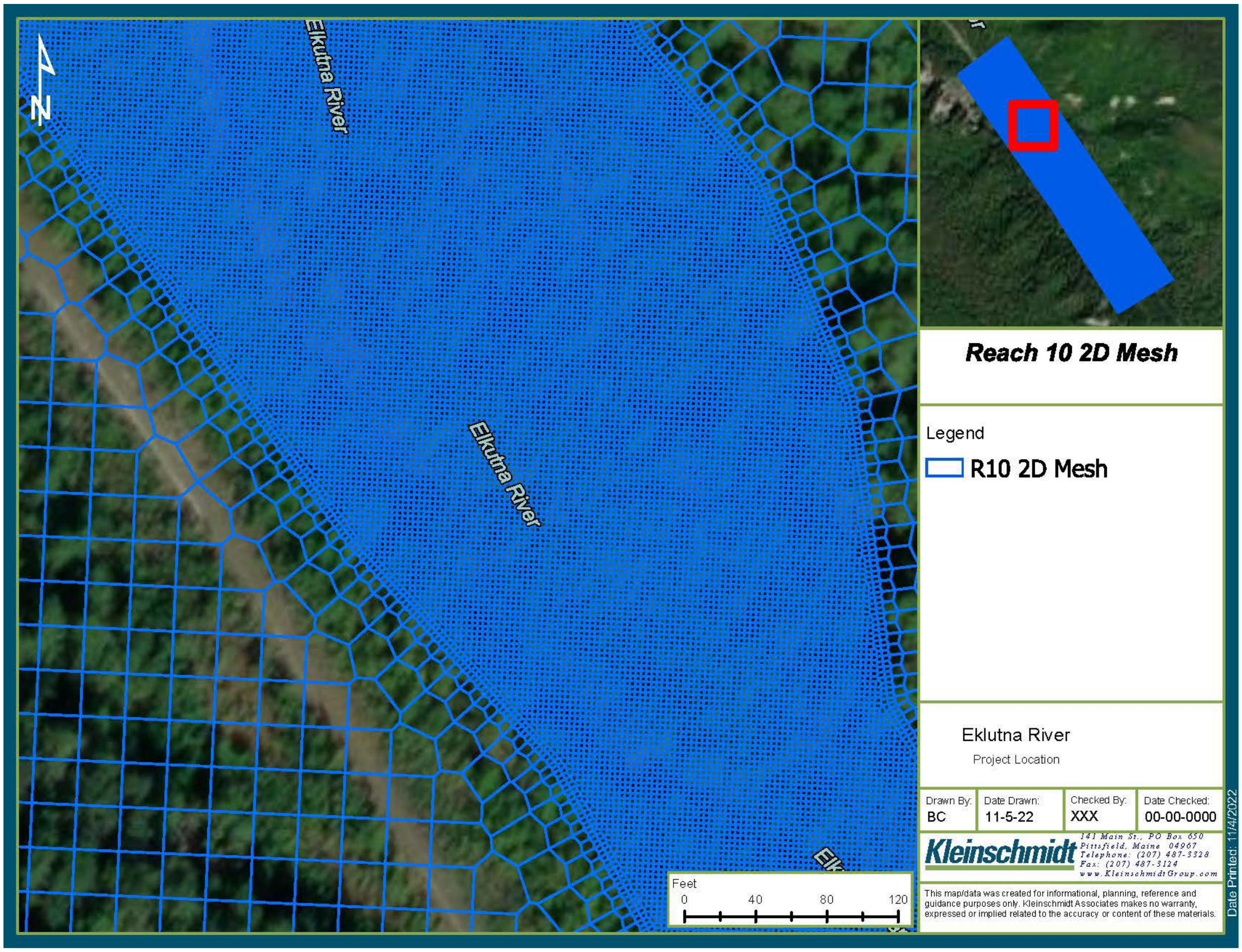



**Figure 4-2 Subsection of Reach 10 of the Eklutna River illustrating the mesh cell sizes used in main channel and floodplain habitats. Smaller mesh sizes were used in the main channel to define complex habitat features. This segment of R10 was 3,744 ft long and contains representative side channel and off-channel habitats.**


**Figure 4-3 Subsection of Reach 6 of the Eklutna River illustrating the mesh cell sizes used in main channel and floodplain habitats. Smaller mesh sizes were used in the main channel to define complex habitat features. This segment of R6 was 1,167 ft long and contained limited side channel and off-channel habitats.**


**Figure 4-4 Subsection of Reach 4 of the Eklutna River illustrating the mesh cell sizes used in main channel and floodplain habitats. Smaller mesh sizes were used in the main channel to define complex habitat features. This segment of R4 was 2,502 ft long and contains the "flooded forest" complex and other representative side channel and off-channel habitats.**

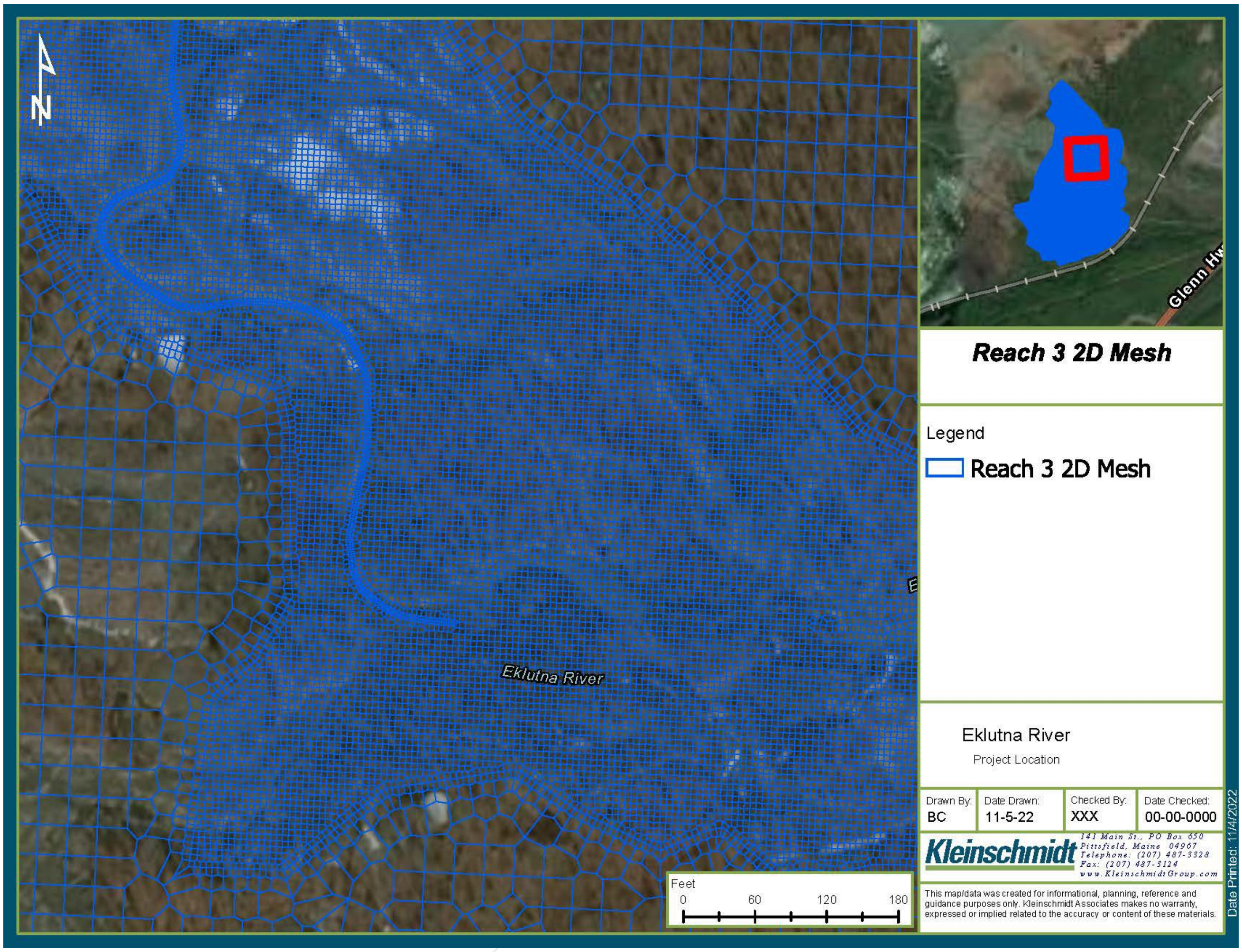



**Figure 4-5 Subsection of Reach 3 of the Eklutna River illustrating the mesh cell sizes used in main channel and floodplain habitats. Smaller mesh sizes were used in the main channel to define complex habitat features. This segment of R3 was 2,183 ft long and contains a braided beaver complex and other representative side channel and off-channel habitats.**

**Table 4-1 Number of cells in each of the four reaches (not including boundary cells).**

| Reach | Number of cells | |
|---|---|---|
| | Hydraulic Model | Habitat Model |
| R3 | 30,383 | 26,677 |
| R4 | 71,282 | 69,863 |
| R6 | 6,122 | 4,294 |
| R10 | 100,275 | 93,055 |

**Table 4-2 Approximate length of each stream reach for hydraulic model and habitat model.**

| Reach | Reach length (ft) | |
|---|---|---|
| | Hydraulic Model | Habitat Model |
| R3 | 2,183 | 2,001 |
| R4 | 2,502 | 2,402 |
| R6 | 1,167 | 783 |
| R10 | 3,744 | 3,443 |

## 4.2 DEFINING 2D HABITAT CELLS

The 2D habitat modeling followed the same PHABSIM guidelines for 1D habitat modeling, but computationally used a different approach for defining habitat cells. In 1D analysis, a computational cell is determined by adjacent verticals in a transect where velocity and depths are measured and reported over a prescribed stream length (usually 1,000 ft). If a cell width is 2 feet, then the computational cell size is 2,000 $ft^2$ in surface area. In the 2D habitat model, a computational cell is defined by the mesh cell size generated from the hydraulic model. If a cell size is 3 ft wide by 3 ft long, the computational cell size is 9 $ft^2$ in surface area. In addition, a computational cell in 1D analysis can be partially wet while a 2D cell in the current study is either dry or wet.

The same simulation flows used in the 2D HEC-RAS modeling (Section 3.4) were applied in the 2D habitat modeling.

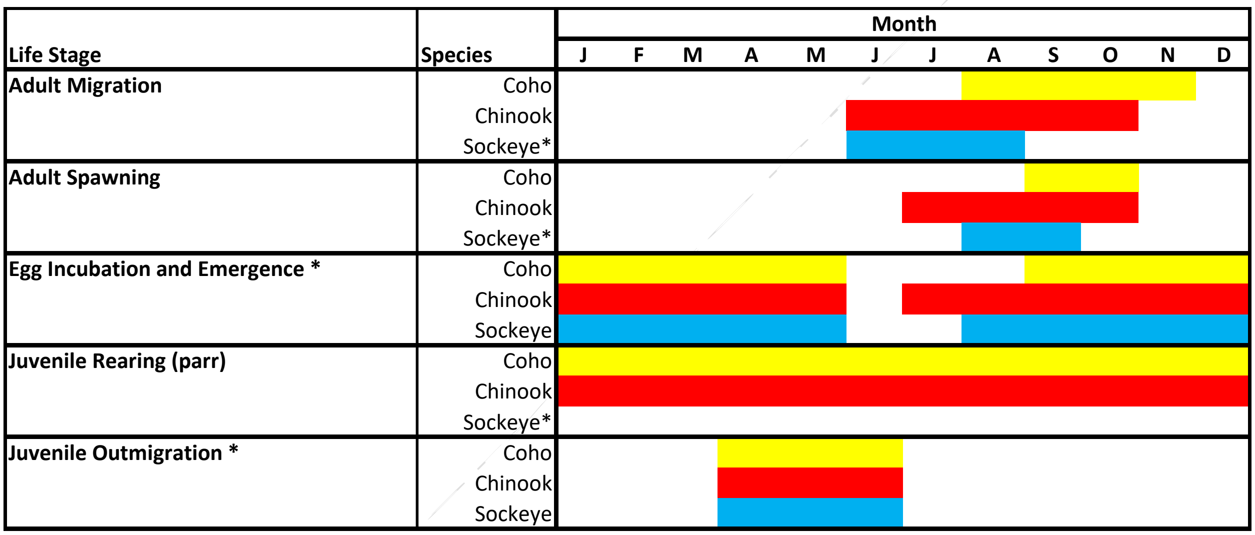
## 4.3 HABITAT SUITABILITY CURVES

HSC curves are designed for use in an instream flow analysis to quantify changes in habitat under various flow regimes. For the 2D habitat analysis, the same HSC curve sets developed for the 1D PHABSIM analysis (Kleinschmidt 2022b) were considered, but in this case were focused solely on juvenile rearing habitats[4] for Chinook and Coho salmon. The curve sets included the variables of depth and velocity; all substrates are considered suitable for juvenile rearing.

[4] As noted above and in the Year 2 Study Plan, the 2D habitat analysis was focused on juvenile rearing habitat and specifically to determine to what extent gains in habitat could be achieved if side channel and off channel areas could be connected via flow.

## 4.4 PERIODICITY AND LIFE STAGE PRIORITY

Periodicity defines the periods of time that a particular life stage of a species is present or biologically significant to the sustainability of that species. Typical life stages considered include adult migration, spawning (and egg incubation), juvenile rearing, and smolt outmigration. Figure 4-6 depicts the species periodicity considered for the Eklutna River including the three species that are the focus of the instream flow assessment, Chinook, Coho, and Sockeye salmon. Unlike the 1D PHABSIM analysis (Kleinschmidt 2022b) that focused on both spawning and juvenile rearing life stages, the 2D habitat modeling only considered the juvenile rearing life stage and therefore was the life stage priority for all months. The spawning life stages did factor into the Time Series B analysis (see Section 5.2.2)




** Not assessed during 2021 River Fish Sampling. Data presented from USACE (2011)*

**Figure 4-6 Summary of seasonal use (periodicity) of the Eklutna River by Chinook Salmon, Coho Salmon, and Sockeye Salmon. Figure based on TU (2018), surveys, and observational data from 2021 surveys as presented in the Year 2 Report (2023, in preparation). The 2D Habitat modeling was focused only on the juvenile rearing life stage. Note: this figure may be updated and applied to future analysis, pending additional information and field observations.**

## 4.5 HABITAT – FLOW RELATIONSHIPS

As noted above, the 2D habitat modeling was facilitated with a python program built within the QGIS platform. However, there is currently no commercially available model for converting 2D HEC-RAS model outputs into habitat-flow relationships. For this, Kleinschmidt developed and applied a separate program utilizing the Python scripts to compute these relationships. This program was subjected to a rigorous QA/QC process to ensure model outputs were accurately representing habitats. This included: exporting detailed simulated hydraulics and habitat indices of each modeled flow to an Excel file for documentation purposes; construction of GIS shape files with attribute tables including hydraulics, geometry, rearing combined suitability indices (CSI), and all other habitat indices of each cell for each flow and each species; comparison of the WSE, velocity, and depths in the shape file attribute tables against those in the Hierarchical Data Format (HDF) designed to store and organize large amounts of data, as a means to QA/QC the hydraulics; and then displaying the modeled WUA vs. flow relationships on a GIS interface to show the habitat modeling results.

Step wise, the computation of habitat vs. flow relationships by species and for each of the modeled flows were derived by first combining the modeled velocities and hydraulic depths of each cell with the HSC curves for rearing to calculate weighted velocity and depth indices, expressed in $V_i$ and $D_i$, respectively. These were then combined for each cell to calculate a combined suitability index (CSI $=V_i \times D_i$) that incorporated both velocity and depth, and then the area (A) of the cell was determined, and finally total weighted useable area (WUA) computed by summing up all cells as $WUA = \sum_{all\ cells} CSI\ \times A$. Figure 4-7 illustrates an example of this for the four reaches for a flow of 75 cfs.

These areas were then summed over the entire habitat model boundary to provide an estimate of total habitat for a given flow. Dividing these areas by the stream lengths of each reach provided an estimate of habitat area per 1,000 ft of stream length. This process was applied to all four reaches (R10, R6, R4, and R3) resulting in the derivation of reach-specific Chinook and Coho juvenile rearing habitat vs. flow relationships (Figure 4-8 and Figure 4-9). These relationships are shown in tabular format in Table 4-3 through Table 4-6.

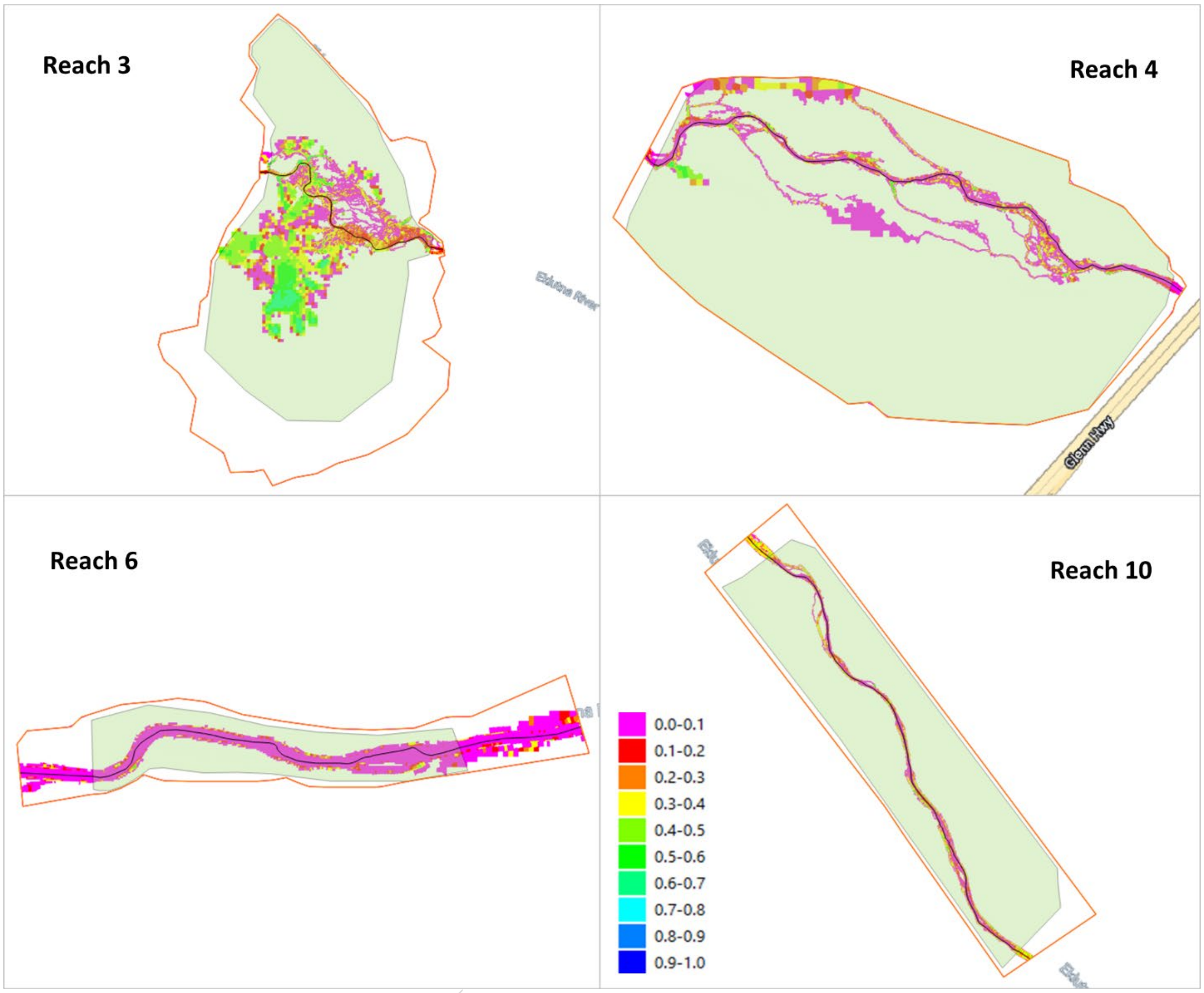



**Figure 4-7 Combined Suitability Index habitat maps for juvenile rearing habitat in Reach 3 (upper left), Reach 4 (upper right), Reach 6 (lower left), and Reach 10 (lower right) for the 75 cfs modeled flow. The legend in Reach 10, also applies to other reaches, with the scale of habitat suitability ranging from high (blue) to low (purple).**

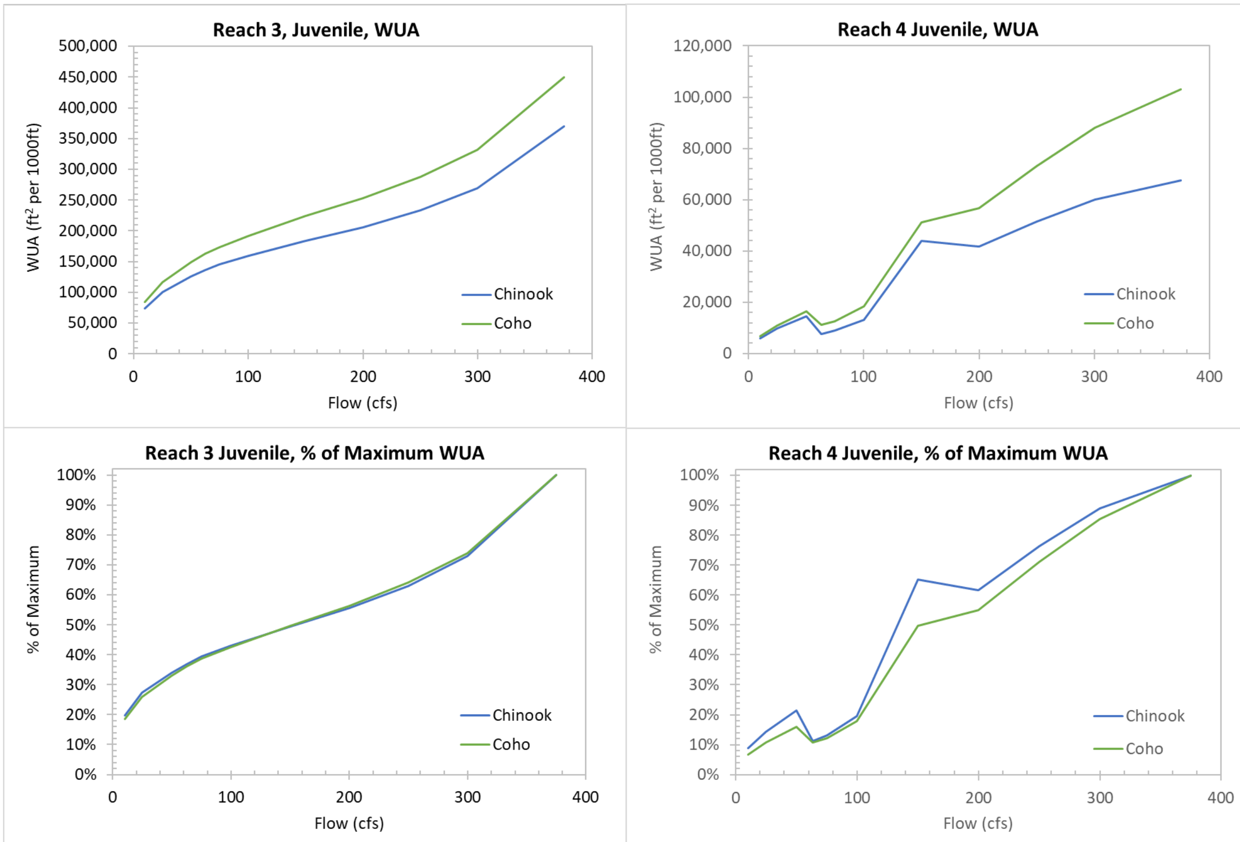



**Figure 4-8 Habitat-flow relationships for Chinook and Coho juvenile rearing habitat for Reach 3 (left panels) and Reach 4 (right panels) produced from 2D habitat modeling. Relationships of habitat area to flow are shown in the upper figures; lower figures depict the same data normalized as a percentage of habitat maximum to flow.**

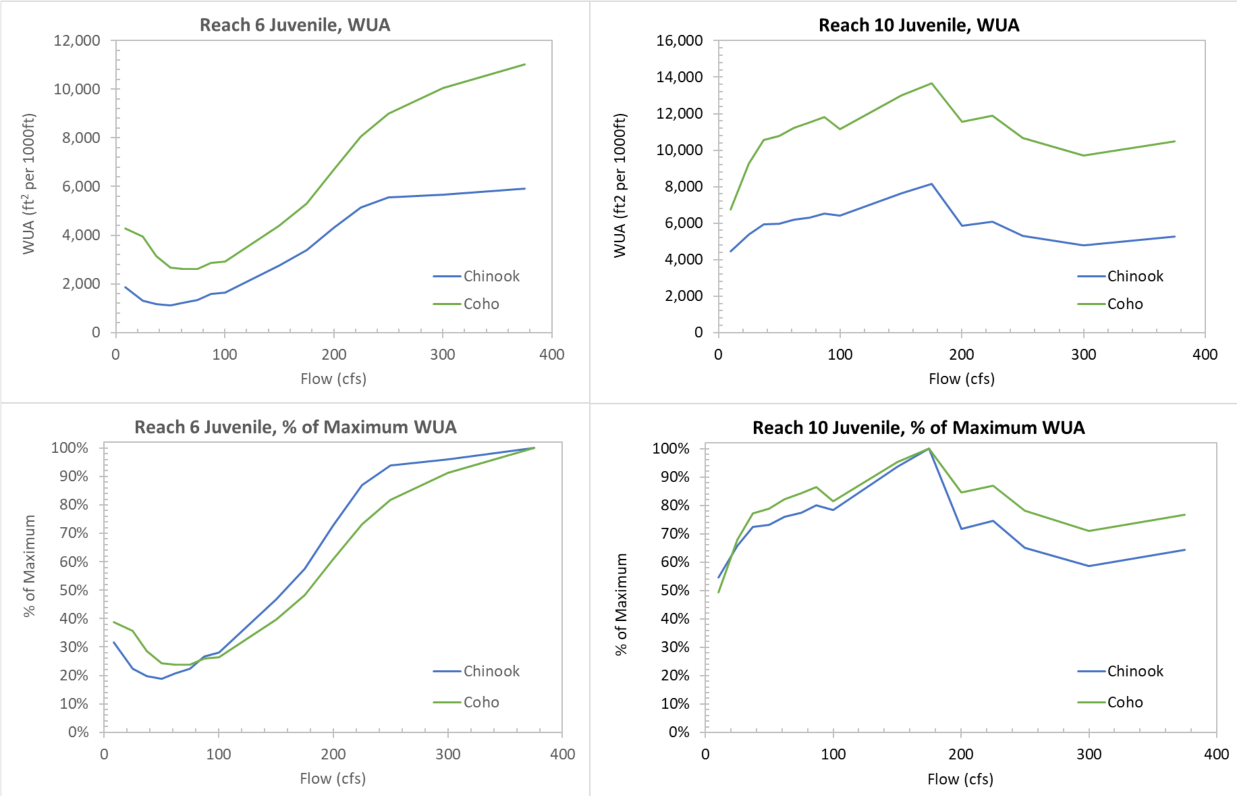



**Figure 4-9 Habitat-flow relationships for Chinook and Coho juvenile rearing habitat for Reach 6 (left panels) and Reach 10 (right panels) produced from 2D habitat modeling. Relationships of habitat area to flow are shown in the upper figures; lower figures depict the same data normalized as a percentage of habitat maximum to flow.**

**Table 4-3 Tabularized juvenile rearing habitat-flow relationships for Chinook (left two columns) and Coho (right two columns) salmon for Reach 3; the second column in each set depicts the data normalized as a percentage of habitat maximum.**

| Q (cfs) | Chinook Juvenile | | Coho Juvenile | |
|---|---|---|---|---|
| | WUA ($ft^2$/1,000 ft) | % Maximum WUA | WUA ($ft^2$/1,000 ft) | % Maximum WUA |
| 10 | 73,223 | 20% | 83,674 | 19% |
| 25 | 100,780 | 27% | 116,734 | 26% |
| 50 | 126,169 | 34% | 148,831 | 33% |
| 62.4 | 136,708 | 37% | 162,256 | 36% |
| 75 | 145,586 | 39% | 173,698 | 39% |
| 100 | 159,224 | 43% | 191,596 | 43% |
| 150 | 183,223 | 50% | 223,611 | 50% |
| 200 | 205,466 | 56% | 253,289 | 56% |
| 250 | 233,100 | 63% | 288,067 | 64% |
| 300 | 269,810 | 73% | 332,114 | 74% |
| 375 | 369,823 | 100% | 449,527 | 100% |

**Table 4-4 Tabularized juvenile rearing habitat-flow relationships for Chinook (left two columns) and Coho (right two columns) salmon for Reach 4; the second column in each set depicts the data normalized as a percentage of habitat maximum.**

| Q (cfs) | Chinook Juvenile | | Coho Juvenile | |
|---|---|---|---|---|
| | WUA ($ft^2$/1,000 ft) | % Maximum WUA | WUA ($ft^2$/1,000 ft) | % Maximum WUA |
| 10 | 5,965 | 9% | 6,812 | 7% |
| 25 | 9,688 | 14% | 10,984 | 11% |
| 50 | 14,459 | 21% | 16,380 | 16% |
| 63.5 | 7,552 | 11% | 11,113 | 11% |
| 75 | 8,909 | 13% | 12,565 | 12% |
| 100 | 13,226 | 20% | 18,294 | 18% |
| 150 | 43,956 | 65% | 51,124 | 50% |
| 200 | 41,596 | 62% | 56,727 | 55% |
| 250 | 51,486 | 76% | 73,202 | 71% |
| 300 | 59,992 | 89% | 87,954 | 85% |
| 375 | 67,461 | 100% | 103,061 | 100% |

**Table 4-5 Tabularized juvenile rearing habitat-flow relationships for Chinook (left two columns) and Coho (right two columns) salmon for Reach 6; the second column in each set depicts the data normalized as a percentage of habitat maximum.**

| Q (cfs) | Chinook Juvenile | | Coho Juvenile | |
|---|---|---|---|---|
| | WUA ($ft^2$/1,000 ft) | % Maximum WUA | WUA ($ft^2$/1,000 ft) | % Maximum WUA |
| 8.4 | 1,877 | 32% | 4,281 | 39% |
| 25 | 1,324 | 22% | 3,941 | 36% |
| 37 | 1,171 | 20% | 3,138 | 28% |
| 50 | 1,115 | 19% | 2,669 | 24% |
| 62 | 1,220 | 21% | 2,627 | 24% |
| 75 | 1,327 | 22% | 2,624 | 24% |
| 87 | 1,579 | 27% | 2,857 | 26% |
| 100 | 1,656 | 28% | 2,908 | 26% |
| 150 | 2,766 | 47% | 4,383 | 40% |
| 175 | 3,399 | 57% | 5,304 | 48% |
| 200 | 4,307 | 73% | 6,700 | 61% |
| 225 | 5,150 | 87% | 8,061 | 73% |
| 250 | 5,548 | 94% | 9,006 | 82% |
| 300 | 5,672 | 96% | 10,051 | 91% |
| 375 | 5,912 | 100% | 11,012 | 100% |

**Table 4-6 Tabularized juvenile rearing habitat-flow relationships for Chinook (left two columns) and Coho (right two columns) salmon for Reach 10; the second column in each set depicts the data normalized as a percentage of habitat maximum.**

| Q (cfs) | Chinook Juvenile | | Coho Juvenile | |
|---|---|---|---|---|
| | WUA ($ft^2$/1,000 ft) | % Maximum WUA | WUA ($ft^2$/1,000 ft) | % Maximum WUA |
| 10 | 4,455 | 55% | 6,742 | 49% |
| 25 | 5,368 | 66% | 9,266 | 68% |
| 37 | 5,919 | 72% | 10,553 | 77% |
| 50 | 5,973 | 73% | 10,774 | 79% |
| 62 | 6,203 | 76% | 11,224 | 82% |
| 75 | 6,320 | 77% | 11,517 | 84% |
| 87 | 6,535 | 80% | 11,825 | 87% |
| 100 | 6,401 | 78% | 11,136 | 81% |
| 150 | 7,642 | 94% | 13,004 | 95% |
| 175 | 8,166 | 100% | 13,666 | 100% |
| 200 | 5,852 | 72% | 11,552 | 85% |
| 225 | 6,090 | 75% | 11,885 | 87% |
| 250 | 5,309 | 65% | 10,678 | 78% |
| 300 | 4,786 | 59% | 9,713 | 71% |
| 375 | 5,252 | 64% | 10,484 | 77% |

All the relationships provide insight as to how increasing flows in the respective reaches influence juvenile rearing habitats, as connectivity is provided to side channel and floodplain habitats. Reaches 3 and 4 provide the best illustration of this. For R3, (the lower most reach), the curves exhibit an ever-increasing amount of juvenile habitat as flows increase. This reach contains a broad mosaic of complex channels that can become connected under different flow conditions (Figure 4-10); portions of this reach are also tidally influenced. As a result, more flow provides more connections to adjoining floodplain areas and rearing habitat continues to increase. The amounts of juvenile rearing habitat predicted for this reach are the highest of all reaches, ranging from ~73,000 $ft^2$ per 1,000 ft at 10 cfs to 450,000 $ft^2$ per 1,000 ft of stream at 375 cfs. Flows even higher than those modeled would still likely provide additional rearing habitat in this reach.

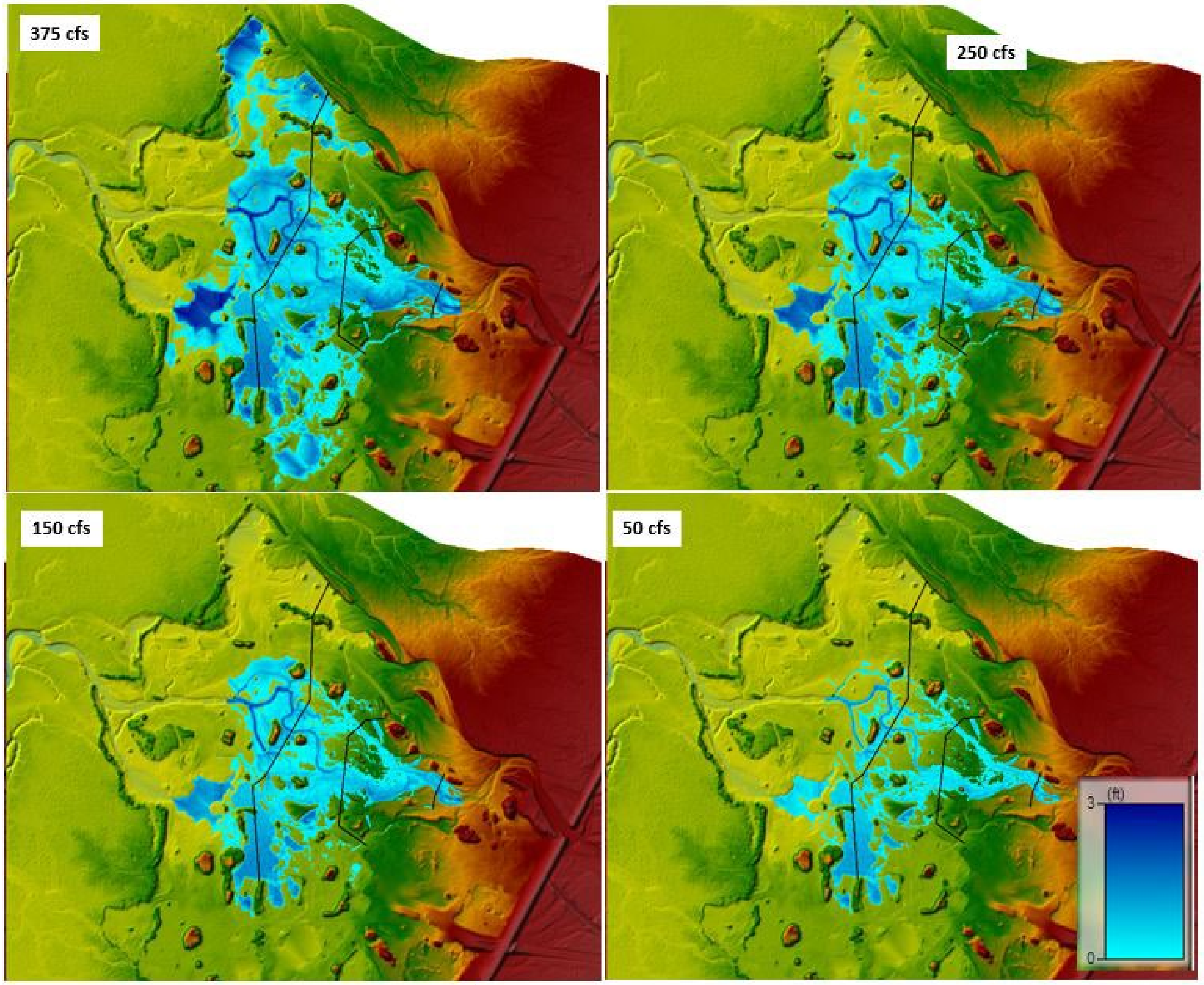



**Figure 4-10 Example of channel connectivity under flows of 50 cfs, 150 cfs, 175 cfs, and 375 cfs for Reach 3 of the Eklutna River.**

As explained in Section 3.6, there are known areas of inundation (ponds) within the Reach 3 modeled area that are not captured in the HEC-RAS model and that are shown as dry.

The habitat vs. flow relationship in R4 similarly shows an increasing trend of habitat with flow, but in this case the curve is punctuated by a habitat decrease around 70 cfs and a general leveling of habitat marked by an inflection in the curve at around 150 cfs, before continuing to increase. The decrease around 70 cfs likely occurs as flows in the main channel begin to exceed velocities suitable for juvenile rearing. With higher flows, although the main channels may not provide suitable rearing habitats, side channel and floodplain habitats begin to be engaged and habitat increases. This increase in habitat continues until flows reach about 150 cfs, where there is a leveling off/inflection point again likely marking an exceedance in velocities within some of the floodplain channels connected under those flows. Continued flow increases engage further floodplain channels and rearing habitat again increases. Figure 4-11 illustrates habitat connectivity under flows ranging from 50 cfs to 375 cfs. Juvenile rearing habitat amounts predicted in this reach range from ~6,000 $ft^2$ per 1,000 ft at 10 cfs to 103,000 $ft^2$ per 1,000 ft at 375 cfs.

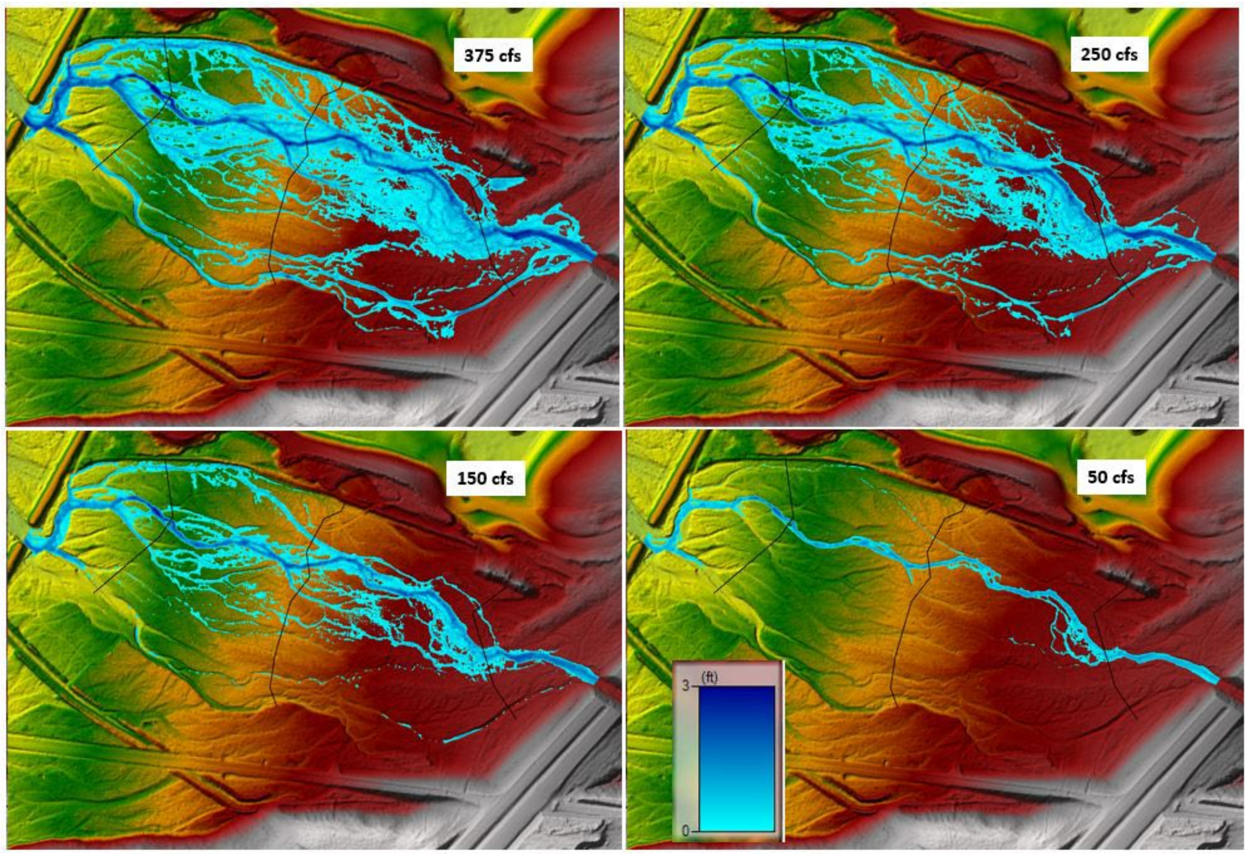



**Figure 4-11 Example of channel connectivity under flows of 50 cfs, 150 cfs, 175 cfs, and 375 cfs for Reach 4 of the Eklutna River.**

Although the habitat vs. flow relationship of R6 appears similar to R3 and R4, there are distinct differences in how this reach of stream responds to flow increases, primarily a function of its channel and floodplain morphology. Reach 6 is confined and flows through a narrow relatively steep canyon that lacks a broad floodplain and complex side-channel and off-channel habitats. As a result, the greatest amount of rearing habitat in the main channel is provided by the lowest flows (~10 cfs) as exhibited on the curve (Figure 4-9). R6 is the only reach (of the four reaches) that exhibits this trend. As flows increase to about 50 cfs, habitat amounts in the main channel continue to decrease, before beginning to increase, marking the point where overbank flows occur. However, unlike R3 and R4, the increased flows are not engaging connections with broad floodplain areas but rather with ever increasing adjoining fringe habitats where velocities can still remain suitable for juvenile rearing (Figure 4-12). Figure 4-13 depicts channel connectivity changes under flows ranging from 25 cfs to 300 cfs. Notably, the amounts of juvenile rearing habitat provided in R6 are relatively small compared to R3 and R4; habitats in R6 range from ~1,100 $ft^2$ per 1,000 ft at 50 cfs to 11,000 $ft^2$ per 1,000 ft at 375 cfs. Of note is that R6 contains extensive deposits of sediment and is subject to large changes in channel morphology under varying flows. This channel instability was one of the reasons it was not selected for study for the 1D PHABSIM analysis.

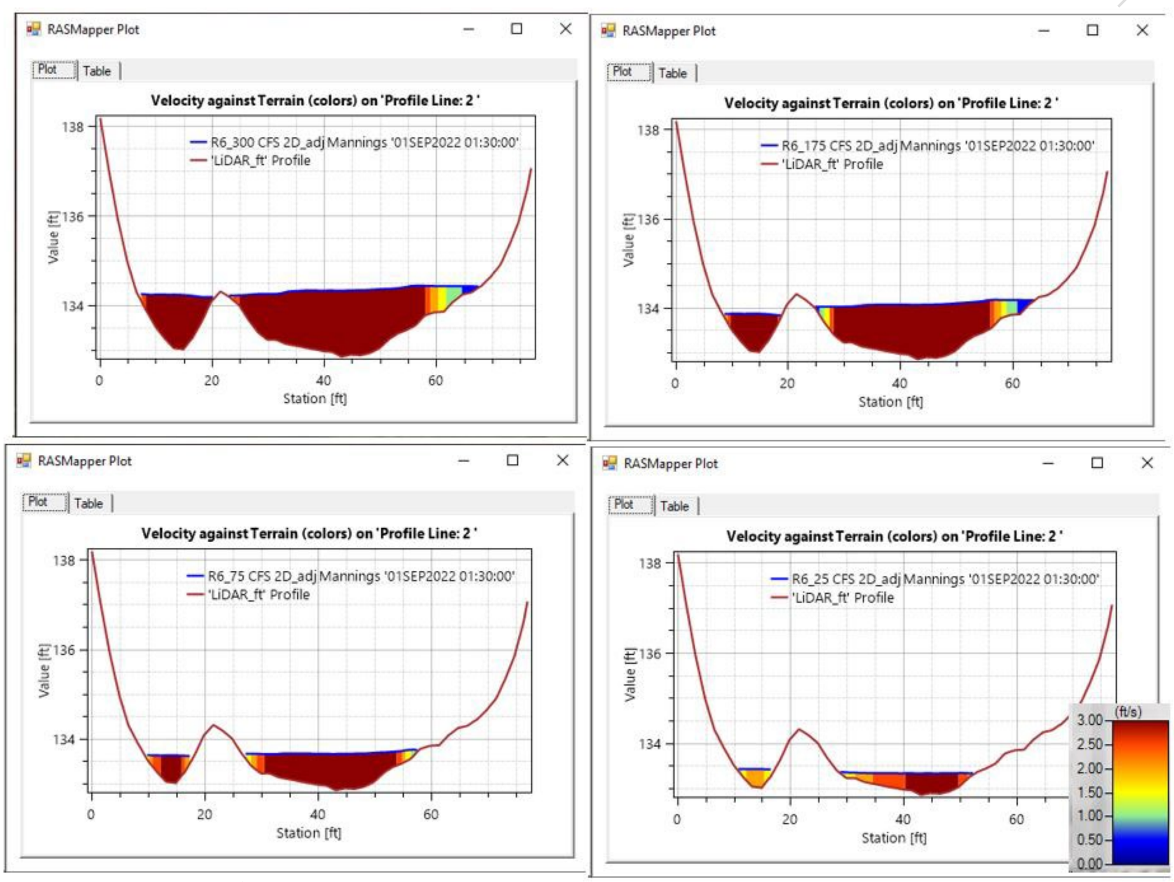



**Figure 4-12 Variation of velocity under four flow conditions (300 cfs – upper left, 175 cfs – upper right, 75 cfs – lower left, 25 cfs – lower right) for a subsection of R6 of the Eklutna River. As flows increase, velocity in the channel increases. Habitats for juvenile Coho and Chinook are mostly located at the fringes of the channel/floodplain where velocities are lowest.**

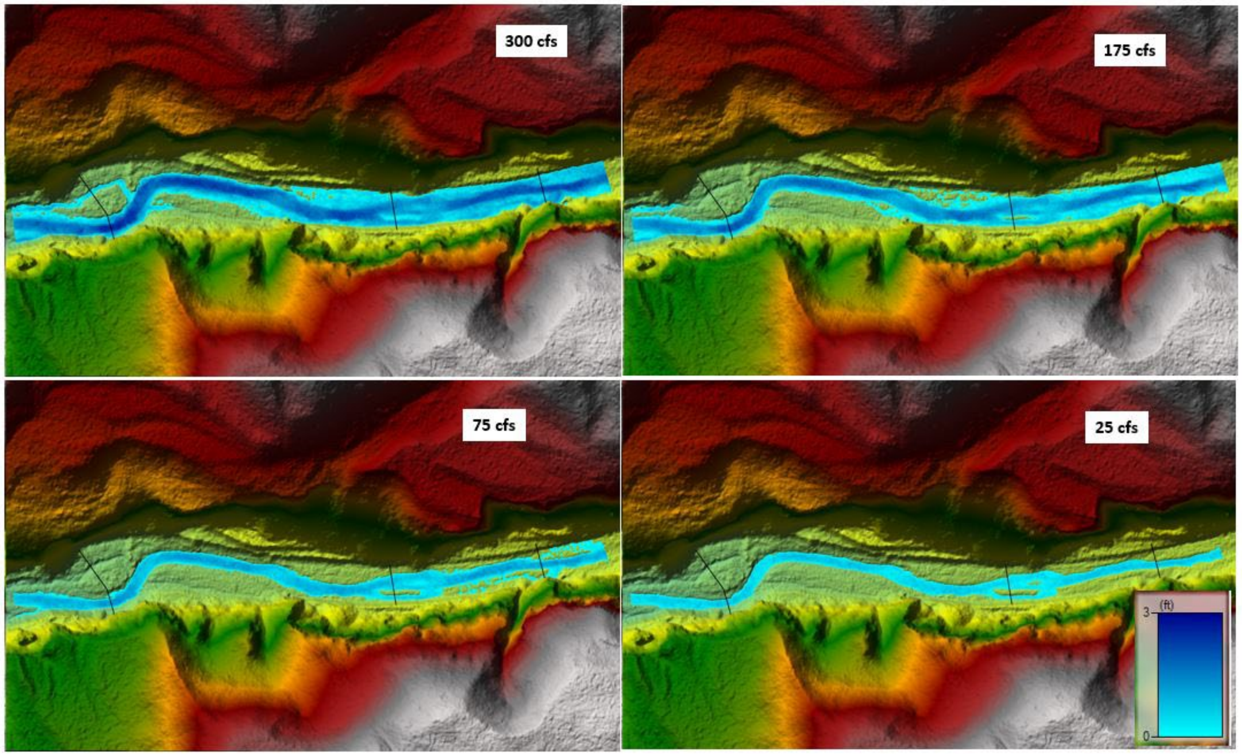



**Figure 4-13 Example of channel connectivity under flows of 300 cfs (upper left panel), 175 cfs (upper right panel), 75 cfs (lower left panel) and 25 cfs (lower right panel) for Reach 6 of the Eklutna River.**

The habitat vs. flow relationship for R10 represents perhaps the best example of how side channel and off-channel habitats would respond in the Eklutna River above Thunderbird Creek. In this case, the shapes of the curves are somewhat jagged with alternating increases and decreases in habitats likely reflective of the channel complexity and the connection with adjacent side and off-channel areas with increases in flow. This is illustrated in Figure 4-14 that shows channel connectivity under a range of flows from 25 cfs to 300 cfs. This is further shown in Figure 4-15 that shows the variation in water surface elevations across different channel features under a range of flow conditions. As flows increase, more channels become connected, but water surface elevations may differ. The punctuated pattern of the curve demonstrates how habitats can alternately blink in and out with flows owing to changing velocity patterns in the newly engaged channels. There are two minor peaks, one at ~85 cfs and one at 225 cfs, and one well defined peak that occurs at 175 cfs (Figure 4-9). Nominally, for the range of flows modeled, R10 provides habitats ranging from ~4,500 $ft^2$ per 1,000 ft at 10 cfs to ~13,500 $ft^2$ per 1,000 ft at 175 cfs. This is the only reach where habitats are not maximized at the highest flow (375 cfs) and indicates that the shape of the habitat vs. flow relationship was likely captured within the range of the modeled flows (10-375 cfs).

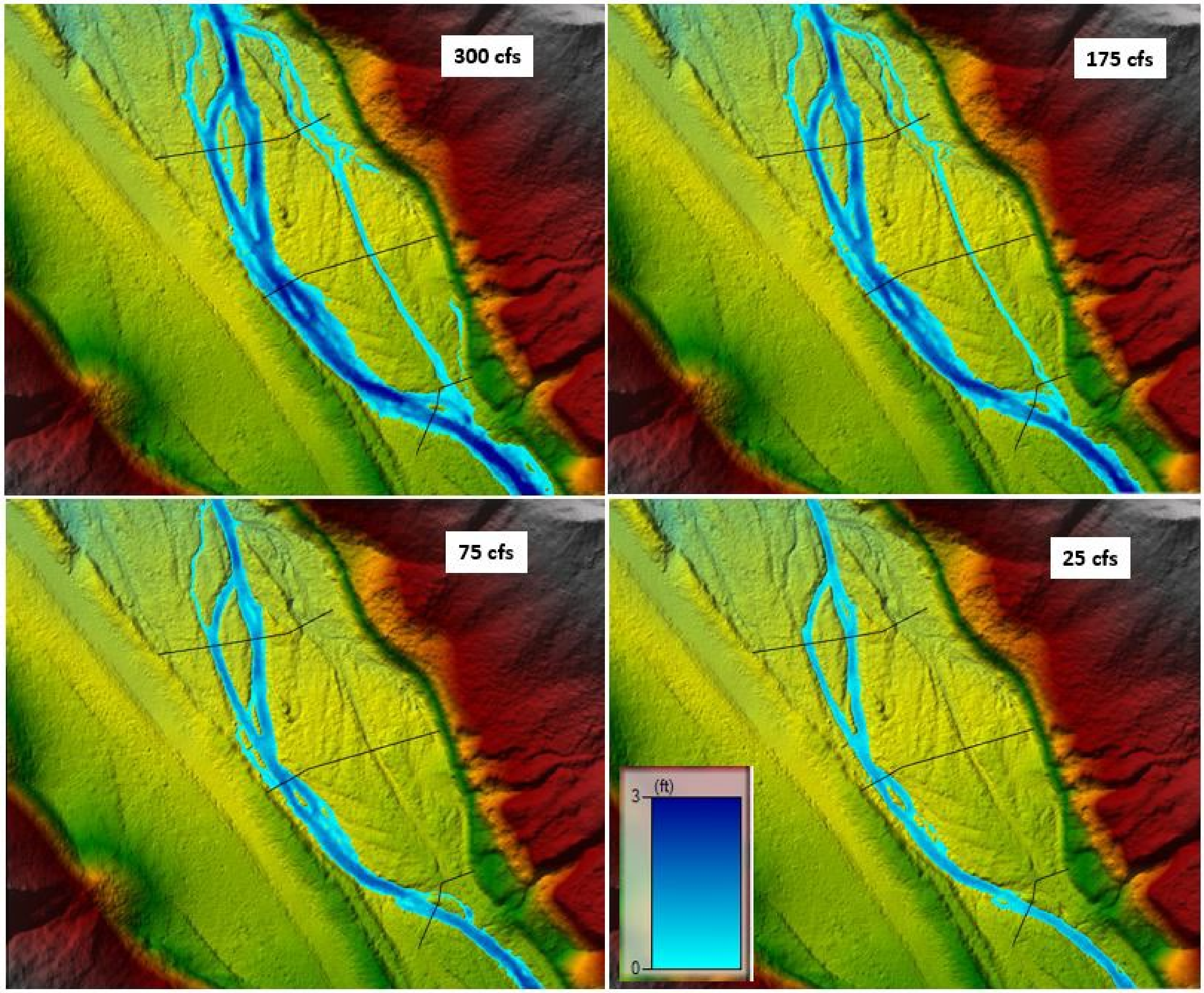



**Figure 4-14 Example of channel connectivity under flows of 300 cfs (upper left panel), 175 cfs (upper right panel), 75 cfs (lower left panel) and 25 cfs (lower right panel) for Reach 10 of the Eklutna River.**

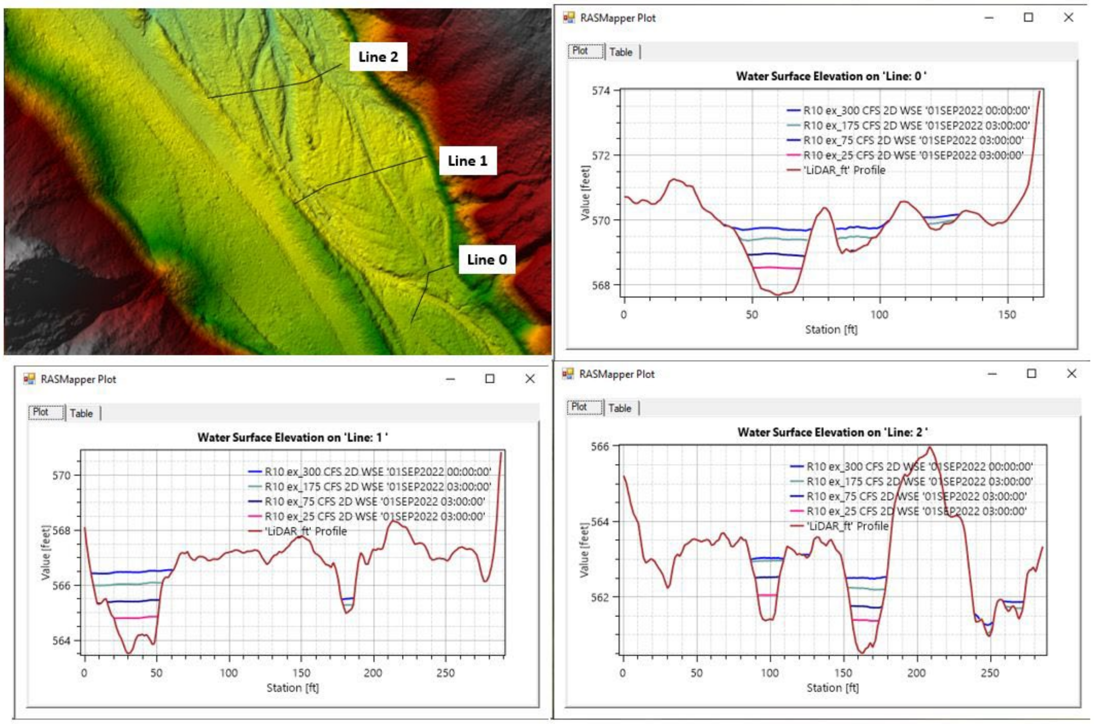



**Figure 4-15 Variation of water surface elevations (WSEs) under four flow conditions (25 cfs to 300 cfs) for a subsection of R10 of the Eklutna River. As flows increase, more channels become hydraulically connected, but WSEs may differ between channels.**

## 4.6 Off-Channel Connectivity Analysis

The output from the 2D HEC-RAS model was also used to explore and provide a preliminary assessment of the amount of potential off-channel habitat expressed as connected surface areas under different flow conditions. The analysis focused on determining the amount of area (in acres) within the model boundaries of each respective reach, with depths of at least 0.5 feet[5]. This area was considered "off-channel habitat" independent of the floodplain substrate of the inundated area. An example showing the extent of inundation for the five different flows (10 cfs, 25 cfs, 75 cfs, 150 cfs, and 375 cfs) is depicted in Figure 4-16 for R10. This analysis was independent of the HSC criteria and simply reflected the areas that would be connected under different flows.

[5] These areas were defined solely using a water depth criterion of 0.5 ft and do not reflect species preference. The 0.5 ft depth was selected as a reasonable basis for defining off-channel habitats.

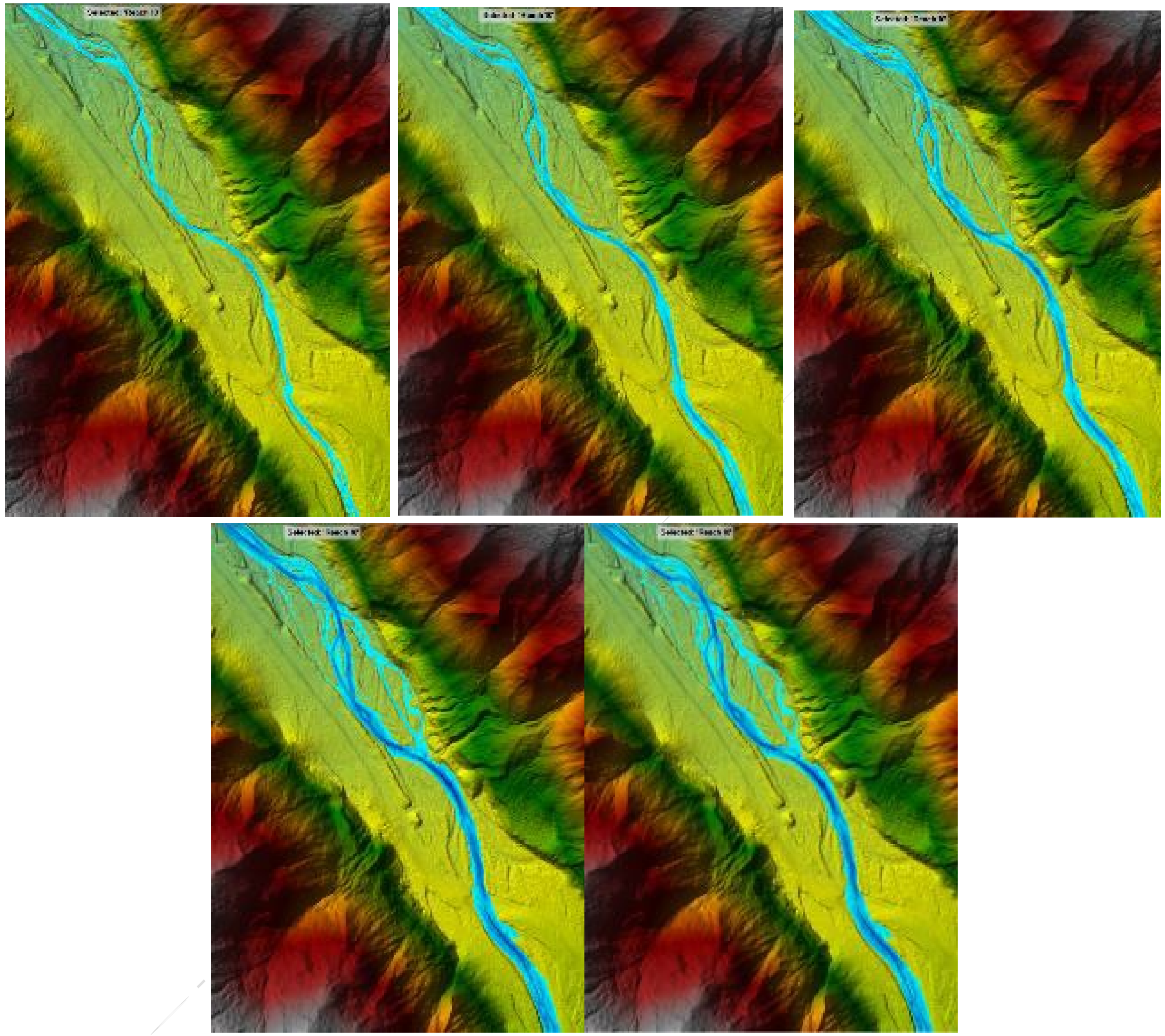


**Figure 4-16 2D Model Results for Reach 10 showing extent of inundation and connectivity for flows of 10 cfs (upper left), 25 cfs (upper center), 75 cfs (upper right), 150 cfs (lower left), 375 cfs (lower right).**

As defined above, the amount of off-channel habitat estimated for each reach is depicted in Table 4-7 and presented as total area (acres) and total acres per mile of main channel stream length. The table shows the relationship between total acres of habitat per stream mile and flow. Figure 4-17 and Figure 4-18 show the relationship between total acres of habitat per stream mile and flow. The information presented in these charts indicates that for Reaches 10, 6, and 3 there are subtle inflection points of diminishing returns, where the amount of habitat added per cfs of flow is the highest. Reach 4 does not appear to have this same inflection point, likely due to the significant number of braided side channels that are accessible at higher flows. The associated flow rate of this inflection point depends on the scaling used in the chart. The inflection points for Reaches 10, 6, and 3 appear to be between 75-150 cfs, 25-75 cfs, and 75-125 cfs, respectively.

**Table 4-7 Off-channel habitat areas estimated in Reaches 10, 6, 4, and 3 of the Eklutna River via the 2D HEC-RAS modeling.**

| Off-Channel Habitat | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Reach** | **3** | | **4** | | **6** | | **10** | |
| **Flow (cfs)** | **Acres** | **Acres/Mi** | **Acres** | **Acres/Mi** | **Acres** | **Acres/Mi** | **Acres** | **Acres/Mi** |
| 10 | 2.56 | 6.25 | 0.21 | 0.45 | 0.01 | 0.05 | 0.63 | 0.90 |
| 25 | 4.02 | 9.83 | 0.64 | 1.37 | 0.18 | 0.84 | 1.22 | 1.73 |
| 75 | 7.03 | 17.17 | 1.25 | 2.67 | 0.48 | 2.21 | 2.35 | 3.32 |
| 150 | 10.14 | 24.76 | 2.18 | 4.66 | 0.67 | 3.08 | 3.27 | 4.64 |
| 375 | 20.85 | 50.91 | 5.93 | 12.67 | 1.21 | 5.53 | 4.43 | 6.28 |

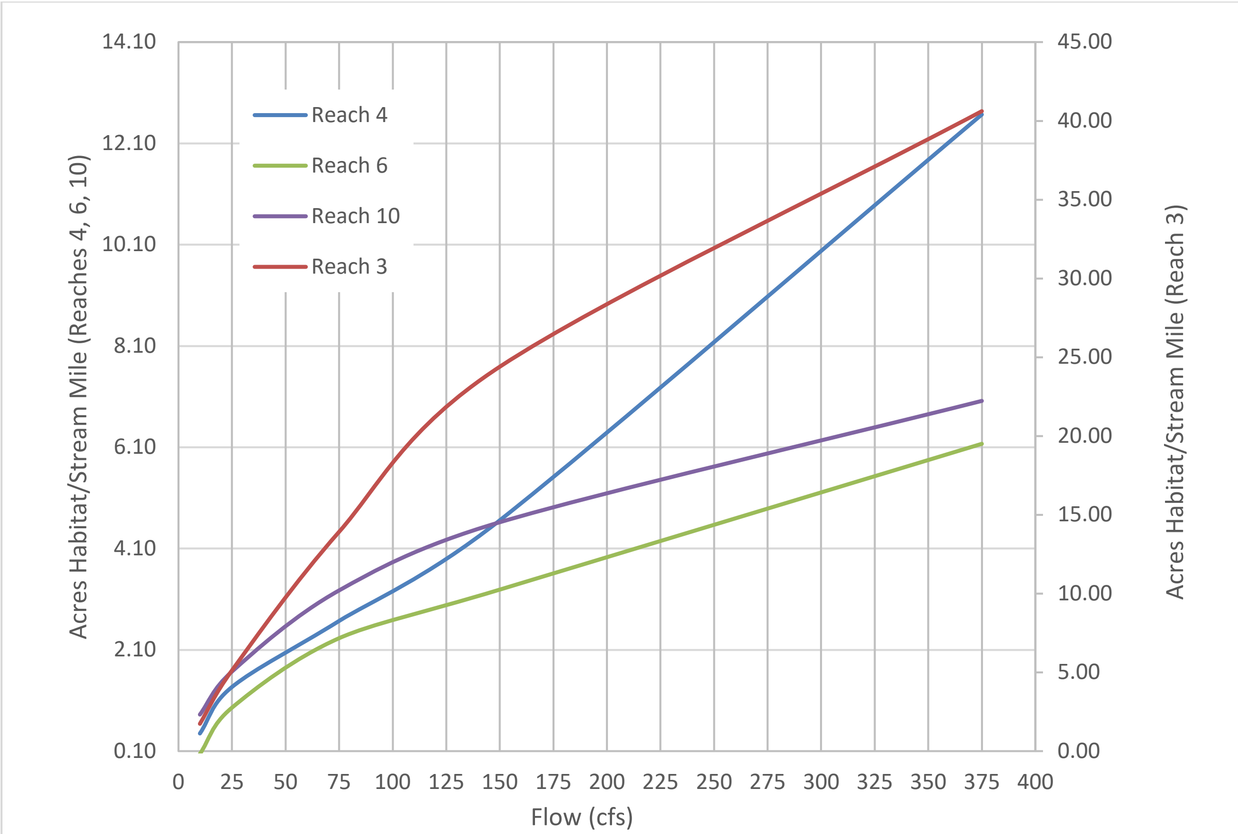



**Figure 4-17 Estimated off channel habitat per mile of stream vs. flow (standard) for Reach 10, Reach 6, Reach 4, and Reach 3 of the Eklutna River based on the 2D HEC-RAS hydraulic model.**

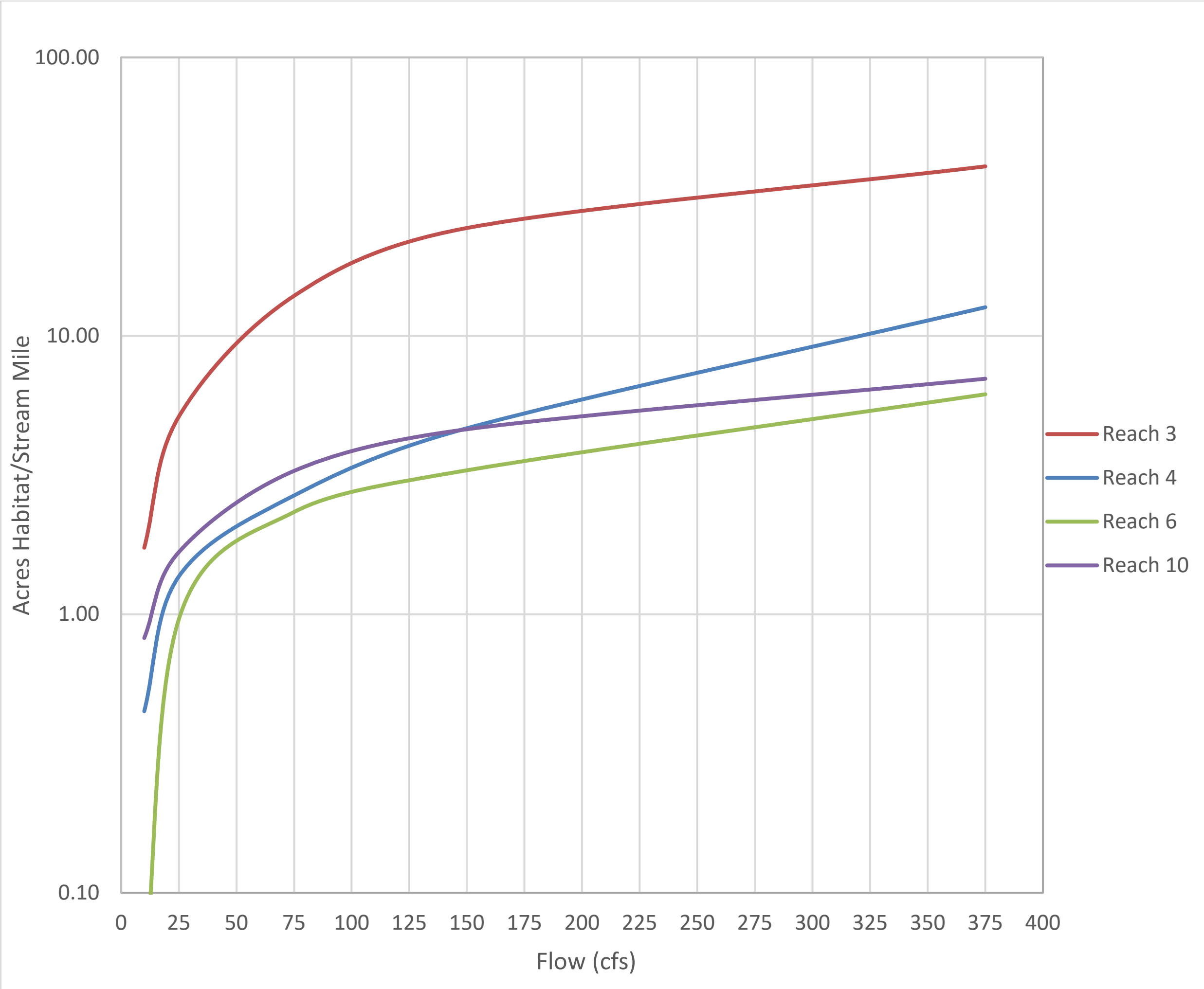



**Figure 4-18 Estimated off channel habitat per mile of stream vs. flow for Reach 10, Reach 6, Reach 4, and Reach 3 of the Eklutna River based on the 2D HEC-RAS hydraulic model (logarithmic).**

## 4.7 Flow Release Levels and Release Options

There were two separate flow release level schedules developed for this analysis, the first based on the 2D juvenile rearing habitat analysis, and the second based on a combined 2D juvenile rearing and 1D PHABSIM spawning habitat analysis. The same three release options described below were considered for both schedules.

### 4.7.1 2D Juvenile Rearing Habitat Flow Release Schedule

Like the 1D PHABSIM analysis (Kleinschmidt 2022b), the 2D habitat vs. flow relationships were then used for deriving potential flow release levels based on providing the 90%, 70%, 50%, and 30% of maximum juvenile rearing habitat flows. The release flows were based on a composite of the R6 and R10 habitat vs. flow relationships above Thunderbird Creek, since this is the river segment that would receive the greatest benefit (as a percentage flow increase over baseline) from flow releases from Eklutna Lake. The habitat-flow relationships for R3 and R4 which are below Thunderbird Creek, were not used for developing flow releases from Eklutna Lake but were considered in the time series analysis[6]. Figure 4-19 displays the individual based protection flows for R6 and R10, and the composited R6 and R10 curves and protection levels that were used for setting flow release levels. The monthly flows are also depicted in Table 4-8. Unlike the 1D PHABSIM analysis that also considered spawning habitat and was the priority life stage during the months of spawning (July-October), the 2D habitat modeling only considered juvenile rearing habitat which occurs in all 12 months.

The four flow release levels were likewise based on three potential flow release locations, Option A – the existing spill gate just below Eklutna Dam; Option B – from the upper Anchorage Water and Wastewater Utility (AWWU) portal located approximately 6,000 ft below the spill gate; and Option C – from the lower AWWU drainage valve located approximately 3000 ft below the lower extent of Reach 9 (see Figure 1-1). The lengths of the Eklutna River influenced by the flow releases would vary depending on release location. Under Option A, the entire length of river would "see" the flow release from the spill gate. Under Option B, the upper 6,000 ft (approximately 1.2 miles) of the Eklutna River above the upper AWWU portal would not be affected by the flow release and would remain essentially dry. Under Option C, approximately 6.8 miles of river downstream from the Eklutna Dam would not receive any flow release. For the 2D habitat modeling, Options A and B would be based on the composited R10 and R6 analysis, since both would benefit from flow releases from either location. For Option C, only R6 would benefit and therefore flows were initially based only on R6 habitat modeling but adjusted to include R10 for reasons discussed in Section 5 below.

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[6] If R3 and R4 had been used in determining flow release levels, the 90%, 70% and 50% flow levels for each would have been at or greater than 200 cfs.

**Table 4-8 Monthly flow releases from Eklutna Lake to the Eklutna River under Baseline conditions (zero flow release) and under 12 different flow release schedules. The four flow release levels (1–4) are flows that provide 90%, 70%, 50%, and 30% of habitat maxima for Chinook and Coho juvenile rearing for all 12 months of the year.**

| Scenario | | Flow Released to Eklutna River (cfs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Baseline | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Option A | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Option B | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Option C | Flow Level 1 | 293 | 293 | 293 | 293 | 293 | 293 | 293 | 293 | 293 | 293 | 293 | 293 |
| | Flow Level 2 | 219 | 219 | 219 | 219 | 219 | 219 | 219 | 219 | 219 | 219 | 219 | 219 |
| | Flow Level 3 | 179 | 179 | 179 | 179 | 179 | 179 | 179 | 179 | 179 | 179 | 179 | 179 |
| | Flow Level 4 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |

Notes:

Option A – flow released to Eklutna River just downstream from Eklutna Dam.

Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam.

Option C – flow released to Eklutna River about 6.8 miles downstream from Eklutna Dam. Note – under the current infrastructure, maximum flow releases from the AWWU Drainage Valve are limited to approximately 110 cfs.

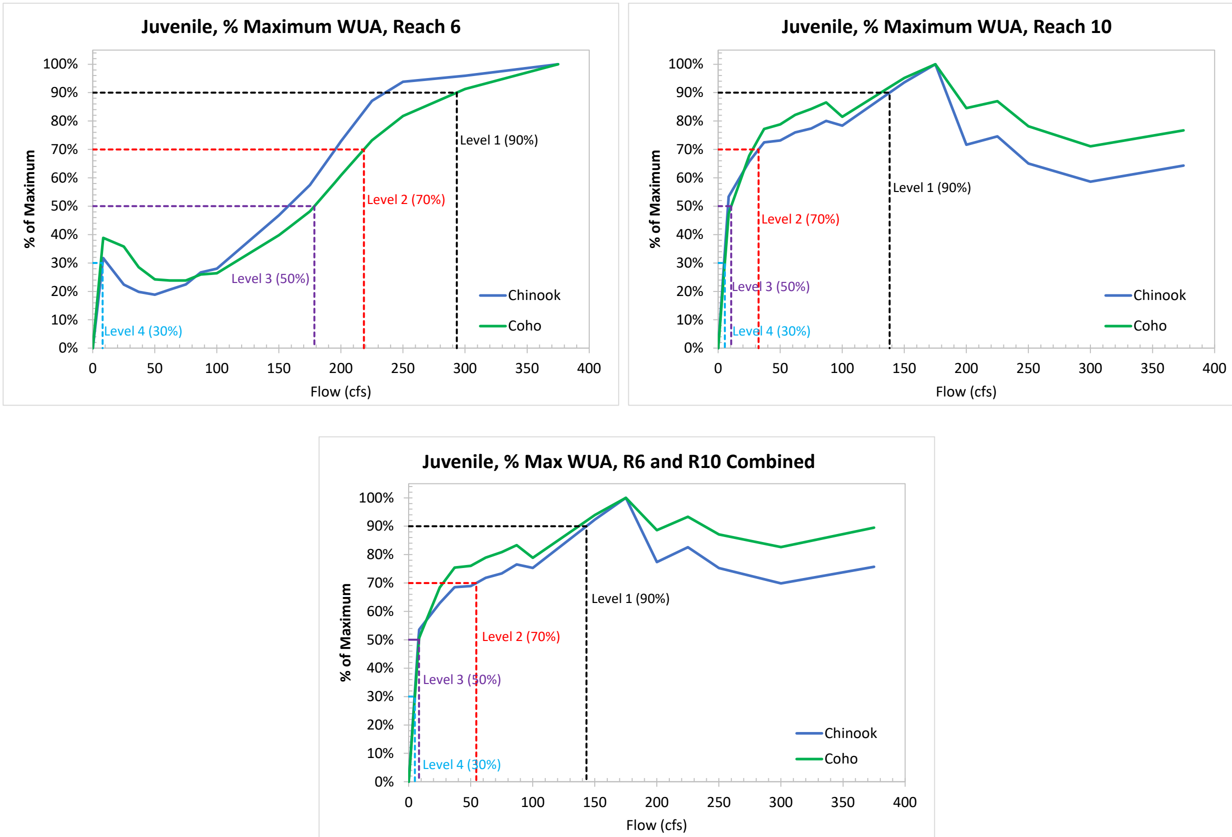


**Figure 4-19 Normalized habitat vs. flow relationships for juvenile rearing showing the Level 1 – 90%, Level 2 – 70%, Level 3 – 50%, and Level 4 – 30% example flow levels identified for the flow release schedules. Flow levels are displayed separately for R6 and R10 (upper figures) and composited for R6 and R10 (lower figure). The composited curve was used in setting flow releases levels.**

### 4.7.1 Combined 2D Juvenile rearing Habitat and 1D Spawning Habitat Flow Release Schedule

A separate flow release level schedule was developed based on the combined 2D juvenile rearing habitat and the 1D PHABSIM spawning habitat vs. flow relationships (Table 4-9). This schedule was like that presented in the 1D PHABSIM TM (Kleinschmidt 2022b) that showed months prioritized by spawning and rearing, but in this case the juvenile rearing flow releases were based on the 2D habitat modeling results. Like above, the same three flow release options were considered for each of the four flow release options.

**Table 4-9 Monthly flow releases from Eklutna Lake to the Eklutna River under Baseline conditions (zero flow release) and under 12 different flow release schedules. The four flow release levels (1–4) are flows that provide 90%, 70%, 50%, and 30% of habitat maxima for Chinook and Coho juvenile rearing for the months extending from December through June and spawning for the months extending from July through October.**

| Scenario | | Flow Released to Eklutna River (cfs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Baseline | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Option A | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 102 | 102 | 102 | 102 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 30 | 30 | 30 | 30 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 18 | 18 | 18 | 18 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 13 | 13 | 13 | 13 | 5 | 5 |
| Option B | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 99 | 99 | 99 | 99 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 25 | 25 | 25 | 25 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 17 | 17 | 17 | 17 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 12 | 12 | 12 | 12 | 5 | 5 |
| Option C | Flow Level 1 | 293 | 293 | 293 | 293 | 293 | 293 | 26 | 26 | 26 | 26 | 293 | 293 |
| | Flow Level 2 | 219 | 219 | 219 | 219 | 219 | 219 | 20 | 20 | 20 | 20 | 219 | 219 |
| | Flow Level 3 | 179 | 179 | 179 | 179 | 179 | 179 | 16 | 16 | 16 | 16 | 179 | 179 |
| | Flow Level 4 | 8 | 8 | 8 | 8 | 8 | 8 | 12 | 12 | 12 | 12 | 8 | 8 |

Notes:
Option A – flow released to Eklutna River just downstream from Eklutna Dam.
Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam.
Option C – flow released to Eklutna River about 6.8 miles downstream from Eklutna Dam. Note – under the current infrastructure, maximum flow releases from the AWWU Drainage Valve are limited to approximately 110 cfs.

# 5.0 TIME SERIES ANALYSIS

The time series analysis followed the same general approach applied for the 1D PHABSIM analysis (Kleinschmidt 2022b) except two different analyses were completed. The time series considered all reaches of the Eklutna River including segments above and below Thunderbird Creek. The first, Time Series A was based on the 2D habitat modeling results for juvenile rearing habitats, and the second, Time Series B based on a combined 1D and 2D habitat results which incorporated both spawning and juvenile rearing habitat. With Time Series A, the analyses were focused on determining rearing habitat in the four 2D reaches (Reaches 10, 6, 4, and 3). With Time Series B, the analyses were focused on determining rearing habitat in a total of nine reaches (2D Reaches 10, 6, 4, and 3 and 1D Reaches 11, 9, 8, 7, and 5). Time Series B also included analyses for spawning habitat in six reaches (1D Reaches 11, 9, 8, 7, 5, and 4) with available substrate information.

Of note is that the Option C flow release schedules depicted in Tables 4-8 and 4-9 that were based on the R6 habitat modeling results were not analyzed for either series. This was because the flow release levels were solely reliant on the juvenile rearing habitat – flow relationships from R6 since based on that flow release location (AWWU drainage valve; Figure 1-1), R6 would be the only reach above Thunderbird Creek affected by flow releases from that location. However, as discussed in Section 4.5, R6 is confined and flows through a narrow relatively steep canyon that generally lacks a broad floodplain and complex side-channel and off-channel habitats. The channel morphology in R6 is unstable with extensive deposits of sediments and loosely consolidated materials residual to the dam removal. Thus, juvenile rearing habitats are primarily associated with fringe areas at channel margins rather than in primary side and off channel areas. As a result, basing flow releases for Option C solely on the juvenile habitat vs. flow relationships for R6 is not biologically justified. Moreover, reliance on that relationship alone (see Figure 4-19, Table 4-8, and Table 4-9) would render flow releases for the 90%, 70%, and 50% of habitat maxima of 293 cfs, 218 cfs, and 178 cfs, respectively. These flows are all higher than the 90% releases when both R10 and R6 are considered together. Nevertheless, to preserve the Option C release location, alternative time series analysis (both for Time Series A and B) were made using the same flow release schedules (based on R10 and R6) used for Option B (Table 5-1 and 5-2).

**Table 5-1 Monthly flow release schedule for the Eklutna River for Options A, B, and C and for Flow Levels 1, 2, 3, and 4. The flow release schedule for Option C was adjusted to correspond to the same flow release schedule as Option B. The four flow release levels (1–4) are flows that provide 90%, 70%, 50%, and 30% of habitat maxima for Chinook and Coho juvenile rearing for all 12 months of the year (Time Series A).**

| Scenario | | Flow[1] Released to Eklutna River (cfs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Baseline | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Option A | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Option B | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Option C | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |

Note 1: These data are based on the modeled habitat-flow relationships developed during 1D and 2D instream flow modeling. There may be limitations of existing or potential-future infrastructure to deliver flows of this magnitude to the river. These limitations will be discussed in the Engineering Feasibility Report.

**Table 5-2 Monthly flow release schedule for the Eklutna River for Options A, B, and C and for Flow Levels 1, 2, 3, and 4. The flow release schedule for Option C was adjusted to correspond to the same flow release schedule as Option B. The four flow release levels (1–4) are flows that provide 90%, 70%, 50%, and 30% of habitat maxima for Chinook and Coho juvenile rearing for the months extending from December through June and spawning for the months extending from July through October (Time Series B).**

| Scenario | | Flow[1] Released to Eklutna River (cfs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Baseline | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Option A | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 102 | 102 | 102 | 102 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 30 | 30 | 30 | 30 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 18 | 18 | 18 | 18 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 13 | 13 | 13 | 13 | 5 | 5 |
| Option B | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 99 | 99 | 99 | 99 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 25 | 25 | 25 | 25 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 17 | 17 | 17 | 17 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 12 | 12 | 12 | 12 | 5 | 5 |
| Option C | Flow Level 1 | 143 | 143 | 143 | 143 | 143 | 143 | 99 | 99 | 99 | 99 | 143 | 143 |
| | Flow Level 2 | 54 | 54 | 54 | 54 | 54 | 54 | 25 | 25 | 25 | 25 | 54 | 54 |
| | Flow Level 3 | 8 | 8 | 8 | 8 | 8 | 8 | 17 | 17 | 17 | 17 | 8 | 8 |
| | Flow Level 4 | 5 | 5 | 5 | 5 | 5 | 5 | 12 | 12 | 12 | 12 | 5 | 5 |

Note 1: These data are based on the modeled habitat-flow relationships developed during 1D and 2D instream flow modeling. There may be limitations of existing or potential-future infrastructure to deliver flows of this magnitude to the river. These limitations will be discussed in the Engineering Feasibility Report.

## 5.1 HYDROLOGY

As discussed in Kleinschmidt (2022b), available flow records from the United States Geological Survey (USGS) and the Native Village of Eklutna (NVE) were used to perform time-series analyses of habitat for three example flow release schedules from Eklutna Lake to the Eklutna River, and for various species/life stage combinations of salmonid species.

The instream flow study reach extends from Eklutna Dam to the zone of tidal influence. Within this reach, Thunderbird Creek is the largest tributary to the Eklutna River, and its confluence is used to divide the Eklutna River into two hydrologic reaches:

1. **Upper Eklutna Segment** – extends from Eklutna Dam to the confluence with Thunderbird Creek. The Upper Eklutna was further divided into the six reaches used for instream flow analyses: R11, R10, R9, R8, R7, and R6. Under baseline conditions, there are no flow releases from Eklutna Dam to these sub-reaches and therefore flows are relatively low.
2. **Lower Eklutna Segment** – extends from the confluence with Thunderbird Creek to the zone of tidal influence. This segment was divided into three reaches used for instream flow analyses: R5, R4, and R3. Under baseline conditions, the flows in these reaches are influenced by inputs from Thunderbird Creek and are therefore relatively high compared to those in the Upper Eklutna segment.

Historical daily flow records are available from the Eklutna River at the Old Glenn Highway Bridge (USGS Gage No. 15280200). These continuous daily records extend from May 1, 2002 to September 29, 2007. During this period there were no flow releases or spill events from Eklutna Lake to the Eklutna River. This period of record forms the basis for the time series analyses reported in this section.

During this period, discrete intermittent flow measurements were performed in the Eklutna River just upstream from the confluence with Thunderbird Creek. These records were available from the USGS (USGS Gage No. 15280100) and from the NVE. Monthly median flows were derived from these data and were used to estimate a continuous daily flow hydrograph.

Continuous daily flows in the Eklutna River at the Old Glenn Highway and above the confluence with Thunderbird Creek are shown in Figure 5-1 for the period from May 1, 2022 to September 29, 2007. The baseline flows in the Upper Eklutna Reach are relatively low in comparison with the flows in the Eklutna River at the Old Glenn Highway.

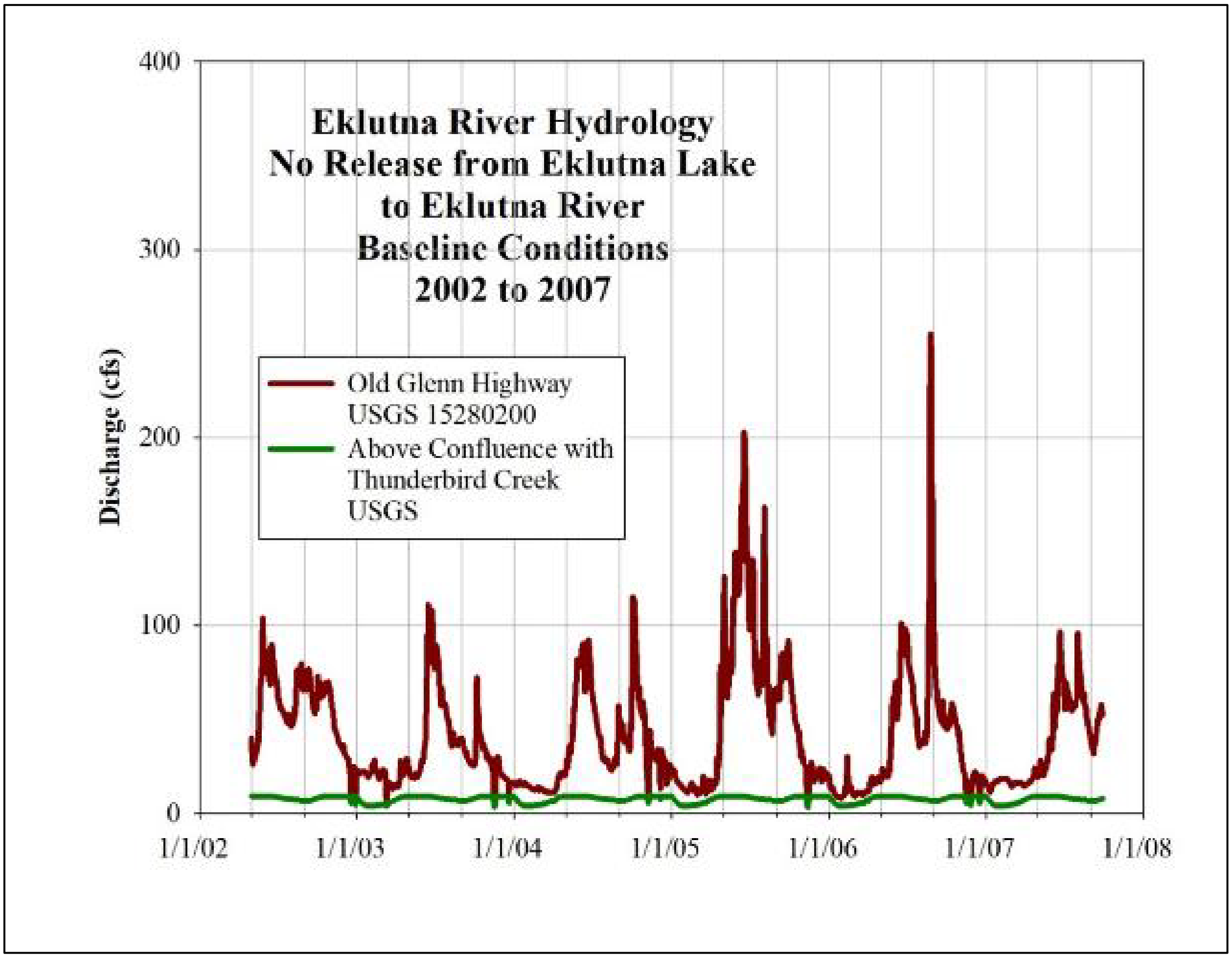


**Figure 5-1 Daily flows in the Eklutna River at the Old Glenn Highway and above the confluence with Thunderbird Creek from May 1, 2002 to September 29, 2007, with no flow releases from Eklutna Lake to the Eklutna River.**

The Upper Eklutna River below Eklutna Dam was visited in late August 2019, and observations were reported in a site reconnaissance trip report (MJA 2019). The Eklutna River was dry below Eklutna Dam. Measurable flow (1 to 2 cfs) was observed in the Eklutna River about 4 miles downstream from Eklutna Dam (River Mile 8.3). This location with noticeable discharge is in R10, and divides R10 into two sub-reaches (Upper Reach 10 and Lower Reach 10). Under baseline conditions, there is no discharge in Upper Reach 10 and there are very small discharges in Lower Reach 10.

The flow in the Eklutna River above the confluence with Thunderbird Creek (River Mile 2.8) was assumed to be 7 cfs (a typical value for late August). Between these two locations on the Eklutna River, it was assumed that the flow in the Eklutna River was proportional to river mile under baseline conditions. Reach 11 extends for about 2.7 miles downstream from Eklutna Dam. Reach 11 is dry under baseline conditions.

## 5.2 Flow Releases Applied in the Time Series

The flow releases applied in the two time series varied according to the schedules in Table 4-8 (Time Series A) and Table 4-9 (Time Series B).

### 5.2.1 Time Series A – 2D Juvenile Habitat Analysis

Under baseline conditions, no flow would be released to the Eklutna River. Three different options (A, B, and C) were considered for where to release the water downstream from Eklutna Dam. Under Option A, the flow would be released to the Eklutna River just downstream from Eklutna Dam. Under Option B, flow would be released to the Eklutna River about 1.2 miles downstream from Eklutna Dam from the existing AWWU portal valve. Under Option C, flow would be released to the Eklutna River from the AWWU drainage portal which is located about 6.8 miles below Eklutna Dam. For each option, the four example flow release levels (Flow Level 1 – 90%, Flow Level 2 – 70%, Flow Level 3 – 50%, and Flow Level 4 – 30%) were considered (see Section 4.7.1) which governed the magnitude of the released flows. The magnitudes of the discharges listed in Table 5-1 were derived from weighted usable area curves for Chinook and Coho juvenile rearing. All three options (Options A, B, and C) were based on habitat in Reaches 10 and 6[7]. In Time Series A, the discharge magnitudes were based on rearing habitat only (for all 12 months of the year).

### 5.2.2 Time Series B – 2D Juvenile and 1D Spawning Habitat Analysis

Under baseline conditions, no flow would be released to the Eklutna River. The magnitudes of the discharges listed in Table 5-2 were derived from weighted usable area curves for Chinook and Coho juvenile rearing for the months extending from December through June, and for spawning for months July through October. All three options (Options A, B, and C) for the juvenile rearing months were based on habitat in R10 and R6, while the flow releases for the spawning months were based on the 1D PHABSIM reaches above Thunderbird Creek; the Option C analysis applied the same flow release schedule as for Option B.

---

[7] The release flows were based on a composite of the R6 and R10 habitat vs. flow relationships above Thunderbird Creek, since this is the river segment that would receive the greatest benefit (as a percentage flow increase over baseline) from flow releases from Eklutna Lake. The habitat-flow relationships for R3 and R4 which are below Thunderbird Creek, were not used for developing flow releases from Eklutna Lake but were considered in the time series analysis.

## 5.3 EXAMPLE ANALYSIS BASED ON TIME SERIES B

To illustrate the process of performing a time series analysis, two runs were selected. These example runs focused on Coho juvenile rearing habitat and were for Time Series B Upper Reach 10, Baseline and Option A, with the Level 2 (70%) flow release. Coho juvenile rearing occurs in the river throughout all 12 months and so the analysis was based on the entire year. In Time Series B, spawning habitat was also analyzed but not presented in this example; results that include spawning habitat are shown in tabular formats in Section 5.4.2.

The daily flow hydrographs in Reach 10 of the Eklutna River are shown in Figure 5-2 for the example runs (Option A, Flow Level 2 – 70% and Baseline conditions). The magnitudes of the Option A Level 2 – 70% flows are several times larger than the magnitudes of the Baseline flows.

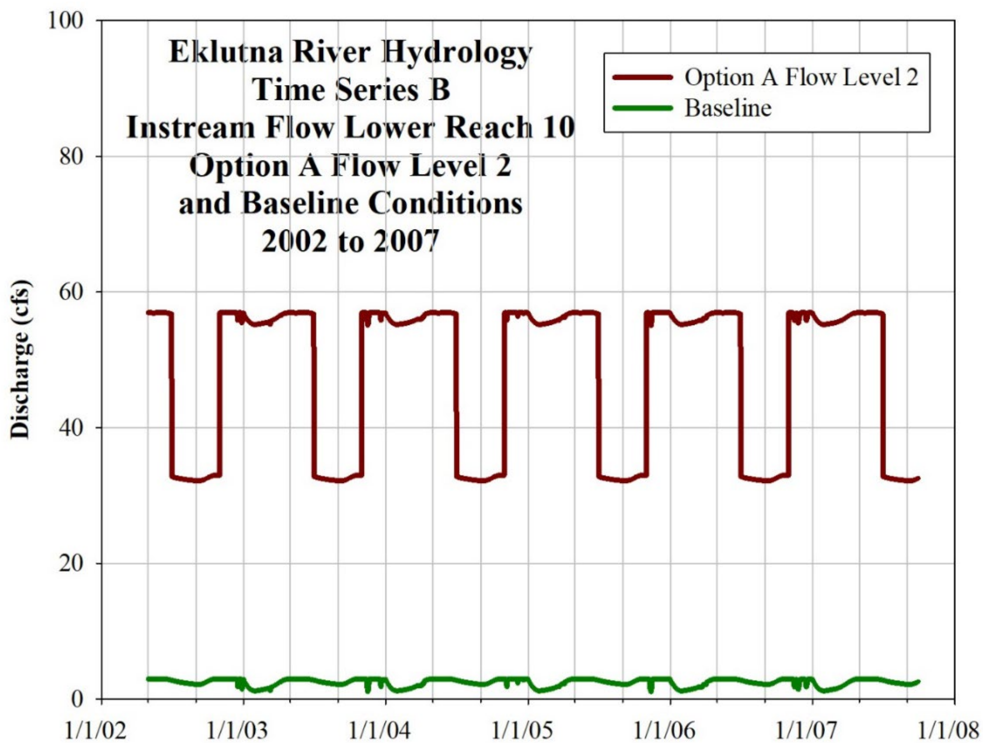


**Figure 5-2 Daily flows in Upper Reach 10 of the Eklutna River for Option A, Level 2 – 70% flow release level and Baseline conditions, Time Series B. Option A – flow released to Eklutna River just downstream from Eklutna Dam.**

A habitat area curve defined as WUA for Coho juvenile rearing in Lower Reach 10 is shown in Figure 5-3. The curve reaches a peak of about 2.1 acres when the discharge is about 175 cfs.

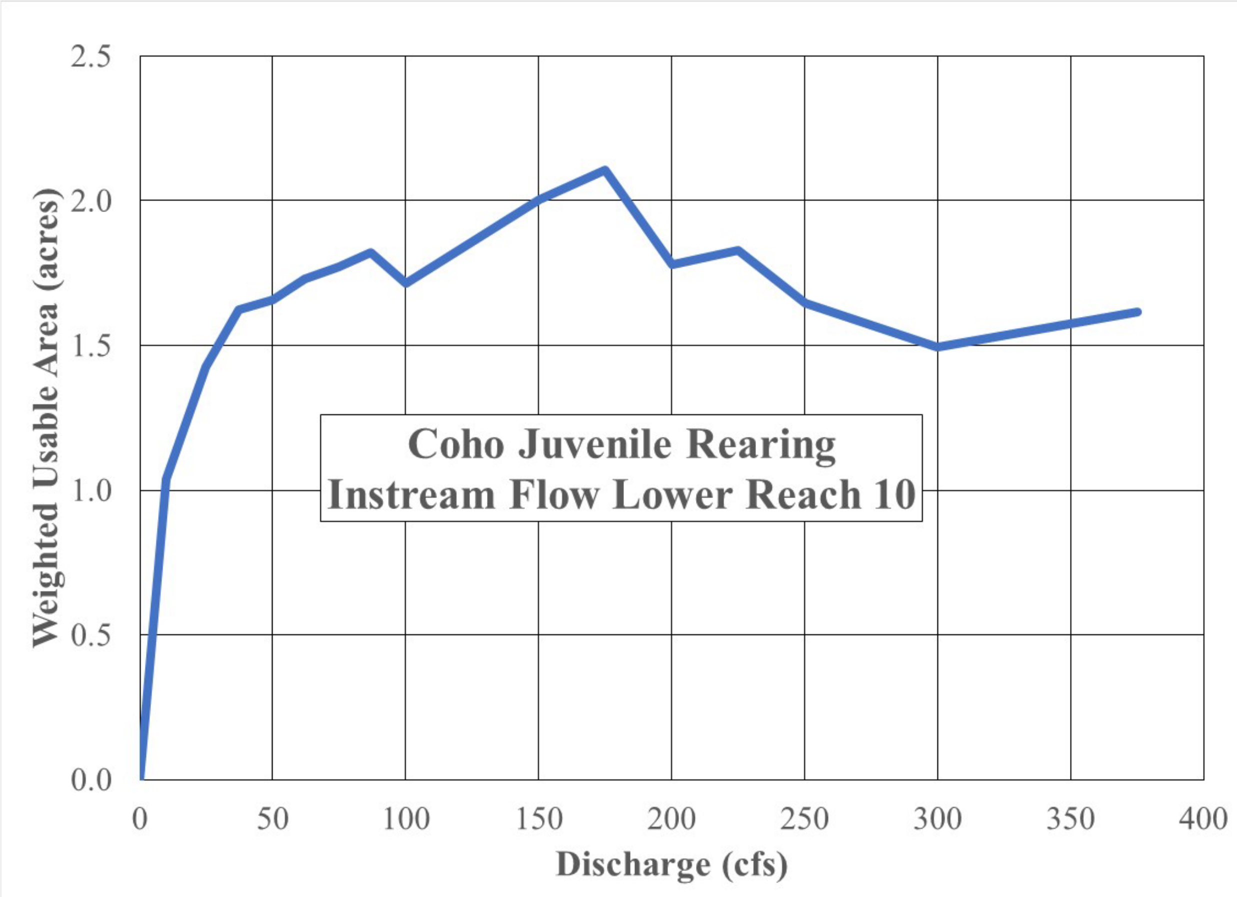


**Figure 5-3 Habitat area (weighted usable area) in Lower Reach 10 for Coho juvenile rearing as a function of flow in the Eklutna River.**

Applying the habitat vs. flow relationship defined in Figure 5-3 to the hydrology data in Figure 5-2 provides a daily time series of Coho juvenile rearing habitat over the same time period (Figure 5-4). The magnitudes of habitat for Option A Flow Level 2 are several times larger than the magnitudes of habitat for Baseline conditions.

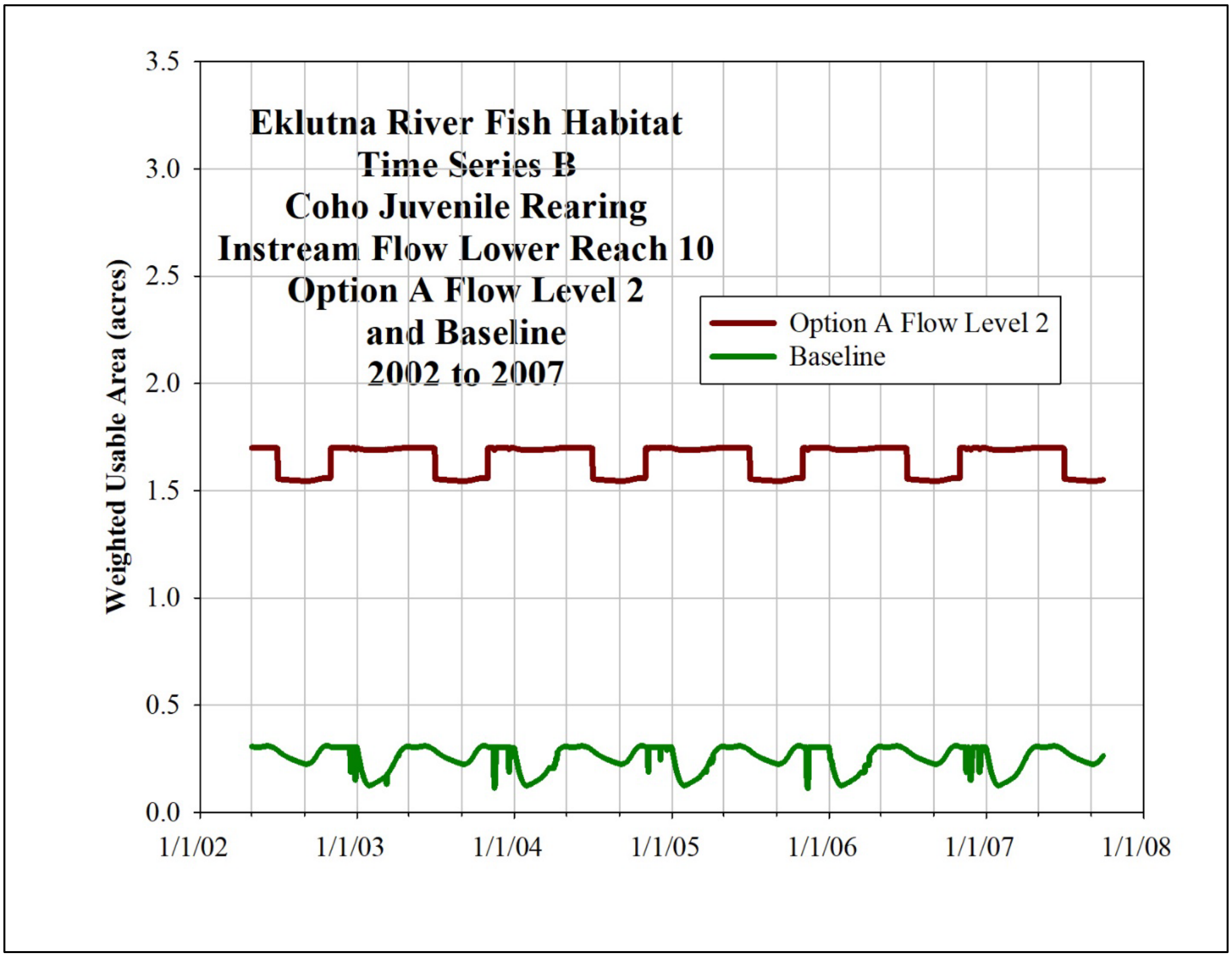


**Figure 5-4 Daily time series of habitat area (weighted usable area) for Coho juvenile rearing in Lower Reach 10, Option A, Flow Level 2 (70%) (upper line) and Baseline conditions (lower line).**

These examples were provided just for Lower Reach 10. Final results for Time Series B were based on the combined totals of juvenile rearing habitat from nine instream flow reaches (Reaches 11, 10, 9, 8, 7, and 6 – above Thunderbird Creek and Reaches 5, 4, and 3 – below Thunderbird Creek). Spawning habitat was also computed based on the 1D PHABSIM analysis for Reaches 11, 9, 8, 7, 5, and 4.

## 5.4 Summary of Time Series Analysis

### 5.4.1 Time Series A

Time-averaged habitat areas (WUA) for Time Series A are summarized in 3. These areas represent the combined total of juvenile rearing habitat from 2D Reaches 3, 4, 6, and 10.

**Table 5-3 Time-averaged habitat area (weighted usable area) for Time Series A for Chinook and Coho juvenile rearing, as determined from four example flow release levels (Level 1 – 90%, Level 2 – 70%, Level 3 – 50%, and Level 4 – 30%) for three flow release location options, A – below Eklutna Dam, Option B – AWWU portal, and Option C – AWWU drainage valve. The flow release schedule for Option C was made the same as for Option B.**

| Scenario | | Time-Averaged Habitat Expressed as Weighted Usable Area (acres) | |
|---|---|---|---|
| | | Juvenile Rearing | |
| | | Chinook | Coho |
| Baseline | | 11.0 | 13.3 |
| Option A | Flow Level 1 | 23.8 | 30.5 |
| | Flow Level 2 | 16.8 | 21.4 |
| | Flow Level 3 | 12.8 | 15.8 |
| | Flow Level 4 | 12.2 | 15.0 |
| Option B | Flow Level 1 | 23.8 | 30.5 |
| | Flow Level 2 | 16.8 | 21.4 |
| | Flow Level 3 | 12.8 | 15.8 |
| | Flow Level 4 | 12.2 | 15.0 |
| Option C | Flow Level 1 | 22.0 | 27.5 |
| | Flow Level 2 | 15.4 | 18.9 |
| | Flow Level 3 | 12.0 | 14.5 |
| | Flow Level 4 | 11.7 | 14.1 |

Note: The Level 1, Level 2, Level 3, and Level 4 releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook and Coho salmon.

The percent increase (with respect to baseline) of time-averaged habitat area (weighted usable area) is listed in Table 5-3. Habitat increases ranged for Chinook from 120% (Flow Level 1 to 10% for Level 4; for Coho, from 130% to 10%.

**Table 5-3 Percent increase (with respect to baseline) of time-averaged habitat area (weighted usable area) Time Series A for Chinook and Coho juvenile rearing as determined from four example flow release levels (Flow Level 1 – 90%, Flow Level 2 – 70%, Flow Level 3 – 50% and Flow Level 4 – 30%) for three flow release location options, A – below Eklutna Dam, B – at upper AWWU portal , and C at AWWU drainage valve. The flow release schedule for Option C was made the same as for Option B. Percentages were rounded to nearest 10%.**

| Scenario | | Time-Averaged Habitat Expressed as Percent Increase above Baseline | |
|---|---|---|---|
| | | Juvenile Rearing | |
| | | Chinook | Coho |
| Baseline | | 0% | 0% |
| Option A | Flow Level 1 | 120% | 130% |
| | Flow Level 2 | 50% | 60% |
| | Flow Level 3 | 20% | 20% |
| | Flow Level 4 | 10% | 10% |
| Option B | Flow Level 1 | 120% | 130% |
| | Flow Level 2 | 50% | 60% |
| | Flow Level 3 | 20% | 20% |
| | Flow Level 4 | 10% | 10% |
| Option C | Flow Level 1 | 100% | 110% |
| | Flow Level 2 | 40% | 40% |
| | Flow Level 3 | 10% | 10% |
| | Flow Level 4 | 10% | 10% |

Habitat duration curves for Chinook juvenile rearing habitat are shown for Time Series A in Figure 5-5. In all cases, habitat gains were achieved when flows were added to the river downstream from Eklutna Dam. For a given level, similar gains in habitat would occur for Options A and B because the release points for both of these options are above Reaches 10, 6, 4, and 3.

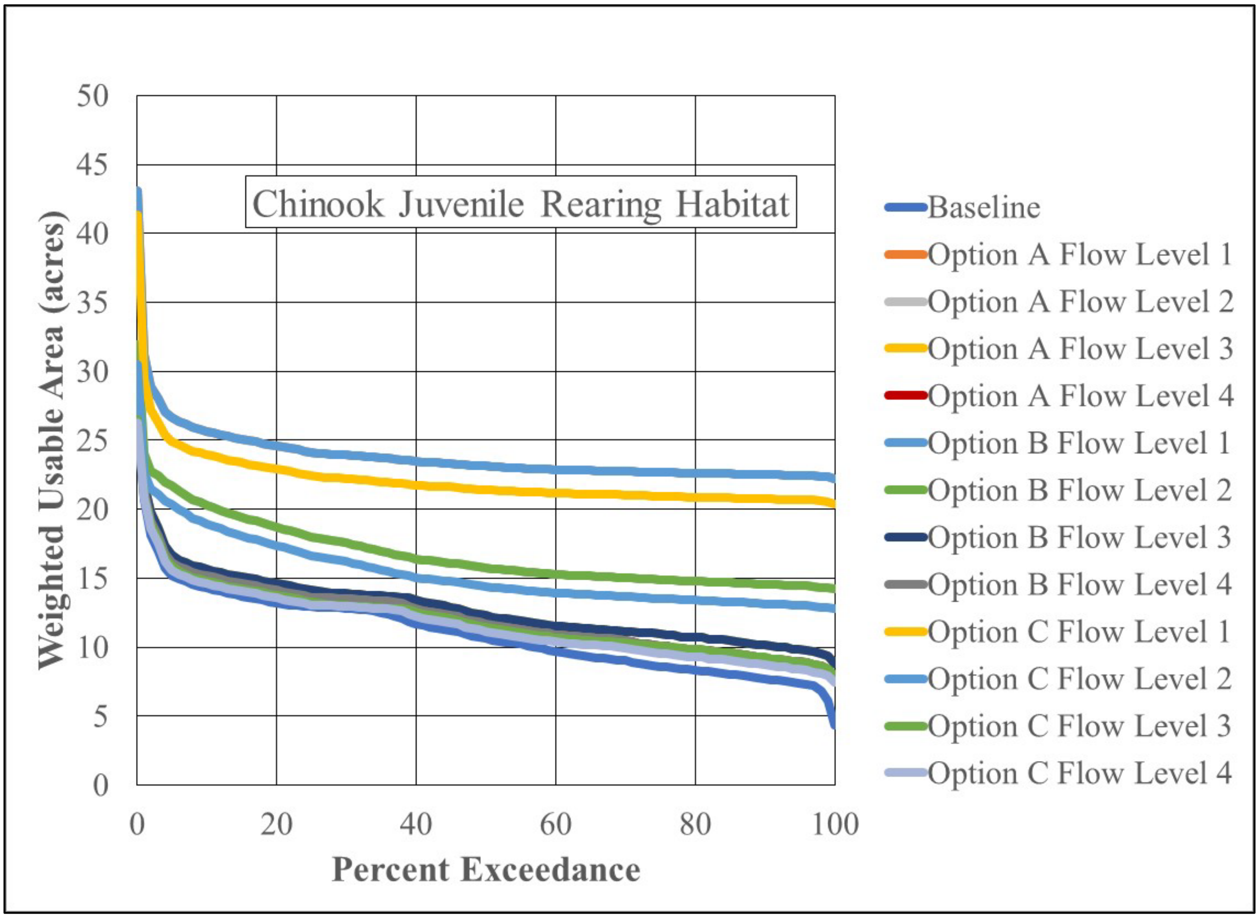


**Figure 5-5 Chinook juvenile rearing habitat duration curves derived from the total habitat from Reaches 3, 4, 6, and 10. Option A – flow released to Eklutna River just downstream from Eklutna Dam. Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam. Option C – flow released to the Eklutna River in Reach 8. The Level 1, Level 2, Level 3, and Level 4 flow releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon. The flow releases for Option C were assumed to be the same as the flow releases for Option B.**

Habitat duration curves for Coho juvenile rearing habitat are shown for Time Series A in Figure 5-6. In all cases, habitat gains were achieved when flows were added to the river downstream from Eklutna Dam. For a given level, similar gains in habitat would occur for Options A and B because the release points for both of these options are above Reaches 10, 6, 4, and 3.

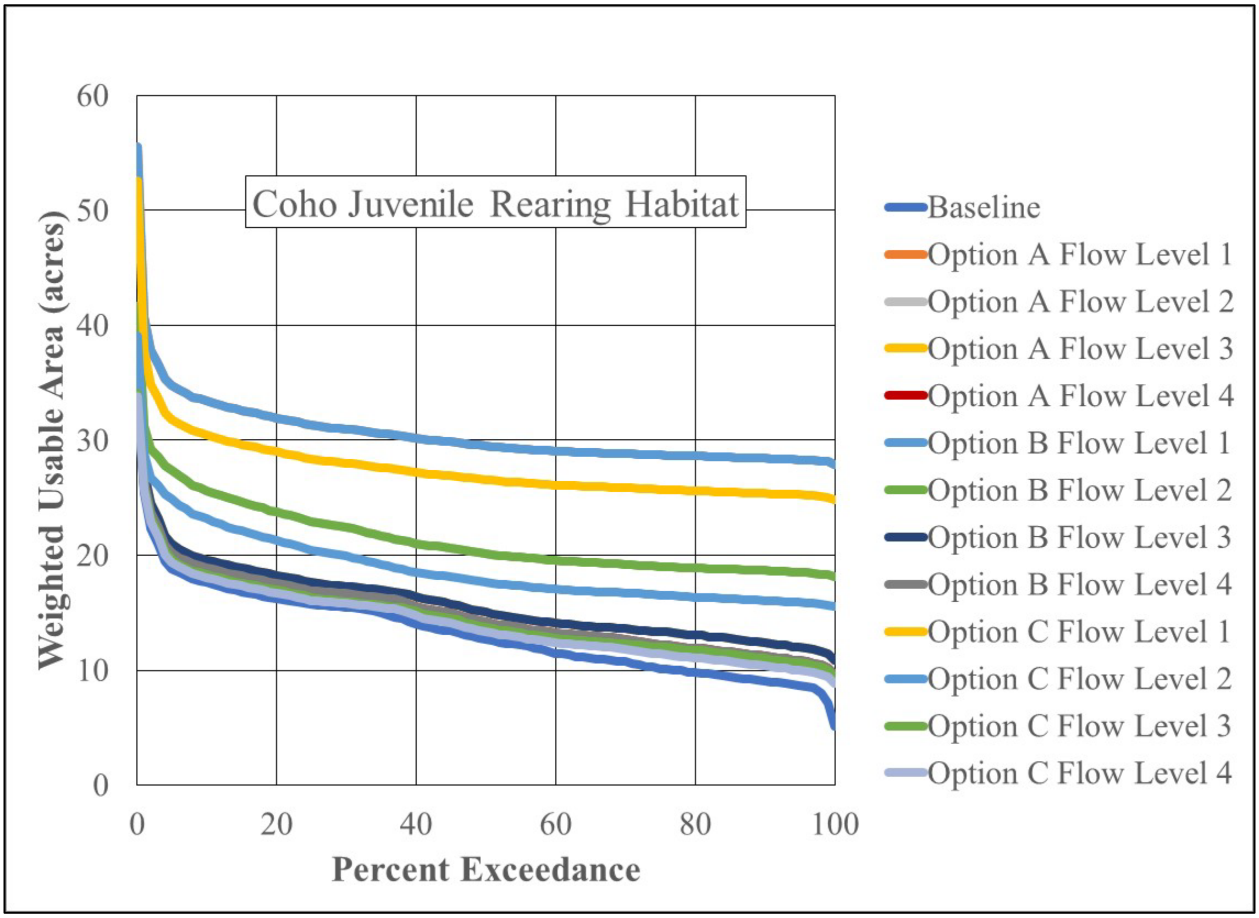


**Figure 5-6 Coho juvenile rearing habitat duration curves derived from the total habitat from Reaches 3, 4, 6, and 10. Option A – flow released to Eklutna River just downstream from Eklutna Dam. Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam. Option C – flow released to the Eklutna River in Reach 8. The Level 1, Level 2, Level 3, and Level 4 flow releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon. The flow releases for Option C were assumed to be the same as the flow releases for Option B.**

### 5.4.2 TIME SERIES B

Time-averaged habitat areas (WUA) for Time Series B are summarized in Table 10-3. These areas represent the combined totals of juvenile rearing habitat from Reaches 3, 4, 5, 6, 7, 8, 9, 10, and 11 (combined 2D and 1D analysis) and for spawning, Reaches 4, 5, 7, 8, 9, and 11 (1D analysis) spawning habitat.

The percent increase (with respect to baseline) of time-averaged habitat area (weighted usable area) for Time Series B is listed in Table 10-4. Habitat increases ranged for Chinook rearing from 260% for Level 1 to 130% for Level 4; 280% to 130% for Coho. Spawning habitat increases ranged from for Chinook, 300% for Level 1 to 170% for Level 4; 270% to 190% for Coho; and 270% for Level 2 to 190% for Level 4 for Sockeye.

**Table 10-3 Time-averaged habitat expressed as weighted usable area (acres) for Chinook and Coho juvenile rearing and for Chinook, Coho, and Sockeye spawning. Time-averaged habitat is reported for the Eklutna River for Options A, B, and C and for Flow Levels 1, 2, 3, and 4. Flows are driven by 2D juvenile rearing habitat from November through June and by 1D spawning habitat for July through October (Time Series B). The flow release schedule for Option C was made the same as the flow release schedule for Option B.**

| Scenario | | Time-Averaged Habitat Expressed as Weighted Usable Area (acres) | | | | |
|---|---|---|---|---|---|---|
| | | Chinook | | Coho | | Sockeye |
| | | Spawning | Juvenile Rearing | Spawning | Juvenile Rearing | Spawning |
| Baseline | | 0.5 | 11.9 | 1.2 | 14.8 | 1.0 |
| Option A | Flow Level 1 | 1.5 | 30.6 | 3.1 | 41.3 | 2.5 |
| | Flow Level 2 | 1.4 | 22.6 | 3.1 | 30.4 | 2.7 |
| | Flow Level 3 | 1.2 | 17.6 | 2.8 | 22.8 | 2.4 |
| | Flow Level 4 | 1.0 | 16.2 | 2.6 | 20.8 | 2.2 |
| Option B | Flow Level 1 | 1.2 | 28.1 | 2.4 | 37.5 | 2.1 |
| | Flow Level 2 | 1.1 | 20.4 | 2.5 | 27.2 | 2.3 |
| | Flow Level 3 | 1.0 | 16.3 | 2.4 | 21.0 | 2.1 |
| | Flow Level 4 | 0.9 | 15.2 | 2.2 | 19.4 | 1.9 |
| Option C | Flow Level 1 | 0.5 | 22.9 | 1.4 | 29.0 | 1.3 |
| | Flow Level 2 | 0.6 | 16.0 | 1.6 | 20.6 | 1.5 |
| | Flow Level 3 | 0.6 | 13.3 | 1.6 | 16.9 | 1.5 |
| | Flow Level 4 | 0.6 | 12.9 | 1.5 | 16.3 | 1.5 |

Note: The Level 1, Level 2, Level 3, and Level 4 releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon.

**Table 5-4 Time-averaged habitat expressed as percent increase above baseline for Chinook and Coho juvenile rearing and for Chinook, Coho, and Sockeye spawning. Time-averaged habitat increases are reported for the Eklutna River for Options A, B, and C and for Flow Levels 1, 2, 3, and 4. Flows are driven by 2D juvenile rearing habitat from November through June and by 1D spawning habitat for July through October (Time Series B). The flow release schedule for Option C was made the same as the flow release schedule for Option B.**

| Scenario | | Time-Averaged Habitat Expressed as Percent Increase above Baseline | | | | |
|---|---|---|---|---|---|---|
| | | Chinook | | Coho | | Sockeye |
| | | Spawning | Juvenile Rearing | Spawning | Juvenile Rearing | Spawning |
| Baseline | | 0% | 0% | 0% | 0% | 0% |
| Option A | Flow Level 1 | 200% | 160% | 170% | 180% | 150% |
| | Flow Level 2 | 170% | 90% | 160% | 110% | 170% |
| | Flow Level 3 | 130% | 50% | 140% | 50% | 140% |
| | Flow Level 4 | 100% | 40% | 120% | 40% | 110% |
| Option B | Flow Level 1 | 130% | 140% | 110% | 150% | 100% |
| | Flow Level 2 | 120% | 70% | 120% | 80% | 130% |
| | Flow Level 3 | 100% | 40% | 100% | 40% | 110% |
| | Flow Level 4 | 70% | 30% | 90% | 30% | 90% |
| Option C | Flow Level 1 | 0% | 90% | 20% | 100% | 30% |
| | Flow Level 2 | 30% | 30% | 40% | 40% | 50% |
| | Flow Level 3 | 20% | 10% | 30% | 10% | 50% |
| | Flow Level 4 | 20% | 10% | 30% | 10% | 50% |

Habitat duration curves for Time Series B for Chinook spawning habitat are shown in Figure 5-6. In all cases, habitat gains were achieved when flows were added to the river downstream from Eklutna Dam. Larger gains in habitat were achieved when flow was added just downstream from Eklutna Dam (Option A) than when added 1.2 miles downstream (Option B).

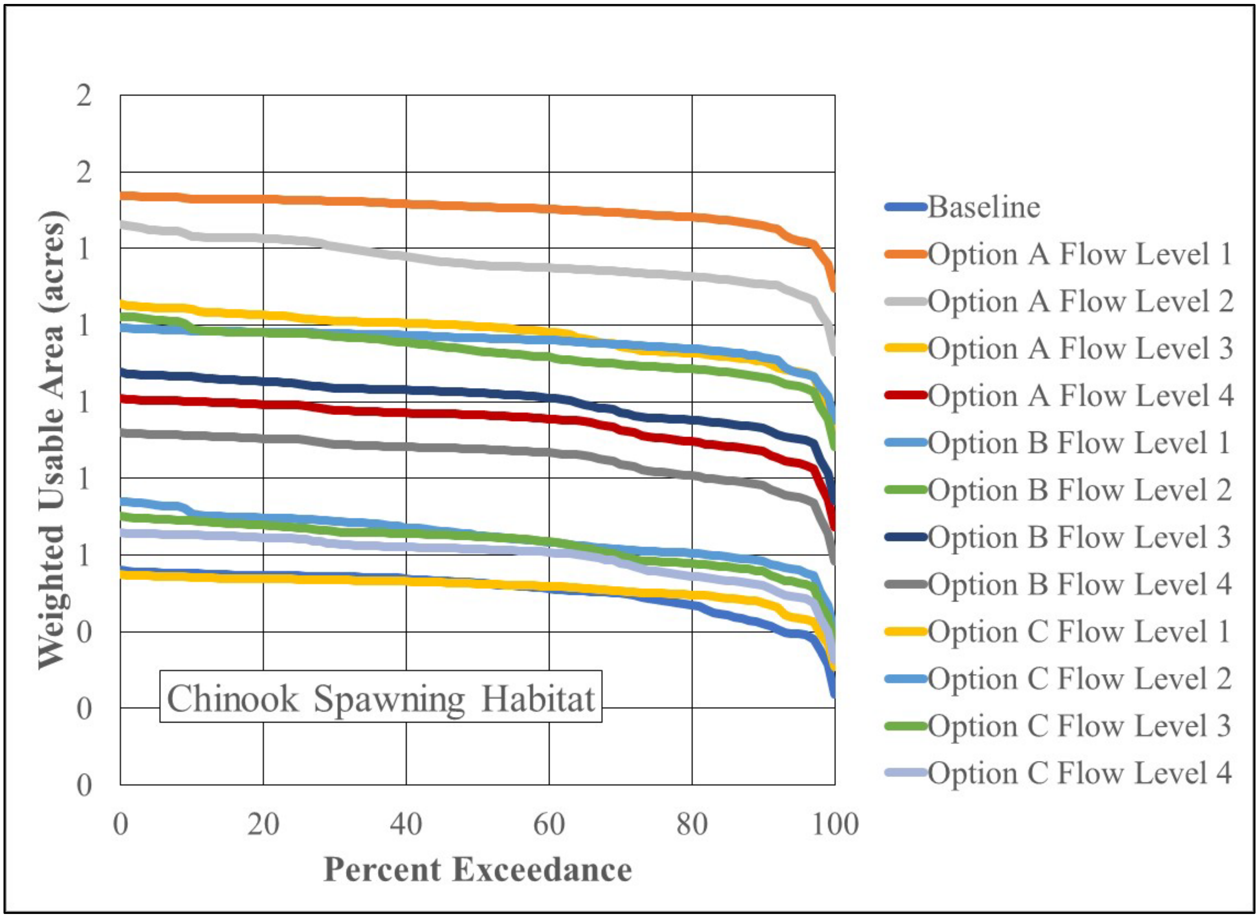


**Figure 5-6 Chinook spawning habitat duration curves derived from the total habitat from Reaches 11, 9, 8, 7, 5, and 4. Option A – flow released to Eklutna River just downstream from Eklutna Dam. Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam. Option C – flow released to the Eklutna River in Reach 8. The Level 1, Level 2, Level 3, and Level 4 flow releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon. The flow releases for Option C were assumed to be the same as the flow releases for Option B.**

Habitat duration curves for Time Series B Chinook juvenile rearing habitat are shown in Figure 5-7. In all cases, habitat gains were achieved when flow was released to the river downstream from Eklutna Dam. Larger gains in habitat were achieved when flow was added to the river just downstream from Eklutna Dam (Option A) than when flow was added to the river 1.2 miles downstream from Eklutna Dam (Option B).

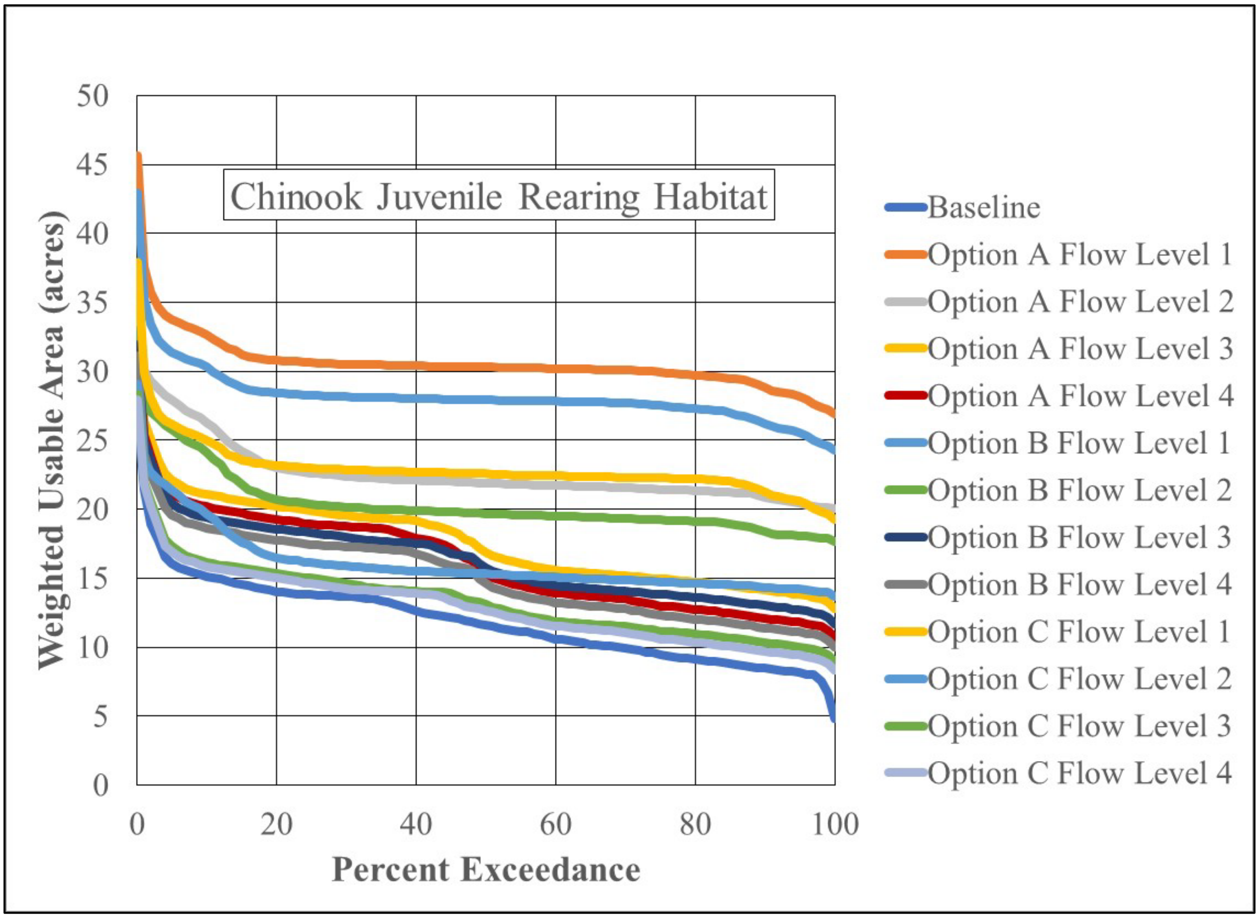


**Figure 5-7 Chinook juvenile rearing habitat duration curves derived from the total habitat from Reaches 11, 10, 9, 8, 7, 6, 5, 4, and 3. Option A – flow released to Eklutna River just downstream from Eklutna Dam. Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam. Option C – flow released to the Eklutna River in Reach 8. The Level 1, Level 2, Level 3, and Level 4 flow releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon. The flow releases for Option C were assumed to be the same as the flow releases for Option B.**

Habitat duration curves for Time Series B for Coho spawning habitat are shown in Figure 5-8. Similar to above, in all cases, habitat gains were achieved when flow was added to the river downstream from Eklutna Dam. Larger gains in habitat were achieved when flow was added to the river just downstream from Eklutna Dam (Option A) than when flow was added to the river 1.2 miles downstream from Eklutna Dam (Option B).

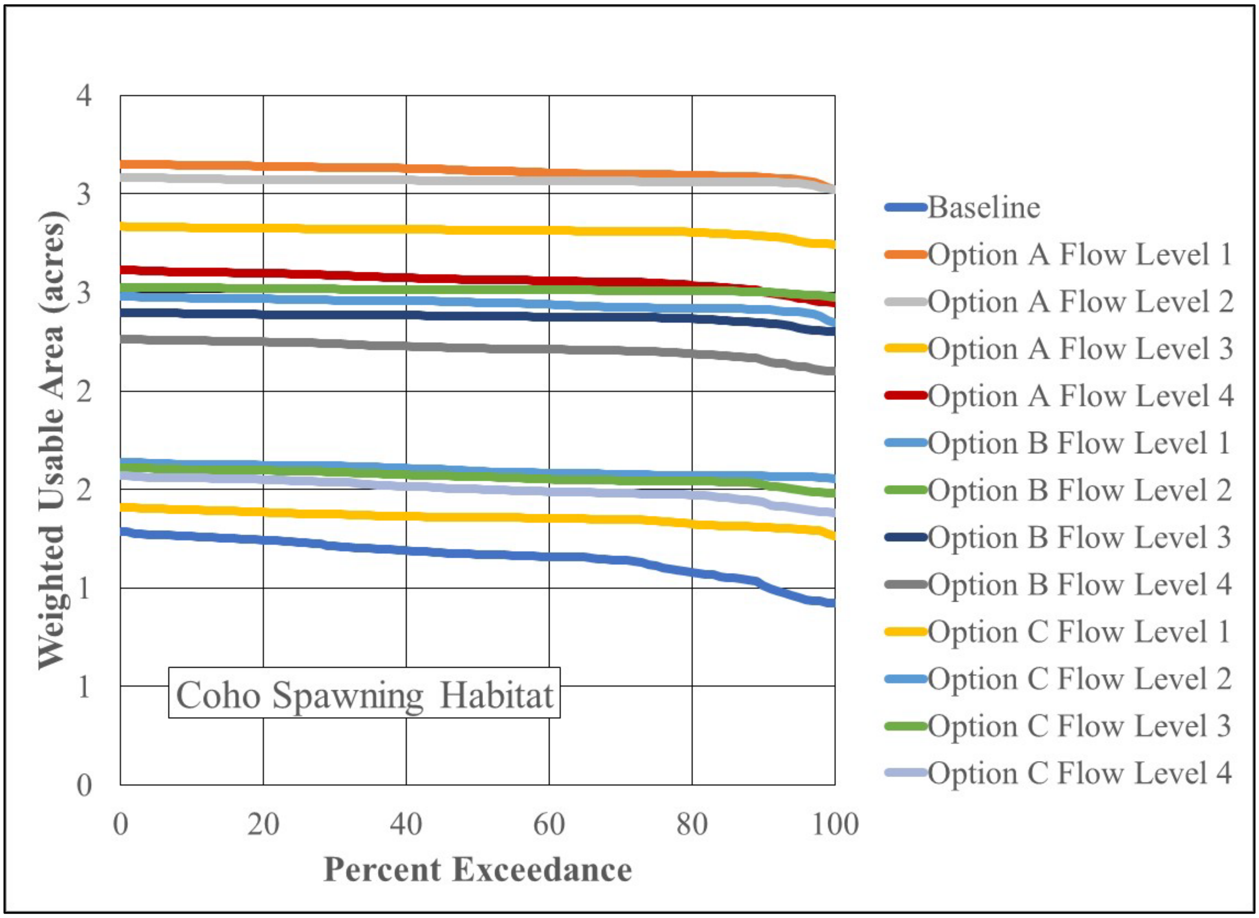


**Figure 5-8 Coho spawning habitat duration curves derived from the total habitat from Reaches 11, 9, 8, 7, 5, and 4. Option A – flow released to Eklutna River just downstream from Eklutna Dam. Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam. Option C – flow released to the Eklutna River in Reach 8. The Level 1, Level 2, Level 3, and Level 4 flow releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon. The flow releases for Option C were assumed to be the same as the flow releases for Option B.**

Habitat duration curves for Time Series B for Coho juvenile rearing habitat are shown in Figure 5-9. In all cases, habitat gains were achieved when flow was added to the river downstream from Eklutna Dam. Larger gains in habitat were achieved when flow was added to the river just downstream from Eklutna Dam (Option A) than when flow was added to the river 1.2 miles downstream from Eklutna Dam (Option B).

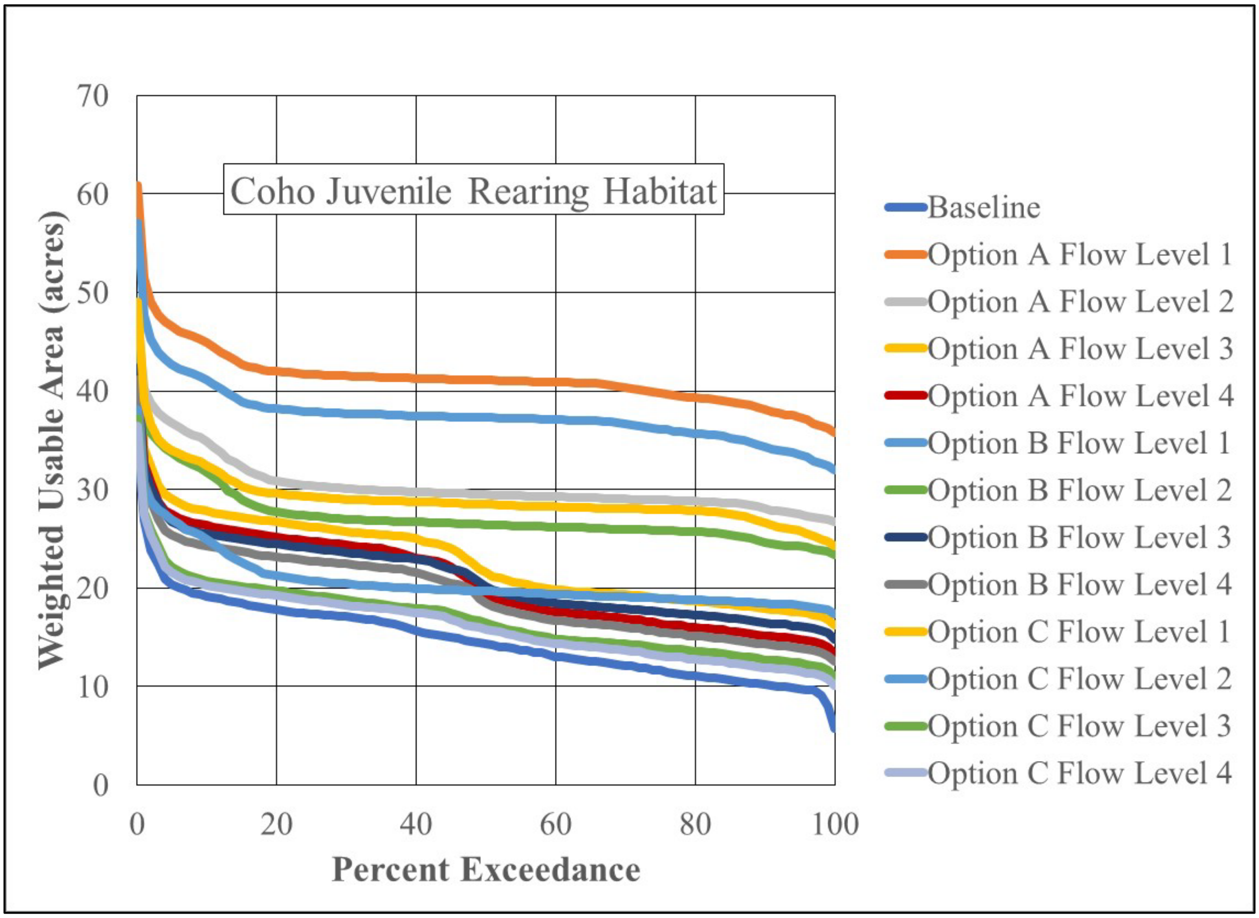


**Figure 5-9 Coho juvenile rearing habitat duration curves derived from the total habitat from Reaches 11, 10, 9, 8, 7, 6, 5, 4, and 3. Option A – flow released to Eklutna River just downstream from Eklutna Dam. Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam. Option C – flow released to the Eklutna River in Reach 8. The Level 1, Level 2, Level 3, and Level 4 flow releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon. The flow releases for Option C were assumed to be the same as the flow releases for Option B.**

Habitat duration curves for Time Series B Sockeye spawning habitat are shown in Figure 5-10 and time-averaged habitat areas (WUA) as listed in Table 10-3. In all cases, habitat gains were achieved when flow was added to the river downstream from Eklutna Dam. Larger gains in habitat were achieved when flow was added to the river just downstream from Eklutna Dam (Option A) than when flow was added to the river 1.2 miles downstream from Eklutna Dam (Option B).

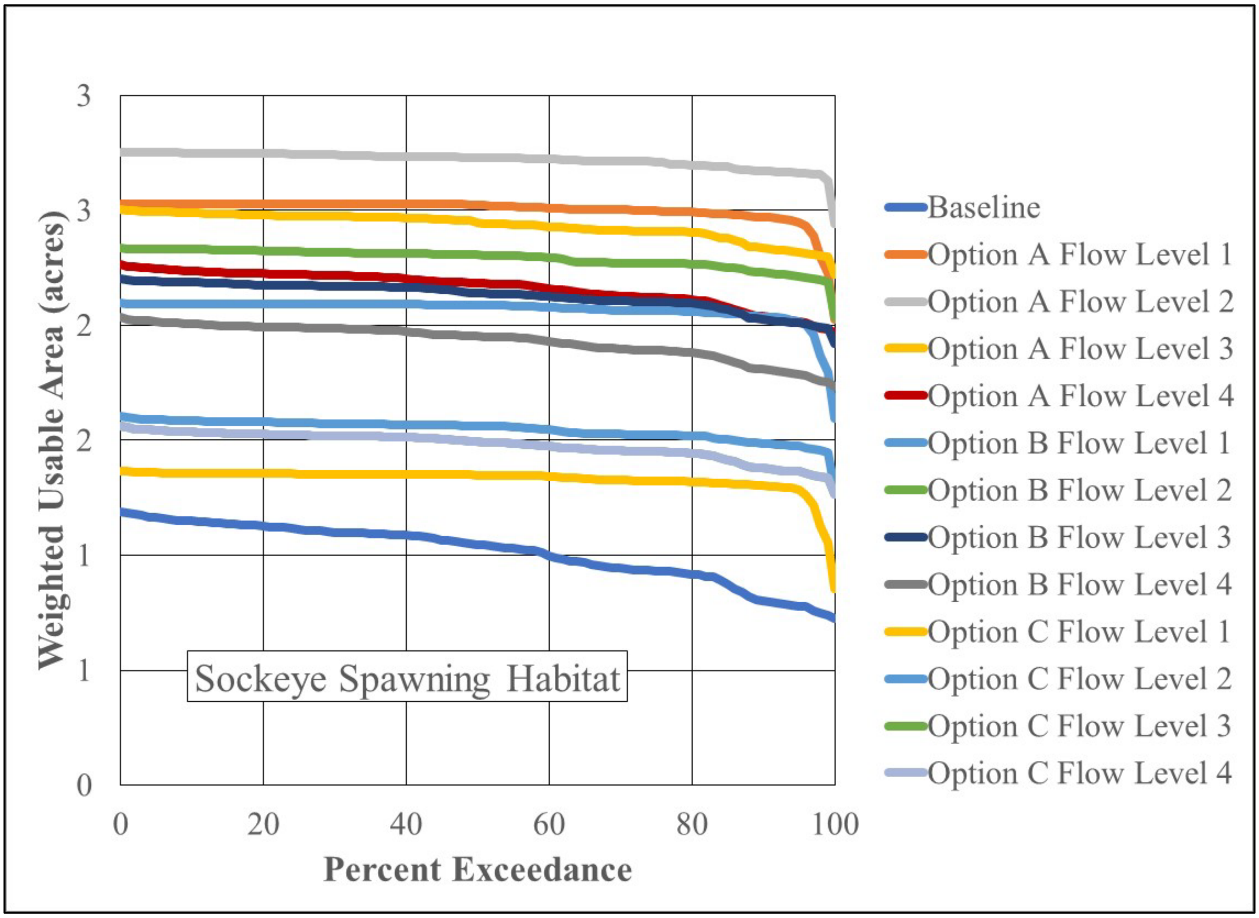


**Figure 5-10 Sockeye spawning habitat duration curves derived from the total habitat from Reaches 11, 9, 8, 7, 5, and 4. Option A – flow released to Eklutna River just downstream from Eklutna Dam. Option B – flow released to Eklutna River about 1.2 miles downstream from Eklutna Dam. Option C – flow released to the Eklutna River in Reach 8. The Level 1, Level 2, Level 3, and Level 4 flow releases represent flows that provide 90%, 70%, 50%, and 30% of the maximum habitat as determined from the habitat vs. flow relationships for Chinook, Coho, and Sockeye salmon. The flow releases for Option C were assumed to be the same as the flow releases for Option B.**

In all cases and for all release options (A, B, and C) analyzed, habitat gains (above baseline) were achieved when water was added to the river downstream from Eklutna Dam. The greatest overall gains occurred under release options A followed closely by B since they affected the most river miles. The Option C release point is ~6.8 miles below the dam and therefore fewer river miles would be affected and habitat gains were overall less than gains for Options A and B.

For illustration purposes, the results of the time series analysis were analyzed on a reach basis and then cumulatively summarized for reaches above and below Thunderbird Creek (Table 5-5). Thunderbird Creek represents the largest contributor to flow to the Eklutna River, but it only affects the lowermost reaches; R3, R4 and R5. On an overall reach basis and under existing baseline conditions (no flow releases from Eklutna Lake with flows resulting from accretion and tributary flow (primarily Thunderbird Creek), Reach 3 would account for about 81 percent (9.7 acres) of the total estimated juvenile rearing habitat of the entire Eklutna River (Table 5-5). This would be followed by R4 (8%), and R5 (3%) which are both below Thunderbird Creek with all reaches above Thunderbird Creek (R6 through R11) cumulatively providing about 7% (0.9 acres) of the baseline habitat totals. For comparative purposes, under Option A and based on Time Series B (juvenile rearing habitat) and with a flow Level 1 release of 143 cfs, the habitat amounts in R3 would increase to 16.7 acres that would represent 55% of the total. The next largest increase in habitats would occur in decreasing order: R11 with 5.4 acres (18%), followed by R4 with 4.1 acres (13%), R10 with 1.8 acres (6%), R7 with 0.9 acres (3%), R8 with 0.7 acres (3%) and then R5 and R6 each with 0.3 acres (1%). These habitat amounts and percentages will differ based on flow release levels from Eklutna Lake.

**Table 5-5. Comparison of juvenile rearing habitat in the Eklutna River by reach under baseline (no flow releases from Eklutna Lake) and Option A-Level 1 flow release (143 cfs). Habitats expressed as acres and percent of total for the entire river. Results from Time Series B analysis.**

| Chinook Juvenile Rearing - Time Series B | | | | |
|---|---|---|---|---|
| | | | | |
| | Baseline | | Option A - Level 1 | |
| | Acres | Percent of Total | Acres | Percent of Total |
| Reach 3 | 9.7 | 81% | 16.7 | 55% |
| Reach 4 | 1.0 | 8% | 4.1 | 13% |
| Reach 5 | 0.4 | 3% | 0.3 | 1% |
| Reach 6 | 0.2 | 2% | 0.3 | 1% |
| Reach 7 | 0.2 | 2% | 0.9 | 3% |
| Reach 8 | 0.2 | 2% | 0.7 | 2% |
| Reach 9 | 0.1 | 1% | 0.4 | 1% |
| Reach 10 | 0.2 | 1% | 1.8 | 6% |
| Reach 11 | 0.0 | 0% | 5.4 | 18% |
| | | | | |
| Lower Eklutna | 11.0 | 93% | 21.1 | 69% |
| Upper Eklutna | 0.9 | 7% | 9.5 | 31% |
| | | | | |
| **Total** | **11.9** | **100%** | **30.6** | **100%** |

# 6.0 FURTHER CONSIDERATIONS AND STUDY LIMITATIONS

The above analysis confirms the utility of the 2D HEC-RAS and habitat modeling and 1D PHABSIM for considering and balancing fish habitat needs amongst other uses of water in the Eklutna River basin, including power production, and potable water supply. The results of the geomorphology and sediment transport modeling, will certainly factor into this analysis, as will results from other studies, e.g., fisheries, water quality, etc.

Like the 1D PHABSIM analysis, the 2D modeling has the most direct applicability to the current conditions and channel morphologies of the Eklutna River.

# 7.0 REFERENCES


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Kleinschmidt Associates (Kleinschmidt). 2022c. Habitat Suitability Criteria (HSC) Curves for the Eklutna River, Alaska. Prepared by D. Reiser, A. Shelly, and M. Gagner for Chugach Electric Association, Matanuska Electric Association, and Municipality of Anchorage. 61 pp.

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# Technical Memo Comment-Response Table

| Comment # | Agency/Interested Party | Draft Two-dimensional Modeling and Habitat Suitability Analysis for Reaches 3, 4, 6, and 10 of the Eklutna River Preliminary Results and Example Flow Technical Memo Section (Page)*"Text"* | Comment | Response |
|---|---|---|---|---|
| | | **Section 1.0 Introduction** | | |
| 1 | USFWS | Section 1.0 Introduction (pages 1-2) "*No study sites were established in Reaches 10, 6, 3, 2, and 1 in part due to accessibility issues during release of the high target flow, susceptibility to channel change due to sediment deposition, tidal influence (R3), and complexity of habitats (braiding and multiple channels) within those reaches. These complex areas contain off-channel habitats frequently used by juvenile salmonids for rearing and may also support some spawning habitats. Light Detection and Ranging (LiDAR) based two-dimensional (2D) hydraulic modeling can provide a reasonable characterization of these complex habitats under a wide range of flows and is not as constrained as 1D PHABSIM modeling . As a result, the following four (4) new study sites were identified for 2D HEC-RAS hydraulic modeling in 2022 (MJA 2022):*<br>• *Reach 10 ...;*<br>• *Reach 6 ...;*<br>• *Reach 4 ...; and*<br>• *Reach 3 ...*<br>*The selection of 2D study sites was made in coordination with the TWG based on results of habitat mapping, review of new 2022 LiDAR, and with consideration of existing sites and transects established for the 1D PHABSIM analysis.*" | The Service recommends completing 2D HEC-RAS modeling for all reaches containing lateral connectivity, especially R3, R4, R10, and R11. The TM acknowledges that 2D hydraulic modeling is better suited than 1D hydraulic modeling for characterizing complex lateral and side channel habitats associated with floodplain activation (Section 1.0, pages 1 and 2). The 2D HEC-RAS model described in the TM can and should be used to understand the extent (acres) and distribution (density and location) of lateral habitat activated at various flow releases. The model would also be useful for identifying floodplain restoration opportunities, i.e., identifying locations where downcutting or infilling would activate historical channels or depressional features. We appreciate the development and calibration of the 2D HEC-RAS hydraulic model including comparison of LiDAR Real-Time Kinematic Global Positioning System (RTK-GPS) elevations and support modeling of additional moderately confined/unconfined reaches. | The original instream flow study plan for the Eklutna River called for 1D HEC-RAS and PHABSIM modeling for Reaches (R) 3 through 11 of the Eklutna River. Using 1D PHABSIM analysis for instream flow analysis is a well-established methodology that adequately captures the habitat-flow relationships of most river channels and floodplains. The applicability of 1D modeling for the Eklutna River was confirmed during multiple site visits to the river leading up to the scheduled 2021 flow releases. Additionally, collecting bathymetric elevation and substrate information during each of the three scheduled flow releases with enough detail to inform 2D models of the river was not feasible. Due to the significant substrate and bathymetric elevation data requirements of 2D habitat modeling, PHABSIM modeling is more applicable/feasible than 2D habitat modeling for rivers like the Eklutna. For these reasons, 2D modeling was not at first considered by the project team.<br><br>However, due to the inability to safely access R6 and R10 during the 2021 flow releases, and due to the off-channel complexity in portions of R3 and R4, the established 1D model approaches were unable to be used for these study reaches. As a result, the project team agreed to conduct some 2D modeling of these noted reaches in order to provide habitat-flow information for these areas.<br><br>As noted in the technical memo, analysis had already been completed for the portions of R3, R4, R6, and R10 that were unable to be studied using the established 1D HEC-RAS and PHASBSIM modeling approaches. The remaining reaches in the Eklutna, including R11, have already been adequately studied using the established 1D HEC-RAS and PHASBSIM modeling approaches. Site observations and the subsequent 1D analysis of R3, R4, R5, R7, R8, R9, and R11 confirmed that the off-channel "floodplain" habitat that is activated during flow releases from 25 to 150 cfs, is adequately captured in the 1D modeling analysis. 2D modeling of these reaches would be redundant and was unnecessary to compute the habitat flow relationships of these reaches. |
| 2 | USFWS | Section 1.2, Overview of 2D HEC-RAS and Habitat Modeling (page 5) "*Sockeye (O. nerka) Salmon are also target species, but juvenile rearing typically occurs in lakes, not rivers and streams (see Section 4).*" | The TM states Sockeye Salmon (O. nerka) rear predominantly in lake habitats, and therefore excludes this species from in-river rearing habitat analyses (Section 1.2, page 5). We point this out to emphasize that changes in salmon (including Sockeye Salmon) rearing habitat quality, quantity, and access will be important metrics for determining the success of PME measures. A flowing channel originating from the base of the dam coupled with fish passage around the dam are the minimum PME measures needed for improving salmon habitat, especially for Sockeye Salmon. | Comment noted. |

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|---|---|---|---|---|
| **Section 3.0 Two-Dimensional (2D) HEC-RAS Hydraulic Model Development** | | | | |
| 3 | USFWS | Section 3.3, Development of 2D Mesh and Selection of Manning's Roughness Values (pages 12 to 14) | Section 3.3, pages 12 to 14: For selecting the Manning's roughness coefficient (Manning's "n"), please elaborate on how the values assigned to road surfaces were adjusted for R10. The adjusted values in Table 3-6 (0.036-0.05) are higher than typical road values, as gravel roads often have a Manning's "n" value that resembles rough asphalt (0.016). These details become more important as the data and model are used to understand floodplain existing conditions and potential restoration opportunities. | The Manning's roughness value (0.036 – 0.05) used for the "road surface" in reach 10 was selected based on site observations during data collection. The "road surface" located in reach 10 is not a traditional gravel roadway. It has a mixture of large cobble, and large gravel with significant boundary vegetation that in many places is intruding into the roadway. There are also larger boulders and intermittent vegetation (grass, brush, small alders) scattered throughout the road. As a result, the roadway looks more like a stream channel than a roadway. We believe a roughness value of 0.036-0.05 for this type of ground condition is reasonable.<br>It is also important to note that due to the low percentage of the modeled area that was established as "roadway" adjusting the roughness value used for this area would be unlikely to change the habitat flow relationships established for reach 10. |
| **Section 4.0 2D Habitat Analysis** | | | | |
| 4 | USFWS | Figures 4-10 (Section 4.5, page 35), Figure 4-11 (Section 4.5, page 36), and Figure 4-17 (Section 4.6, page 43) | The Service recommends the 2D HEC-RAS models for all modeled reaches at flows up to historical bankfull levels, like what is depicted in Figures 4-10 (Section 4.5, page 36), Figure 4-11 (Section 4.5, page 37), and Figure 4-17 (Section 4.6, page 43). Figure 4-17 shows an increase in lateral habitat (side channels and wetland/beaver complexes) accessibility across a range of stream flows. We encourage using this approach to understand flow-related rearing habitat gains and inform measures for protecting, mitigating damages to, and enhancing (PME) fish and wildlife. Complete and accurate depictions of habitat flow relationships across the range of modeled sites and flows is necessary to make an informed decision. | As noted in the technical memo, 2D analysis has already been completed for the portions of R3, R4, R6, and R10 that were unable to be studied using the established 1D HEC-RAS and PHASBSIM modeling approaches. The remaining reaches in the Eklutna River, including R11, have already been adequately studied using the established 1D HEC-RAS and PHASBSIM modeling approaches. Site observations and the subsequent 1D analysis of reaches R3, R4, R5, R7, R8, R9, and R11 confirmed that the off-channel "floodplain" habitat that is activated during flow releases from 25 to 150 cfs, is adequately captured in the 1D modeling analysis. 2D modeling of these reaches would be redundant and is unnecessary to compute the habitat -flow relationships of these reaches. |

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|---|---|---|---|---|
| 5 | USFWS | Section 4.3 Habitat Suitability Curves, footnote 4 (page 26) "*As noted above and in the Year 2 Study Plan, the 2D habitat analysis was focused on juvenile rearing habitat and specifically to determine to what extent gains in habitat could be achieved if side channel and off channel areas could be connected via flow.*" | The Service is supportive of the HEC-RAS model and applications to "determine to what extent gains in habitat could be achieved if side channel and off channel areas could be connected via flow" (Section 4.3, page 26) and we encourage this approach be used to inform flow releases. However, to understand how variable stream flows affect rearing habitat availability, river reaches with floodplain connectivity must be modeled. Floodplain activation as a metric is more useful and biologically relevant than in-channel rearing habitat availability for evaluating functional lifts associated with variable stream flows under different PME alternatives. These habitats are dynamic by nature and therefore may not lend themselves well to 1D physical habitat simulation. The 2D HEC-RAS model, however, is quite useful for visualizing lateral floodplain activation throughout less confined reaches. | As is noted in the technical memo Two-Dimensional Modeling and Habitat Suitability Analysis for Reaches 3, 4, 6, and 10, 2D analysis has already been completed for the portions of R3, R4, R6, and R10 that were unable to be studied using the established 1D HEC-RAS and PHASBSIM modeling approaches. The remaining reaches in the Eklutna River, including R11, have already been adequately studied using the established 1D HEC-RAS and PHASBSIM modeling approaches. Site observations and the subsequent 1D analysis of reaches R3, R4,R5, R7, R8, R9, and R11 confirmed that the off-channel "floodplain" habitat that is activated during flow releases from 25 to 150 cfs, is adequately captured in the 1D modeling analysis. Therefore, 2D modeling of these reaches would be redundant and is unnecessary to compute the habitat - flow relationships of these reaches. |
| **Section 5.0 Time Series Analysis** | | | | |
| 6 | USFWS | Section 5.2.1, Time Series A - 2D Juvenile Habitat Analysis, footnote 7 (page 54) "*The release flows were based on a composite of the R6 and R10 habitat vs. flow relationships above Thunderbird Creek, since this is the river segment that would receive the greatest benefit (as a percentage flow increase over baseline) from flow releases from Eklutna Lake. The habitat-flow relationships for R3 and R4 which are below Thunderbird Creek, were not used for developing flow releases from Eklutna Lake but were considered in the time series analysis.*"<br><br>Section 5.4.2, Time Series B, (page 79) "*For comparative purposes, under Option A and based on Time Series B (juvenile rearing habitat) and with a flow Level 1 release of 143 cfs, the habitat amounts in R3 would increase to 16.7 acres that would represent 55% of the total. The next largest increase in habitats would occur in decreasing order: R11 with 5.4 acres (18%), followed by R4 with 4.1 acres (13%), R10 with 1.8 acres (6%), R7 with 0.9 acres (3%), R8 with 0.7 acres (3%) and then R5 and R6 each with 0.3 acres (1%).*" | The Time Series Analysis should be conducted with R6 omitted. Reaches R6 and R10 were chosen as model inputs as they would "receive the greatest benefit as a percentage of flow increase over baseline" (Section 5.2.1, page 54). However, under a 143 cfs increase in stream flows, R6 would contribute a modest 1 percent to total Eklutna River rearing habitat availability; R11, in contrast, would contribute 18 percent (Section 5.4.2, page 70). Because R6 functions more as a transport reach than juvenile rearing habitat, it is important to remove R6 from all rearing habitat availability analyses intended to inform flow prescriptions. We further recommend a standardizing variable such as flow-related habitat contributions by acres per lineal stream mile, as opposed to percent of total potential habitat within that reach. An alternative for standardization is percent of total, river-wide habitat.<br>We recommend modeling all reaches upstream of the Thunderbird Creek confluence to accurately depict changes in available rearing habitat under the three flow release location options. Table 5-3, Figure 5-5, and Figure 5-6 (Section 5.4.1, pages 58 to 62) show no difference in suitable habitat between releases originating from the dam versus downstream of the Anchorage Water and Wastewater Utility infrastructure because the percent of available habitat is presented only for R6 and R10, and presented as a percentage of total potential rearing habitat within only those reaches. | Reach 6 should not be excluded from the instream flow analysis. First, the amount of available habitat in R6, or lack thereof, does not overly skew the reported rearing habitat availability in the Eklutna River, it simply includes what is estimated to occur in that reach. Second, it would be scientifically indefensible to arbitrarily omit a given reach from analysis simply because it contains low amounts of a particular type of habitat. The time series analysis as presented in the Year 2 Instream Flow report provides a comparative assessment of spawning and rearing habitats in each reach of the Eklutna River, and as well, compares the habitat amounts between reaches in the Upper versus Lower Eklutna River as demarcated by Thunderbird Creek. |

# Technical Memo Comment-Response Table

| Comment # | Agency/Interested Party | Draft Two-dimensional Modeling and Habitat Suitability Analysis for Reaches 3, 4, 6, and 10 of the Eklutna River Preliminary Results and Example Flow Technical Memo Section (Page)*"Text"* | Comment | Response |
|---|---|---|---|---|
| **General Comments** | | | | |
| 7 | USFWS | General | We recommend removing R6 from any model or composite used to correlate instream flow levels with rearing habitat availability for Eklutna River upstream of the Thunderbird Creek confluence. The TM acknowledges that R6 is a transport reach (Section 4.5, page 36) and that it contributes the least amount of rearing habitat to the system (0.3 acre or 1 percent; Section 5.4.2, page 70). At the watershed scale, juvenile salmonids depend upon mainstem, tributary, and lateral floodplain habitats to move, feed, and grow (Quinn and Petersen 1996; Kahler et al. 2001; Jeffres et al. 2008). The extent and accessibility of lateral, floodplain, and tributary habitats is particularly critical for overwintering species, such as Coho Salmon (*Oncorhynchus kisutch* ) and Chinook Salmon (*O. tshawytscha* ), because fish size at the onset of winter is strongly correlated to survivability (Roni 2013). In this regard, modeling rearing habitat in reaches with limited floodplain connectivity, like R6, does not provide meaningful context for understanding rearing habitat availability within the Eklutna River.<br><br>We recommend replacing R6 with R11 for models that correlate instream flows to rearing habitat availability, which was not considered in rearing habitat dependent flow analyses. Reach R11 contributes the greatest amount of potential rearing habitat to the system (Section 5.4.2, page 70) and was the site of the original reference reach. We therefore recommend that R6 and all composite models containing R6 be removed from any rearing habitat analysis, and that R11, the original reference reach, be included and modeled in a 2D environment both with and without PHABSIM suitability curves applied. | Reach 6 was unable to be accessed during the 2021 flow releases and thus could not be analyzed with the established 1D HEC-RAS and PHASBSIM modeling approaches. As a result, no habitat-flow information was available for this reach at the conclusion 1D analysis. To fill this knowledge gap, 2D habitat modeling was used to compute the habitat - flow relationships of R6.<br>As is noted in the technical memo, R6 has been identified as a transport reach within the Eklutna River. However, this does not exclude the reach from the scope of the instream flow study. Due to the safety concerns with accessing the site during the 2021 flow releases, the next best modeling approach (2D) was used for this reach.<br><br>The amount of available habitat in R6, or lack thereof, does not overly skew the reported rearing habitat availability in the Eklutna River. Including R6 in the instream flow analysis is within the scope of this study. Moreover, replacing R6 results with R11, or essentially doubling up the R11 results is not scientifically sound given the wide disparity in habitat characteristics between those two reaches.<br><br>The habitat flow relationships within R11 have already been computed using the established 1D HEC-RAS and PHASBSIM modeling approaches. Site observations and the subsequent 1D analysis of R11 confirmed that the off-channel "floodplain" habitat that is activated during flow releases from 25 to 150 cfs, is adequately captured in the 1D modeling analysis. 2D modeling of this reach would be redundant and is unnecessary to compute the habitat-flow relationships of these reaches. |
| 8 | USFWS | General | Furthermore, please consider all affected reaches when evaluating benefits associated with water releases, including R3 and R4. These two reaches, which are below the confluence of Thunderbird Creek, were removed from the composite suitability curve analysis because they show direct and limitless relationships between flows and floodplain rearing habitat activation. As such, they would result in minimum flows exceeding 200 cubic feet per second (cfs; Section 4.7.1, page 45). Section 5.2.2 explains that while Reaches 3 and 4 were considered in the time series analysis, the habitat-flow relationships for these reaches were not used for developing flow releases because they would have the least benefit (as a percentage of flow increase over baseline) from Eklutna Lake flow releases.<br><br>We recommend potential benefits be measured not in terms of percent change within reach, but as the proportion of total habitat contributed across all reaches. The omission of these reaches results in the selection of a lower flow threshold. The rationale for their omission is not biologically sound and therefore needs further justification. | In the technical memorandum, the benefits of the four flow release levels for all reaches were only shown for illustration purposes for juvenile rearing habitats; see Table 5-5 of the January 10, 2023 TM. Since then, the benefits for all reaches for both spawning and juvenile rearing habitats for all three species has been computed and is presented in the Draft Year 2 Instream Flow report. |