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Project: **Skagit River Tributary Instream Flow Habitat Assessment**

Client: Skagit Basin Water Task Force Work Group

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Executive Summary

This instream flow study established the relationship between an index of fish habitat suitability (Area Weighted Suitability, AWS) and stream flow in the Skagit River tributary, Grandy Creek. The AWS for the Chinook salmon (*Oncorhynchus tshawytscha*), Coho salmon (*Oncorhynchus kisutch*), and Steelhead trout (*Oncorhynchus mykiss*); including spawning, fry rearing, and juvenile rearing life-stages were combined with the historical baseline and potential future changes in flow over time, simulating changes to habitat value. The predicted changes to habitat value enables stakeholders to compare future climate-modified habitat value with the historical record and make proactive decisions on managing Grandy Creek.

The Washington State Joint Legislative Task Force on Water Supply through Washinton State University (WSU) engaged Thomas Gast & Associates Environmental Consultants (TGAEC) to conduct the instream flow study, develop a simulated historic flow record, and compare the resultant habitat value to habitat value under potential climate and development-modified scenarios. TGAEC conducted standard one-dimensional Physical Habitat Simulation (PHABSIM) model instream flow study on six miles of Grandy Creek. The studies included stakeholder involvement, habitat mapping, transect selection and placement, habitat suitability criteria (HSC) development, hydraulic field measurement, flow simulation, habitat modeling, and hydrologic analysis. The body of this report includes the methodology, summary results, and example comparisons. The detailed results are included in the Appendices. The Annexes contain the HSC, and Hydrologic Analysis technical memos, Habitat Typing GIS and Excel files, and digital photos of the habitat typing, transect installation and the low and high calibration flows.

TGAEC collaborated with Dr. Koehler of Visual Analytics on a novel method of presenting habitat time series, using raster plots for viewing and understanding the data. In addition to the standard habitat duration graphs, results include raster plots of the climate-modified water resource alternatives and habitat time series for Grandy Creek.

Staff observed spawning salmon in Reach 1, the lower half of Grandy Creek only. A 120 feet series of cascades and water falls immediately upstream of the beginning of Reach 2 is a potential partial or full barrier to upstream migration. No adult salmonids or redds were observed in that reach.

Both reaches are characterized primarily by shallow riffle habitat with few pools. Ample spawning gravel is present in both reaches, but instream cover is primarily restricted to the banks.

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All of the rearing Area Weighted Suitability (AWS) curves are low and mostly flat, with the exception of steelhead fry in the Upper Reach, a result of the sparse in-channel cover. In the Lower Reach Chinook spawning habitat value rises steeply from low flows up to 60 cfs, peaks at approximately 80 cfs, and declines at higher flows. Coho spawning habitat value increases steeply from low flows to 25 cfs, peaks at approximately 70 cfs, and declines moderately at higher flows. Steelhead spawning habitat value increases steeply from low flows to 50 cfs, peaks at approximately 70 cfs, and declines moderately at higher flows.

In the Upper Reach, Chinook spawning habitat value rises steeply from low flows up to 50 cfs, peaks at approximately 70 cfs, and is nearly flat at higher flows. Coho spawning habitat value increases steeply from low flows to 35 cfs, peaks at approximately 50 cfs, and is mostly flat at higher flows. Steelhead spawning habitat value increases steeply from low flows to 45 cfs, and continues to rise moderately at higher flows.

No stream gauge record is available for Grandy Creek. A synthetic baseline hydrology was developed from previous gauging on the adjacent Alder Creek. Two climate change hydrologic scenarios and a potential increase in water consumption from development were created to compare the climate change and population adjusted habitat value to the baseline habitat value. Most of the potential change in stream flow would occur during the summer months, affecting those life-stages present during the summer, including Chinook spawning, Coho juvenile rearing, and steelhead fry and juvenile rearing.

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Acronyms and Abbreviations

AFY Acre feet per year

AWS Area Weighted Suitability (alternate name for WUA)

DEM Digital Elevation Model

HSC Habitat Suitability Criteria

HU Habitat Unit

IFG Instream Flow Group

IFIM Instream Flow Incremental Methodologies

IPCC Intergovernmental Panel on Climate Change

NOAA National Oceanic and Atmospheric Administration

PDO Pacific Decadal Oscillation

PHABSIM Physical Habitat Simulation model developed by the U.S. Fish and Wildlife Service

PHDI Palmer Hydrologic Drought Index

POR Period of Record

RCP Representative concentration pathways

RCP Representative Concentration Pathways

RHABSIM Riverine Habitat Simulation software conversion and enhancement of PHABSIM by TRPA

SEFA System for Environmental Flow Analysis, software enhancing the capabilities of RHABSIM, RYHABSIM, and PHABSIM developed by T. Payne, I. Jowett, and B. Milhouse.

TGAEC Thomas Gast & Associates Environmental Consultants

TRPA Thomas R. Payne and Associates

USACE United States Army Corps of Engineers

USGS United States Geological Survey

WDFW Washington Department of Fish and Wildlife

WRIA Water Resource Inventory Area

WSEL Water Surface Elevation

WSU Wahington State University

WUA Weighted Usable Area, a Habitat Index (old name for AWS)

Introduction

Salmonids in the Skagit River watershed use tributary streams to spawn and rear. Population growth and climate change will alter the amount and timing of streamflow and will impact salmonid spawning and rearing habitat in the Skagit River tributaries. This instream flow study models the relationship between streamflow and salmonid habitat in Grandy Creek. We compare the available fish habitat under natural flow conditions to projected fish habitat under a climate change scenario as well as two future growth scenarios.

Larry Wasserman, on behalf of the Swinomish Indian Tribe, submitted the proposal, "Updated Skagit River Habitat and Flow Assessment" for the Skagit Basin Water Task Force Work Group.

Study Area

The study area consists of Grandy Creek from the confluence with the Skagit River to Grandy Lake (Figure 1). The stream channel is approximately six miles long. Grandy Creek has a drainage area of approximately 18.9 square miles and elevations ranging from 123 feet to 4770 feet. The mean basin slope, as computed by 30-meter DEM, is 29.3%. Approximately 50% of the basin area is composed of steep slopes (>30%). (Figure 1). Lower Grandy Creek, mostly south of Highway 20, is dominated by rural residential and small agriculture. North of Highway 20, the land use transitions to forestry and recreation. Baker Lake Road follows the Grandy Creek channel upstream to Grandy Lake. In this area, the stream channel is constricted by steep banks. The instream flow study ended at Grandy Lake.

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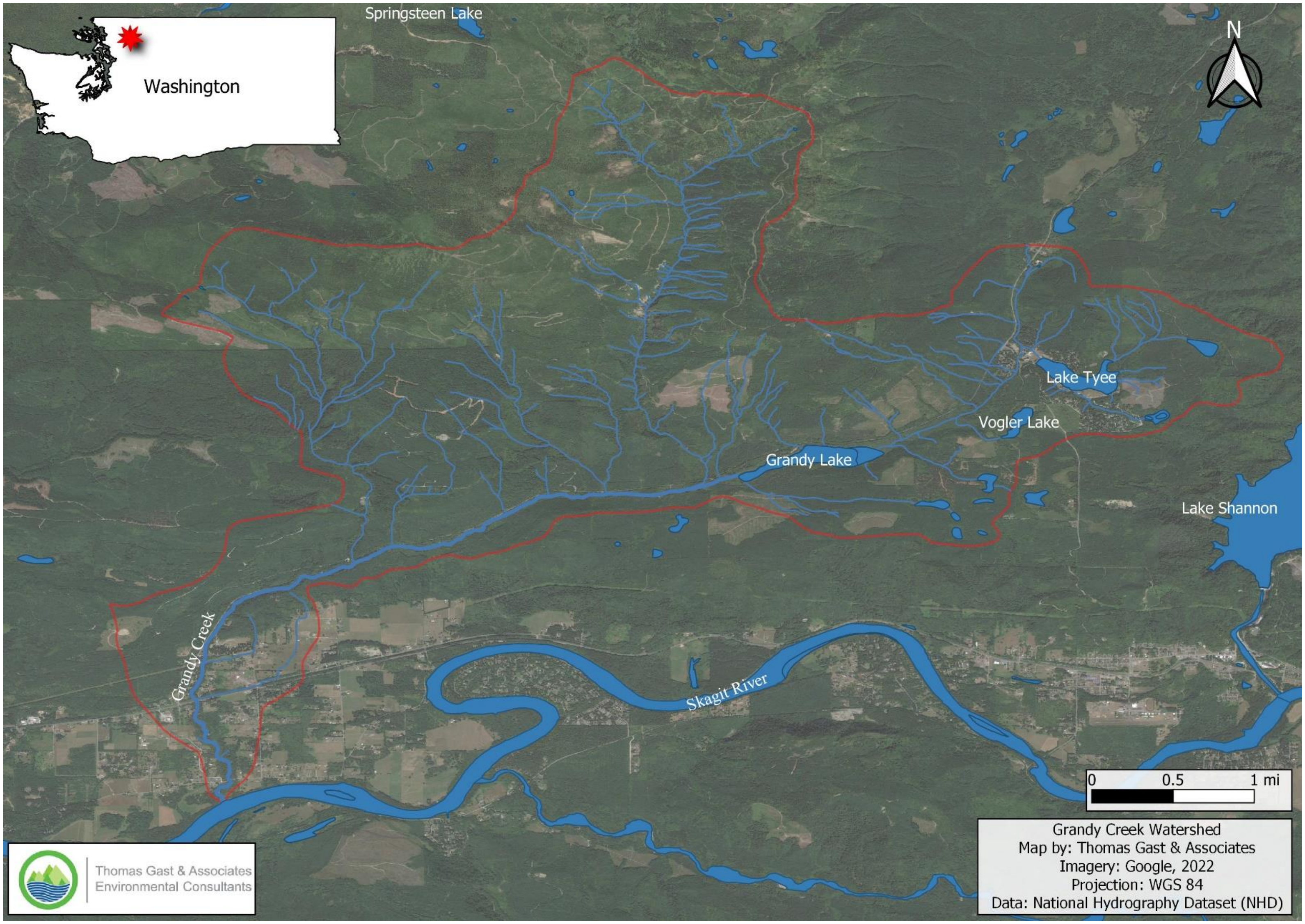

Figure 1. Grandy Creek Watershed and Instream Flow Study Area (confluence with the Skagit river to Grandy Lake).

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Methodology

Development of a relationship between suitable aquatic habitat and river flow for selected species and life stages within the Instream Flow Incremental Methodologies (IFIM) and PHABSIM framework depends on the measurement or estimation of physical habitat parameters (depth, velocity, substrate/cover) within the study reach. Generally, the distribution of these parameters at given river flows are determined at points along transect lines across the stream channel, positioned to account for spatial and flow-related variability. A variety of hydraulic modeling techniques can be used to simulate water depth and velocity as a function of river flow; substrate and cover values are generally fixed at a given point. With physical habitat thus characterized for a range of river flows, the suitability of the habitat (for a particular species and life stage) at each point is scaled from zero to one, usually by multiplying together the corresponding suitability values for depth, velocity, and substrate from the appropriate habitat suitability criteria (HSC) curves. These point estimates of suitability are then used to weight the physical area of the study represented by each point, and the weighted areas are accumulated for the entire study reach to produce an index of useable habitat as a function of river flow for each species and life stage.

The physical area represented by each transect point depends on the design of the PHABSIM study. This study used the mesohabitat typing, or habitat mapping, approach originally described by Morhardt et al. (1983) and summarized by Bovee et al. (1998). In this design, mesohabitats (broadly defined habitat generalizations) were mapped over the entire study reach, such that each area of the waterway was characterized by general habitat types, and the total length and proportion of the study reach assigned to each mesohabitat type was determined.

Physical habitat parameters (river flow dependent depth and velocity, substrate, and cover) representative of each mesohabitat type were measured or modeled at one or more transects placed within the mesohabitat area. The exact number and placement of transects placed in a mesohabitat type depended on the proportion of the study reach represented by each mesohabitat type, as well as practical issues such as accessibility. Generally, the total number of transects was distributed among mesohabitat types in proportion to the length of the study reach represented by each mesohabitat. The physical area represented by each transect point was then determined by both the lateral distribution of points on a transect, and the length or proportion of the study reach that each transect represented.

Stakeholder Involvement

An initial virtual study plan meeting was held on October 5, 2022, and was attended by WDFW, Ecology and Swinomish Tribal representative. Stakeholders were also invited to the PHABSIM transect installation fieldwork. A progress report was presented to the Washington Joint Legislative Task Force on Water Supply Meeting on October 17, 2022.

Habitat Mapping

Habitat mapping consists of identifying the type (e.g. pools, runs, and riffles) and measuring the length of individual macrohabitat units over the total distance of stream courses within a

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project area (Morhardt et al. 1983). The method allows each transect where hydraulic data is collected to be given a weight proportional to the quantity of habitat represented by that transect. Mapping was conducted by walking the stream channel while deploying biodegradable cotton thread from a surveyor's hip chain to measure total distance. The location and length of each individual macrohabitat type was calculated by noting the distance from a downstream base reference point to upstream boundaries. Reference points were marked using surveyor's flagging every 500 feet (generally at the nearest hydraulic control) as well as GPS waypoints. These marks serve as temporary and fixed, known reference points from which to relocate specific habitat units or other features of interest during the stream studies. In addition to habitat classifications, TGAEC staff recorded the percentage of suitable spawning gravel present within each habitat unit by visual estimation. Field staff also noted observations of salmonid redds, the presence of adult live fish, and fish carcasses at the time of survey. During the survey, habitat unit lengths were measured using hip-chain, as well as GPS tracking software. Data were recorded in QField electronic field forms, uploaded, and QA/QC'd in QGIS desktop software.

The mapping information was used to determine reach boundaries, the percentages of various macrohabitats, assist with selection of study sites, and placement of transects for the hydraulic data collection. Each habitat unit was also evaluated for appropriateness for PHABSIM modeling. Such conditions that prohibit satisfactory hydraulic simulation included complex hydraulic conditions associated with strongly transverse flow conditions, plunge pools, or unique split channel configurations. Potentially dangerous and unsafe habitat units, such as those near dangerous falls or cascades, were also identified for subsequent elimination as candidates for hydraulic modeling.

The individual macrohabitat identifications and distances were entered into a database program to create a sequential map of habitat units along the entire length of stream that was surveyed. The database allowed for the computation of the percent abundance of any macrohabitat type within the entire study area or within designated reaches. The mapping data and location markers aided in the relocation of individual habitat units for subsequent inspection and transect selection. Figure 2 is a photo of a salmon carcass encountered during habitat mapping the Lower Reach.

Figure 2. Salmon carcass encountered during habitat typing in the Lower Reach.

PHABSIM: Transect Selection and Installation

Habitat mapping forms the basis for transect selection. Percent contribution of individual habitat types to total habitat is derived from the total length of a given reach. The PHABSIM

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habitat analysis relies upon hydraulic conditions measured along stream cross sections, or transects, placed in a variety of different macrohabitats. Habitat unit selection and transect placement was conducted by TGAEC. Actual habitat unit selection and transect placement was accomplished with a combination of random selection and professional judgment through the following procedure:

1. The macrohabitat type with the lowest percentage of abundance within each study segment was used as the basis for random selection (provided that the habitat type was ecologically significant and made up greater than 5% of the total study reach) and sequentially numbered. Several units were selected by random number.

2. In the field, the first selected unit was relocated and, if it was modelable, reasonably typical, and it appeared safe to collect hydraulic data during high flows, a transect was placed that would best represent the habitat type. The second or higher randomly selected units were used only if initial units were rejected.

3. At least one example of each remaining more-abundant habitat type was then located in the immediate vicinity of the random transect (upstream or downstream) until the additional study transects were placed in other macrohabitat units. This created a study site and transect "cluster", which reduced data collection travel time.

Calibration Flows

Calibration flows are the flows at which water surface elevations and velocities are measured and from which the model simulations are built. A total of three sets of calibration flow measurements, high, middle and low were made at each transect. Generally, the simulations will be valid for a range of flows from forty percent of the low calibration flow to 250 percent of the high calibration flow. Velocities at each transect station were measured at all safe calibration flows. In the case of unregulated rivers, such as the stream in this study, calibration flow targets were identified, but the measurements were opportunistic depending on the weather during the sampling period.

Field Data Collection

Water Surface Elevation and Velocity Measurements

One complete set of depths and velocity measurements was collected at each transect at the middle flow or the flow level that could be effectively and safely measured. Data were collected using wading/velocity measurement techniques for shallow habitats.

The amount and type of data collected is suitable for use in a hydraulic simulation with the PHABSIM computer model in the one-velocity mode for the entire range of flows (Payne 1987). The one-flow model of PHABSIM has been shown to calculate habitat values very close to those obtained with three full sets of depth and velocity data (Payne 1988b); however, the preferred Washington method uses the three-velocity regression method (WDFW 2022).

Field data collection and the form of data recording basically followed the guidelines established in the Instream Flow Group (IFG) field techniques manuals (Trihey and Wegner

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1981; Milhous et al. 1984; Bovee 1997). Additional quality control checks that have been found valuable during previous applications of the simulation models were employed. The techniques for measuring discharge generally followed the guidelines outlined by Rantz (1982). A minimum of 20 wetted stations per stream transect were be established, with a goal of no less than 15 wetted stations at the lowest measured flow. The boundaries of each station along each transect were normally at consistent increments, but significant changes in velocity, substrate, depth, or other important stream habitat features sometimes required additional stationing.

Substrate and Cover Characterization

Substrate and cover attributes and codes used in this study are described in Tables 1 and 2. The substrate was coded as ab.c, where "a" is the dominant substrate code, "b" is the subdominant substrate code, and "c" is the percent of represented by the subdominant substrate.

Table 1. Substrate size and codes.

Substrate Type	Size	Code
Silt, clay, organic		1
Sand		2
Small gravel	0.1 – 0.5 "	3
Medium gravel	0.5 – 1.5 "	4
Large gravel	1.3 – 3"	5
Small cobble	3 – 6 "	6
Large cobble	6 – 12 "	7
Boulder	> 12"	8
Bedrock		9

Table 2. Cover types and codes.

Code	Cover
0.00	none
00.1	undercut bank
00.2	overhanging veg near or touching water (incl branches) <3ft above SZF WSE
00.3	rootwad
00.4	log jam/submerged brush
00.5	log parallel to bank
00.6	aquatic veg
00.7	short grass <1ft
00.8	tall dense grass >3ft
00.9	veg >3ft above SZF WSE

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Quality Assurance/Quality Control

To assure quality control in the collection of field data, the following data collection procedures and protocols were utilized:

Temporary staff gauges were established and continually monitored throughout the course of collecting data. If significant changes occurred, water surface elevations were re-measured following collection of transect water velocity data.

Independent benchmarks were established for each set of transects. The benchmark was an immovable tree, boulder, or other naturally occurring object not subject to tampering. Upon establishment of headpin and tailpin elevations, a level loop was shot to verify the elevations established with the auto-level. Acceptable error tolerances on level loop measurements were set at 0.02 feet. This tolerance was also applicable to both headpin and tailpin measurements, unless extenuating circumstances (e.g., pins under sloped banks, shots through dense foliage) accounted for the discrepancies, and the accompanying headpin or tailpin met the tolerance criteria.

Water surface elevations were measured on both banks on each transect. If possible, on more complex and uneven transects, such as riffles, water surface elevations were also measured at multiple locations across a transect. An attempt was made to measure water surface elevations at the same location (station or distance from pin) across each transect at each calibration flow. Water surface elevation measurements were obtained by placing the bottom of the stadia rod at the water surface until a meniscus formed at the base or selecting a stable area next to the water's edge.

Pin and water surface elevations were calculated on-site during field measurement and compared to previous measurements. Changes in stage since the previous flow measurement were calculated. Patterns of stage change were compared between transects and determined if reasonable. If any discrepancies were discovered, potential sources of error were explored, corrected where possible, and noted.

All calculations were completed in the field, given adequate time and daylight. Pin elevations and changes in water surface elevations were compared between flows on the same transect. Discharges were calculated on-site and were compared between transects during the same flow (high, mid, and low). If an excessive amount of discharge (greater than 10% of the stream flow) was noted for an individual transect cell, additional adjacent stations were established to more precisely define the velocity distribution patterns at that portion of the transect.

Photographs were taken of all transects, downstream, across, and upstream at the three calibration flows. Photographs were taken from the same location at each of the flows, if possible. Photographs provided a valuable record of physical conditions and water surface levels that were utilized during hydraulic model calibration.

All data (stationing, depth profiles, velocities, substrate/cover codes) were entered into the RHABSIM computer files. Internal data graphing routines were then used to review the bottom and velocity profiles for each transect separately and in context with others for quality control purposes. All data gaps (e.g., missing velocities) or discrepancies (e.g., conflicting records) were identified and corrected using available sources, such as field notes, photographs, or adjacent data points.

Transect Weighting

The number of transects selected for each habitat type was determined by the percentage of the study reach represented by each habitat type. In this way each habitat type was represented approximately in proportion to that which was mapped. Each transect was then weighted so that each habitat type was represented in the exact proportion to that existent in the study area.

Hydraulic Simulation

The purpose of hydraulic simulation under the PHABSIM framework is to simulate depths and velocities in streams under varying stream flow conditions. Simulated depth and velocity data were then used to calculate the physical habitat, either with or without substrate and/or cover information. All data were entered into the RHABSIM software used for this analysis.

Water Surface Prediction

The water surface elevations, in conjunction with the transect profiles, were used to determine water depths at each flow. Water depth is an important parameter for determining the physical habitat suitability. Either a dual stage/discharge rating (Dual SDR) curve based on measured data or a channel conveyance method (MANSQ) that relies on the Manning's N roughness equation was used to create the rating curves.

The Dual SDRlog/log regression method uses a stage-discharge relationship to determine water surface elevations. Each cross section is treated independently of all others in the data set. A minimum of three stage-discharge measurement pairs were used to calibrate the stage-discharge relationship. The quality of the rating curves is evaluated by examination of mean error and slope output from the model. Mean errors of less than 10% is considered acceptable and less than 5% is very good. In general, the slope between groups of transects should be similar.

MANSQ only requires a single stage-discharge pair and utilizes Manning's equation and channel shape to determine a rating curve; however, it is generally validated by additional stage-discharge measurements. This modeling method involves an iterative process where a beta coefficient is adjusted until a satisfactory result is obtained. In situations where irregular channel features occur on a cross section, for instance bars or terraces, MANSQ is often better at predicting higher stages than log/log. MANSQ is most often used on riffle or run transects and is generally not considered as effective in establishing rating curves for transects that have backwater effects from downstream controls, such as pools. It can also be useful as a test and verification of log/log relationships.

Velocity Simulation

Simulated velocities were based on measured data and a relationship between a fixed roughness coefficient (Manning's n) and depth. The 3- flow velocity regression method in RHABSIM was used to simulate velocities. In some cases, roughness was modified for individual cells if substantial velocity errors are noted at simulation flows. Velocity Adjustment Factors (VAF's), the degree in which measured velocity and discharge is adjusted to simulated velocity and simulated discharge are an indication of the quality of hydraulic simulations. These are examined to detect any significant deviations and determine if velocities remained

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consistent with stage and total discharge. VAF's in the range of 0.8 to 1.2 at the calibration (measured) flow are considered acceptable, 0.95 to 1.05 is considered excellent.

Habitat Suitability Criteria

Method of Selection

Habitat Suitability Criteria (HSC) define the habitat requirements of the species/life-stages of interest. If no site-specific HSC are developed, HSC are selected from the plethora of curves developed for other studies. Not all HSC are transferable from one stream to another. For example, HSC developed for *O. mykiss* inhabiting a small mountain stream upstream of an impassable barrier do not define the habitat requirements of steelhead in a large river. Likewise, habitat requirements vary with the life-stage of each species and HSC are typically specified for each life-stage. Although there are many HSC available, care must be taken to establish transferability by examining the source metrics (e.g. river size, geographic location, number of observations, etc.).

The results of a PHABSIM instream flow study are determined by both the hydraulic data collected and the HSC selected. Mark Allen from Normandeau, Inc., an expert in HSC development with more than 30 years of experience, developed the Grandy Creek HSC. He used a plethora of previous HSC studies, the WDFW fallback curves, and professional judgement. The curves were presented and agreed on during the initial stakeholder meeting. A complete HSC technical memo is presented in Attachment 2.

Target Species

Species and life stages selected for habitat modeling are presented in Table 3. Chinook salmon in the Skagit watershed exhibit both ocean-type (sub yearling outmigration) and stream-type (yearling outmigration) life histories. Ocean- type represent over 90% of the total freshwater production of Chinook (Zimmerman and Kinsel 2015). Stream-type juveniles are mostly associated with the snowmelt dominated watersheds (Kudo et al 2017, Beechie 2006). Grandy Creek is a rain dominated watershed. For this study, the periodicity of the ocean-type life history was used.

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Table 3. Target species and life stages selected for modeling in Grandy Creek. Blue indicates that the species could be present. The grey for Chinook juvenile represents the stream-type life-history pattern, if present.

Lower Skagit River Salmonid Life Stage Periodicity												
Species/Lifestage	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Chinook Salmon												
Spawning[1,2]												
Incubation/Fry[1,2,6]												
Juvenile[1,2,3]												
Dwnstm Migrat.[1,2,3,6]												
Coho Salmon												
Spawning[2,4]												
Incubation/Fry[4]												
Juvenile[2,4]												
Dwnstm Migrat.[2,4,6]												
Steelhead												
Spawning[2,5,6]												
Incubation/Fry[2,5,6]												
Juvenile[2,5]												
Dwnstm Migrat.[2,5]												
Literature Cited: 1. Zimmerman et al 2015; 2. Lowery et al 2020; 3. Beamer 2014; 4. Woodward et al. 2017; 5. Myers et al 2015; 6. Duke, 1999												

Habitat Suitability Curves

For each of the species and life-stages listed above, HSC were drawn from the Washington Department of Fish and Wildlife and Washington Department of Ecology's "Fallback" curves (WDFW & WDE 2022). However, the 2022 HSC update did not include any HSC representing salmonid fry, and the 2022 update did not include HSC for coho juveniles. Consequently, we developed new HSC curves for salmon and steelhead fry and referred to the WDFW/WDE's 2004 update for coho juvenile curves. The new HSC curves used to represent habitat selectivity for salmon and steelhead fry were developed by utilizing an averaging methodology intended to characterize the central tendency of the existing HSC curves.

Tabular HSC values are presented in Appendix A and the technical memo describing the selection process is in Attachment 2. Figures 3-11 depict the HSC used in the Grandy Creek Instream Flow Study. The X-axis in each figure is labeled "Value", and is either depth, velocity, substrate code, or cover code, depending on the suitability curve.

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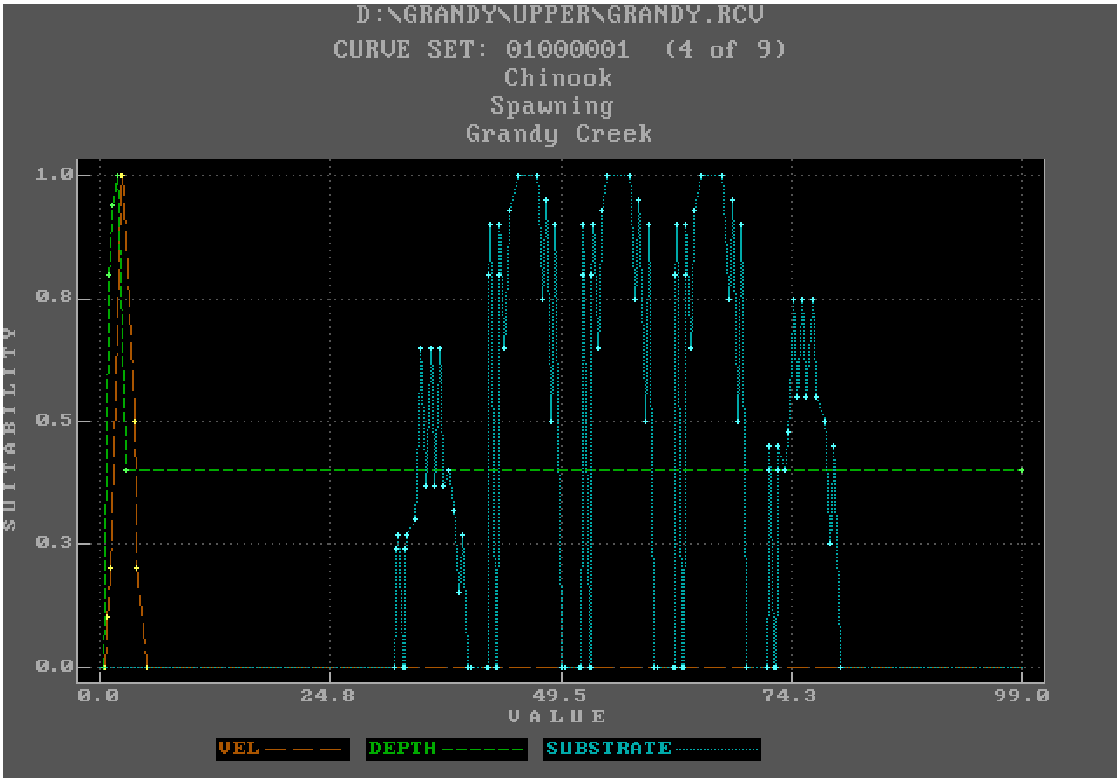

Figure 3. Chinook spawning HSC.

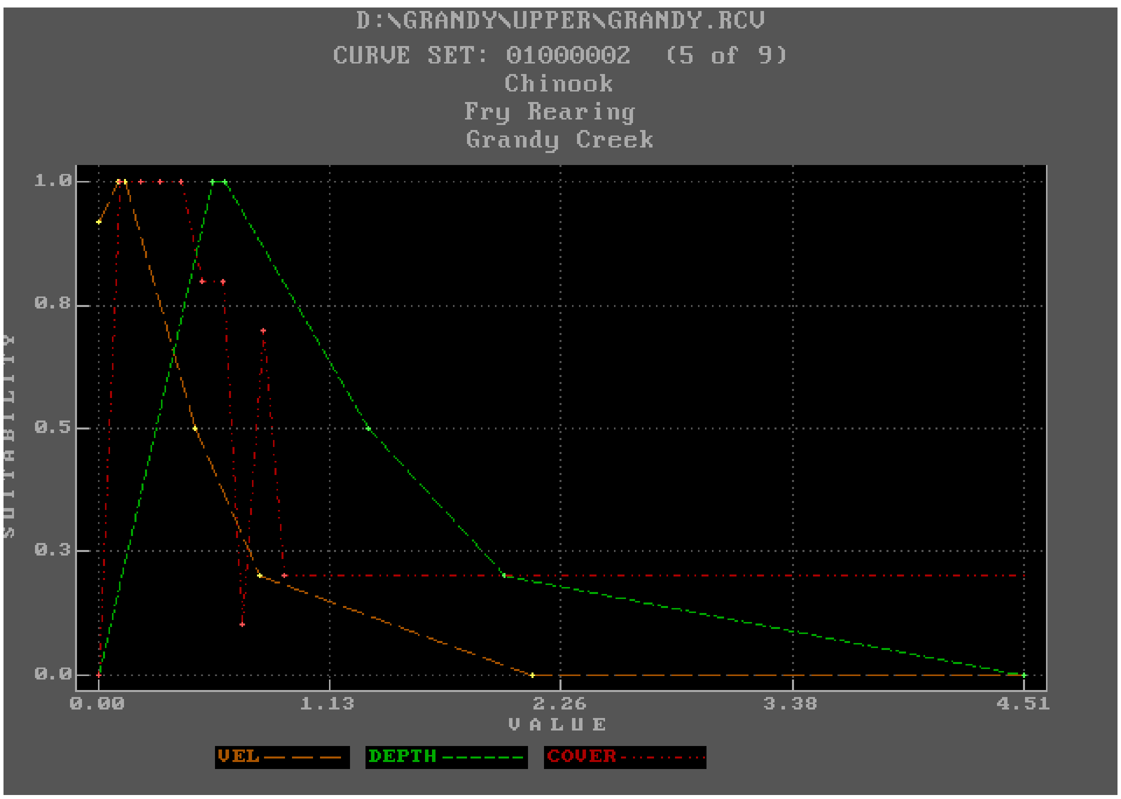

Figure 4. Chinook fry rearing HSC.

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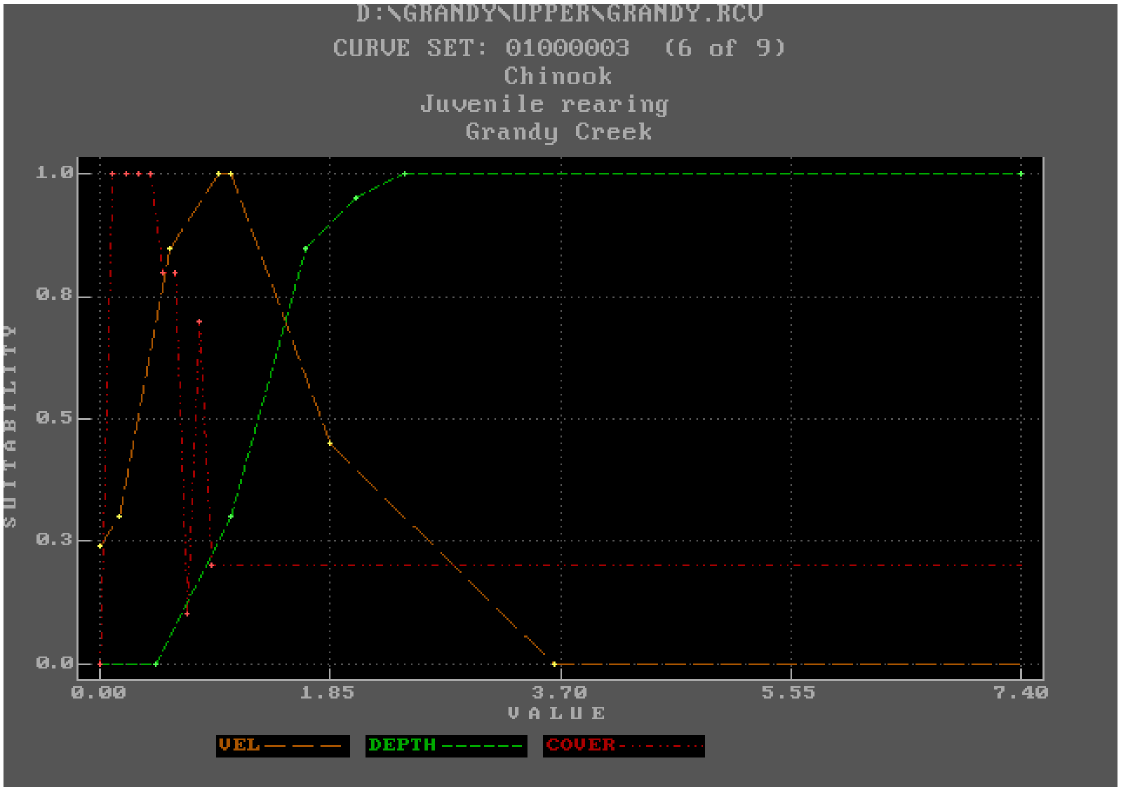

Figure 5. Chinook juvenile rearing HSC.

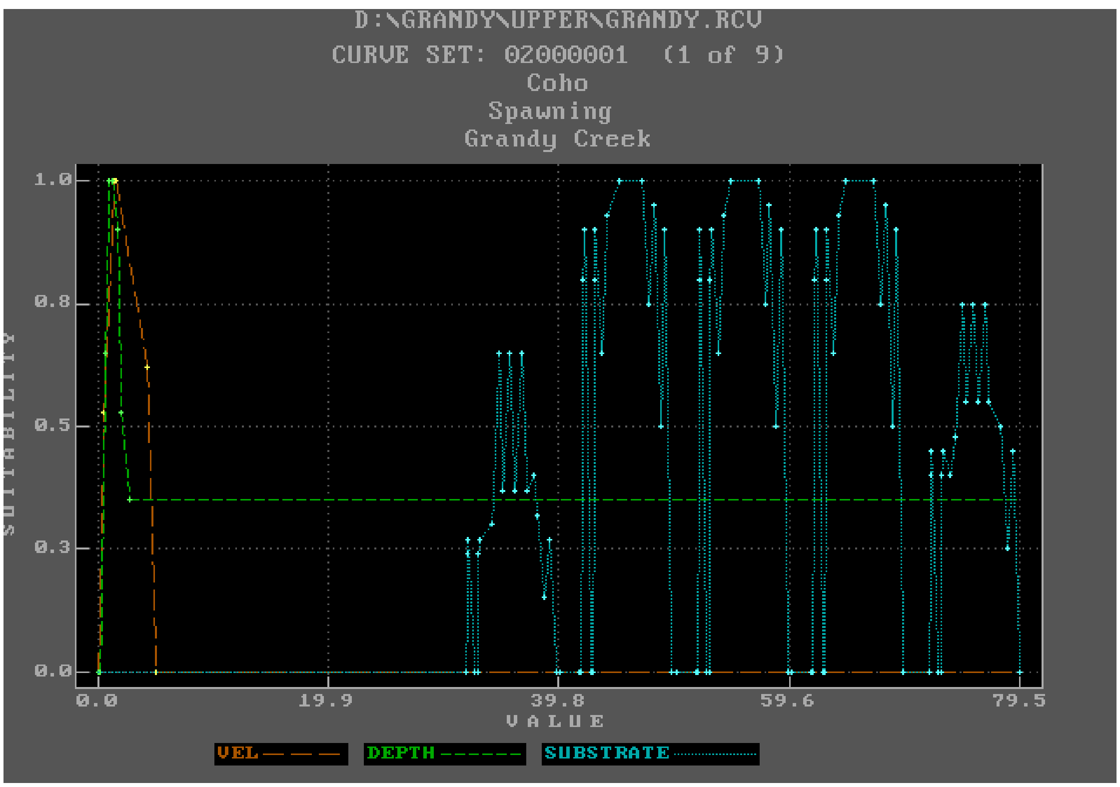

Figure 6. Coho spawning HSC.

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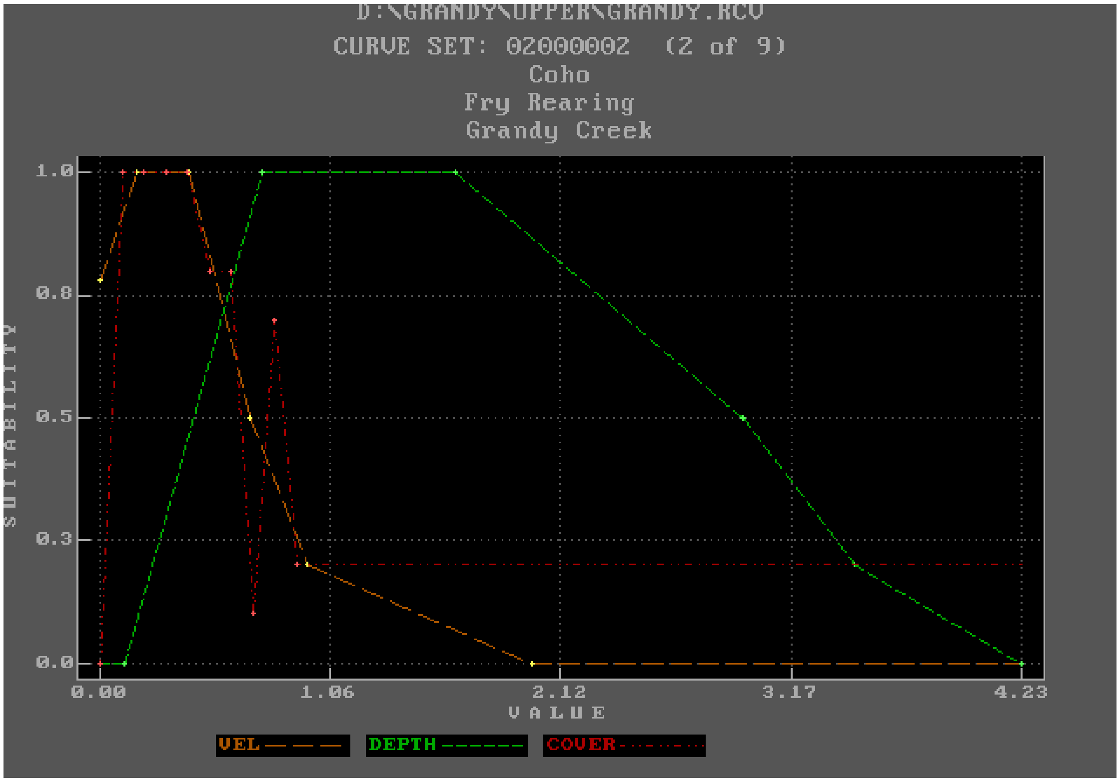

Figure 7. Coho fry rearing HSC.

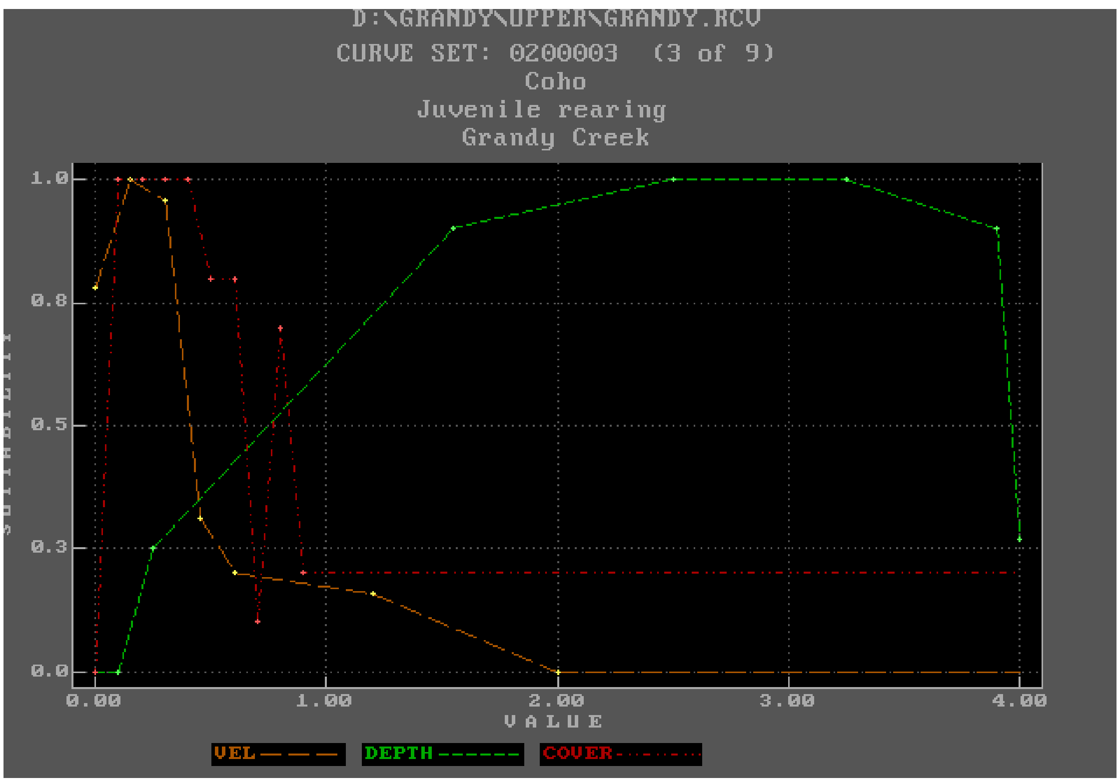

Figure 8. Coho juvenile rearing HSC.

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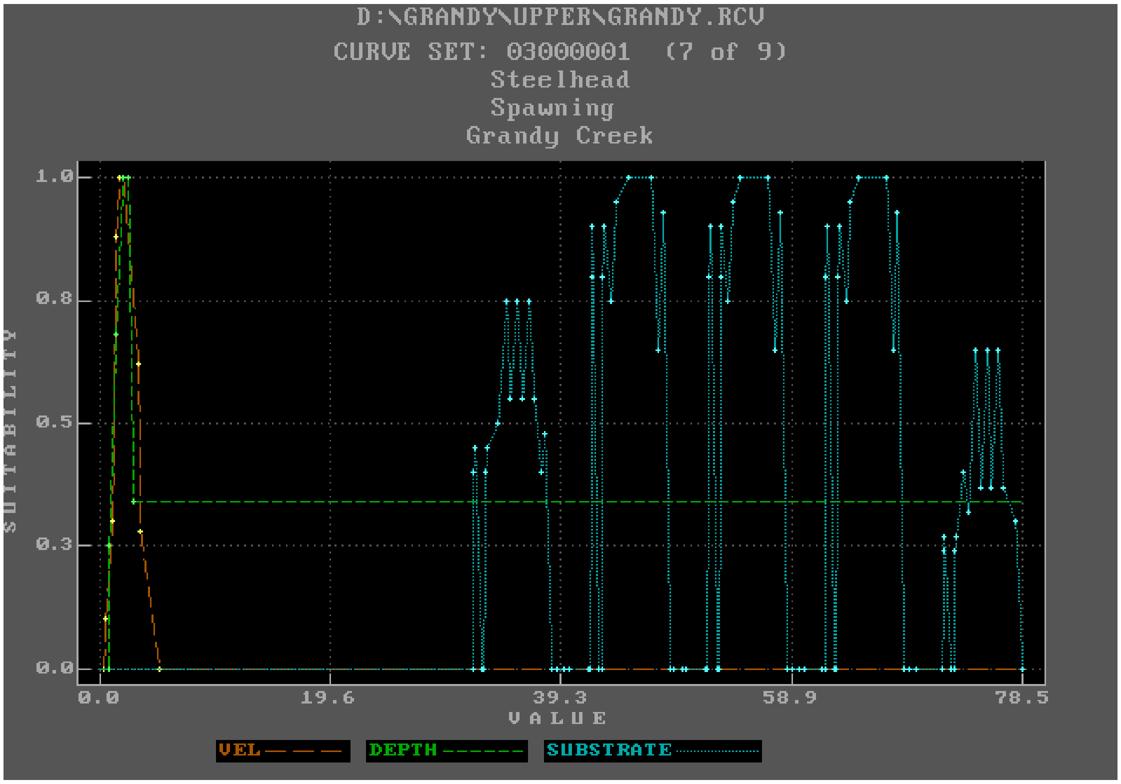

Figure 9. Steelhead spawning HSC.

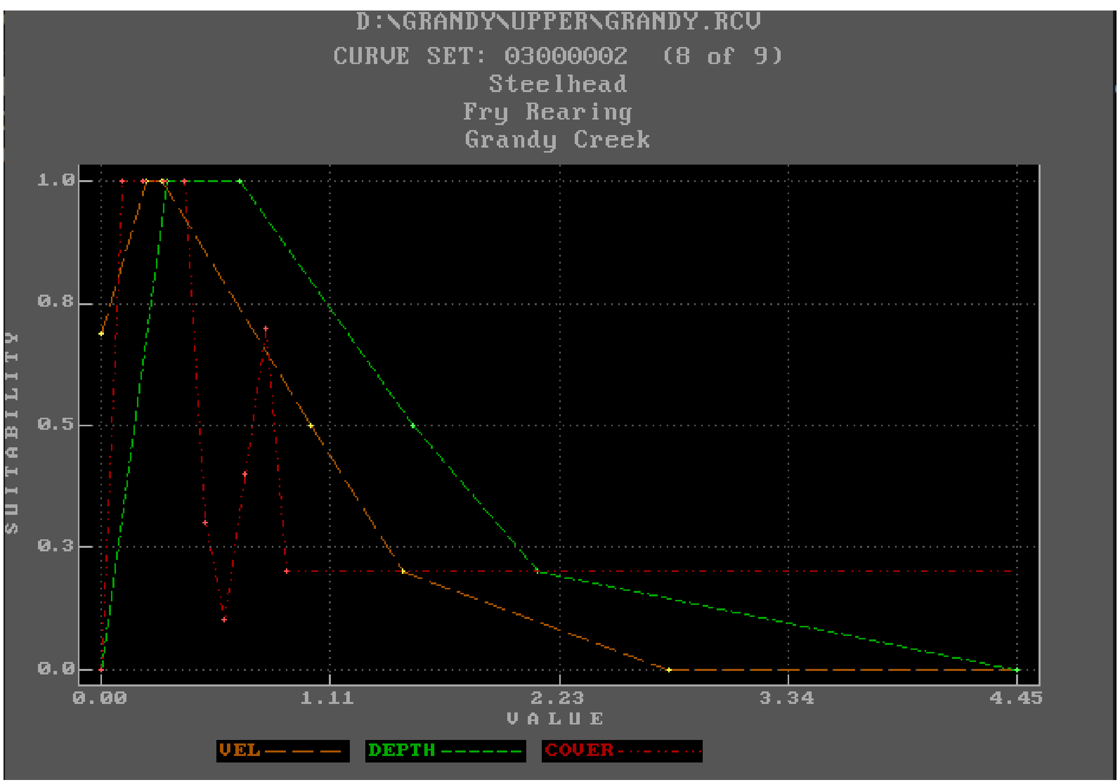

Figure 10. Steelhead fry rearing HSC.

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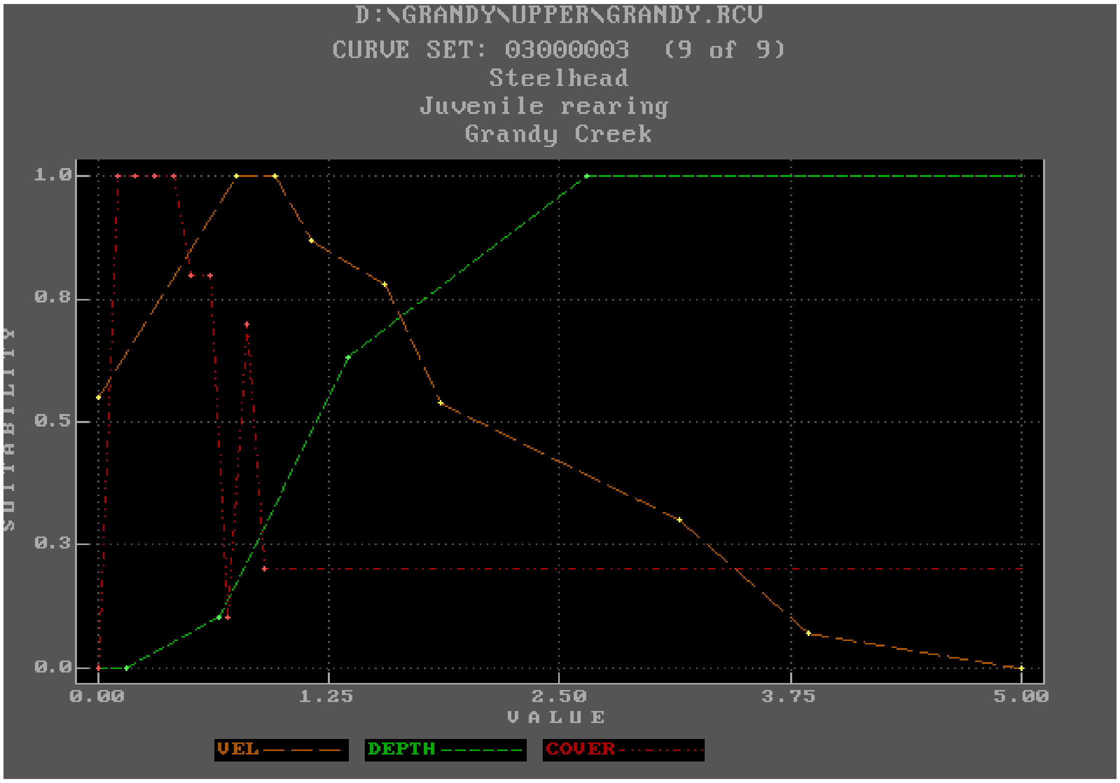

Figure 11. Steelhead juvenile rearing HSC.

Habitat Simulation

Combining the hydraulic and HSC components generates the habitat suitability (AWS/WUA) index. Unlike hydraulic modeling and calibration, there are a limited number of decisions to make prior to production runs. Transects are weighted according to the percentage of habitat types present in the reach. The range of flows to model, and specific flows within that range, are determined largely by the suitability of the hydraulic data for extrapolation and general flows of interest. Generally, the range of flows of interest are those mandatory either as minimum standards or seasonal requirements, but can also be based on natural flows. The habitat index was computed based on a multiplicative procedure:

$$Ci = Vi * Di * Si$$

Where:
Ci = Cell suitability composite index value
Vi = Velocity suitability value associated with cell
Di = Depth suitability value associated with cell
Si = Substrate or other channel suitability value associated with cell

The cell composite number is then multiplied by the cell width to produce number of square feet of area in that cell. For each transect, all the cells' areas are summed to produce a total number of square feet of usable habitat available at a specified flow. This result is then multiplied by the percentage the individual transect represents as a proportion of all transects being modeled. All transect results are then summed to produce overall habitat suitability in square feet.

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Hydrology

The hydrologic analysis evaluated historic hydrologic conditions in Grandy Creek and modeled future conditions assuming two scenarios of climate change and population growth in the watershed to best understand the impacts to spawning and rearing salmonids. Historic gauge data from adjacent Alder Creek were used to develop a synthetic hydrograph for Grandy Creek. The detailed analysis is reported in Attachment 3.

Time Series Analysis

Utilization and interpretation of habitat modeling output, namely habitat index curves, presents a challenge from both a technical and functional perspective. The habitat versus flow relationships derived from PHABSIM represent a conceptual association between flow and habitat. Though some basic inference can be made from this relationship, evaluation without incorporating flow regimes can lead to erroneous interpretations. This analysis is particularly valuable when considering a suite of species and life stages with varying habitat versus flow relationships, and instances when known life history needs may not be directly exhibited in the habitat versus flow relationship output from PHABSIM.

The tendency to look at the maximum or "peak" of a habitat index curve greatly oversimplifies the results. For example, maximum spawning habitat may occur at a flow that rarely exists in a given reach. Additionally, the amount of habitat can be the same at two flows, one lower and one higher than the maximum (Figure 12). Because the amount of habitat available at any given time of year is a function of hydrology, incorporating a time-series analysis provides a more realistic view of available habitat. Such an analysis is important when determining effects of different flow regimes that may result from changes in water usage. Times series involves matching the habitat index for a given species or life stage to flow, as illustrated in Figure 13.

The basis for habitat time series analysis is that habitat is a function of stream flow and that stream flow varies over time. Habitat time series displays the temporal habitat change for a particular species and life stage during selected seasons or critical time periods under various flow scenarios. Typically, results are represented by habitat duration curves indicating the quantity of habitat that is equaled or exceeded over the selected time period. We present additional raster plots to allow superior visualization of the seasonal and yearly variation in habitat, as well as the difference between baseline and climate/development impacted habitat.

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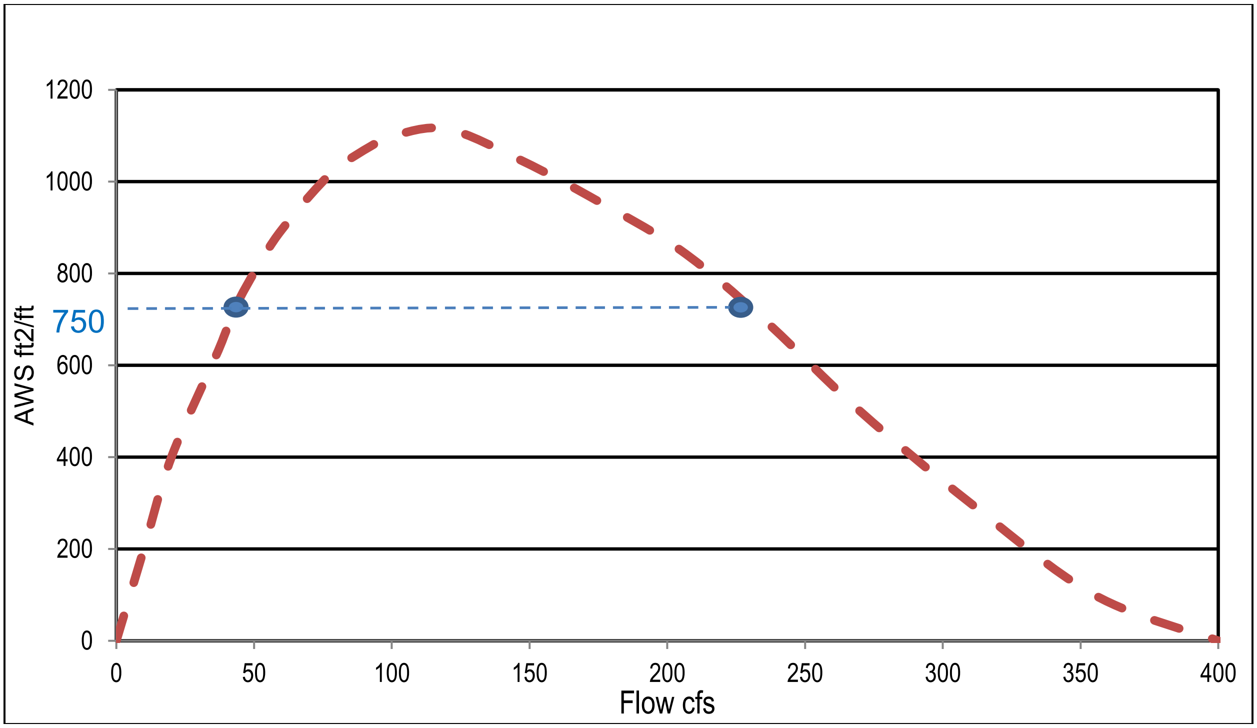

Figure 12. Generic habitat index curve illustrating equal AWS values at two different flows.

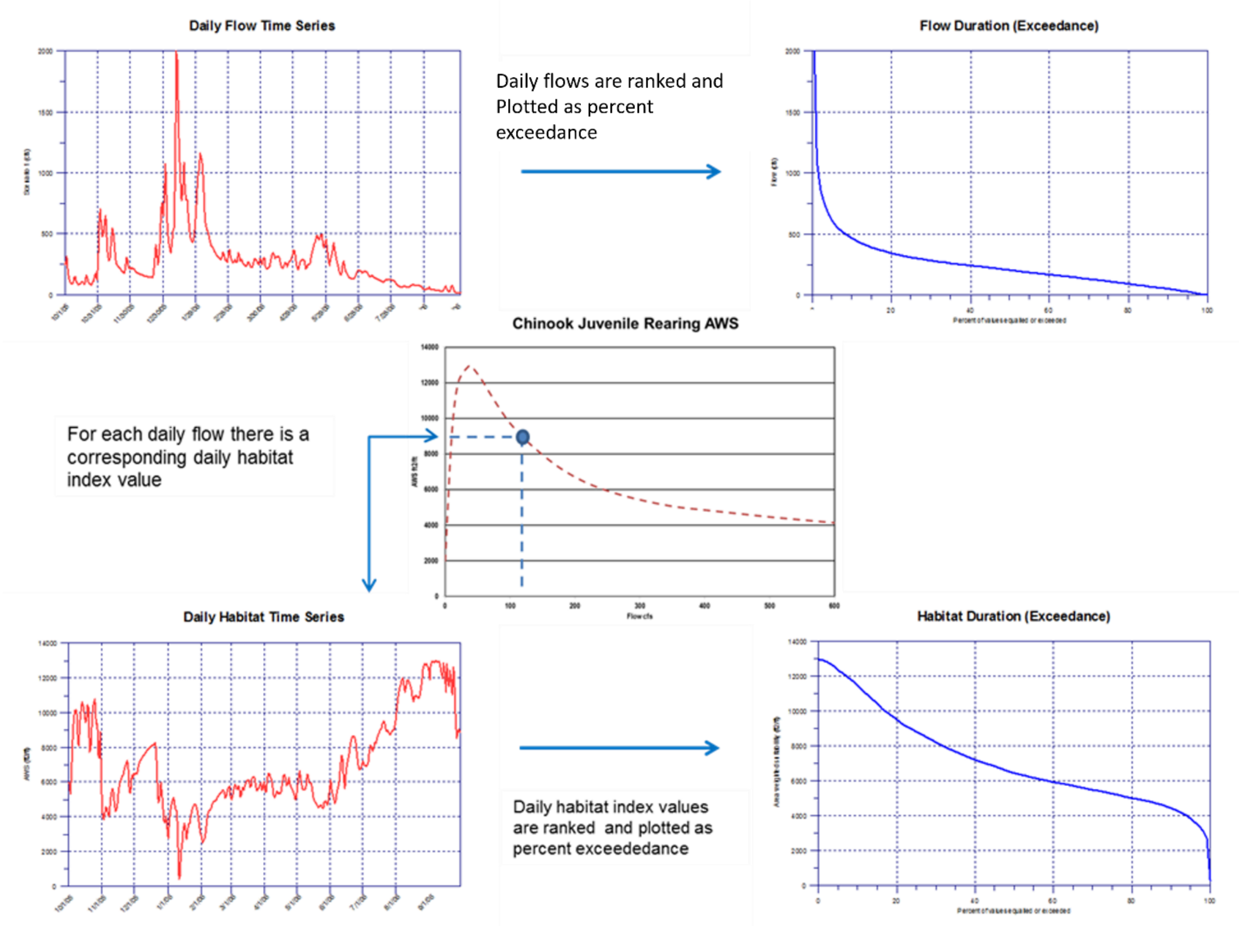

Figure 13. Time series process.

Results

Habitat Mapping

TGAEC staff surveyed a total of 30,876 feet of Grandy Creek stream channel between September 6 and September 9, 2022 (Figure 14). Reach 1 was a total of 15,966 ft and Reach 2 14,910 ft, divided by the West Fork Grandy Creek confluence (habitat unit (HU) 50). Both reaches were dominated by shallow low-gradient riffle habitats. Followed by riffles, the next most common habitat type was glide, which increased in frequency with distance upstream in Reach 2 (Table 4). Although pools made up a low percentage of habitat types in Grandy Creek, riffles with pockets were frequently encountered in Grandy Creek. There was also a significant beaver pool present at the top of Reach 2 (HU 92) which showed signs of recent activity. Spawning activity was observed in Reach 1, but not in Reach 2. The cascade immediately upstream of the reach break may represent a partial or complete barrier to upstream migration.

Overall, riffles made up approximately 80% of Grandy Creek habitat (Figure 15). Glides made up 7% and 10% of Reach 1 and 2, respectively. Pools represented 4-5% of the surveyed length in both reaches.

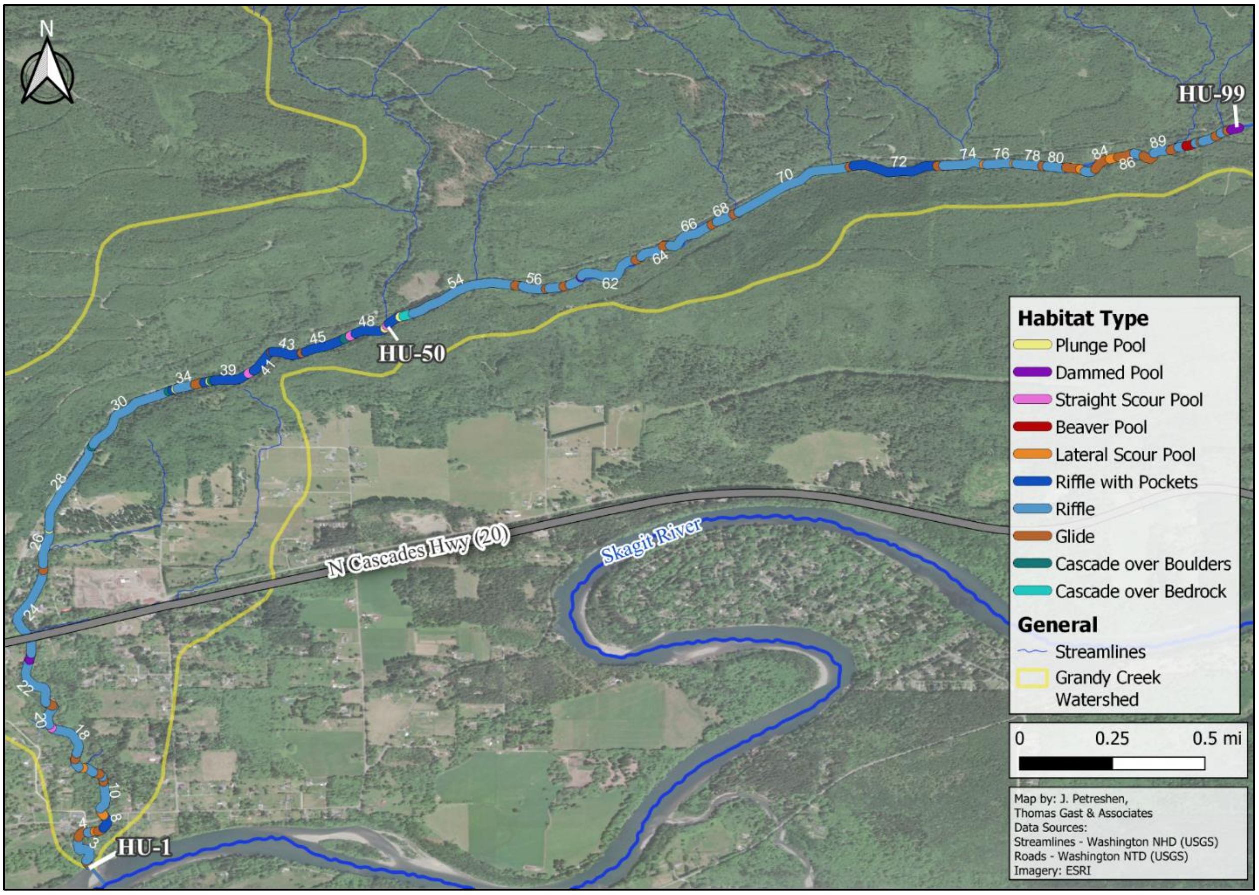

Figure 14. Habitat units (HU) in Grandy Creek, starting with HU-1 near the mouth of Grandy Creek and extending upstream to HU-99 near Grandy Lake. The top of HU-50 acts as a reach break.

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Table 4. Summary of habitat units in Reaches 1 and 2, including the average unit length, total length, and the portion of the entire section that is composed of the specific habitat unit. NA indicates that no habitat units of that type were encountered.

Habitat Unit (Level III)	Mean Length (ft)		Total Length (ft)	
	Reach 1	Reach 2	Reach 1	Reach 2
Beaver Pool	NA	320	NA	320
Cascade over Bedrock	52	120	NA	120
Cascade over Boulders	NA	NA	209	NA
Dammed Pool	102	123	102	245
Glide	108	110	1184	1864
Lateral Scour Pool	76	60	229	238
Plunge Pool	20	210	78	210
Riffle	705	521	10571	10416
Riffle with Pockets	424	749	3393	1497
Straight Scour Pool	50	110	200	NA
Total Surveyed Length (ft)	319	311	15966	14910

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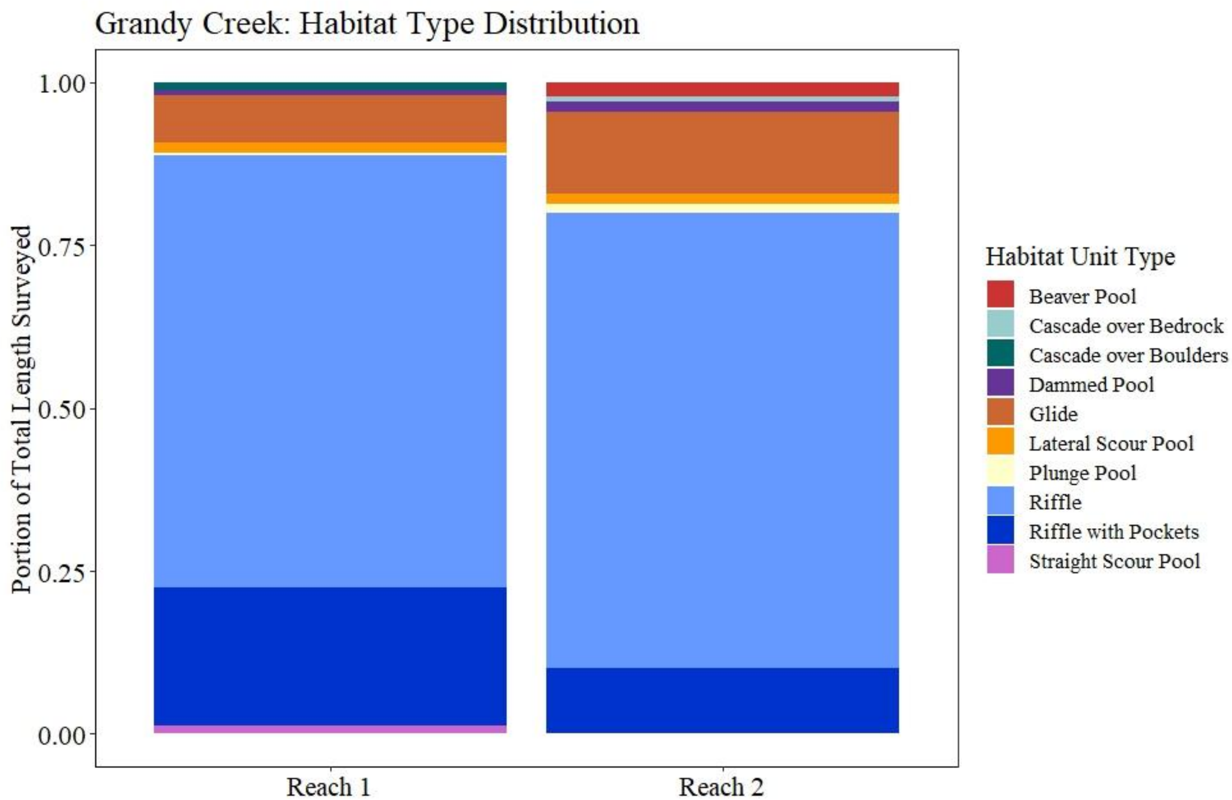

Figure 15. Distribution of habitat types between two main reaches: Reach 1 (HU-1 – HU-50) and Reach 2 (HU-51 – HU-99).

Study Site and Transect Selection

The study area was broken into two reaches at the confluence of the West Fork of Grandy Creek. Study sites were established by randomly selecting the least available habitat type, locating the habitat unit and placing a transect to represent the unit. Additional transects were then established in other habitat types in the immediate vicinity in general proportion to availability. A total of 10 cross sections were used to represent hydraulic and habitat conditions in each reach (Table 5). Figure 16 depicts the transect locations. Transect installation occurred between September 27 and 30, 2022. Transect installation and low calibration flow photos are presented in Attachment 5.

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Table 5. Number, length, and weighting of habitat types in Grandy Creek, Reach 1 and Reach 2.

Combined Habitat Types Reach 1							
Habitat Type	Number of Units	Length Feet	Length Percent	Length Normalized	Percent Normalized	Number of Transects	Transect weighting
Pool	12	609	4%	440	3%	1	0.028883
Glide	11	1184	7%	1122	7%	1	0.073651
Riffle	15	10571	66%	10279	67%	6	0.112457
Riffle with Pockets	8	3393	21%	3393	22%	2	0.111363
Rapid	0	0	0%	0	0%	0	0
Cascade	4	209	1%	0	0%	0	0
Total Reach 1	50	15966		15234			

Combined Habitat Types Reach 2							
Habitat Type	Number of Units	Length Feet	Length Percent	Length Normalized	Percent Normalized	Number of Transects	Transect weighting
Pool	8	1013	7%	448	3%	1	0.03109
Glide	18	2049	14%	2049	14%	1	0.142193
Riffle	20	10416	69%	10416	72%	7	0.103262
Riffle with Pockets	2	1497	10%	1497	10%	1	0.103886
Rapid	0	0	0%	0	0%	0	0
Cascade	1	120	1%	0	0%	0	0
Total Reach 2	49	15095		14410			

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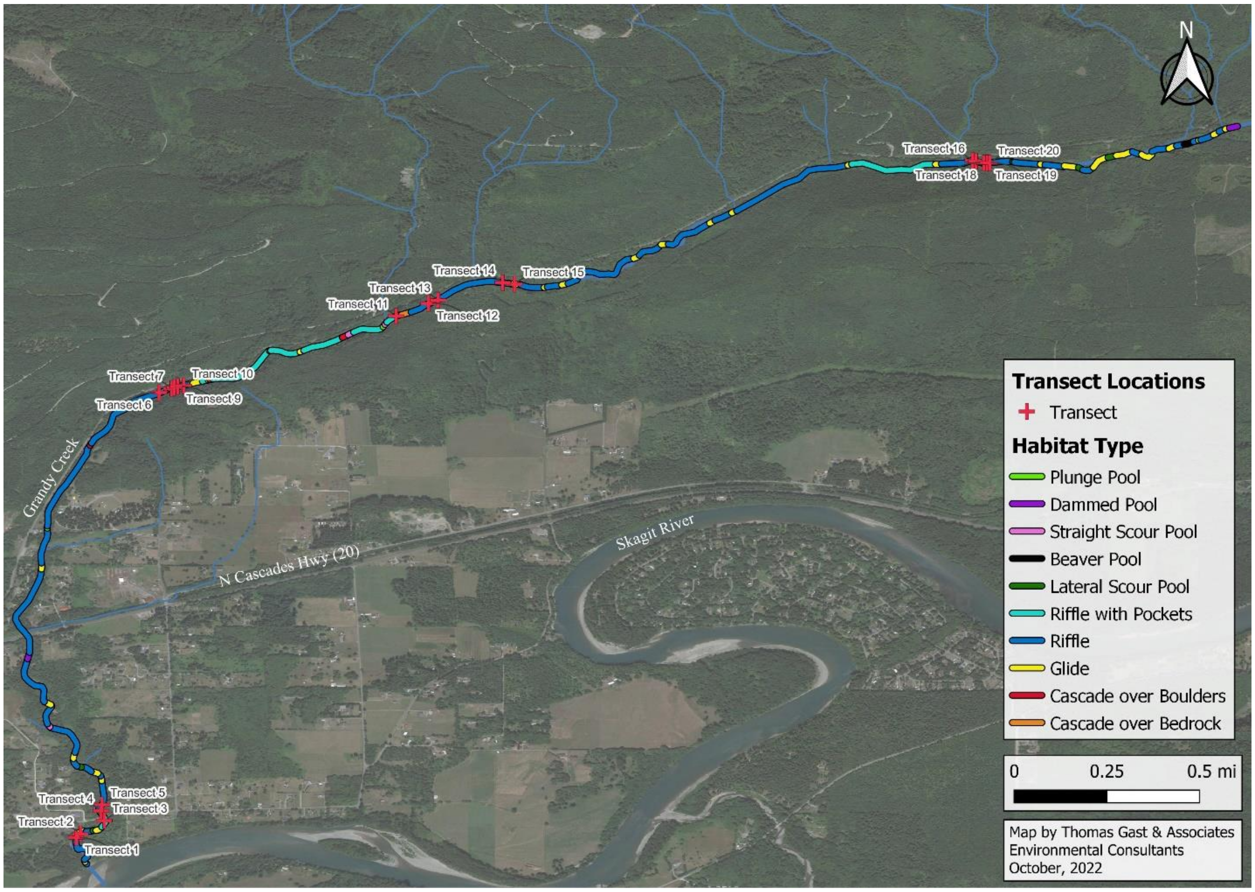

Figure 16. Transect locations. Transect 1-10 are in the Lower Reach 1, and transects 11-20 are in the Upper Reach 2.

Calibration Flows

Initially this instream flow study was required to be completed by June, 2023. This requirement necessitated the risky method of targeting ascending calibration flows. There is no flow control on Grandy Creek, nor is there a stream gauge, and calibration flows had to target natural flows. The risky part of targeting the ascending limb of the hydrology is that the stream flow can increase quickly from low flow to high flow and not return to low flow until the following year. High flows can also alter the channel shape, making lower calibration flows incompatible. Unfortunately, that is exactly what happened. It rained so hard the night after collecting the middle calibration flow data that the stream flow increased to the highest flow of the year, well above our high flow target and safe working conditions. That flow also changed the hydraulic control and channel shape on several of the transects. An extension to the initial completion date enabled re-collection of the low and middle calibration flows on the much less risky descending limb of the hydrology in the summer and fall of 2023. Riffle 1 is the most extreme example. Figures 16 and 17 depict the changes to the Riffle Transect 1 from the high flow event.

Another challenge occurred during the final low calibration flow data collection in the fall of 2023. Pink salmon (*Oncorhynchus gorbuscha*) spawned throughout the Lower Reach. The redds and carcasses can be seen in Figures 18. These minor channel changes degraded the quality of

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the rating curves in the Lower Reach. Table 6 lists the dates, discharge, and average water surface elevations for the calibration flows. Appendix C depicts the calibration flow profiles, water surface elevations, and velocities.

Figure 17. Initial low calibration flow data collection at Riffle 1 near the Skagit River confluence in the fall of 2022.

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Figure 18. Second low calibration flow data collection in the fall of 2023. The significant channel changes from the high flow event required that the calibration flow data be collected a second time. Note the channel changes from Figure 17 and the pink salmon redds and carcasses upstream of the transect tape.

Figure 19. Pink salmon carcass photographed during the low calibration flow data collection.

Table 6. Lower Reach calibration flows and average water surface elevations (WSEL).

	Cross-section	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Habitat		Riffle	Glide	Riffle w/pockets	Riffle	Riffle	Riffle	Riffle w/pockets	Pool	Riffle	Riffle
Discharge	High	46.11	48.88	49.48	49.70	51.39	50.56	52.77	57.76	55.40	65.73
	Mid	34.91	30.82	32.99	30.16	27.00	32.70	29.25	33.64	34.91	34.75
	Low	8.23	7.57	7.73	8.03	6.91	9.01	7.69	9.53	9.79	9.83
	Mid2/3	30.38	34.94	35.96	33.34	33.20	40.60	43.16	42.49	34.48	41.36
	Low	8.28	7.63	8.09	7.38	7.13	7.63	6.69	8.94	8.18	8.52
WSEL	High	95.94	93.57	99.08	95.38	96.18	97.65	97.59	98.02	100.84	101.87
	Mid	96.42	94.35	98.83	95.28	96.01	97.41	97.25	97.65	100.61	101.69
	Low	96.19	93.94	98.34	94.95	95.74	97.02	96.89	97.03	100.19	101.27
	Mid2/3	95.87	93.44	98.83	95.28	96.01	97.54	97.46	97.77	100.68	101.77
	Low2	95.63	93.09	98.39	94.84	95.77	97.03	96.88	97.01	100.20	101.28
Date	High	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023
	Mid	11/2/2022	11/2/2022	11/2/2022	11/2/2022	11/2/2022	11/2/2022	11/2/2022	11/2/2022	11/2/2022	11/2/2022
	Low	9/27/2022	9/27/2022	9/27/2022	9/27/2022	9/27/2022	9/28/2022	9/28/2022	9/28/2022	9/28/2022	9/28/2022
	Mid2	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023
	Low2	10/11/23	10/11/23	10/11/2023	10/11/23	10/11/203	10/12/23	10/12/23	10/12/23	10/12/23	10/12/23

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Table 7. Upper Reach calibration flows and water surface elevations (WSEL).

	Cross-section	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
Habitat		Riffle w/pockets	Riffle	Riffle	Riffle	Glide	Riffle	Riffle	Pool	Riffle	Riffle
Discharge	High	40.76	51.34	39.53	35.46	37.47	22.28	22.22	25.84	21.80	25.46
	Mid	23.49	22.09	18.47	14.52	18.58	13.53	16.11	12.59	11.34	13.95
	Low	7.78	6.38	5.93	4.62	5.22	3.88	4.34	4.69	4.83	3.53
	Mid2/3	12.18	11.71	9.94	8.44	9.25	7.04	8.44	7.89	7.03	7.93
	Low	6.80	5.89	4.59	5.34	4.63	3.79	4.09	3.51	3.71	4.88
WSEL	High	98.29	96.93	101.17	97.75	95.97	97.19	98.51	96.74	97.59	98.68
	Mid	97.84	96.55	100.90	96.85	96.16	97.06	98.40	96.81	97.35	98.48
	Low	97.35	96.20	100.55	96.58	95.89	96.87	98.14	96.40	97.10	98.25
	Mid2/3	97.60	96.42	100.64	97.23	95.55	96.87	98.23	96.23	97.32	98.35
	Low2	97.44	96.19	100.50	97.17	95.44	96.78	97.99	96.09	97.23	98.19
Date	High	3/15/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023
	Mid	11/3/2022	11/3/2022	11/3/2022	11/3/2022	11/3/2022	11/3/2022	11/3/2022	11/3/2022	11/3/2022	11/3/2022
	Low	9/28/2022	9/30/2022	9/30/2022	9/29/2022	9/29/2022	9/29/2022	9/29/2022	9/29/2022	9/29/2022	9/29/2022
	Mid2	7/7/2023	7/7/2023	7/7/2023	7/7/2023	7/7/2023	7/6/2023	7/6/2023	7/6/2023	7/6/2023	7/6/2023
	Low2	10/11/23	10/12/23	10/12/23	10/12/23	10/12/23	10/11/23	10/13/23	10/13/23	10/13/23	10/12/23

Hydraulic Simulation

Hydraulic simulation was completed in the RHABSIM software. The Lower and Upper Reaches were modeled separately. The SEFA software has since been updated to be able to use the multiple velocity regression model used in Washington State.

Stage-Discharge

The dual stage/discharge method was used to calculate the rating curves for all transects. Where appropriate, riffle rating curves used the channel conveyance method. Table 8 lists the transect weights and rating curve methods.

Overall, stage-discharge metrics fell well within the bounds of acceptability. All but two transects had a mean error of less than 5 percent for log/log rating curve (Table 9).

Velocity

Some adjustments to roughness and Manning's N were made in selected cells to account for unrealistic simulated velocities at high flows. In addition, adjustments were made to edge cells if predicted velocities at higher flows were excessively high (i.e. higher than adjacent cells in the main channel) or remained excessively low. Calibration summaries are presented in Appendix D and simulated velocity and WSEL plots are presented in Appendix E.

Table 8. Transect weighting and stage/discharge rating curve calculation method.

XS Name	Percent	WSL Method

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XS1 Riffle	11.25	Log/Log Regression
XS2 Glide	7.37	Log/Log Regression
XS3 RifPoc	11.14	Log/Log Regression
XS4 Riffle	11.25	Log/Log Regression
XS5 Riffle	11.25	Channel Conveyance
XS6 Riffle	11.25	Channel Conveyance
XS7 RifPoc	11.14	Log/Log Regression
XS8 Pool	2.89	Log/Log Regression
XS9 Riffle	11.25	Log/Log Regression
XS10 Riffle	11.25	Channel Conveyance
XS 11 RifPoc	10.39	Log/Log Regression
XS 12 Riffl	10.33	Channel Conveyance
XS 13 Riffl	10.33	Log/Log Regression
XS 14 Riffl	10.33	Log/Log Regression
XS 15 Glide	14.22	Log/Log Regression
XS 16 Riffl	10.33	Log/Log Regression
XS 17 Riffl	10.33	Channel Conveyance
XS 18 Pool	3.11	Log/Log Regression
XS 19 Riffl	10.33	Log/Log Regression
XS 20 Riffl	10.33	Channel Conveyance

Table 9. Measured flow, calibration flow (velocity acquisition flow), stage-discharge rating curve mean error and method and VAF for transects in five reaches of the Hood River.

Name	N	A	B	Mean % error	Variance	Std. Dev.
XS1 Riffle	3	54.4548	4.1897	4.4556	8.4049	2.89911
XS2 Glide	3	3.051	4.817	6.9032	17.8025	4.2193
XS3 RifPoc	3	17.613	2.7405	3.7266	4.0432	2.01078
XS4 Riffle	3	23.0526	2.8962	0.5434	0.1372	0.37047
XS5 Riffle	3	111.9591	1.8868	2.8032	1.9708	1.40385
XS6 Riffle	3	8.7402	3.6012	1.6251	1.2329	1.11037
XS7 RifPoc	3	13.8904	3.2111	1.1614	0.6478	0.80484
XS8 Pool	3	8.1644	2.7658	4.4042	8.208	2.86496
XS9 Riffle	3	9.3626	3.6911	2.9344	3.3304	1.82493
XS10 Riffle	3	4.0435	4.8729	4.4067	9.3507	3.0579
XS 11 RifPoc	3	35.0384	1.2167	2.6159	1.6589	1.288
XS 12 Riffl	3	11.5798	3.126	3.3592	2.7032	1.64414
XS 13 Riffl	3	45.0904	1.2418	4.5491	5.3384	2.31049
XS 14 Riffl	3	48.8793	0.9293	4.0847	5.9067	2.43037
XS 15 Glide	3	58.3597	1.4649	3.3707	3.0768	1.75408
XS 16 Riffl	3	47.5594	1.4531	1.9547	0.9535	0.97648
XS 17 Riffl	3	15.556	3.0854	6.3589	9.3828	3.06313
XS 18 Pool	3	14.4931	2.495	3.1382	2.5119	1.58489
XS 19 Riffl	3	57.2679	1.4342	0.234	0.0125	0.11201
XS 20 Riffl	3	11.6734	3.3511	2.242	1.132	1.06395

Habitat/Flow Relationship

AWS values in tabular format are presented in Appendix F.

Lower Reach

Chinook spawning habitat value rises steeply from low flows up to 60 cfs, peaks at approximately 80 cfs, and declines at higher flows. Chinook juvenile and fry habitat is very low at low flows, rising only slightly throughout the range of flows (Figure 20).

Coho spawning habitat value increases steeply from low flows to 25 cfs, peaks at approximately 70 cfs, and declines moderately at higher flows. Coho juvenile and fry habitat is very low at low flows, rising only slightly throughout the range of flows (Figure 21).

Steelhead spawning habitat value increases steeply from low flows to 50 cfs, peaks at approximately 70 cfs, and declines moderately at higher flows. Steelhead fry habitat is very low at low flows, rising moderately to 70 cfs, and remains flat throughout the remainder of the

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range of flows. Steelhead juvenile habitat is very low at low flows, rising only slightly throughout the range of flows (Figure 22).

Upper Reach

Chinook spawning habitat value rises steeply from low flows up to 50 cfs, peaks at approximately 70 cfs, and is nearly flat at higher flows. Chinook juvenile and fry habitat is very low at low flows, rising only slightly throughout the range of flows (Figure 23).

Coho spawning habitat value increases steeply from low flows to 35 cfs, peaks at approximately 50 cfs, and is mostly flat at higher flows. Coho juvenile and fry habitat is very low at low flows, rising only slightly throughout the range of flows (Figure 24).

Steelhead spawning habitat value increases steeply from low flows to 45 cfs, and continues to rise moderately at higher flows. Steelhead fry habitat is low at low flows, rising throughout the remainder of the range of flows. Steelhead juvenile habitat is very low at low flows, rising only slightly throughout the range of flows (Figure 25).

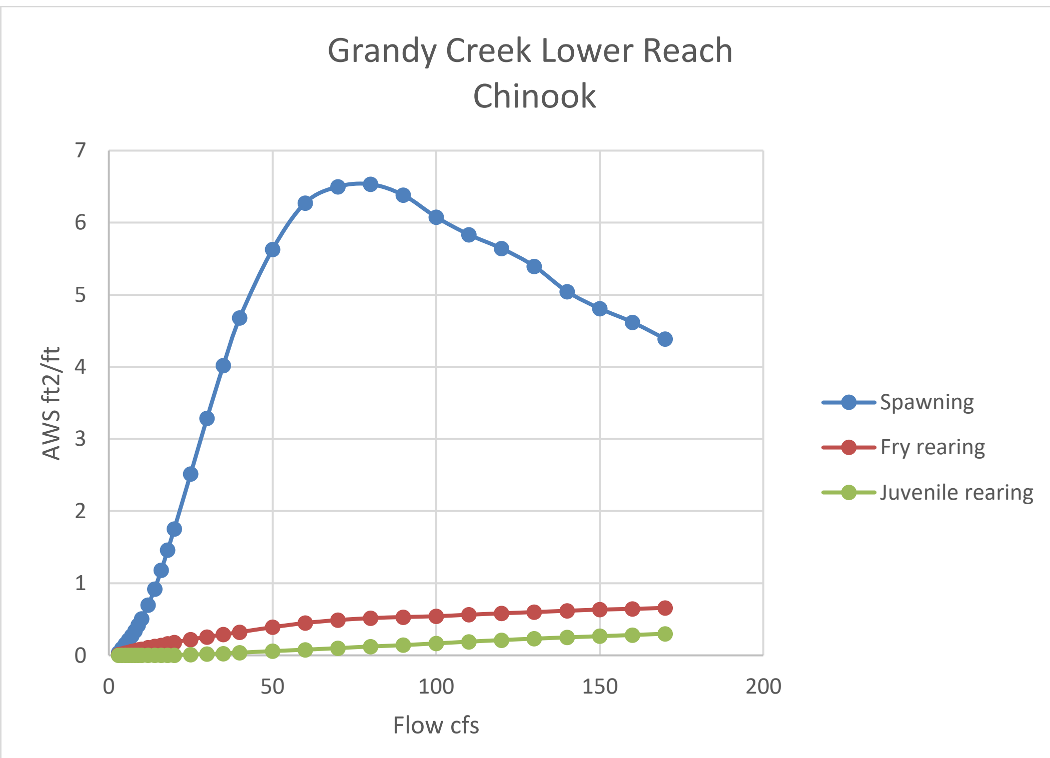

Figure 20. Lower Reach Chinook AWS curves.

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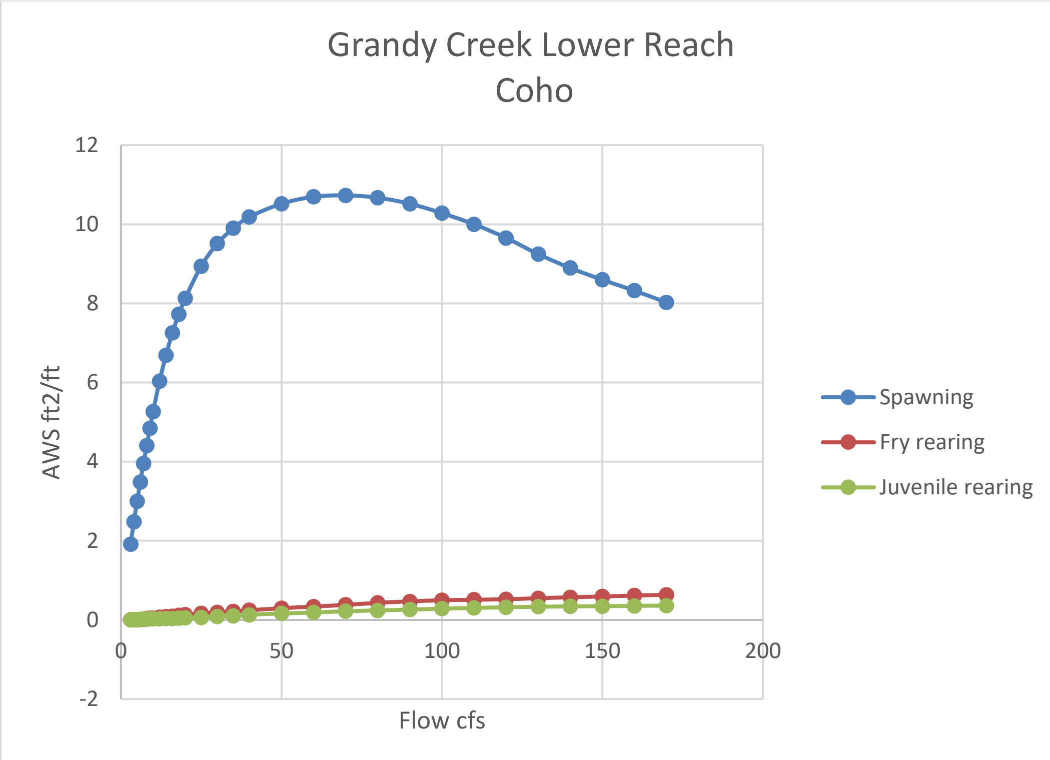

Figure 21. Lower Reach Coho AWS curves.

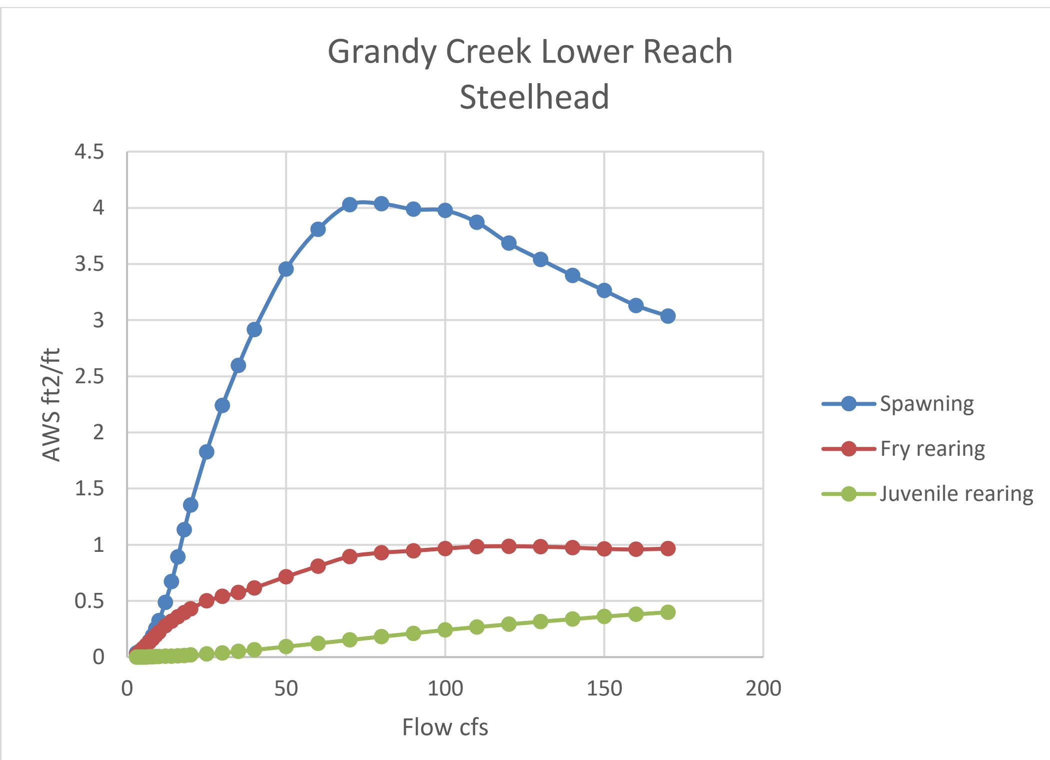

Figure 22. Lower Reach Steelhead AWS curves.

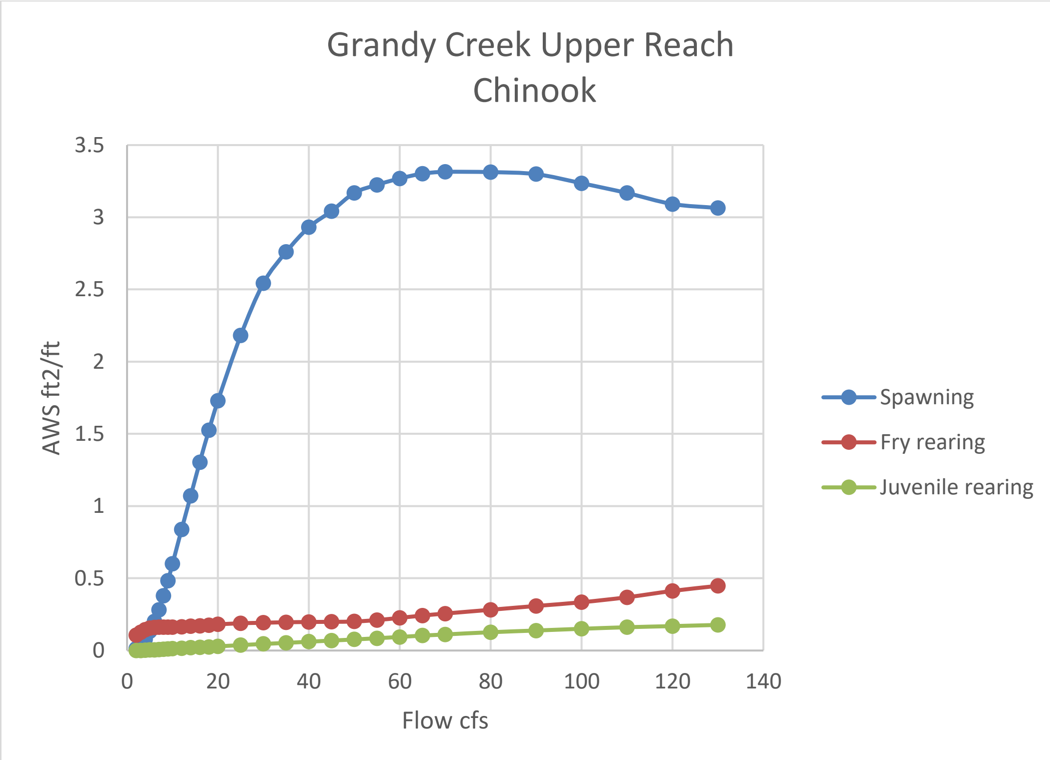

Figure 23. Upper Reach Chinook AWS curves.

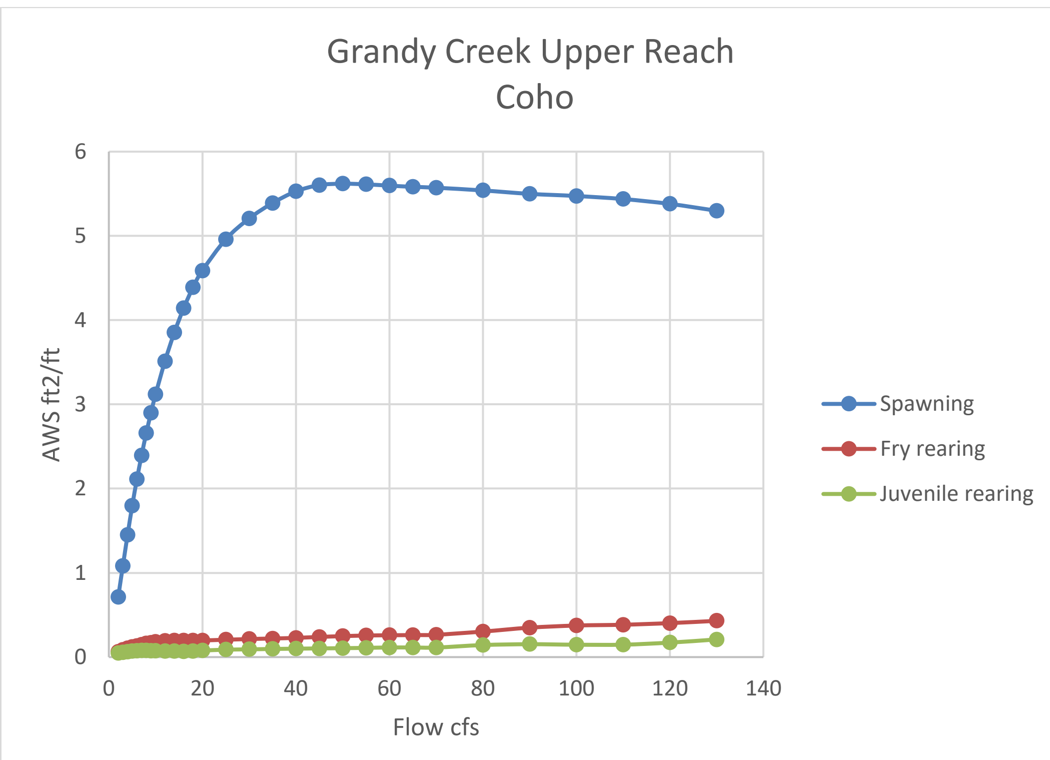

Figure 24. Upper Reach Coho AWS curves.

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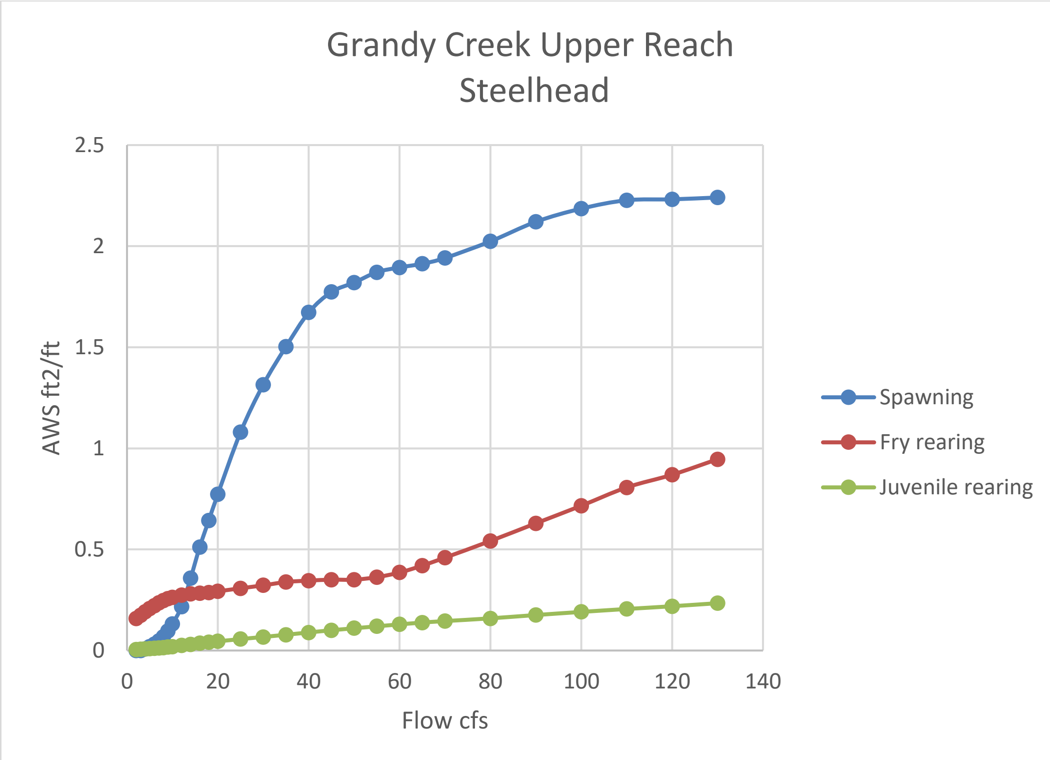

Figure 25. Upper Reach Steelhead AWS curves.

Hydrology

The hydrologic analysis evaluates historic hydrologic conditions in Grandy Creek and models future conditions assuming two scenarios of climate change and population growth in the watershed to best understand the impacts to spawning and rearing salmonids. The detailed analysis is reported in Attachment 3.

The hydrologic analysis would be best conducted with a daily streamflow record at the site. However, no daily stream flow record exists for Grandy Creek. A review of existing data shows the USGS station for Grandy Creek (12195000) lists 11 individual field measurements between August 16, 1951 and September 18, 2001. These measurements were made during summer (late-May to mid-September) with widely-spaced timing, with the largest gap in measurements being 30 years (1971 to 2001). As such, the nearby USGS streamgage at Alder Creek near Hamilton, WA (station 12196000) was used to generate the daily discharge dataset for Grandy Creek.

To estimate the daily flow for Grandy Creek, data from the Alder Creek streamgage was modified by an adjustment factor based on the drainage areas of Alder Creek and Grandy Creek watersheds. The location of the USGS gage station and the mouth of Grandy Creek were used to determine the drainage area for the two basins.

Adjustment factor = Grandy Creek Drainage Area / Alder Creek Drainage Area

Adjustment factor = 18.9 mi^2 / 10.7 mi^2 = 1.77

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Two advantages for using the Alder Creek location are 1) the USGS quality controlled and approved daily discharge records for Alder Creek and 2) the close proximity of the two watersheds (Figure 26). Because the two watersheds adjoin, this analysis assumes that both watersheds experience the same storms during the period of record. A traditional hydrograph for the generated Grandy Creek discharge is shown in Figure 27.

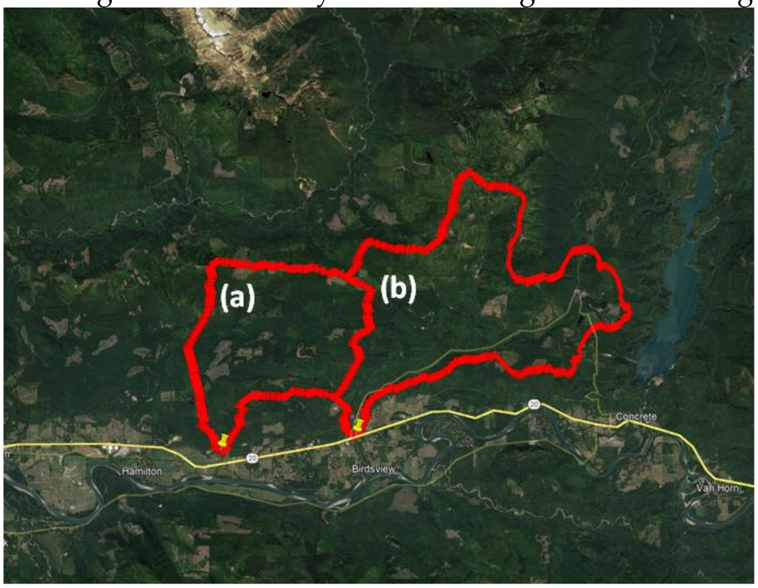

Figure 26. Relative locations of Alder Creek (a) and Grandy Creek (b) watersheds.

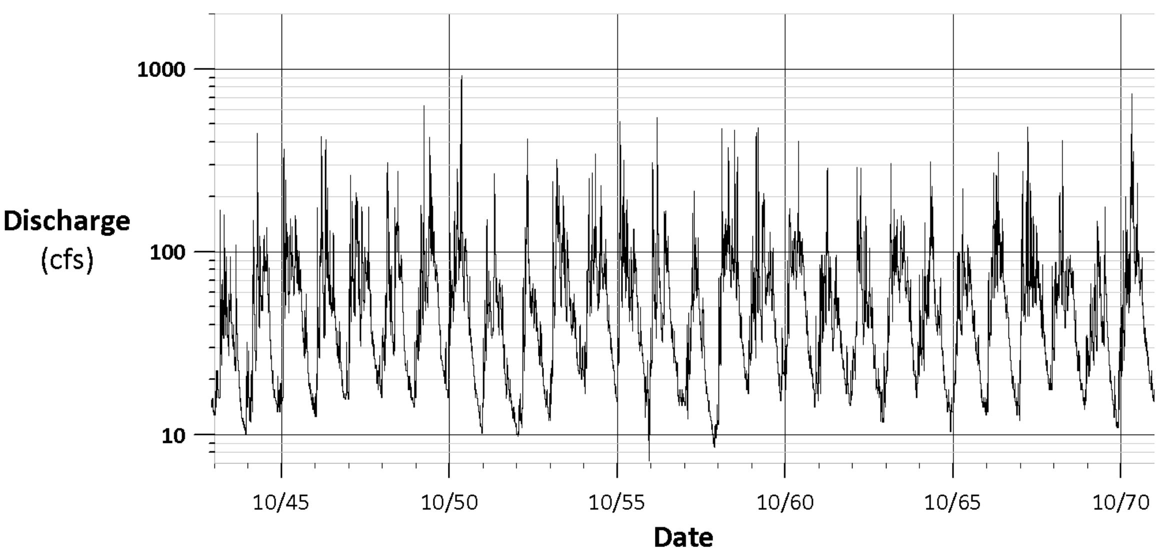

Figure 27. Daily mean flow hydrograph, Grandy Creek (water years 1944 to 1971).

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An alternate discharge plot, a raster hydrograph, presents more details than a traditional hydrograph (Figure 28). This uses a "heat map" method where the x-axis is "Day of Water Year", the y-axis is "Water Year", and discharge is represented by color. Three extreme low flows are shown in September 1956, in 1958 with an extended drought with associated lower flows, and in 1970 where the annual daily maximum occurred in April. Such details are difficult to identify in a traditional hydrograph.

Other observations in Figure 28 include individual storms (blue), recessions (smeared green/yellow), and drought periods (deep red/white). The absence of patterns is also important to identify. Snowmelt runoff would be seen as increased discharge during the May to July timeframe; the lack of such a pattern indicates that there is little snowpack runoff in Grandy Creek.

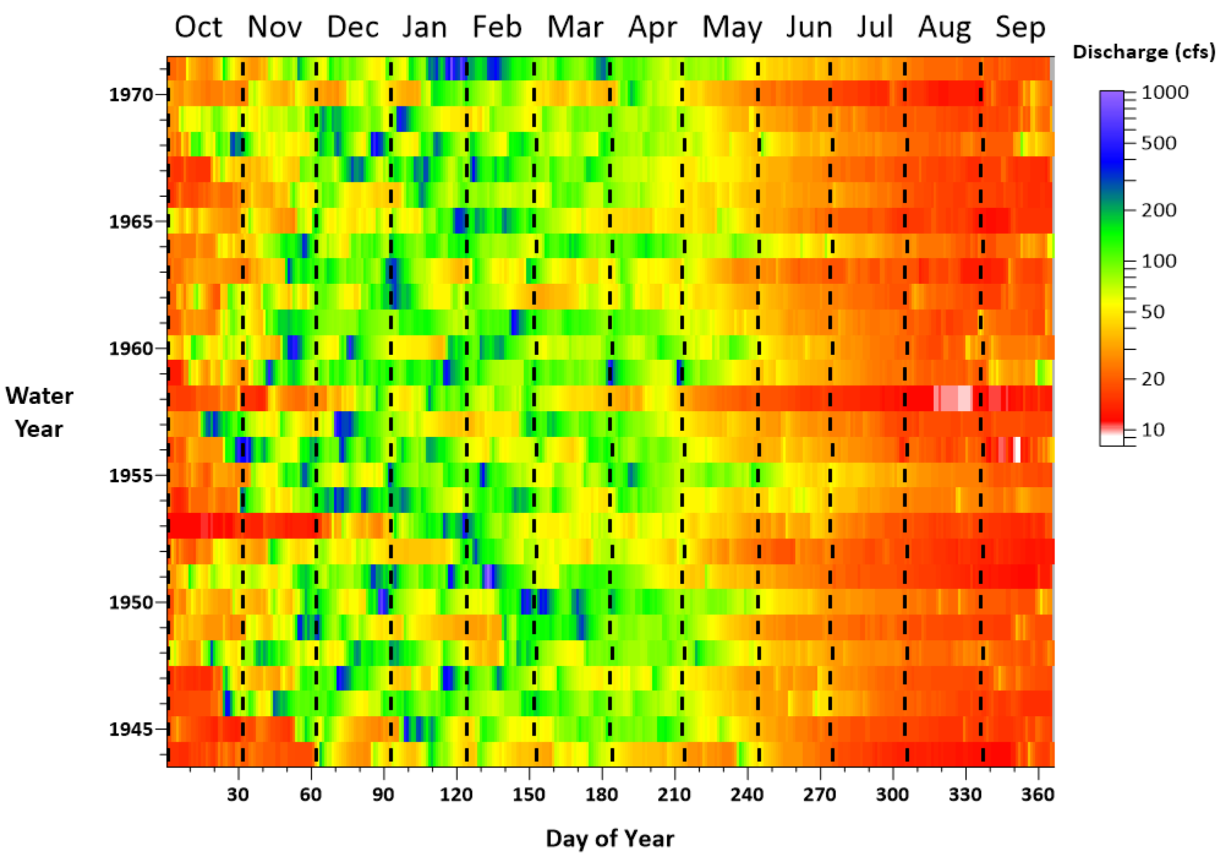

Figure 28. Daily mean flow raster hydrograph, Grandy Creek (water years 1944 to 1971).

Climate Change

The change in summer streamflow (June – Sept.) is predicted under two climate scenarios relative to the 1980 – 2009 time period (Chegwidden et al., 2017). Summer streamflow in Grandy Creek is predicted to decrease by 15% under the lower emissions scenario. Under the higher scenario, the summer streamflow is expected to decrease 20%. These predicted changes in streamflow were applied to the Grandy Creek summer streamflow record and are presented in Figure 29.

Representative concentration pathways (RCP) describe possible future global greenhouse gas and aerosol emissions scenarios. One scenario used for this report, RCP 4.5, is described by the Intergovernmental Panel on Climate Change (IPCC) as a moderate scenario in which emissions peak around year 2040 and then decline. The other scenario, RCP 8.5, is the highest baseline emissions scenario where emissions continue to rise until year 2100. Climate change projected under RCP 8.5 can be assumed to be more severe than RCP 4.5 (Cal-adapt, 2023).

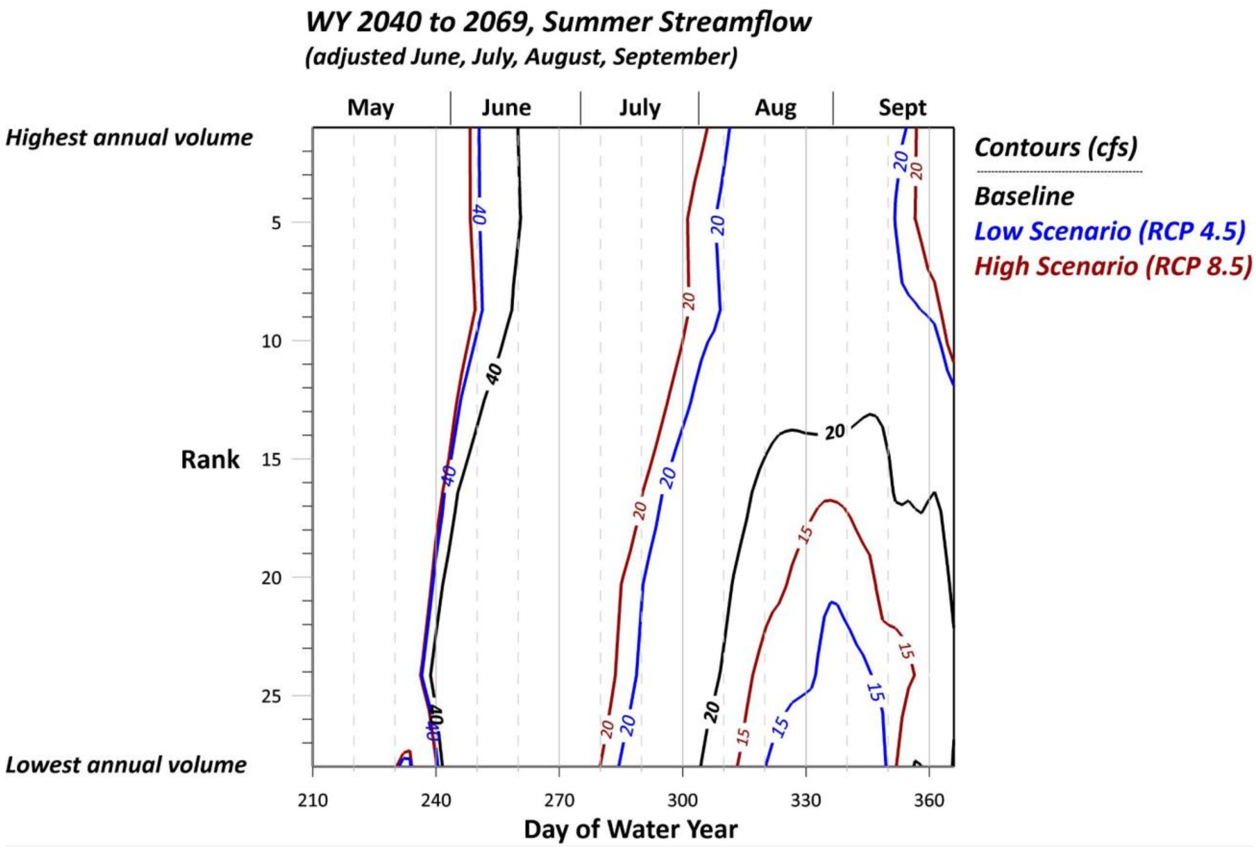

Figure 29. Summer Streamflow (adjusted Grandy Creek June, July, August, September discharges). Climate change scenarios for the time period between 2040 and 2069 (2050's). Baseline, Low Scenario (RCP 4.5), High Scenario (RCP 8.5).

Water Demands and Future Development

In addition to the two climate change scenarios developed for Grandy Creek, increased water demand from future development was also applied to the simulated flow record, producing four separate flow scenarios:

1. Flow (cfs), low climate scenario, summer -15% (cfs)
2. Flow (cfs), high climate scenario, summer - 20% (cfs)
3. Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs)
4. Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs)

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Grandy Creek watershed contains 19 state-issued water rights that provide use for domestic, municipal, irrigation, and recreational purposes. Water right holders diverting and/or storing surface water from Grandy Creek include Lake Tyee, Creekside Camping, and Grandy Creek Resort public water systems. Table 10 summarizes the annual allotted water for each purpose of use in Grandy Creek. Irrigation primarily consists of watering grass/hay, gardens, and lawns. In addition to existing surface water rights, there are 98 permit-exempt wells in Grandy Creek watershed whose water diversions are not monitored or accounted for in this study.

Table 10. Water rights in Grandy Creek watershed and total possible volumes allotted for consumption in acre-feet per year (afy). Table modified from 2019 WRIA 4 Water Use Study.

Purpose of Use	Allotted Volume (afy)	Estimated Use (afy)	Percent Used
Municipal	141.0	62.4	44%
Domestic Multiple	29.0	16.2	56%
Domestic Single	2.0	0.4	20%
Irrigation	82.0	1.0	1%
Recreation - Beautification	343.2	151.0	44%

Municipal water use is expected to increase by 7% by 2040 in the Water Resource Inventory Area (WRIA) 4, which Grandy Creek falls within (Yoder et al., 2021). Total irrigation water demand in this region is minimal relative to the Lower Skagit (WRIA 3) and there are no known reports indicating the expansion of irrigated lands in Grandy Creek watershed.
Although the municipal water use is predicted to increase, streamflow in Grandy Creek is protected under the Instream Resources Protection Program rule (WAC 173-503) which may impact the ability to develop property in the Grandy Creek basin. Under this rule, new exempt wells for single-family residences are limited and must be approved by Skagit County. Any applicant for a residential building permit must demonstrate legal and adequate water availability for their parcel in order to attain a permit from the County. This Instream Flow rule does not impact existing water rights, such as those listed in Table 10 above.

In addition, Skagit County designated Grandy Creek as a "Low Flow Stream," indicating that it is a limited surface water source under Skagit County Code Critical Areas Ordinance Title 14.24.340 Subsection (3)(c) (Skagit County iMap). Developers may bypass these water right limitations by connecting to a public water supply, mitigating impacts to instream flows, or being eligible for the Skagit River Basin Mitigation Program, which offers a limited quantity of water to landowners within a specified zone. However, majority of land parcels surrounding Grandy Creek fall outside this Mitigation Program zone (Skagit River Basin Mitigation Map).

Streamflow and Habitat Time Series

Due to the barrier to migration at the bottom of the Upper Reach, only the Lower Reach was used for habitat time-series analysis.

An example flow time series for the historic Grandy Creek flow scenario and corresponding Chinook spawning habitat time series are presented in Figure 30. When dealing with an extensive period of almost 30 years, details can be lost, but certain events stand out such as high peak flows in water years 1940, 1951, and 1971. The seasonality of the high winter and low summer flows can also be seen. These events are depicted in more detail in Figure 31, with the AWS values for Chinook spawning and stream flow on the same plot. As can be seen, lower habitat values occur during lower flow periods (e.g. summer). But low habitat values can also occur at very high flows, during the winter. The traditional method of evaluating a habitat time-series is with a flow duration plot. But, as described in the method section (Figure 12), both the high and low lows contribute to the low habitat values. The Lower Reach habitat duration curve for Chinook spawning is shown in Figure 32. The habitat duration curve is restricted to the period when Chinook spawning occurs, July through October. An alternative, visually enhanced, means of viewing the habitat time-series is illustrated in the raster habitat plot (Figure 33). The raster habitat plot allows the viewer to identify the seasonality of the habitat value as well as individual events and anomalous years.

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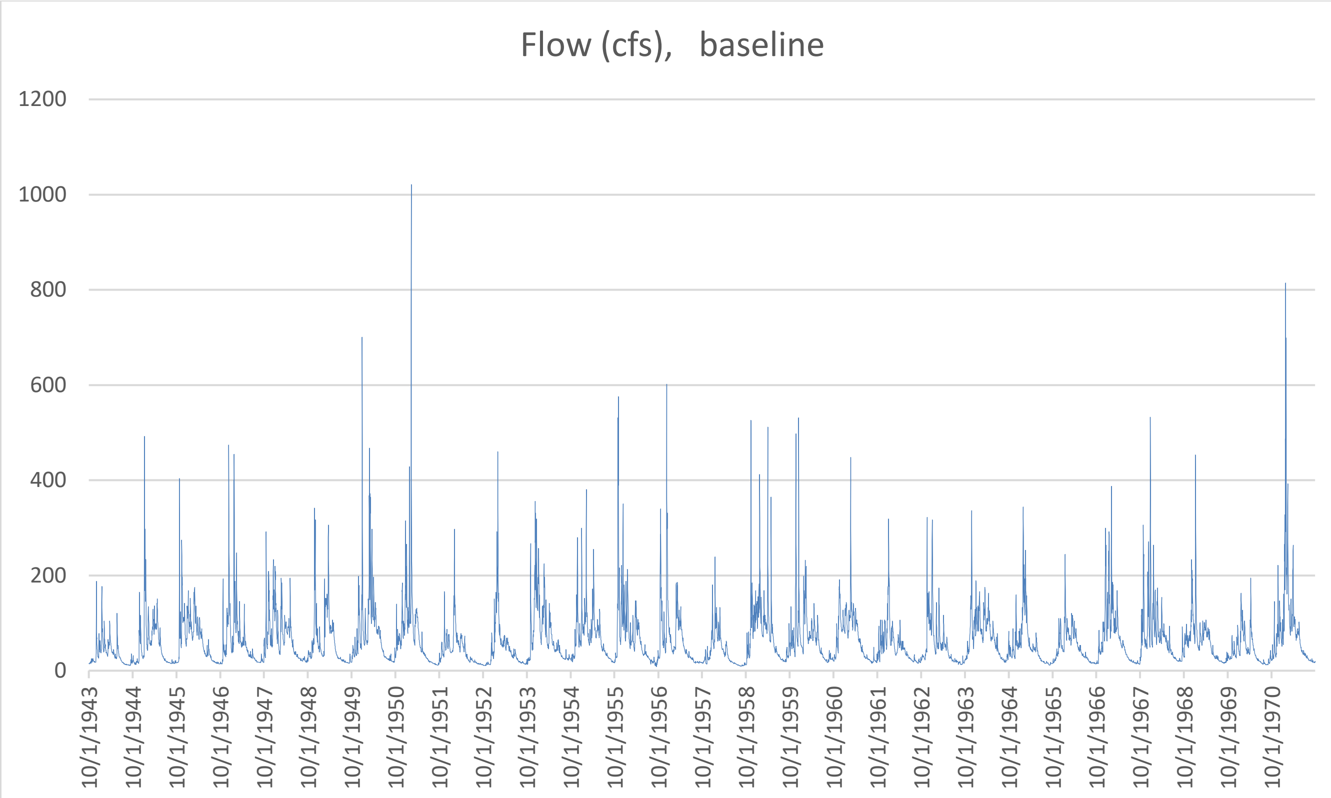

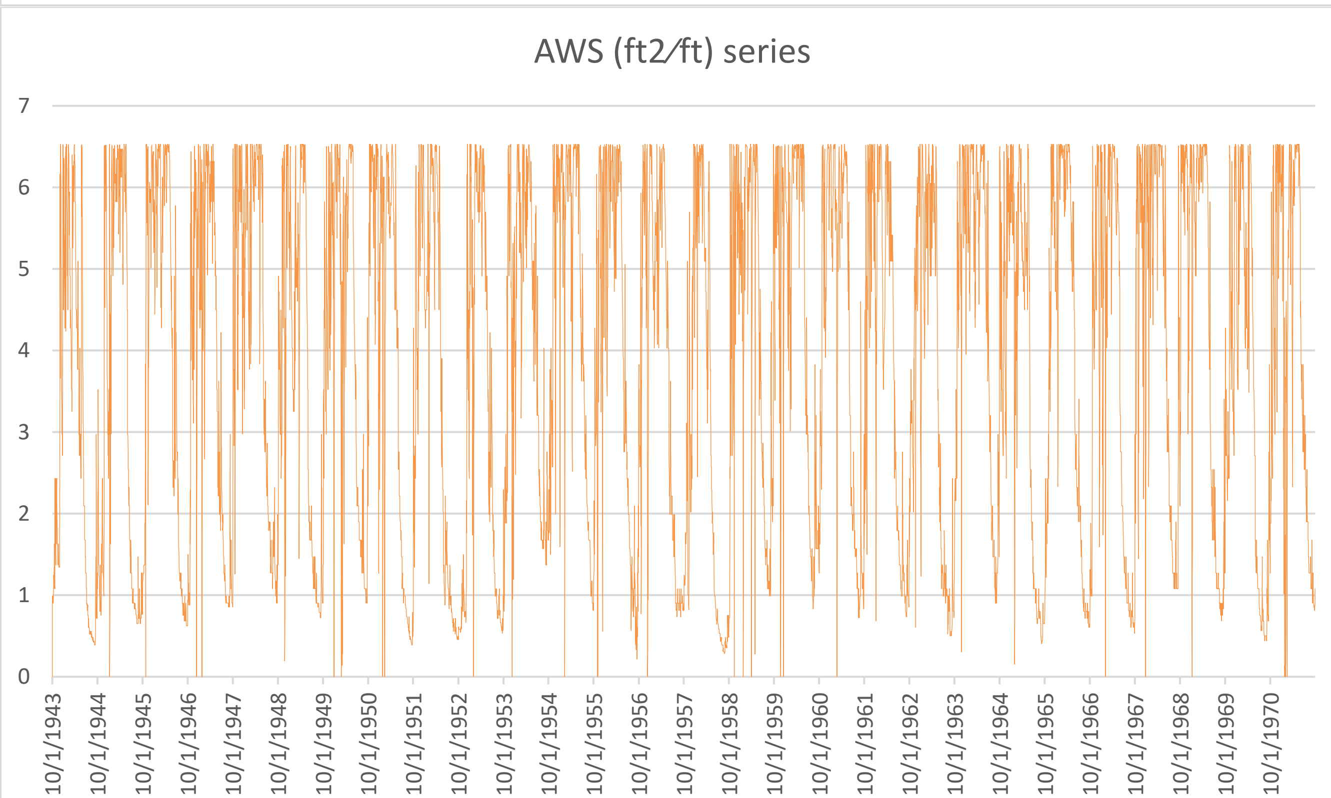

Figure 30. Flow time series (top) and Chinook spawning habitat time series (bottom) for 29 years of historic flow in Grandy Creek.

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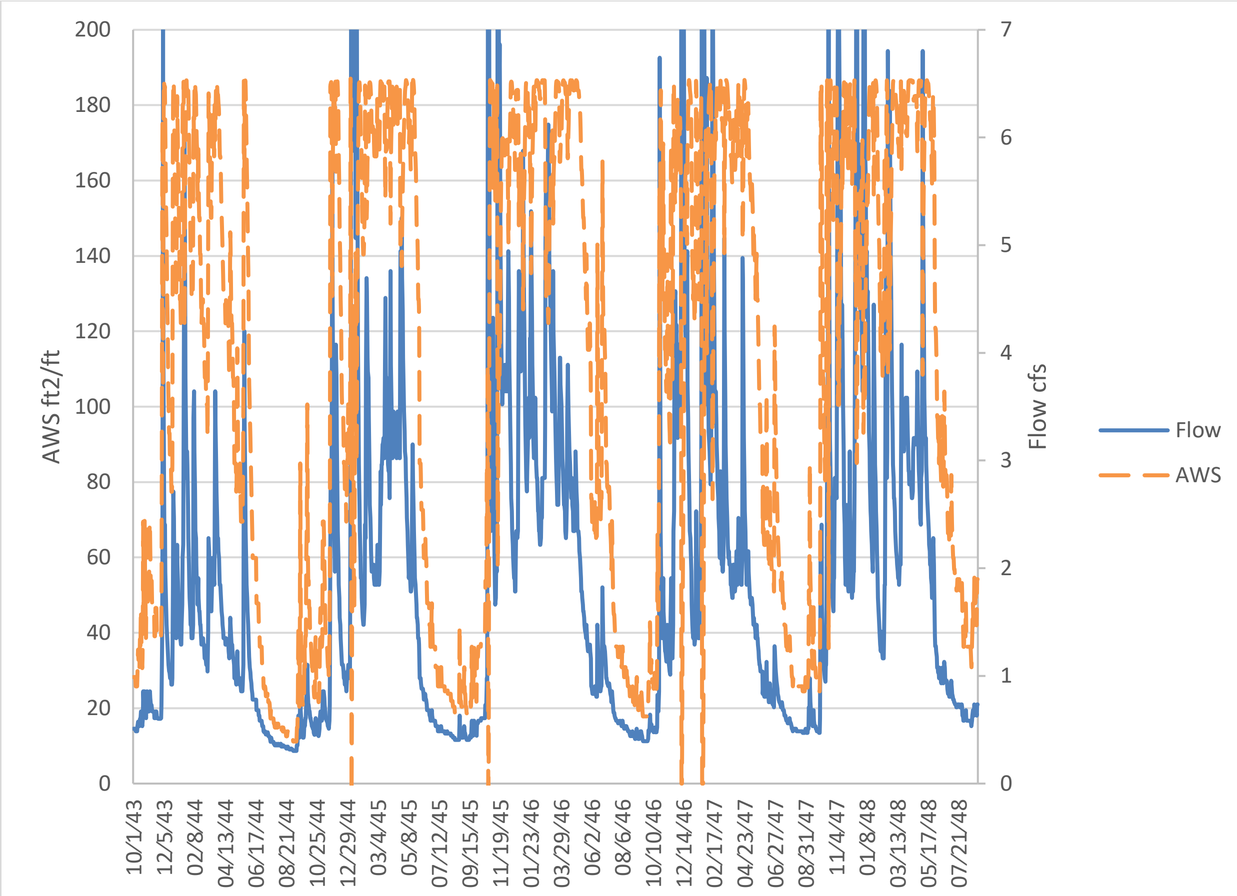

Figure 31. Overlay of flow time series and Chinook spawning habitat time series for a selected time period from the Lower Reach.

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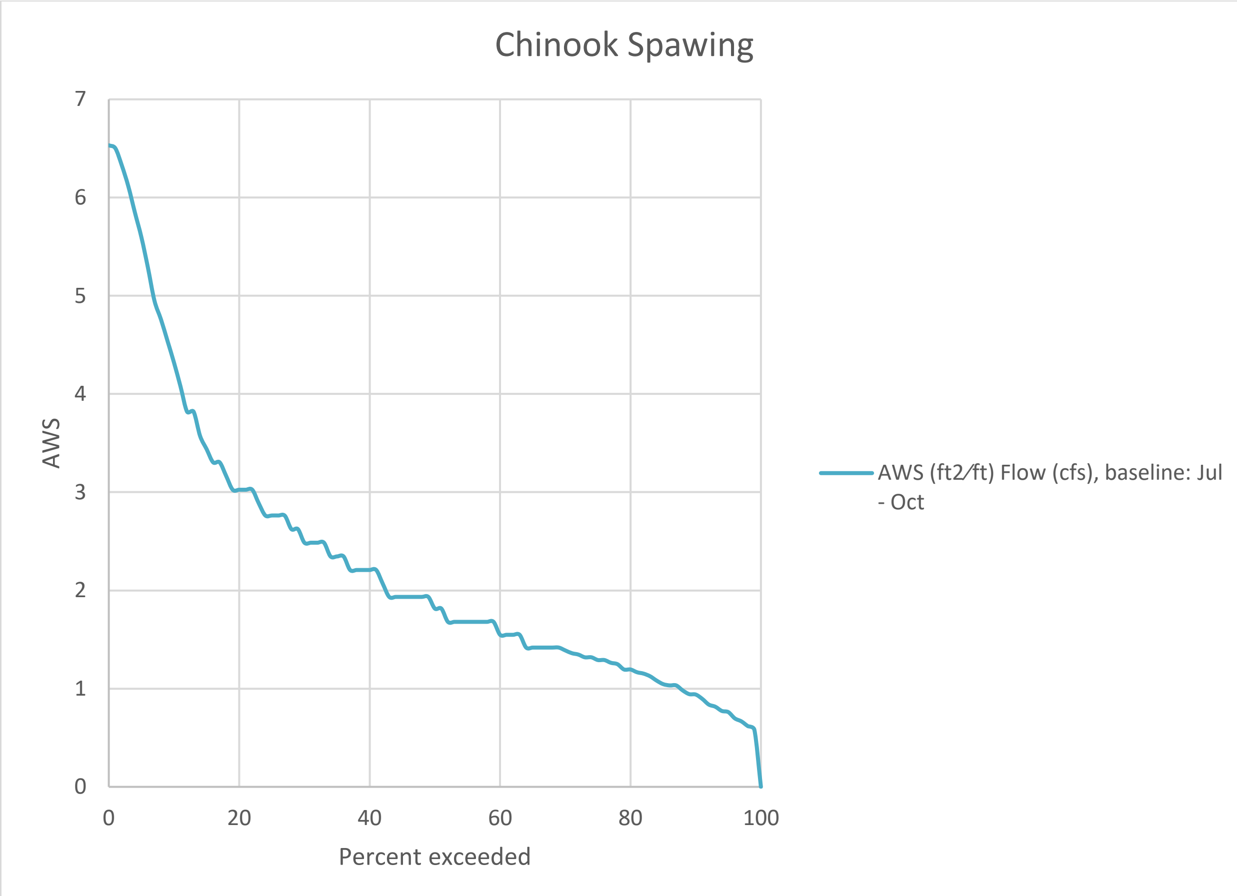

Figure 32. Lower Reach habitat duration curve for Chinook Spawning.

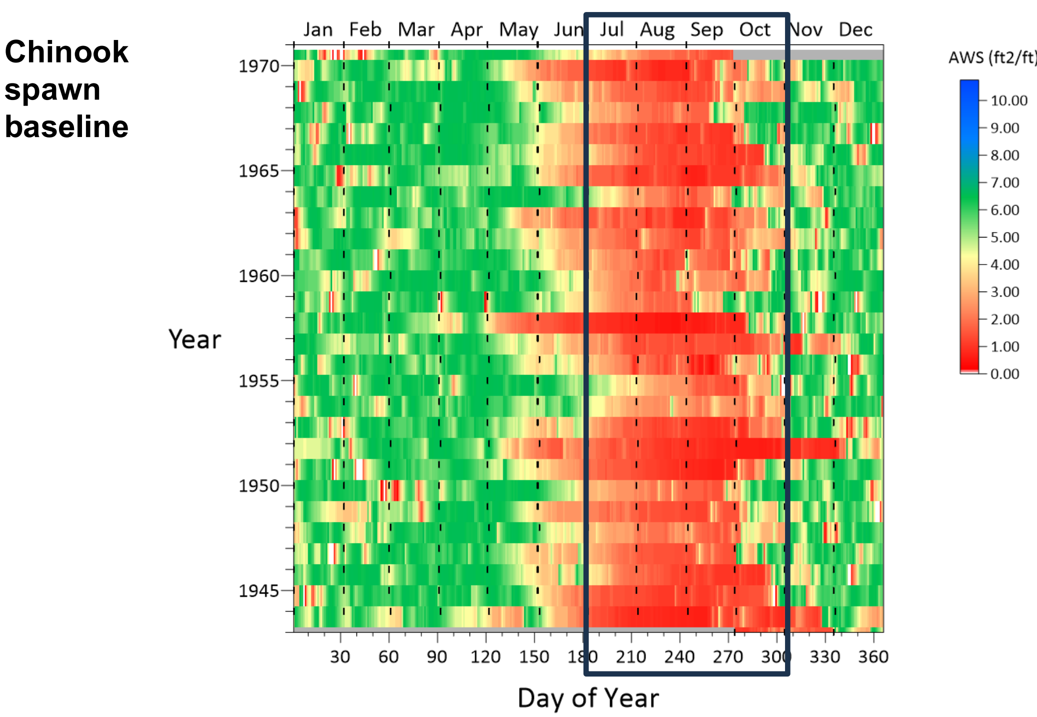

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Figure 33. Raster plot of the Chinook spawning AWS. The box indicates the Chinook spawning timing.

Comparison of Projected Climate and Development Scenarios

Flow duration curves provide a means to compare different flow regimes with respect to the amount of time certain flow levels occur. Figure 34 shows that all four climate change and development scenarios will lower the habitat value in Grandy Creek. In this case, since Chinook spawn in the late summer and early fall, during the low flow period, the lower habitat values are due to lower climate/development summertime flows, and do not include the low AWS values due to very high wintertime flows. Of the Chinook life-stages, spawning represents the greatest impact from the altered hydrology due to spawning occurring in the summertime period when the hydrology is mostly impacted. Chinook fry do not rear in the summer months and juveniles only rear in the one summer month of June (Figures 35 and 36). The climate/development hydrology impacts are small. The habitat duration curves for all species, life-stages, and hydrologic scenarios are presented in Appendix G.

An alternative method of the change in habitat is with the raster plot. In Figure 37, the comparison between Chinook spawning habitat value (the boxed area) shows the negative (deeper red) influence of the climate/development scenarios. Another method visualizing the change in habitat value is by subtracting the baseline AWS from the scenario AWS (Figure 38). The spawning period is from July through October, representing an almost universal decline in habitat. Figures 39 and 40 show that Chinook fry habitat is little impacted by climate change or development, and that Chinook juvenile habitat is impacted little, except in the month of June.

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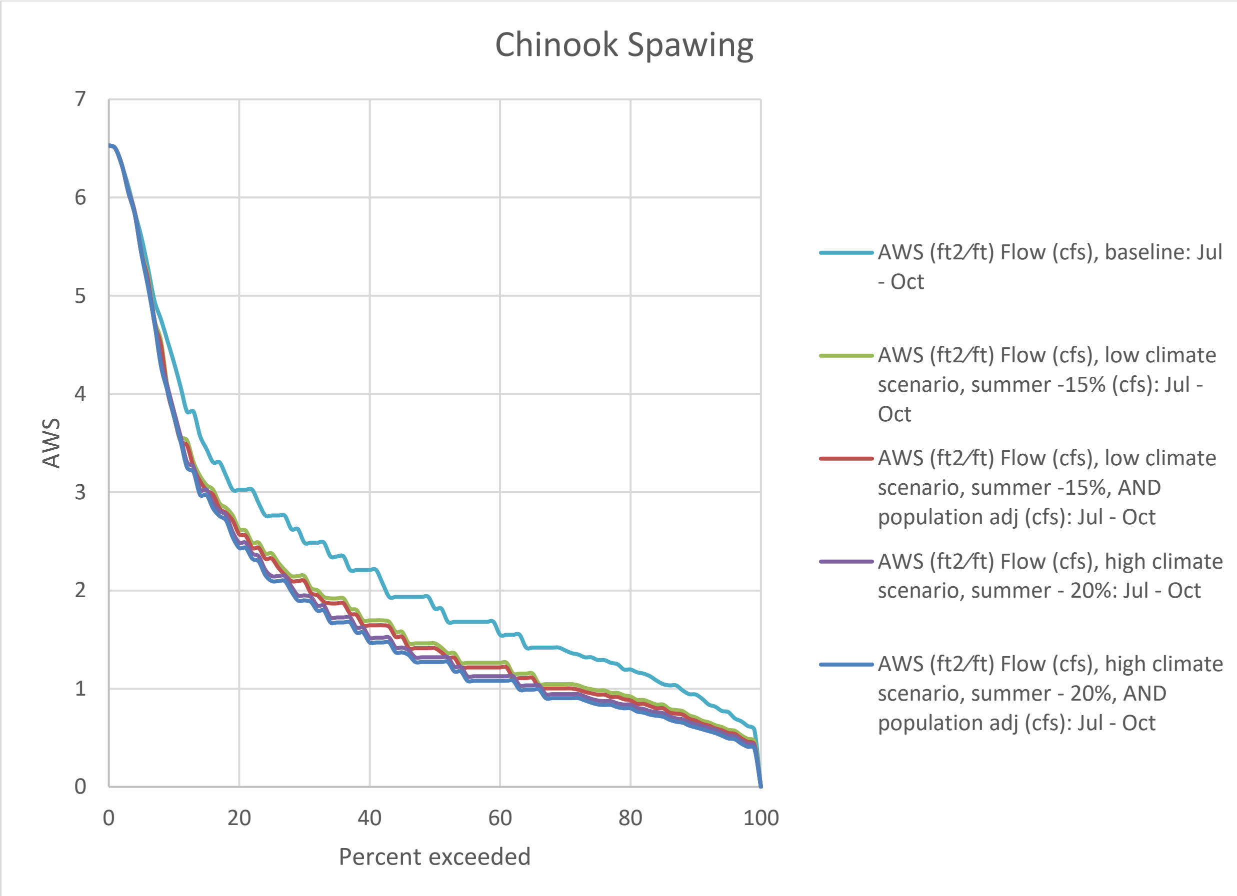

Figure 34. Lower Reach Chinook spawning habitat duration curves for the baseline hydrology and projected climste and development scenarios.

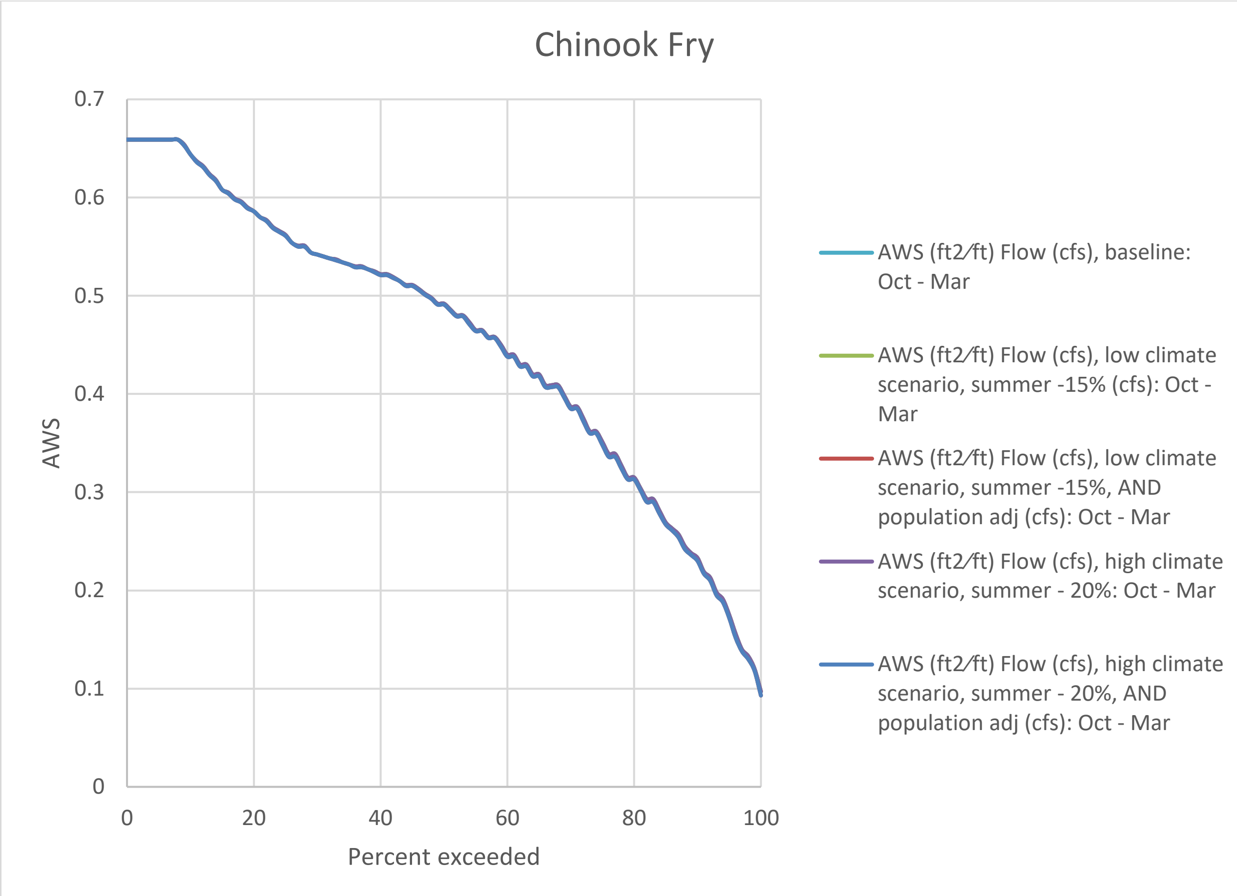

Figure 35. Chinook fry habitat duration curves.

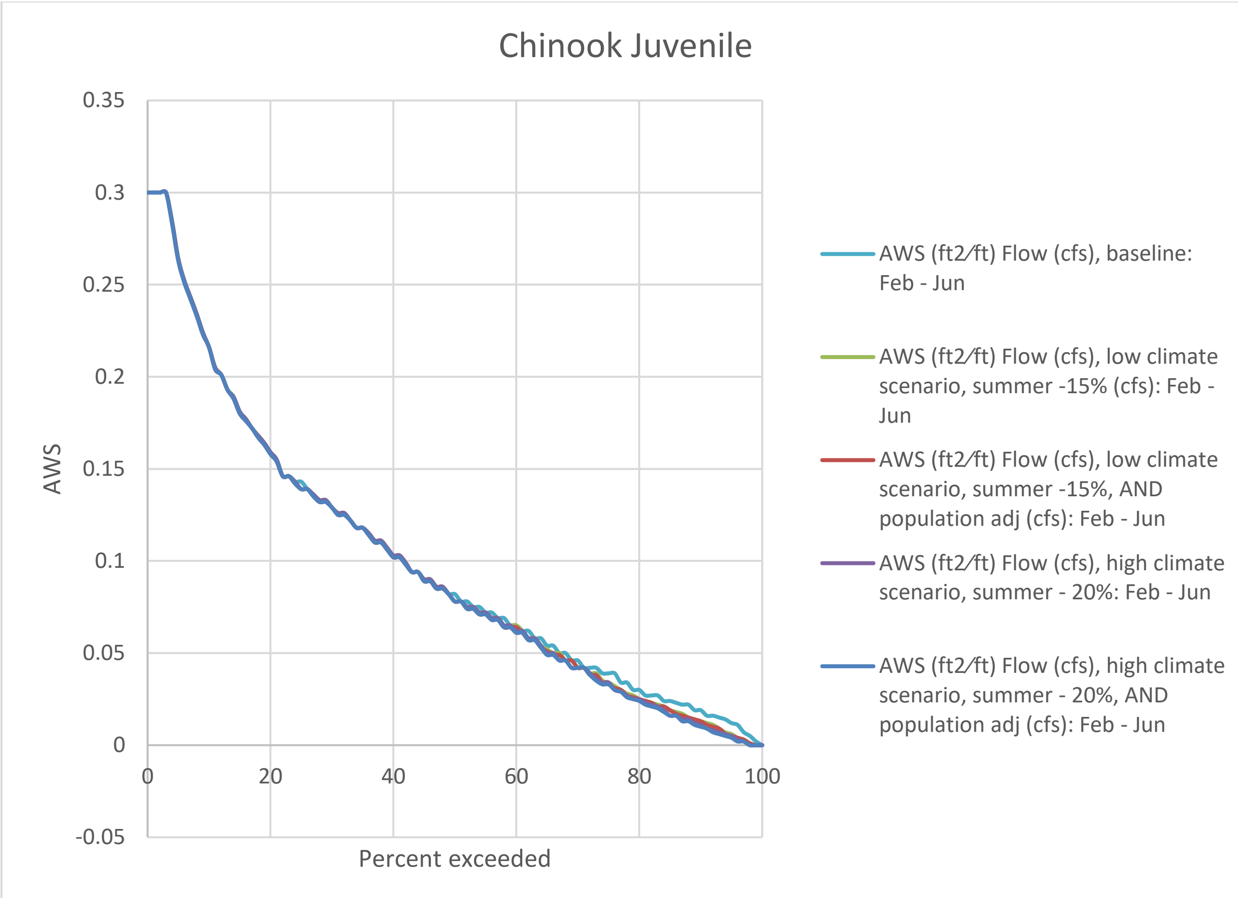

Figure 36. Chinook juvenile habitat duration curves.

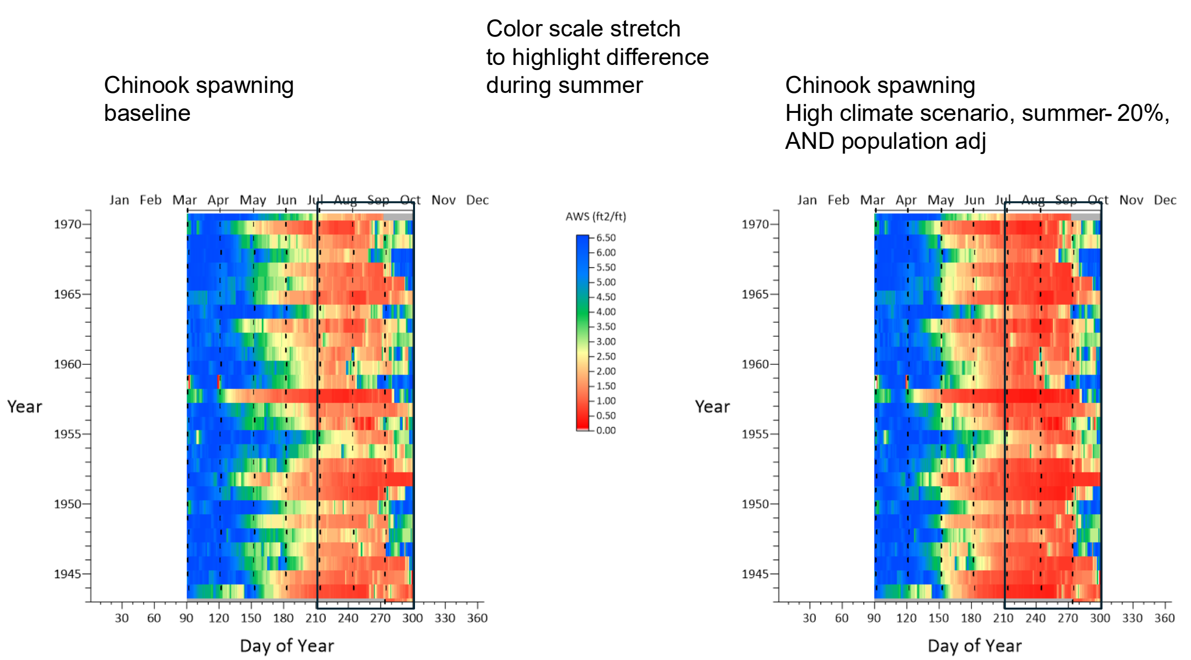

Figure 37. Chinook spawning AWS over baseline and high climate/development impact.

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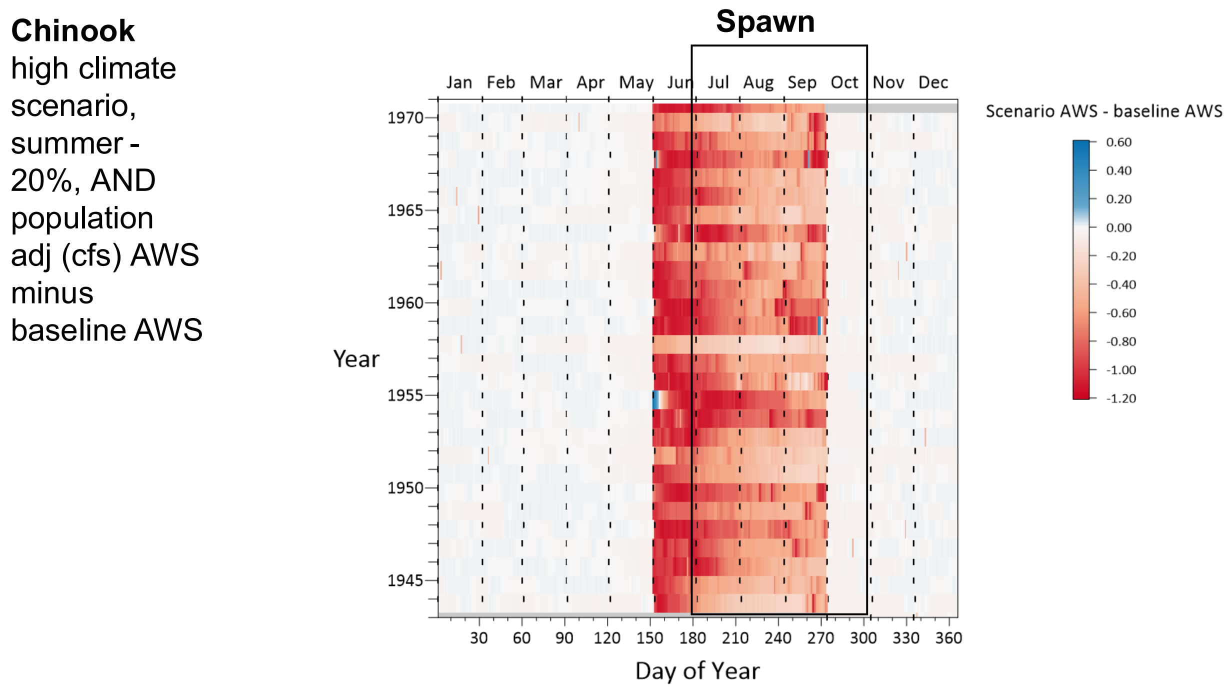

Figure 38. Change in the Lower Reach Chinook spawning AWS due to high emission climate change and potential development.

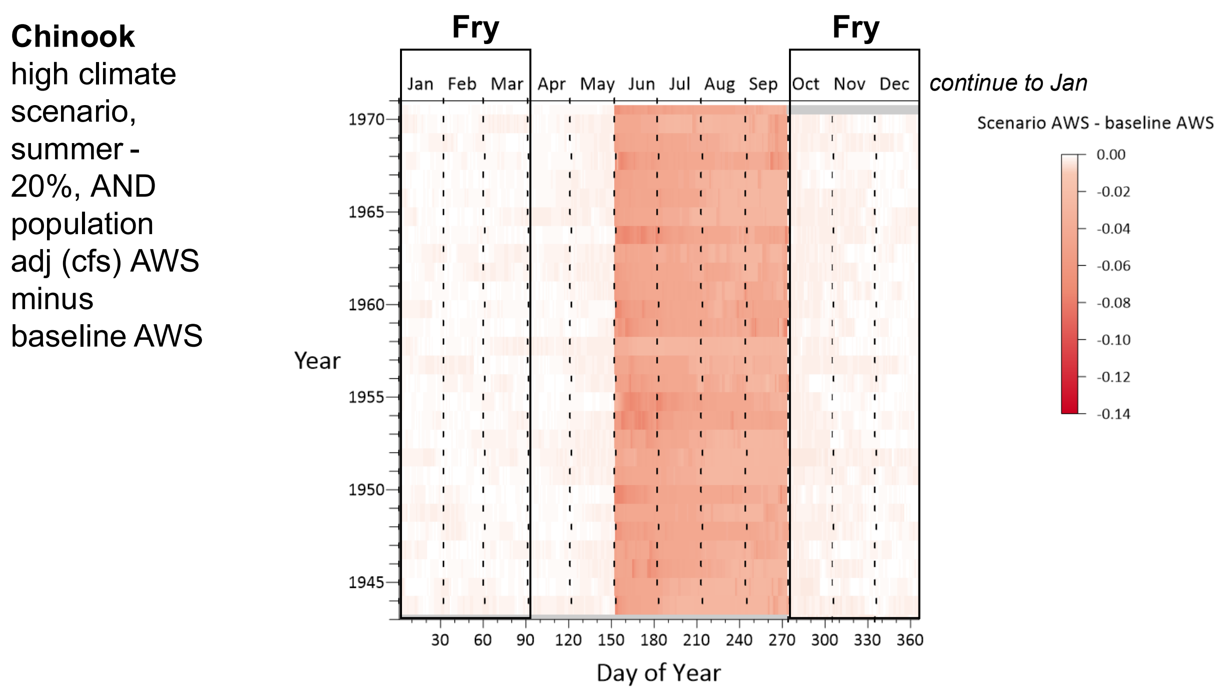

Figure 39. Change in Chinook fry AWS due to high emission climate change and potential development.

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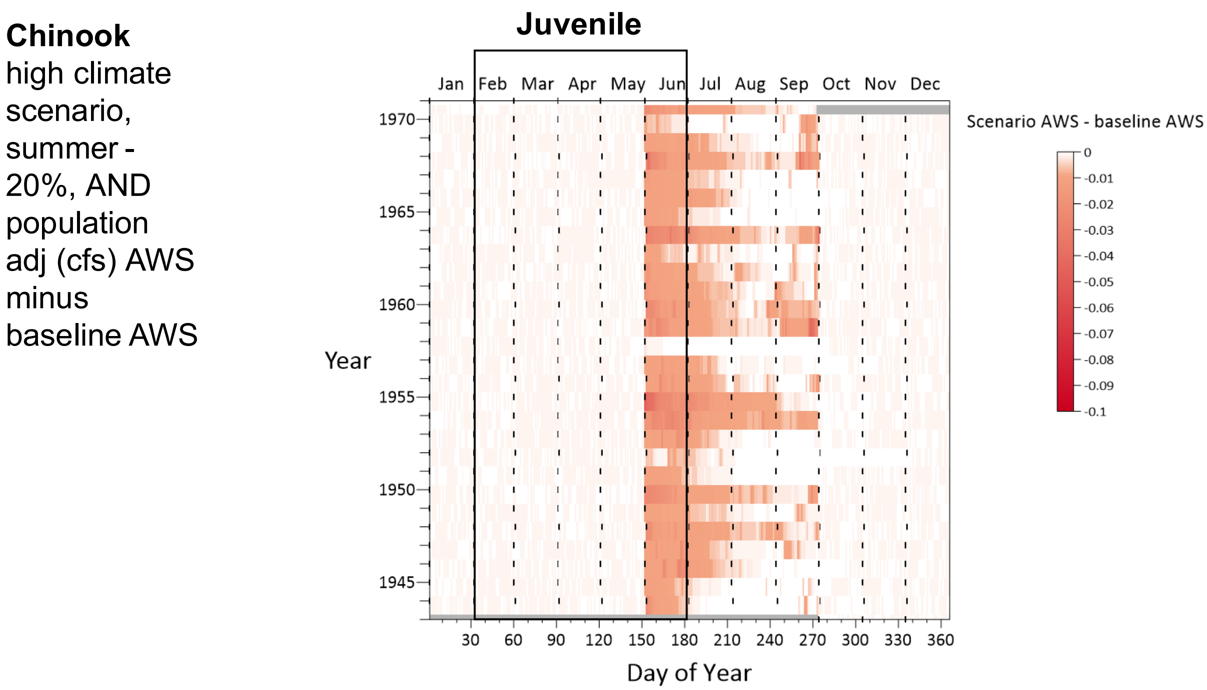

Figure 40. Change in Chinook juvenile AWS due to high emission climate change and potential development.

Discussion

The habitat typing indicated that there is a lack of pool habitat. Whereas, Flosi et al (2010) suggest that pool habitat should comprise 40% of the total length, Grandy Creek has 4% pool habitat in the Lower Reach and 7% in the Upper Reach. While there is ample spawning habitat in the lower reach, adult holding habitat is also essential for spawning success. Adult holding habitat was not modeled; however, the small number of pools indicates that is could be limiting.

While spawning redds and carcasses were observed in the Lower Reach, none were observed in the Upper Reach. The cascade at the downstream end of the Upper Reach appears to act as at least a partial barrier to upstream migration. Adult salmonids were seen jumping at the falls, but none achieving passage. The AWS curves were created for both reaches, but only the Lower Reach AWS was used for time-series analysis.

There is one conclusion common to all species and rearing life-stages: the hydraulic habitat index, AWS, indicates low habitat suitability for rearing in all reaches for all reasonable flows. Low, flat AWS curves indicate that changes in flow have little influence on rearing habitat. Pool habitats are scarce and instream cover is limited. Instream cover, where present, is mostly restricted to the margins, creating only a narrow strip of rearing habitat along each stream bank. If feasible, restoration of rearing habitat would have more influence on the availability than changes in flow.

The hydrologic analysis indicated that the changes to the stream flow from climate change and development would primarily impact the summer low flow period. Only species life-stages that utilize the summer would be impacted by the climate and development-altered hydrology. These species and life-stages include steelhead fry and juveniles, coho juveniles, and Chinook spawning.

Instream flow studies rarely answer the question, "What is the best flow?" That question is answered by balancing biological, social, and economic needs. Even when considering only a single species, the index of hydraulic habitat for different life-stages will respond differently to changing flow and no one flow will be the best for all life-stages. The results of this instream flow study provide tools to assess the biological impacts to hydraulic habitat for the species of interest due to changes in flow. The primary tools for assessing responses to changing flow are the AWS curves (Figures 20 -25), habitat duration curves in Appendix G, and raster plots in Appendix H.

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List of Appendices

List of Attachments

Appendix A: Habitat Mapping

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Habitat Mapping Grandy Creek

Habitat Unit (HU)	datetime	habtype	hip chain_length (ft)	cumulative	width_avg (ft)	depth_avg (ft)	depth_max (ft)	spwn_grav?	spwn_gravel %	notes
1	9/6/2022 9:37	Riffle	59	59	15			TRUE	80	trail, dam crossing creek and backing up flow
2	9/6/2022 9:45	Glide	62	121	16	0.8		TRUE	70	redd and spawning fish present
3	9/6/2022 10:00	Riffle	549	670	20	0.7	1.6	TRUE	70	lwd jam along bend. sm side channel half way thru riddle, pool like.
4	9/6/2022 10:10	Glide	217	887	25	1	2	TRUE	15	redd present. small riffle mid unit
5	9/6/2022 10:27	Riffle	53	940	28	0.9	1.4	TRUE	55	
6	9/6/2022 10:28	Lateral Scour Pool	31	971	20	2	2.4	TRUE	5	lwd enhanced
7	9/6/2022 10:32	Glide	115	1086	28	1.1	1.7	TRUE	45	old bridge trestle at top of unit. redd i n middle of habitat unit. small riffle transition at end of unit into pool
8	9/6/2022 10:44	Riffle with Pockets	335	1421	13	1	2.2	TRUE	30	passed under bridge. dead spawned female under bridge. reds present at top of unit.
9	9/6/2022 12:17	Lateral Scour Pool	131	1552	24	2	4.2	TRUE	15	lwd on left bank with large cut bank
10	9/6/2022 12:28	Riffle	626	2178	32	0.7	2.5	TRUE	50	small pockets of pools. small glide at bottom
11	9/6/2022 12:36	Glide	111	2289	31	0.9	2.6	TRUE	30	lwd present, small lateral scour pool at top
12	9/6/2022 12:48	Riffle	85	2374	35	0.4	0.6	TRUE	40	
13	9/6/2022 13:00	Glide	130	2504	25	1.5	2.7	TRUE	60	lwd on left bank with scour
14	9/6/2022 13:04	Riffle	180	2684	15	0.7	1.8	TRUE	55	channel splits into 2 channels
15	9/6/2022 13:07	Lateral Scour Pool	67	2751	28	2.2	2.8	TRUE	10	lwd and rip rap on right bank
16	9/6/2022 13:13	Riffle	198	2949	28	0.8	1.6	TRUE	40	
17	9/6/2022 13:17	Glide	139	3088	30	1.6	2.1	TRUE	15	
18	9/6/2022 13:30	Riffle	801	3889	24	0.7	1.6	TRUE	20	splits into 2 channels in lower half of unit
19	9/6/2022 13:33	Straight Scour Pool	51	3940	27	1.8	2.2	TRUE	10	
20	9/6/2022 13:40	Riffle	406	4346	32	0.7	2	TRUE	25	

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21	9/6/2022 13:45	Glide	133	4479	25	1	1.4	TRUE	25	
22	9/6/2022 14:08	Riffle	1102	5581	35	0.75	2.1	TRUE	40	small pool midway in unit below lwd log jam, log jam approx. 100 long. human made dam 1.5 ft in height at top end of riffle
23	9/6/2022 14:19	Dammed Pool	102	5683	45	1.4	1.8	TRUE	10	human made dam at bottom creating pool
24	9/6/2022 14:44	Riffle	1910	7593	33	0.65	2.1	TRUE	35	
25	9/6/2022 15:11	Glide	132	7725	35	0.9	1.1	TRUE	10	human made dam at bottom creating glide break
26	9/6/2022 15:30	Riffle	781	8506	23	0.75	1.6	TRUE	15	small partial cascade in middle of unit
27	9/6/2022 15:32	Plunge Pool	20	8526	35	1.5	2.2	TRUE	5	small cascade at top creating pool. water diversion pump at top of pool
28	9/6/2022 15:54	Riffle	1854	10380	25	0.8	1.3	TRUE	30	
29	9/6/2022 15:58	Cascade over Boulders	53	10433	28	1	1.4	FALSE	5	
30	9/6/2022 16:31	Riffle	1672	12105	35	0.9	2.2	TRUE	15	more large boulders than lower in creek
31	9/6/2022 16:38	Cascade over Boulders	49	12154	20	2	4	FALSE	0	
32	9/6/2022 16:43	Riffle with Pockets	61	12215	22	1.1	1.5	TRUE	10	
33	9/6/2022 16:48	Plunge Pool	34	12249	35	1.7	2.5	TRUE	10	
34	9/6/2022 16:54	Riffle	295	12544	30	0.75	1.4	TRUE	30	
35	9/6/2022 16:57	Glide	47	12591	25	1.4	1.8	TRUE	40	
36	9/6/2022 17:04	Riffle with Pockets	177	12768	28	0.6	0.9	TRUE	25	
37	9/6/2022 17:06	Plunge Pool	14	12782	25	1.8	2.2	TRUE	5	
38	9/6/2022 17:13	Cascade over Boulders	53	12835	15	1.2	1.6	FALSE	0	
39	9/7/2022 9:40	Riffle with Pockets	583	13418	30	1.4	2.8	TRUE	15	split chan first half of unit.
40	9/7/2022 9:44	Straight Scour Pool	48	13466	25	1.8	3.6	TRUE	5	pool with boulders.
41	9/7/2022 9:57	Riffle with Pockets	533	13999	18	1.5	3.2	TRUE	15	lwd spanning channel with small pool in middle of unit.

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42	9/7/2022 10:00	Glide	26	14025	16	1.2	1.9	TRUE	5	
43	9/7/2022 10:15	Riffle with Pockets	360	14385	40	1	1.9	TRUE	20	land slide mid riffle
44	2022-09-07T10:17:56.568	Glide	72	14457	12	1.6	3.1	TRUE	10	ds of trib
45	9/7/2022 10:33	Riffle with Pockets	664	15121	30	1.7	2.8	TRUE	15	small cascade near bottom of unit and small pool/glide ds of cascade.
46	2022-09-07T10:36:56.015	Cascade over Boulders	54	15175	35	1.9	2.8	TRUE	5	
47	9/7/2022 10:39	Straight Scour Pool	22	15197	30	1.8	3.3	TRUE	10	
48	9/7/2022 10:54	Riffle with Pockets	680	15877	25	2.2	2.7	TRUE	10	low gradient riffle/high gradient riffle alternating
49	9/7/2022 10:58	Plunge Pool	10	15887	30	2.8	3.7	TRUE	0	
50	9/7/2022 11:07	Straight Scour Pool	79	15966	15	3	4.3	TRUE	5	at trib confl.
51	9/7/2022 11:13	Riffle with Pockets	137	137	10	1.5	2.3	TRUE	5	fast riffle over bldrs, transition to brx. access from rd limited going us.
52	9/7/2022 11:26	Plunge Pool	210	347	6	3.5	6	FALSE	0	two plunge pools swift water
53	9/7/2022 11:31	Cascade over Bedrock	120	467	12	3	6	FALSE	0	cascade series w sm plunge pool in middle.
54	9/7/2022 12:21	Riffle	1850	2317	15	3	5.8	TRUE	20	rel low gradient riffle w cobbl n gravl.
55	9/7/2022 12:26	Glide	52	2369	15	0.7	0.9	TRUE	15	side chan present, trickle.
56	9/7/2022 12:31	Riffle	369	2738	12	0.6	1.4	TRUE	20	low gradient. sm pool nr bottom of unit
57	9/7/2022 12:34	Glide	40	2778	15	1.2	1.7	TRUE	10	good for q meas.
58	9/7/2022 12:40	Riffle	290	3068	12	0.8	1.8	TRUE	30	
59	9/7/2022 12:42	Glide	54	3122	12	1.4	1.9	TRUE	5	
60	9/7/2022 12:46	Riffle	219	3341	10	0.8	1.2	TRUE	30	beaver dam at top of riffle
61	9/7/2022 12:47	Dammed Pool	15	3356		2.2	2.8	TRUE	15	
62	9/7/2022 13:01	Riffle	1068	4424	20	0.8	2.4	TRUE	25	channel splits and converges multiple times

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63	9/7/2022 13:04	Glide	46	4470	12	1.5	2.9	TRUE	15	good q location. rtwad and pool at top of unit, small.
64	9/7/2022 13:11	Riffle	460	4930	20	0.6	1.5	TRUE	20	
65	9/7/2022 13:13	Glide	150	5080	15	0.9	3.2	TRUE	50	good q location, small 30 ft of riffle in middle of unit
66	9/7/2022 13:37	Riffle	750	5830	15	0.9	3.2	TRUE	35	log jams (3) creating smALL POCKETS OF POOLS. channels spilts inyo sm side chan.
67	2022-09-07T13:41:11.760	Glide	84	5914	15	0.7	1.4	TRUE	40	good q location
68	9/7/2022 13:47	Riffle	390	6304	18	0.9	2.4	TRUE	30	chan splits into multiple
69	9/7/2022 13:49	Glide	40	6344	12	1	1.5	TRUE	25	good q if trib isnt following
70	9/7/2022 14:25	Riffle	2041	8385	14	1	2.4	TRUE	25	no trib visible, some bridges but no water or outlet
71	9/7/2022 14:27	Glide	185	8570	12	1.5	2	TRUE	15	sm glide w sm pool at tup of unit. ok for q meas
72	9/7/2022 14:53	Riffle with Pockets	1360	9930	18	1.2	2.5	TRUE	15	small pockets of glides present
73	9/7/2022 15:19	Glide	30	9960	15	1.4	1.9	TRUE	5	
74	9/7/2022 15:31	Riffle	740	10700	12	1.3	1.9	TRUE	25	
75	9/7/2022 15:32	Lateral Scour Pool	45	10745	15	1.4	2.2	TRUE	10	landslide and lwd formed
76	9/7/2022 15:38	Riffle	467	11212	12	0.8	1.1	TRUE	25	
77	9/7/2022 15:41	Lateral Scour Pool	38	11250	12	1.6	3.2	TRUE	5	
78	9/7/2022 15:46	Riffle	280	11530	10	1.2	1.5	TRUE	15	channel splits into 2
79	9/7/2022 15:48	Glide	46	11576	10	0.7	0.9	TRUE	35	
80	2022-09-07T15:53:34.390	Riffle	417	11993	8	0.8	1.2	TRUE	30	
81	9/7/2022 15:57	Glide	210	12203	6	0.6	1.5	TRUE	50	algae and fish present. transition to shallow loo w flow water loss of algae
82	2022-09-07T16:04:57.762	Lateral Scour Pool	35	12238	10	1.4	2.3	TRUE	25	
83	9/7/2022 16:12	Riffle	185	12423	6	0.5	0.8	TRUE	50	

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84	9/7/2022 16:21	Glide	270	12693	5	0.3	0.5	TRUE	65	shallow glide with smallpox rifle pockets
85	9/7/2022 16:23	Lateral Scour Pool	120	12813	15	1.8	2.3	TRUE	25	pool along bend, rtwad present. ppl living. another poo. just us separated by sm riffle
86	9/7/2022 16:35	Glide	320	13133	5	0.5	0.8	TRUE	65	mostly glide w little water, lots algae. small riff.e sections in between long glides. lwd jam at top of unit.
87	9/7/2022 16:39	Riffle	151	13284	5	0.4	0.8	TRUE	60	
88	9/7/2022 17:00	Glide - estimated lenth	185	13469	12	0.8	1	TRUE	30	lwd and landslide in channel.
89	9/7/2022 17:06	Riffle	292	13761	10	0.6	2.1	TRUE	30	
90	2022-09-07T17:09:04.343	Glide	109	13870	8	0.8	1.9	TRUE	10	small pool at top of unit.
91	9/8/2022 9:03	Riffle	123	13993	10	0.5	1.5	TRUE	45	
92	9/8/2022 9:25	Beaver Pool	320	14313	12	2	3.6	TRUE	10	long pool, beaver dam approx 100 ft from bottom of unit. fine sediment.
93	9/8/2022 9:28	Riffle	64	14377	8	0.5	0.9	TRUE	50	
94	9/8/2022 9:33	Glide	40	14417	10	1	2	TRUE	5	
95	9/8/2022 9:40	Riffle	190	14607	10	0.5	0.9	TRUE	40	larger grained sediment. ends at atv trail
96	9/8/2022 9:47	Glide	140	14747	12	0.8	1.5	TRUE	25	
97	2022-09-08T09:49:46.284	Riffle	70	14817	10	0.4	0.6	TRUE	10	
98	9/8/2022 9:52	Glide	48	14865	15	0.5	1	TRUE	10	
99	9/8/2022 9:59	Dammed Pool	230	15095	15	2	2.8	FALSE	0	beaver dam in middle of dammed pool. lots of fine silt. becomes narrow, slow moving pool at upper end.

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Appendix B: Tabular HSC

Grandy HSC
Steelhead, Chinook, Coho

Curve Set ID: 01000001
Species Name: Chinook
Life Stage: Spawning
Conditions: Grandy Creek
Attribute 1 Name: SUBSTRATE
VELOCITY data pairs: 8
DEPTH data pairs: 6
SUBSTRATE data pairs: 92

VELOCITY		DEPTH		SUBSTRATE	
0.55	0.0000	0.35	0.0000	31.70	0.0000
0.65	0.1000	0.95	0.8000	31.80	0.2400
1.15	0.2000	1.25	0.9400	31.90	0.2700
2.25	1.0000	1.75	1.0000	32.50	0.0000
2.35	1.0000	2.75	0.4000	32.70	0.0000
3.75	0.5000	99.00	0.4000	32.80	0.2400
3.85	0.2000			32.90	0.2700
5.00	0.0000			33.90	0.3000
				34.50	0.6500
				34.90	0.3700
				35.50	0.6500
				35.90	0.3700
				36.50	0.6500
				36.90	0.3700
				37.50	0.4000
				37.90	0.3200
				38.50	0.1500
				38.90	0.2700
				39.50	0.0000
				39.90	0.0000
				41.50	0.0000
				41.70	0.0000
				41.80	0.8000
				41.90	0.9000
				42.50	0.0000
				42.70	0.0000
				42.80	0.8000
				42.90	0.9000
				43.50	0.6500
				43.90	0.9300
				44.90	1.0000
				46.90	1.0000
				47.50	0.7500
				47.90	0.9500
				48.50	0.5000
				48.90	0.9000
				49.50	0.0000
				49.90	0.0000

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3	3	51.50	0.0000	3
3	3	51.70	0.0000	3
3	3	51.80	0.8000	3
3	3	51.90	0.9000	3
3	3	52.50	0.0000	3
3	3	52.70	0.0000	3
3	3	52.80	0.8000	3
3	3	52.90	0.9000	3
3	3	53.50	0.6500	3
3	3	53.90	0.9300	3
3	3	54.50	1.0000	3
3	3	56.90	1.0000	3
3	3	57.50	0.7500	3
3	3	57.90	0.9500	3
3	3	58.50	0.5000	3
3	3	58.90	0.9000	3
3	3	59.50	0.0000	3
3	3	59.90	0.0000	3
3	3	61.50	0.0000	3
3	3	61.70	0.0000	3
3	3	61.80	0.8000	3
3	3	61.90	0.9000	3
3	3	62.50	0.0000	3
3	3	62.70	0.0000	3
3	3	62.80	0.8000	3
3	3	62.90	0.9000	3
3	3	63.50	0.6500	3
3	3	63.90	0.9300	3
3	3	64.50	1.0000	3
3	3	66.90	1.0000	3
3	3	67.50	0.7500	3
3	3	67.90	0.9500	3
3	3	68.50	0.5000	3
3	3	68.90	0.9000	3
3	3	69.50	0.0000	3
3	3	71.70	0.0000	3
3	3	71.80	0.4000	3
3	3	71.90	0.4500	3
3	3	72.50	0.0000	3
3	3	72.70	0.0000	3
3	3	72.80	0.4000	3
3	3	72.90	0.4500	3
3	3	73.50	0.4000	3
3	3	73.90	0.4800	3
3	3	74.50	0.7500	3
3	3	74.90	0.5500	3
3	3	75.50	0.7500	3
3	3	75.90	0.5500	3
3	3	76.50	0.7500	3
3	3	76.90	0.5500	3
3	3	77.90	0.5000	3
3	3	78.50	0.2500	3
3	3	78.90	0.4500	3
3	3	79.50	0.0000	3

```
--------------------------------------------------------------------------
-------
Curve Set ID: 01000002
Species Name: Chinook
  Life Stage: Fry Rearing
  Conditions: Grandy Creek
Attribute 2  Name: COVER
    VELOCITY data pairs:   6
       DEPTH data pairs:   6
       COVER data pairs:  10
--------------------------------------------------------------------------
-------

   VELOCITY             DEPTH             COVER
    0.00   0.9200 ³    0.00   0.0000 ³    0.00   0.0000
    0.09   1.0000 ³    0.55   1.0000 ³    0.10   1.0000
    0.13   1.0000 ³    0.61   1.0000 ³    0.20   1.0000
    0.47   0.5000 ³    1.31   0.5000 ³    0.30   1.0000
    0.78   0.2000 ³    1.98   0.2000 ³    0.40   1.0000
    2.11   0.0000 ³    4.51   0.0000 ³    0.50   0.8000
                  ³                  ³    0.60   0.8000
                  ³                  ³    0.70   0.1000
                  ³                  ³    0.80   0.7000
                  ³                  ³    0.90   0.2000
--------------------------------------------------------------------------
-------
Curve Set ID: 01000003
Species Name: Chinook
  Life Stage: Juvenile rearing
  Conditions: Grandy Creek
Attribute 2  Name: COVER
    VELOCITY data pairs:   7
       DEPTH data pairs:   6
       COVER data pairs:  10
--------------------------------------------------------------------------
-------

   VELOCITY             DEPTH             COVER
    0.00   0.2400 ³    0.45   0.0000 ³    0.00   0.0000
    0.15   0.3000 ³    1.05   0.3000 ³    0.10   1.0000
    0.55   0.8500 ³    1.65   0.8500 ³    0.20   1.0000
    0.95   1.0000 ³    2.05   0.9500 ³    0.30   1.0000
    1.05   1.0000 ³    2.45   1.0000 ³    0.40   1.0000
    1.85   0.4500 ³    7.40   1.0000 ³    0.50   0.8000
    3.65   0.0000 ³                  ³    0.60   0.8000
                  ³                  ³    0.70   0.1000
                  ³                  ³    0.80   0.7000
                  ³                  ³    0.90   0.2000
--------------------------------------------------------------------------
-------
Curve Set ID: 02000001
Species Name: Coho
  Life Stage: Spawning
  Conditions: Grandy Creek
```

```
Attribute 1  Name: SUBSTRATE
    VELOCITY data pairs:   6
       DEPTH data pairs:   8
   SUBSTRATE data pairs:  92
-------------------------------------------------------------------------
-------
```

VELOCITY		DEPTH		SUBSTRATE	
0.00	0.0000	0.00	0.0000	31.70	0.0000
0.45	0.5300	0.15	0.0000	31.80	0.2400
1.25	1.0000	0.55	0.6500	31.90	0.2700
1.45	1.0000	0.85	1.0000	32.50	0.0000
4.25	0.6200	1.15	1.0000	32.70	0.0000
5.00	0.0000	1.55	0.9000	32.80	0.2400
		1.95	0.5300	32.90	0.2700
		2.75	0.3500	33.90	0.3000
				34.50	0.6500
				34.90	0.3700
				35.50	0.6500
				35.90	0.3700
				36.50	0.6500
				36.90	0.3700
				37.50	0.4000
				37.90	0.3200
				38.50	0.1500
				38.90	0.2700
				39.50	0.0000
				39.90	0.0000
				41.50	0.0000
				41.70	0.0000
				41.80	0.8000
				41.90	0.9000
				42.50	0.0000
				42.70	0.0000
				42.80	0.8000
				42.90	0.9000
				43.50	0.6500
				43.90	0.9300
				44.90	1.0000
				46.90	1.0000
				47.50	0.7500
				47.90	0.9500
				48.50	0.5000
				48.90	0.9000
				49.50	0.0000
				49.90	0.0000
				51.50	0.0000
				51.70	0.0000
				51.80	0.8000
				51.90	0.9000
				52.50	0.0000
				52.70	0.0000
				52.80	0.8000
				52.90	0.9000

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³                     ³  53.50   0.6500 ³
³                     ³  53.90   0.9300 ³
³                     ³  54.50   1.0000 ³
³                     ³  56.90   1.0000 ³
³                     ³  57.50   0.7500 ³
³                     ³  57.90   0.9500 ³
³                     ³  58.50   0.5000 ³
³                     ³  58.90   0.9000 ³
³                     ³  59.50   0.0000 ³
³                     ³  59.90   0.0000 ³
³                     ³  61.50   0.0000 ³
³                     ³  61.70   0.0000 ³
³                     ³  61.80   0.8000 ³
³                     ³  61.90   0.9000 ³
³                     ³  62.50   0.0000 ³
³                     ³  62.70   0.0000 ³
³                     ³  62.80   0.8000 ³
³                     ³  62.90   0.9000 ³
³                     ³  63.50   0.6500 ³
³                     ³  63.90   0.9300 ³
³                     ³  64.50   1.0000 ³
³                     ³  66.90   1.0000 ³
³                     ³  67.50   0.7500 ³
³                     ³  67.90   0.9500 ³
³                     ³  68.50   0.5000 ³
³                     ³  68.90   0.9000 ³
³                     ³  69.50   0.0000 ³
³                     ³  71.70   0.0000 ³
³                     ³  71.80   0.4000 ³
³                     ³  71.90   0.4500 ³
³                     ³  72.50   0.0000 ³
³                     ³  72.70   0.0000 ³
³                     ³  72.80   0.4000 ³
³                     ³  72.90   0.4500 ³
³                     ³  73.50   0.4000 ³
³                     ³  73.90   0.4800 ³
³                     ³  74.50   0.7500 ³
³                     ³  74.90   0.5500 ³
³                     ³  75.50   0.7500 ³
³                     ³  75.90   0.5500 ³
³                     ³  76.50   0.7500 ³
³                     ³  76.90   0.5500 ³
³                     ³  77.90   0.5000 ³
³                     ³  78.50   0.2500 ³
³                     ³  78.90   0.4500 ³
³                     ³  79.50   0.0000 ³
------------------------------------------------------------------------
-------
Curve Set ID: 02000002
Species Name: Coho
  Life Stage: Fry Rearing
  Conditions: Grandy Creek
Attribute 2  Name: COVER
    VELOCITY data pairs:   6
```

```
       DEPTH data pairs:   6
       COVER data pairs:  10
-------------------------------------------------------------------------
-------

   VELOCITY           DEPTH           COVER
    0.00   0.7800 ³    0.11   0.0000 ³    0.00   0.0000
    0.17   1.0000 ³    0.74   1.0000 ³    0.10   1.0000
    0.41   1.0000 ³    1.63   1.0000 ³    0.20   1.0000
    0.69   0.5000 ³    2.95   0.5000 ³    0.30   1.0000
    0.95   0.2000 ³    3.46   0.2000 ³    0.40   1.0000
    1.98   0.0000 ³    4.23   0.0000 ³    0.50   0.8000
                  ³                  ³    0.60   0.8000
                  ³                  ³    0.70   0.1000
                  ³                  ³    0.80   0.7000
                  ³                  ³    0.90   0.2000
-------------------------------------------------------------------------
-------
Curve Set ID: 0200003
Species Name: Coho
  Life Stage: Juvenile rearing
  Conditions: Grandy Creek
Attribute 2  Name: COVER
    VELOCITY data pairs:   7
       DEPTH data pairs:   7
       COVER data pairs:  10
-------------------------------------------------------------------------
-------

   VELOCITY           DEPTH           COVER
    0.00   0.7800 ³    0.10   0.0000 ³    0.00   0.0000
    0.15   1.0000 ³    0.25   0.2500 ³    0.10   1.0000
    0.30   0.9600 ³    1.55   0.9000 ³    0.20   1.0000
    0.45   0.3100 ³    2.50   1.0000 ³    0.30   1.0000
    0.60   0.2000 ³    3.25   1.0000 ³    0.40   1.0000
    1.20   0.1600 ³    3.90   0.9000 ³    0.50   0.8000
    2.00   0.0000 ³    4.00   0.2700 ³    0.60   0.8000
                  ³                  ³    0.70   0.1000
                  ³                  ³    0.80   0.7000
                  ³                  ³    0.90   0.2000
-------------------------------------------------------------------------
-------
Curve Set ID: 03000001
Species Name: Steelhead
  Life Stage: Spawning
  Conditions: Grandy Creek
Attribute 1  Name: SUBSTRATE
    VELOCITY data pairs:   9
       DEPTH data pairs:   6
   SUBSTRATE data pairs:  90
-------------------------------------------------------------------------
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   VELOCITY           DEPTH           SUBSTRATE
```


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0.25	0.0000	3	0.65	0.0000	3	31.70	0.0000	3
0.35	0.1000	3	0.75	0.2500	3	31.80	0.4000	3
1.05	0.3000	3	1.25	0.6800	3	31.90	0.4500	3
1.35	0.8800	3	1.85	1.0000	3	32.50	0.0000	3
1.55	1.0000	3	2.35	1.0000	3	32.70	0.0000	3
1.95	1.0000	3	2.75	0.3400	3	32.80	0.4000	3
3.25	0.6200	3			3	32.90	0.4500	3
3.45	0.2800	3			3	33.90	0.5000	3
5.00	0.0000	3			3	34.50	0.7500	3
		3			3	34.90	0.5500	3
		3			3	35.50	0.7500	3
		3			3	35.90	0.5500	3
		3			3	36.50	0.7500	3
		3			3	36.90	0.5500	3
		3			3	37.50	0.4000	3
		3			3	37.90	0.4800	3
		3			3	38.50	0.0000	3
		3			3	38.90	0.0000	3
		3			3	39.50	0.0000	3
		3			3	39.90	0.0000	3
		3			3	41.50	0.0000	3
		3			3	41.70	0.0000	3
		3			3	41.80	0.8000	3
		3			3	41.90	0.9000	3
		3			3	42.50	0.0000	3
		3			3	42.70	0.0000	3
		3			3	42.80	0.8000	3
		3			3	42.90	0.9000	3
		3			3	43.50	0.7500	3
		3			3	43.90	0.9500	3
		3			3	44.90	1.0000	3
		3			3	46.90	1.0000	3
		3			3	47.50	0.6500	3
		3			3	47.90	0.9300	3
		3			3	48.50	0.0000	3
		3			3	48.90	0.0000	3
		3			3	49.50	0.0000	3
		3			3	49.90	0.0000	3
		3			3	51.50	0.0000	3
		3			3	51.70	0.0000	3
		3			3	51.80	0.8000	3
		3			3	51.90	0.9000	3
		3			3	52.50	0.0000	3
		3			3	52.70	0.0000	3
		3			3	52.80	0.8000	3
		3			3	52.90	0.9000	3
		3			3	53.50	0.7500	3
		3			3	53.90	0.9500	3
		3			3	54.50	1.0000	3
		3			3	56.90	1.0000	3
		3			3	57.50	0.6500	3
		3			3	57.90	0.9300	3
		3			3	58.50	0.0000	3
		3			3	58.90	0.0000	3

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                     ³                   ³    59.50    0.0000 ³
                     ³                   ³    59.90    0.0000 ³
                     ³                   ³    61.50    0.0000 ³
                     ³                   ³    61.70    0.0000 ³
                     ³                   ³    61.80    0.8000 ³
                     ³                   ³    61.90    0.9000 ³
                     ³                   ³    62.50    0.0000 ³
                     ³                   ³    62.70    0.0000 ³
                     ³                   ³    62.80    0.8000 ³
                     ³                   ³    62.90    0.9000 ³
                     ³                   ³    63.50    0.7500 ³
                     ³                   ³    63.90    0.9500 ³
                     ³                   ³    64.50    1.0000 ³
                     ³                   ³    66.90    1.0000 ³
                     ³                   ³    67.50    0.6500 ³
                     ³                   ³    67.90    0.9300 ³
                     ³                   ³    68.50    0.0000 ³
                     ³                   ³    68.90    0.0000 ³
                     ³                   ³    69.50    0.0000 ³
                     ³                   ³    71.70    0.0000 ³
                     ³                   ³    71.80    0.2400 ³
                     ³                   ³    71.90    0.2700 ³
                     ³                   ³    72.50    0.0000 ³
                     ³                   ³    72.70    0.0000 ³
                     ³                   ³    72.80    0.2400 ³
                     ³                   ³    72.90    0.2700 ³
                     ³                   ³    73.50    0.4000 ³
                     ³                   ³    73.90    0.3200 ³
                     ³                   ³    74.50    0.6500 ³
                     ³                   ³    74.90    0.3700 ³
                     ³                   ³    75.50    0.6500 ³
                     ³                   ³    75.90    0.3700 ³
                     ³                   ³    76.50    0.6500 ³
                     ³                   ³    76.90    0.3700 ³
                     ³                   ³    77.90    0.3000 ³
                     ³                   ³    78.50    0.0000 ³
-------------------------------------------------------------------------
-------
Curve Set ID: 03000002
Species Name: Steelhead
  Life Stage: Fry Rearing
  Conditions: Grandy Creek
Attribute 2  Name: COVER
    VELOCITY data pairs:   6
       DEPTH data pairs:   6
       COVER data pairs:  10
-------------------------------------------------------------------------
-------

   VELOCITY            DEPTH            COVER
    0.00    0.6900 ³    0.00    0.0000 ³     0.00    0.0000
    0.22    1.0000 ³    0.32    1.0000 ³     0.10    1.0000
    0.29    1.0000 ³    0.67    1.0000 ³     0.20    1.0000
    1.02    0.5000 ³    1.51    0.5000 ³     0.30    1.0000
```


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1.46	0.2000	2.12	0.2000	0.40	1.0000
2.76	0.0000	4.45	0.0000	0.50	0.3000
				0.60	0.1000
				0.70	0.4000
				0.80	0.7000
				0.90	0.2000

```
Curve Set ID: 03000003
Species Name: Steelhead
  Life Stage: Juvenile rearing
  Conditions: Grandy Creek
Attribute 2  Name: COVER
    VELOCITY data pairs:   9
       DEPTH data pairs:   4
       COVER data pairs:  10
```

VELOCITY		DEPTH		COVER	
0.00	0.5500	0.15	0.0000	0.00	0.0000
0.75	1.0000	0.65	0.1000	0.10	1.0000
0.95	1.0000	1.35	0.6300	0.20	1.0000
1.15	0.8700	2.65	1.0000	0.30	1.0000
1.55	0.7800			0.40	1.0000
1.85	0.5400			0.50	0.8000
3.15	0.3000			0.60	0.8000
3.85	0.0700			0.70	0.1000
5.00	0.0000			0.80	0.7000
				0.90	0.2000

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Appendix C: Transect Profiles, Calibration Flow Velocities, and Water Surface Elevations

The calibration flows were measured at each transect. The Figure C1 dedicts the transect locations and the Tables C1 and C2 itemizes the average water surface elevation (WSEL), measured discharge, and date of measurements. Values are in feet and feet/second.

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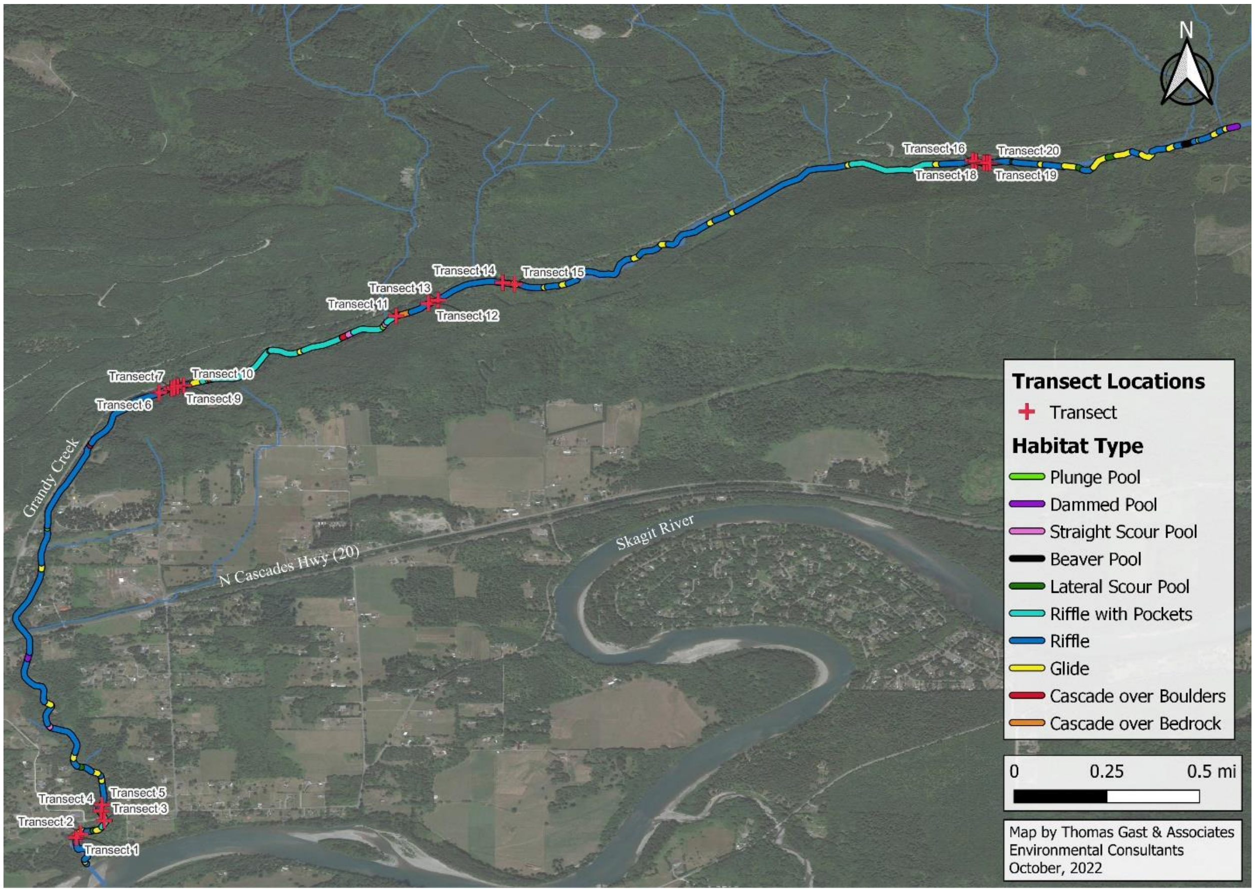

Figure C1. Transect location map.

Table C1. Lower Reach calibration flows and average water surface elevations (WSEL).

	Cross-section	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Habitat		Riffle	Glide	Riffle w/pockets	Riffle	Riffle	Riffle	Riffle w/pockets	Pool	Riffle	Riffle
Discharge	High	46.11	48.88	49.48	49.70	51.39	50.56	52.77	57.76	55.40	65.73
	Mid2/3	30.38	34.94	35.96	33.34	33.20	40.60	43.16	42.49	34.48	41.36
	Low	8.28	7.63	8.09	7.38	7.13	7.63	6.69	8.94	8.18	8.52
WSEL	High	95.94	93.57	99.08	95.38	96.18	97.65	97.59	98.02	100.84	101.87
	Mid2/3	95.87	93.44	98.83	95.28	96.01	97.54	97.46	97.77	100.68	101.77
	Low2	95.63	93.09	98.39	94.84	95.77	97.03	96.88	97.01	100.20	101.28
Date	High	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023	3/15/2023
	Mid2	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023	6/7/2023
	Low2	10/11/23	10/11/23	10/11/2023	10/11/23	10/11/203	10/12/23	10/12/23	10/12/23	10/12/23	10/12/23

Table C2. Upper Reach calibration flows and water surface elevations (WSEL).

	Cross-section	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20
Habitat		Riffle w/pockets	Riffle	Riffle	Riffle	Glide	Riffle	Riffle	Pool	Riffle	Riffle
Discharge	High	40.76	51.34	39.53	35.46	37.47	22.28	22.22	25.84	21.80	25.46
	Mid2/3	12.18	11.71	9.94	8.44	9.25	7.04	8.44	7.89	7.03	7.93
	Low	6.80	5.89	4.59	5.34	4.63	3.79	4.09	3.51	3.71	4.88
WSEL	High	98.29	96.93	101.17	97.75	95.97	97.19	98.51	96.74	97.59	98.68
	Low	97.35	96.20	100.55	96.58	95.89	96.87	98.14	96.40	97.10	98.25
	Low2	97.44	96.19	100.50	97.17	95.44	96.78	97.99	96.09	97.23	98.19
Date	High	3/15/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023	3/16/2023
	Mid2	7/7/2023	7/7/2023	7/7/2023	7/7/2023	7/7/2023	7/6/2023	7/6/2023	7/6/2023	7/6/2023	7/6/2023
	Low2	10/11/23	10/12/23	10/12/23	10/12/23	10/12/23	10/11/23	10/13/23	10/13/23	10/13/23	10/12/23

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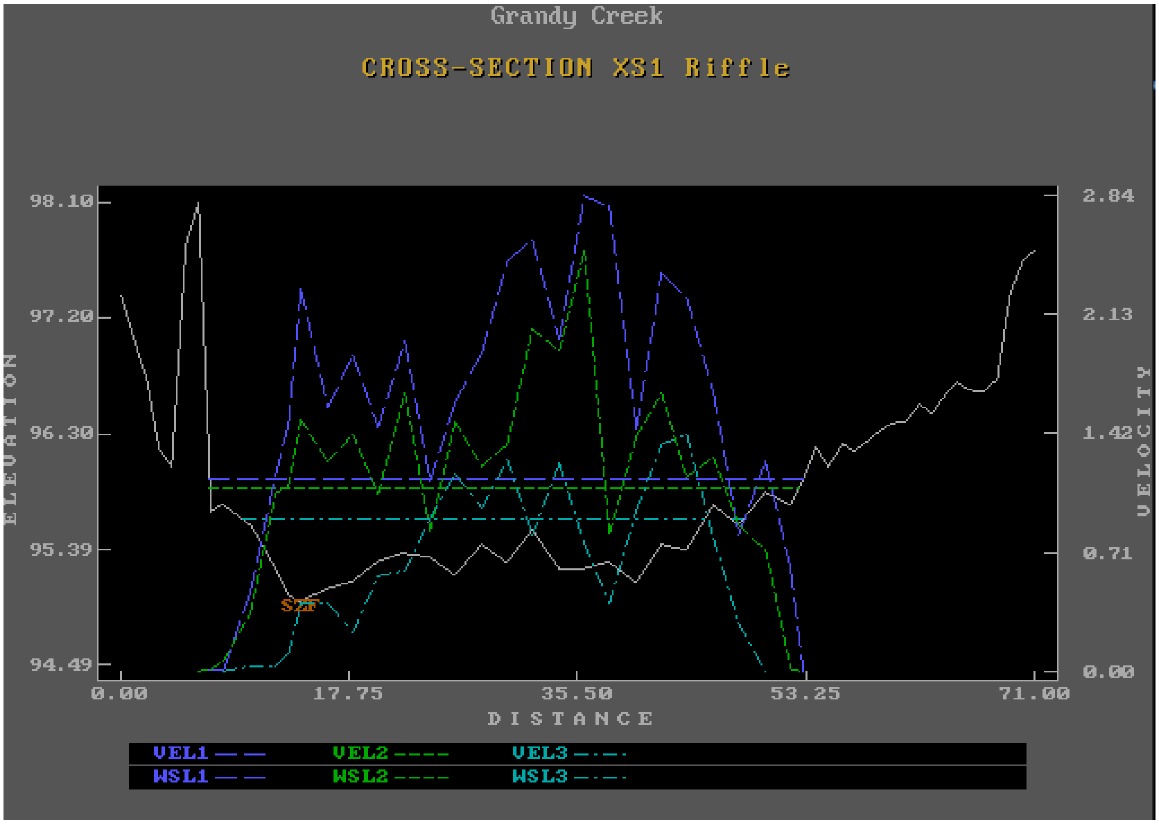

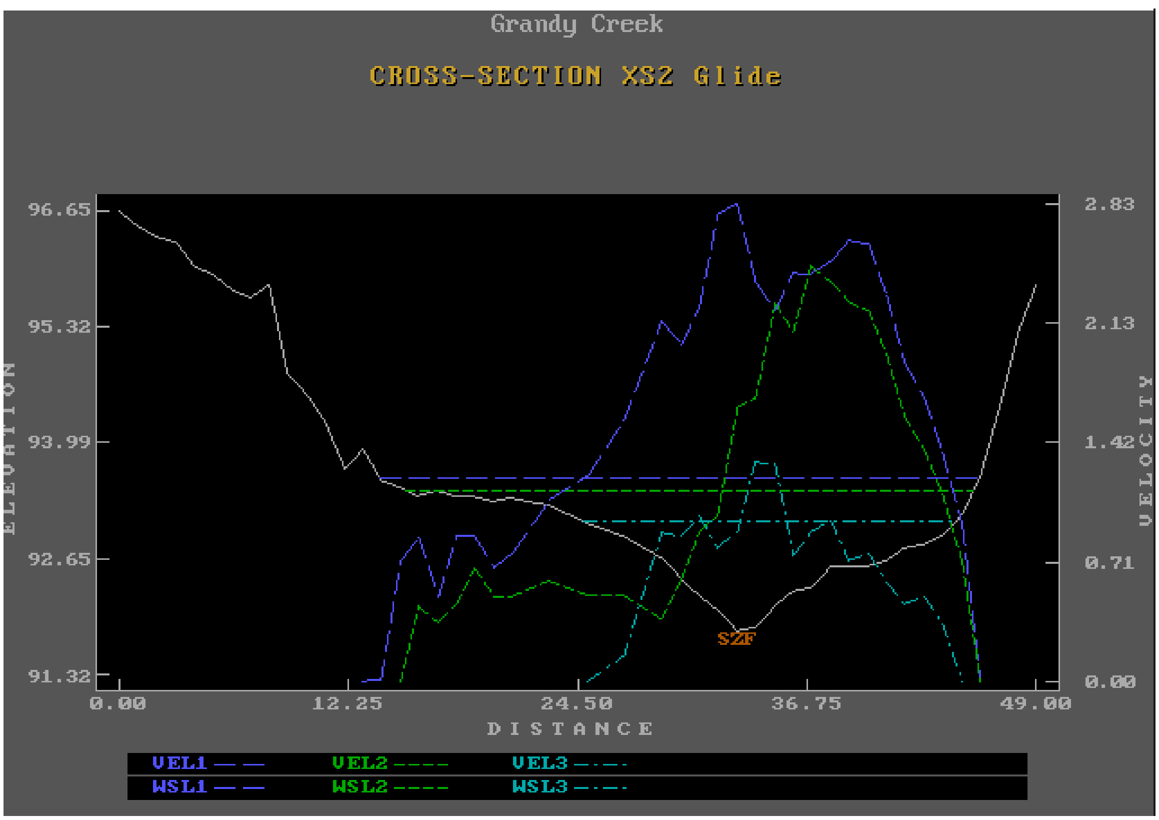

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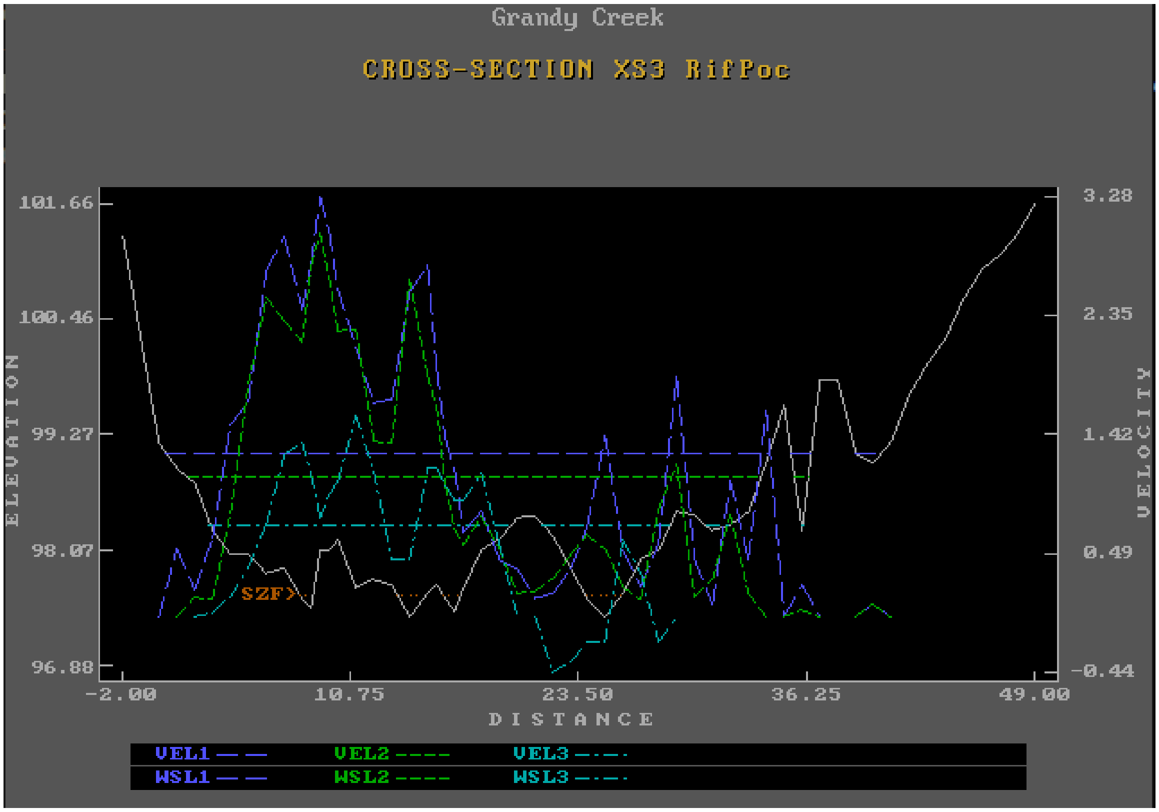

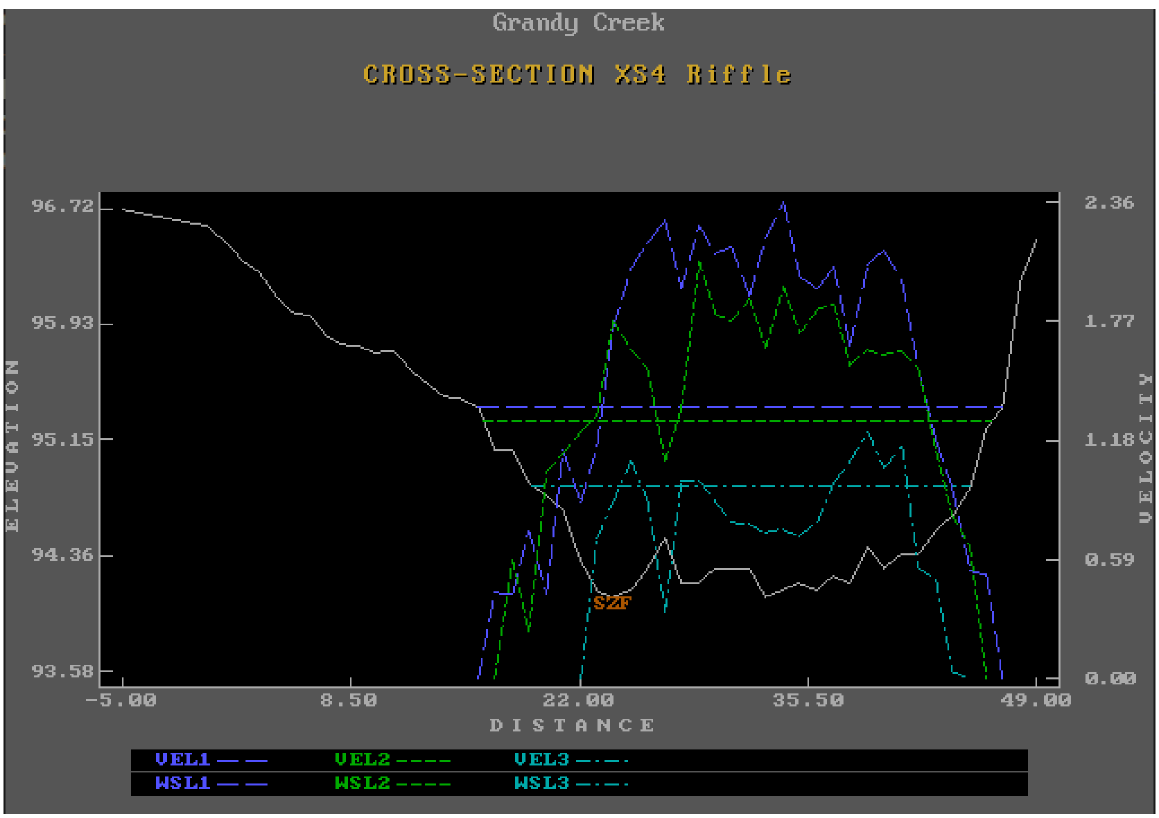

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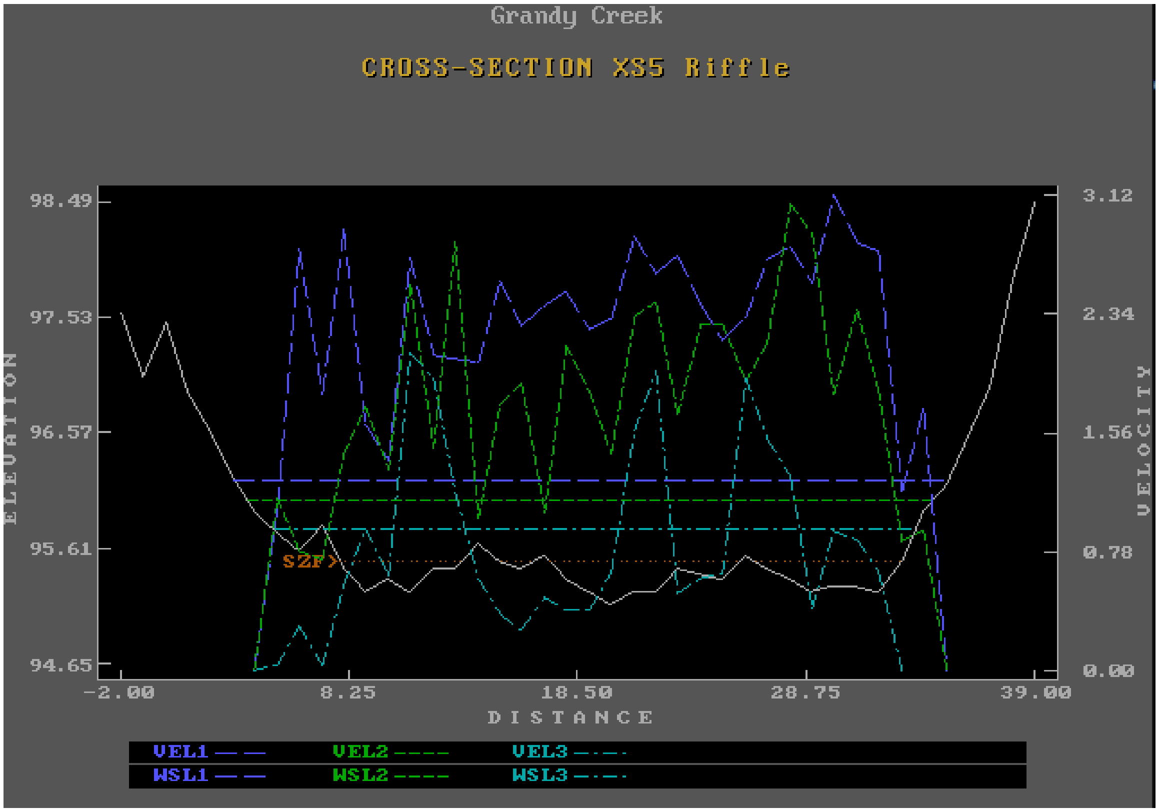

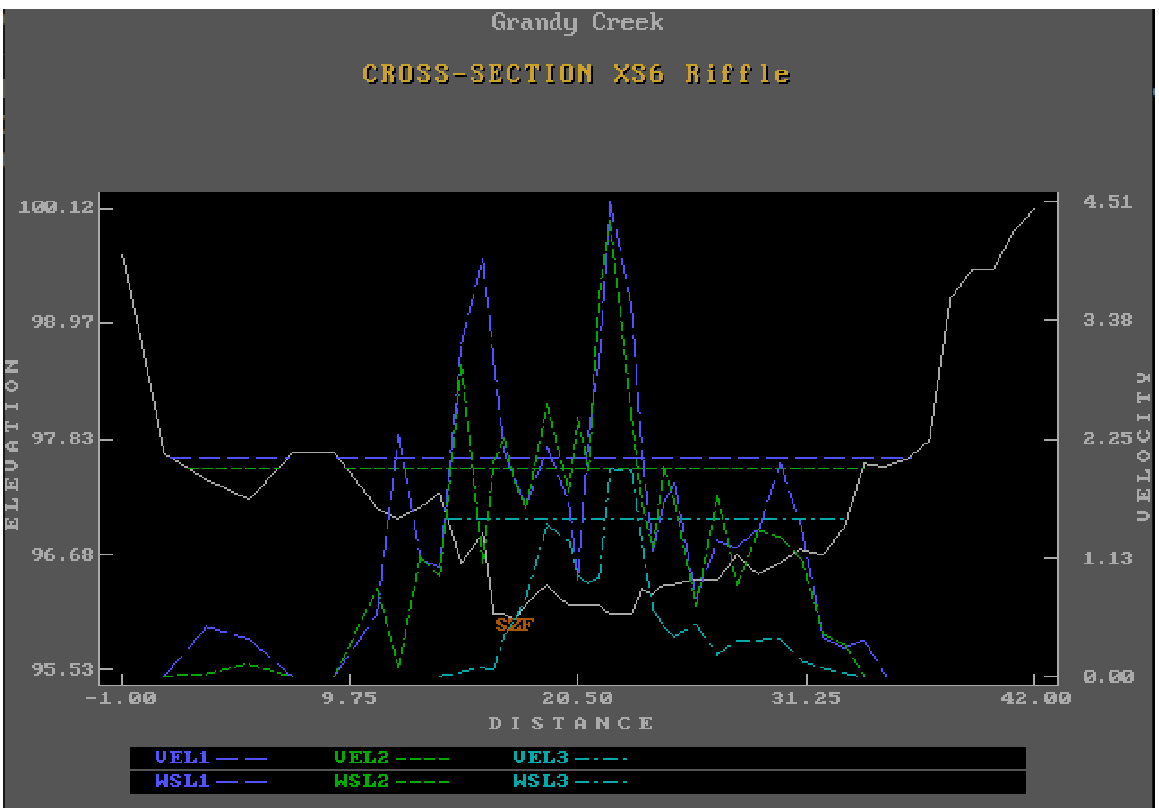

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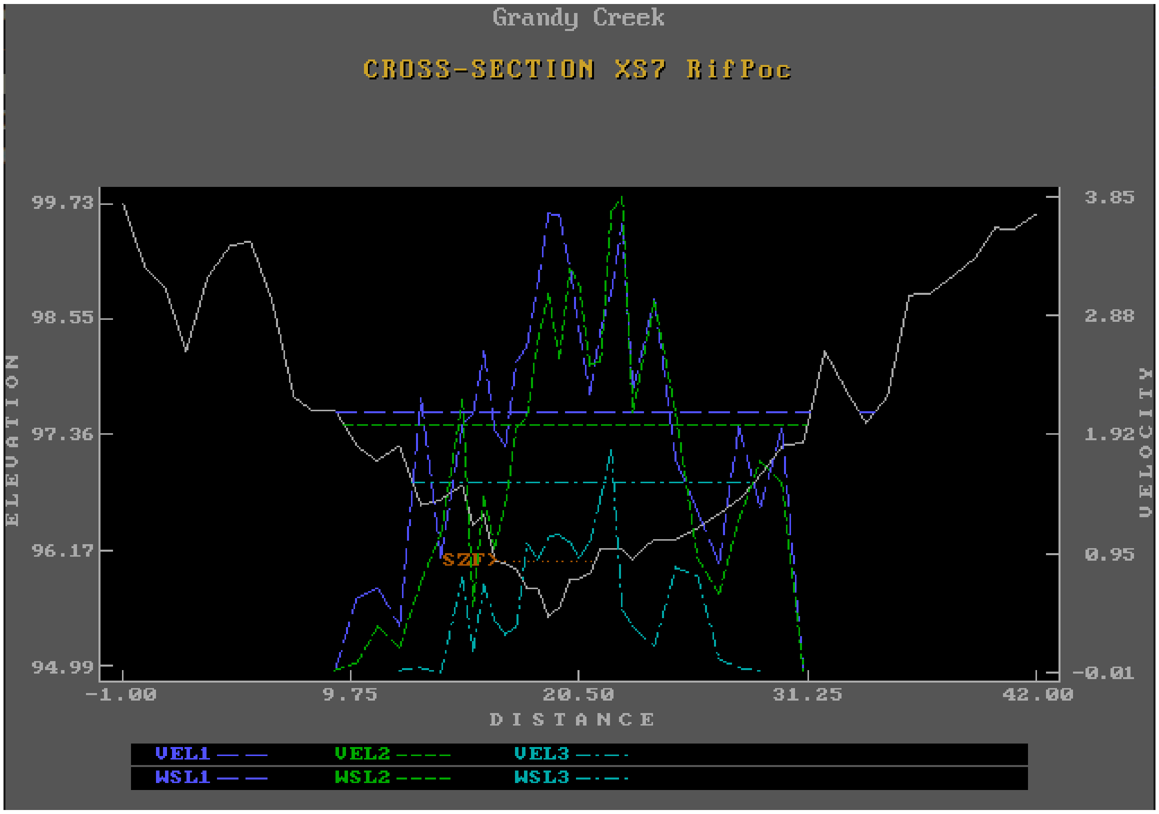

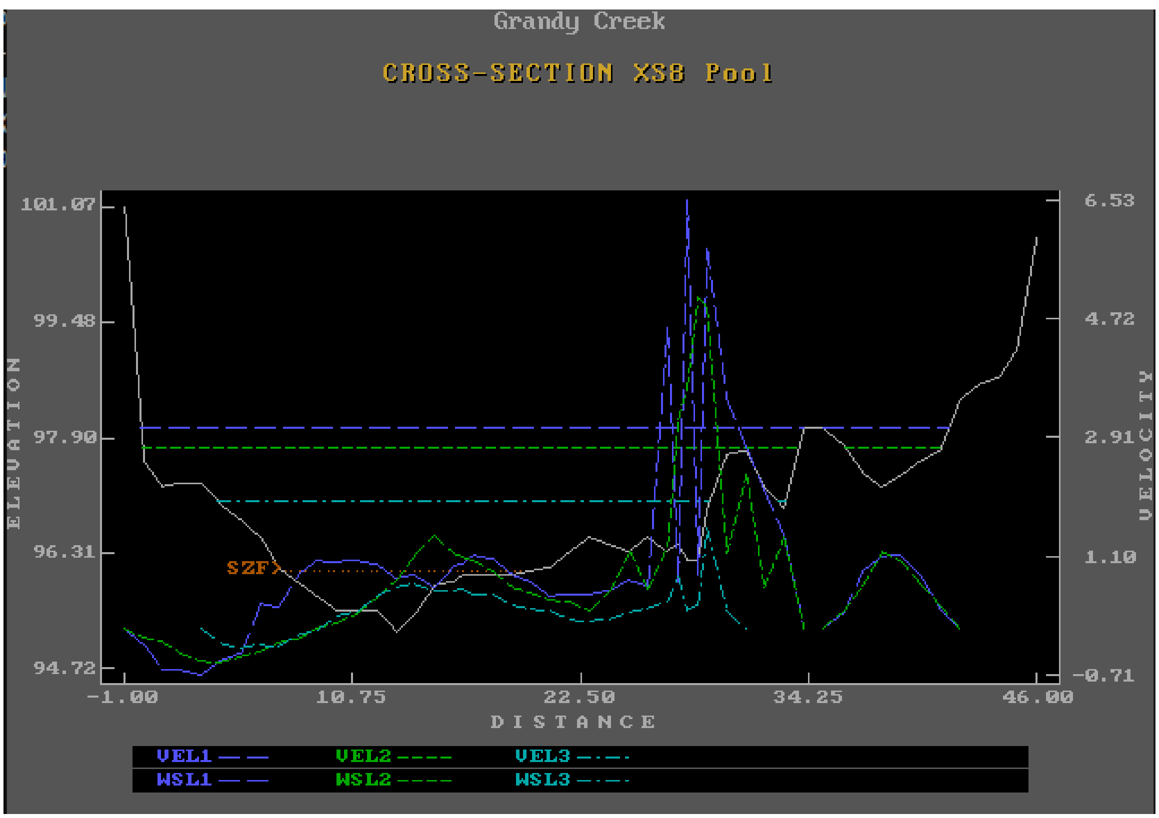

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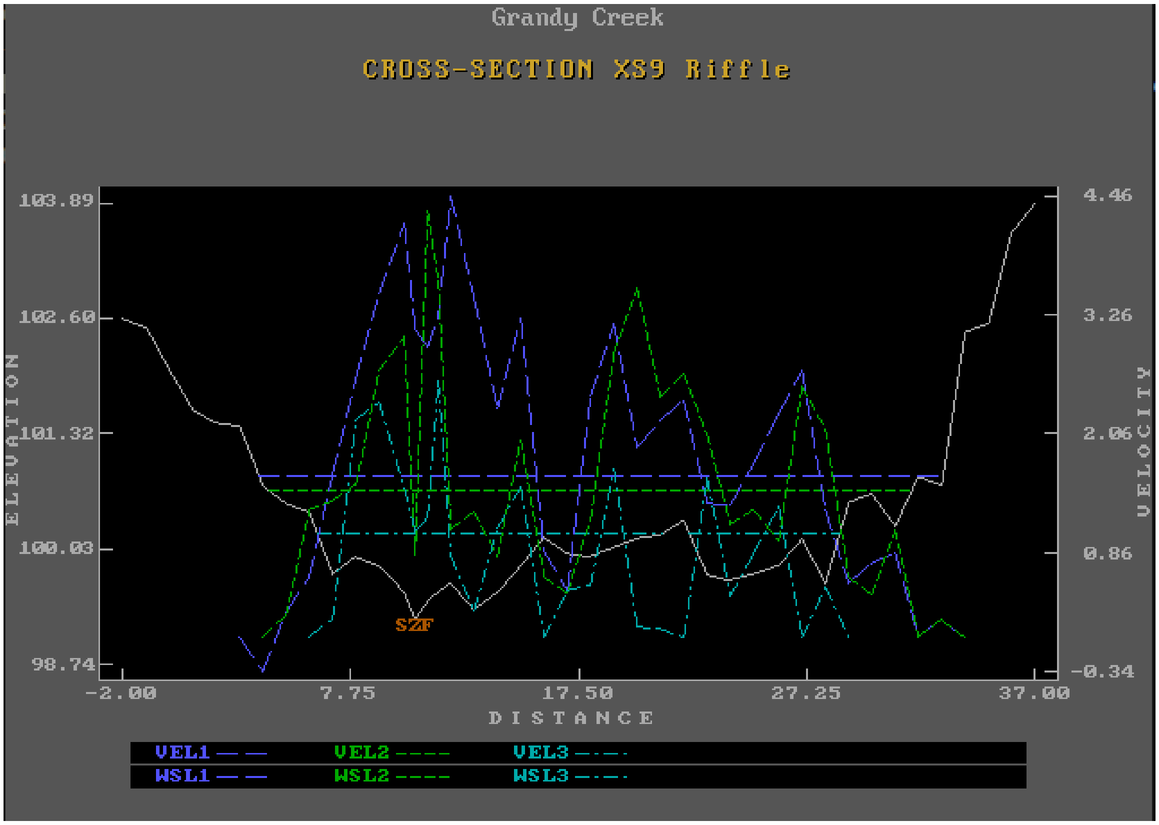

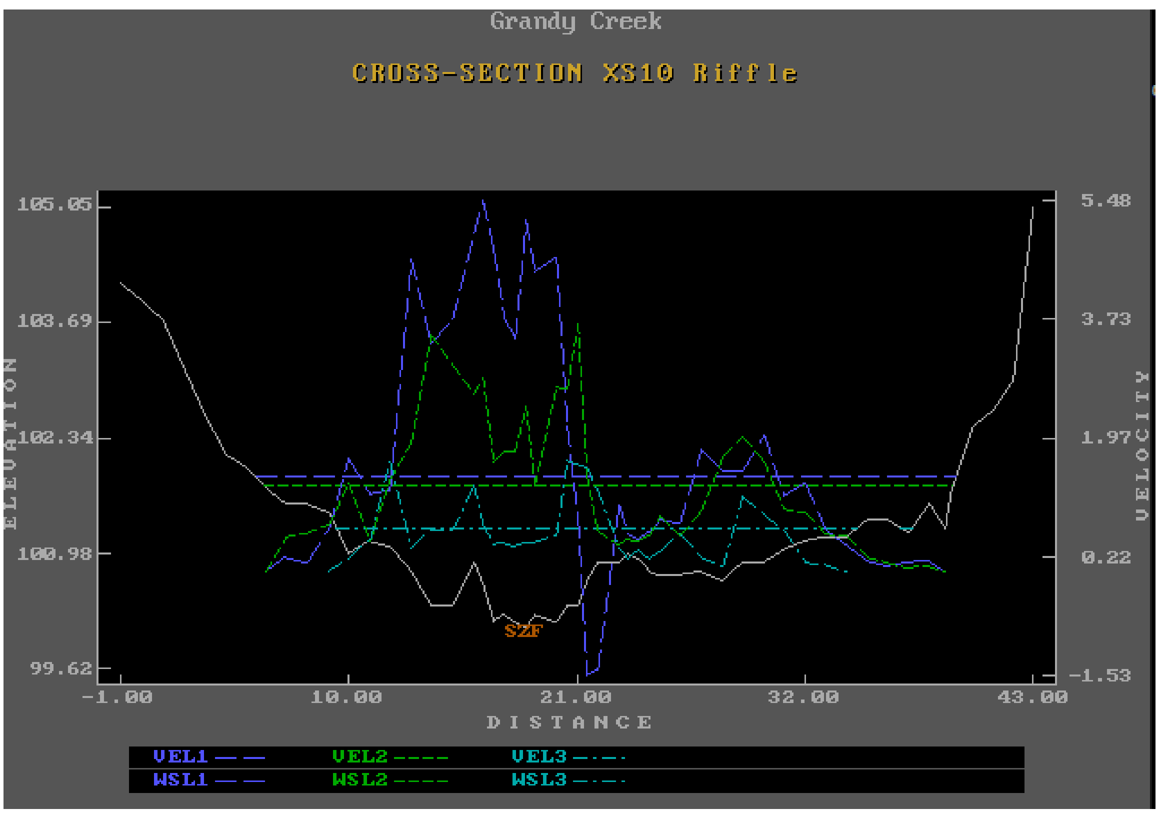

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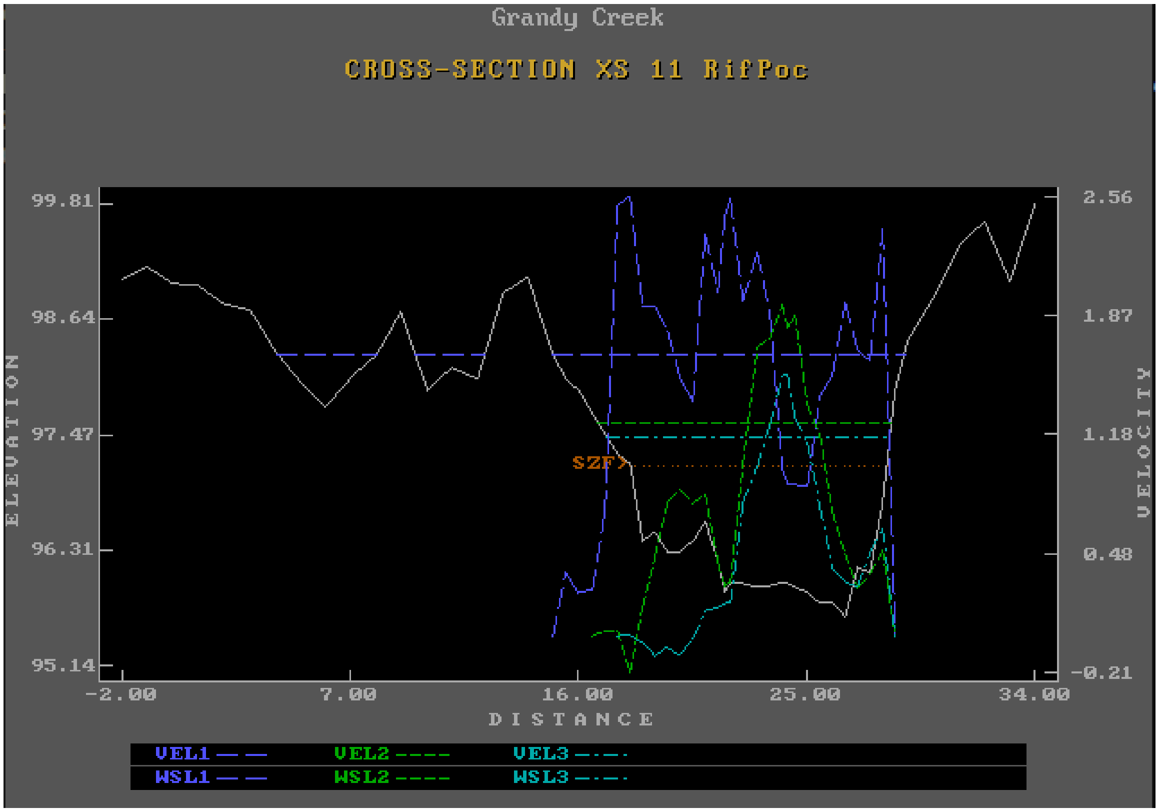
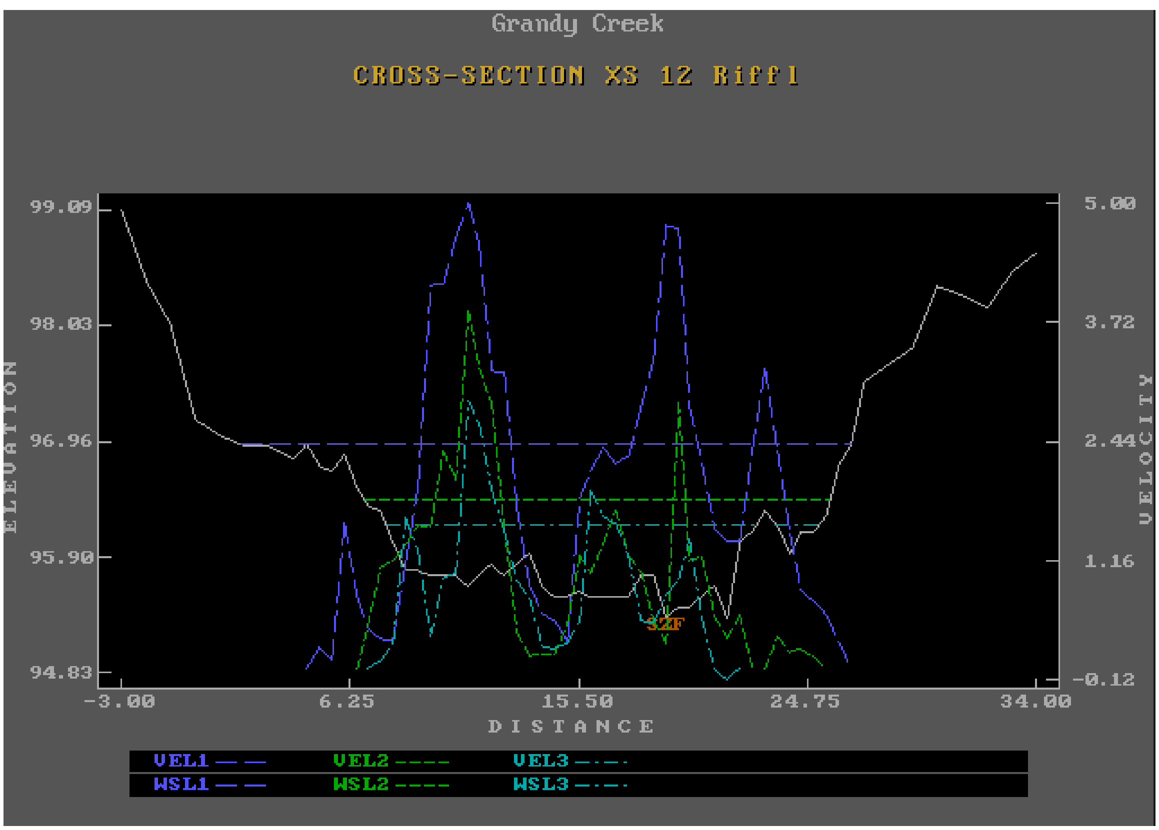
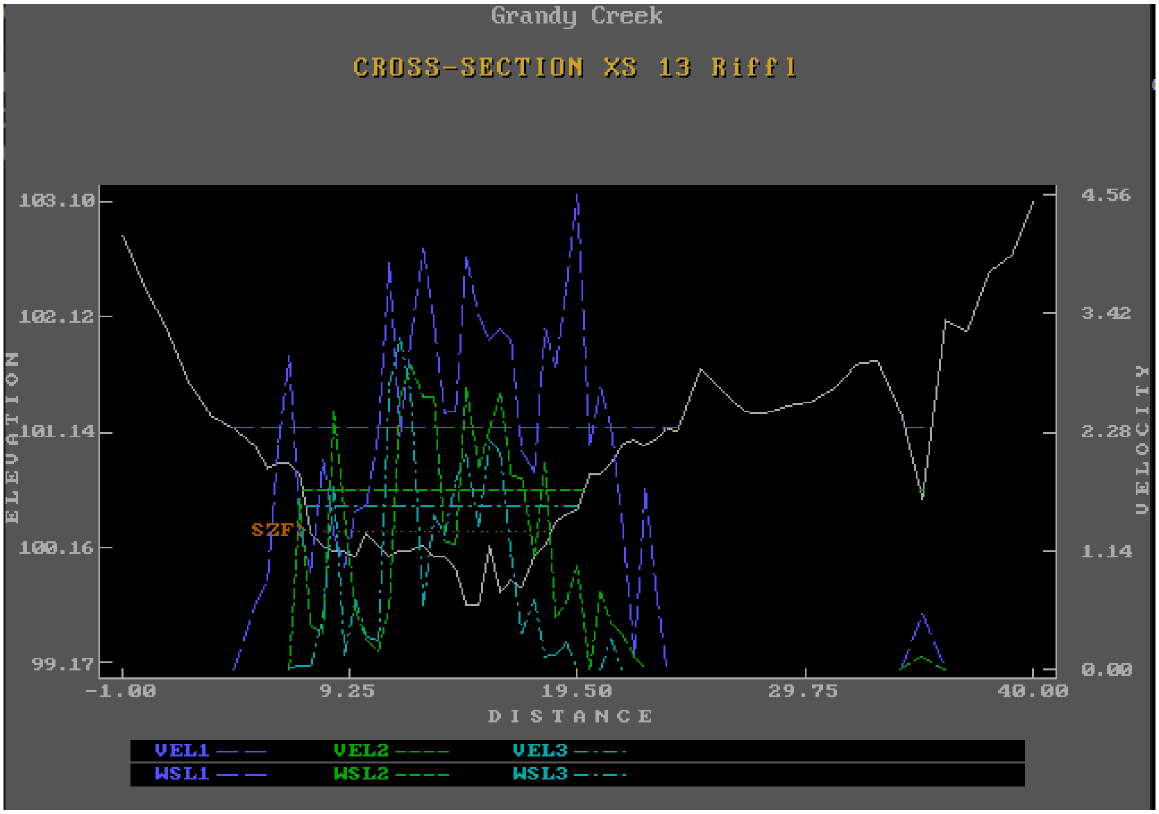
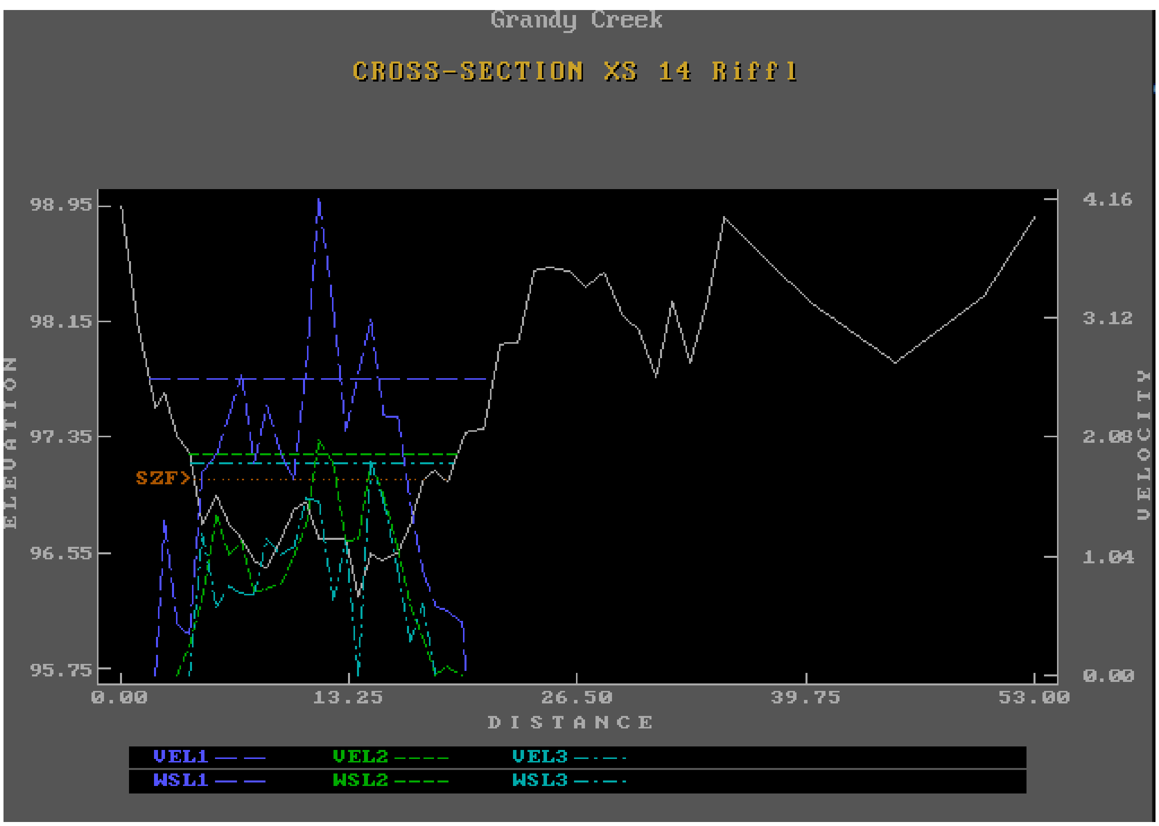

Grandy Creek
CROSS-SECTION XS 11 RifPoc
99.81
98.64
97.47
96.31
95.14
ELEVATION
2.56
1.87
1.18
0.48
-0.21
VELOCITY
SZF
-2.00
7.00
16.00
25.00
34.00
DISTANCE
VEL1
VEL2
VEL3
WSL1
WSL2
WSL3


Grandy Creek
CROSS-SECTION XS 12 Riff1
99.09
98.03
96.96
95.90
94.83
ELEVATION
5.00
3.72
2.44
1.16
-0.12
VELOCITY
SZF
-3.00
6.25
15.50
24.75
34.00
DISTANCE
VEL1
VEL2
VEL3
WSL1
WSL2
WSL3





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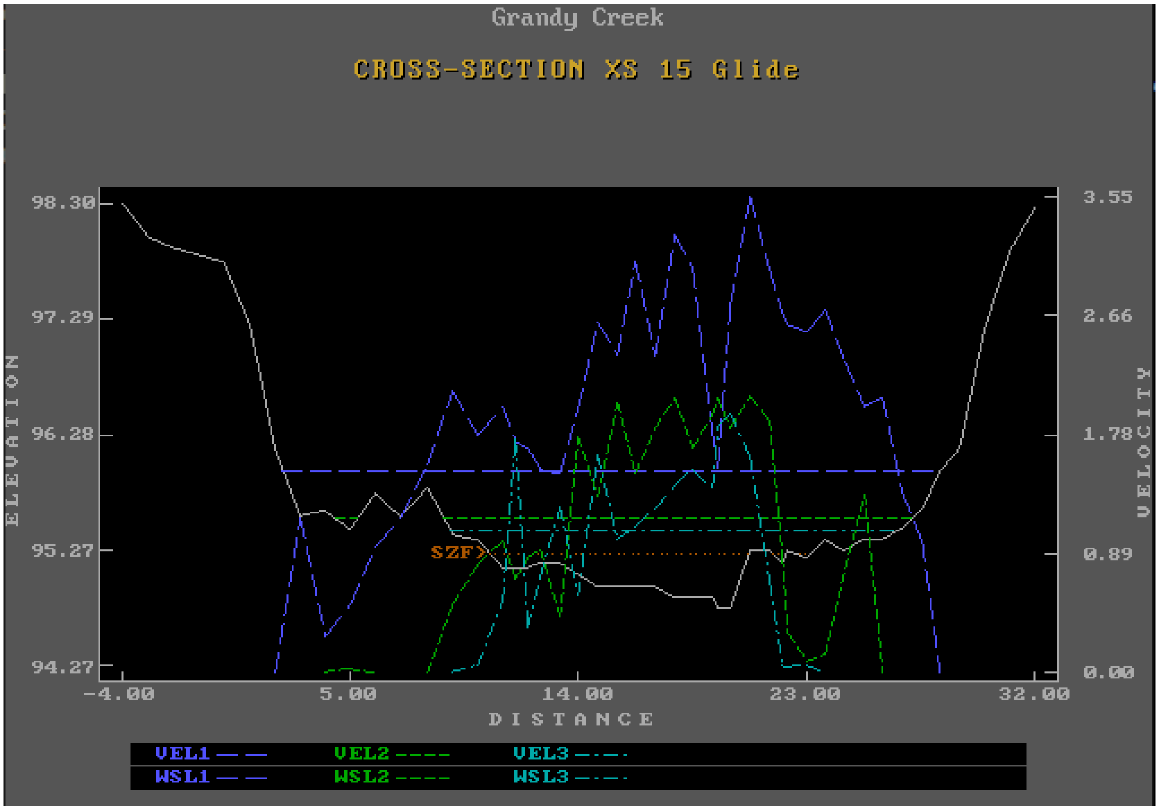

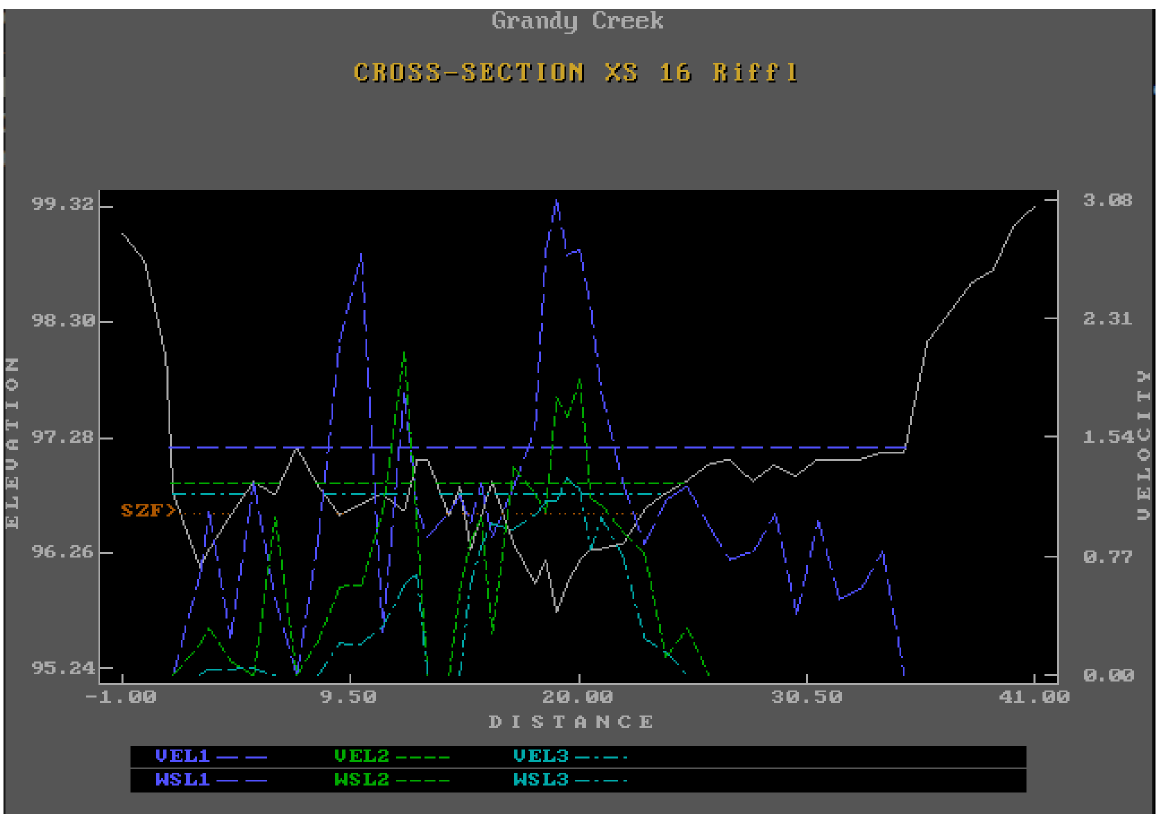

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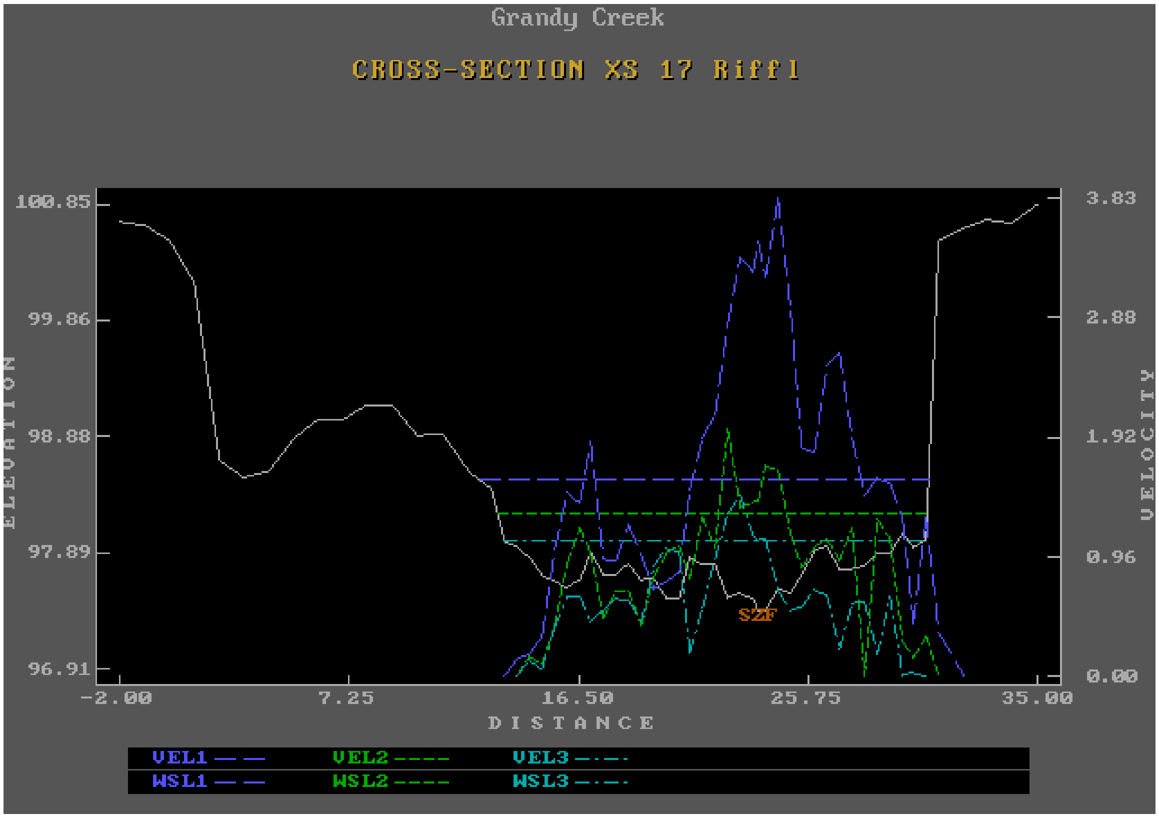

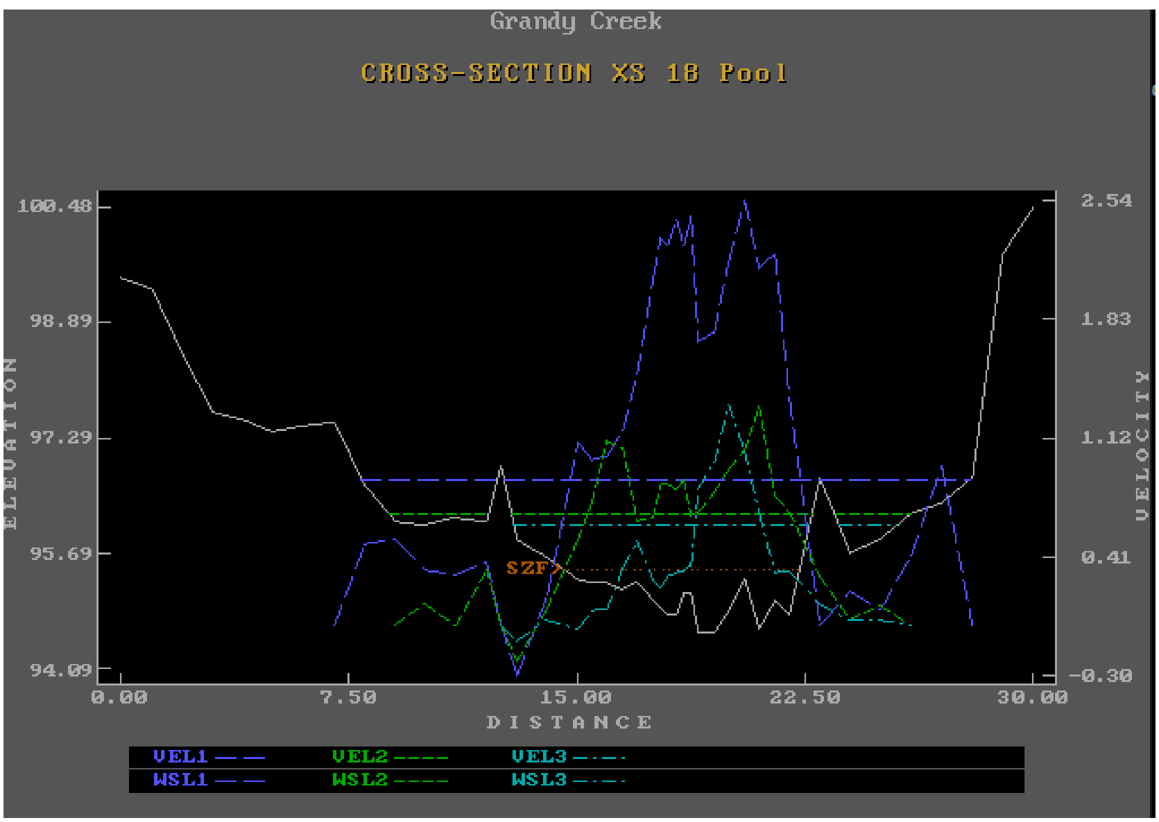

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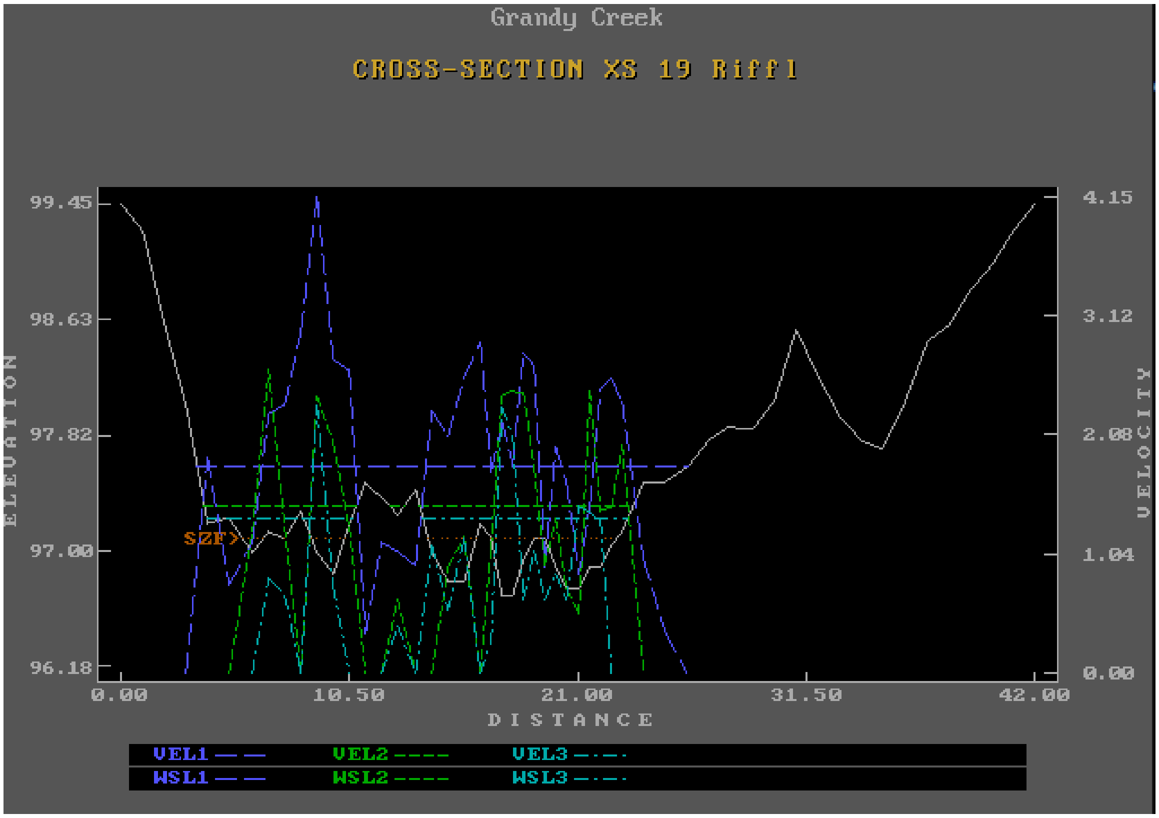

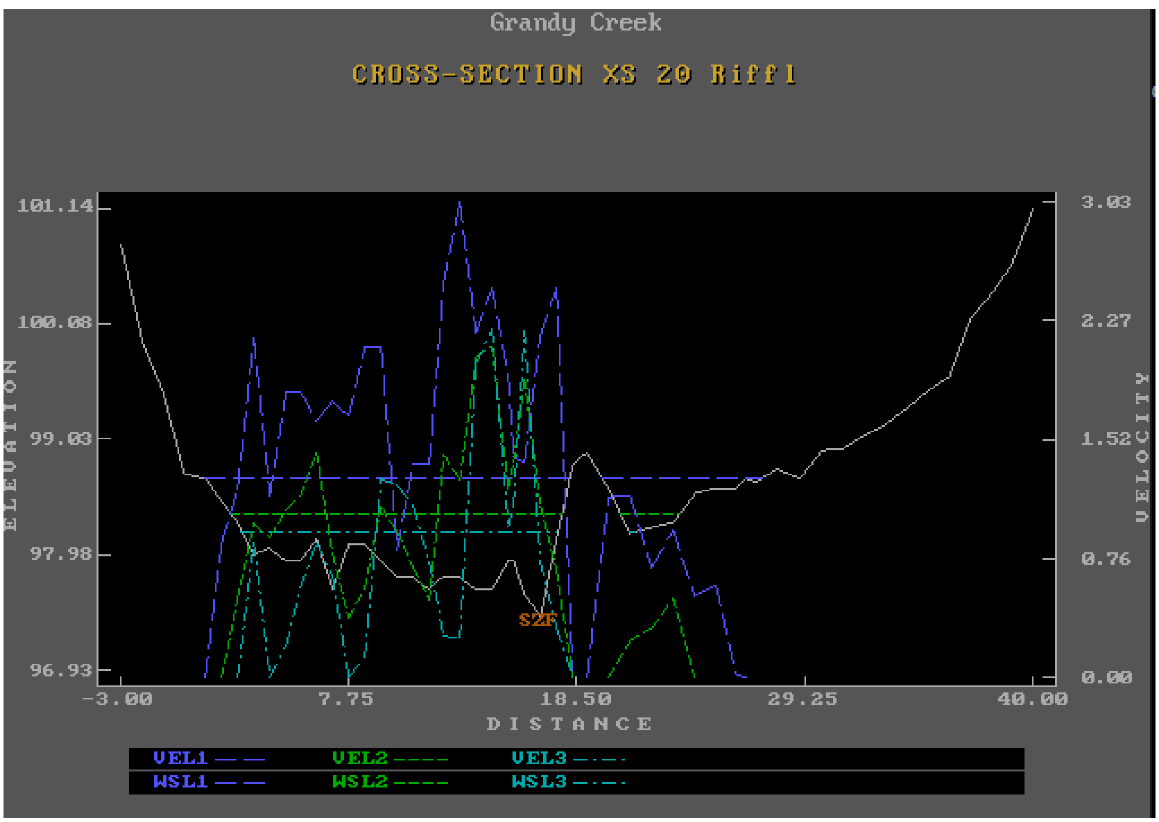

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Appendix D: PHABSIM Calibration Summaries

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Lower Reach, 10 cross sections, feet

```
-----------------------------------------------------------------------------
-----
Units: U.S.

Number of Calibration Flows: 30
-----------------------------------------------------------------------------
-----
CROSS-SECTION #   1  XS1 Riffle
Points = 51
 Slope = .0025
   SZF = 94.99

Weighting Factor = 1
Cross-section represents  11.250% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .3843521
Log/Log Regression B =  .238753
WSL = 0.3844 * Flow ^ 0.2388 + 94.99

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2

-----------------------------------------------------------------------------
-----
CROSS-SECTION #   2  XS2 Glide
Points = 46
 Slope = .0025
   SZF = 91.82

Weighting Factor = 1
Cross-section represents   7.370% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .8872716
Log/Log Regression B =  .1755957
WSL = 0.8873 * Flow ^ 0.1756 + 91.82

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
```

```
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2

-------------------------------------------------------------------------
-----
CROSS-SECTION #   3  XS3 RifPoc
Points = 56
 Slope = .0025
   SZF = 97.6

Weighting Factor = 1
Cross-section represents  11.140% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .3345035
Log/Log Regression B =  .3734553
WSL = 0.3345 * Flow ^ 0.3735 + 97.60

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2

-------------------------------------------------------------------------
-----
CROSS-SECTION #   4  XS4 Riffle
Points = 51
 Slope = .0025
   SZF = 94.08

Weighting Factor = 1
Cross-section represents  11.250% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .4304823
Log/Log Regression B =  .2870203
WSL = 0.4305 * Flow ^ 0.2870 + 94.08

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
```


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```
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2

--------------------------------------------------------------------------
-----
CROSS-SECTION #   5  XS5 Riffle
Points = 42
 Slope = .0025
   SZF = 95.5

Weighting Factor = 1
Cross-section represents  11.250% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: Yes
BETA = .3816


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2

--------------------------------------------------------------------------
-----
CROSS-SECTION #   6  XS6 Riffle
Points = 45
 Slope = .0025
   SZF = 96.03

Weighting Factor = 1
Cross-section represents  11.250% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: Yes
BETA = .3698142


   >>> Velocity Calibrations <<<
Vel Calculation Method: 1-vel calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
```


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```
Vels calibrated to VelSet:  1

----------------------------------------------------------------------------
-----
CROSS-SECTION #   7  XS7 RifPoc
Points = 52
 Slope = .0025
   SZF = 96.062

Weighting Factor = 1
Cross-section represents  11.140% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .4598519
Log/Log Regression B =  .2988865
WSL = 0.4599 * Flow ^ 0.2989 + 96.06

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2

----------------------------------------------------------------------------
-----
CROSS-SECTION #   8  XS8 Pool
Points = 51
 Slope = .0025
   SZF = 96.06

Weighting Factor = 1
Cross-section represents   2.890% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .4114316
Log/Log Regression B =  .3830028
WSL = 0.4114 * Flow ^ 0.3830 + 96.06

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2
```


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```
----------------------------------------------------------------------------
-----
CROSS-SECTION #   9  XS9 Riffle
Points = 42
 Slope = .0025
   SZF = 99.24

Weighting Factor = .5
Cross-section represents  11.250% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .5489275
Log/Log Regression B =  .2690174
WSL = 0.5489 * Flow ^ 0.2690 + 99.24

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2

----------------------------------------------------------------------------
-----
CROSS-SECTION #  10  XS10 Riffle
Points = 53
 Slope = .0025
   SZF = 100.124

Weighting Factor = 0
Cross-section represents  11.250% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: Yes
BETA = .421018


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 2
```

Upper Reach, 10 cross sections, feet

```
CROSS-SECTION #   1  XS 11 RifPoc
Points = 53
 Slope = .0025
   SZF = 97.15833

Weighting Factor = 1
Cross-section represents  10.390% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  6.320876E-02
Log/Log Regression B =  .7776599
WSL = 0.0632 * Flow ^ 0.7777 + 97.16

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   2  XS 12 Riffl
Points = 61
 Slope = .0025
   SZF = 95.332

Weighting Factor = 1
Cross-section represents  10.330% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: No
BETA = .3178326


   >>> Velocity Calibrations <<<
Vel Calculation Method: 1-vel calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Vels calibrated to VelSet:  1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   3  XS 13 Riffl
```

```
Points = 61
 Slope = .0025
   SZF = 100.2931

Weighting Factor = 1
Cross-section represents  10.330% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: No
BETA = .2650869


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   4  XS 14 Riffl
Points = 47
 Slope = .0025
   SZF = 97.05817

Weighting Factor = 1
Cross-section represents  10.330% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: No
BETA = .2939788


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   5  XS 15 Glide
```


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```
Points = 46
 Slope = .0025
   SZF = 95.2361

Weighting Factor = 1
Cross-section represents  14.220% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  8.076636E-02
Log/Log Regression B =  .6075218
WSL = 0.0808 * Flow ^ 0.6075 + 95.24

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   6  XS 16 Riffl
Points = 50
 Slope = .0025
   SZF = 96.60818

Weighting Factor = 1
Cross-section represents  10.330% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: No
BETA = .2951924


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   7  XS 17 Riffl
Points = 57
```


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```
 Slope = .0025
   SZF = 97.405

Weighting Factor = 1
Cross-section represents  10.330% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: No


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   8  XS 18 Pool
Points = 42
 Slope = .0025
   SZF = 95.47

Weighting Factor = 1
Cross-section represents   3.110% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Log/Log Regression
Log/Log Regression A =  .349214
Log/Log Regression B =  .3884409
WSL = 0.3492 * Flow ^ 0.3884 + 95.47

   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
Log/Log Regression Vels from Two-Stage/Discharge Method (IOC8=2).
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #   9  XS 19 Riffl
Points = 53
 Slope = .0025
   SZF = 97.08308
```

```
Weighting Factor = .4999999
Cross-section represents  10.330% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: No
BETA = .1964739


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
CROSS-SECTION #  10  XS 20 Riffl
Points = 52
 Slope = .0025
   SZF = 97.425

Weighting Factor = 0
Cross-section represents  10.330% of Total Reach.

   >>> WSL Calibrations <<<
WSL Calculation Method: Channel Conveyance
Channel Conveyance Equation: Manning N
Use Weighted Area Hydraulic Radius: Yes
Reduce Hydraulic Radius to HR at S.Z.F.: No
BETA = .1636742


   >>> Velocity Calibrations <<<
Vel Calculation Method: Regression calibration
Vel Algorithm: Manning's N
Use Given N's: Yes
BETA =-.1
IOC14: B = avg of cells with 3+ given vels for cells with 1+ given
vel(s).
BMAX = 1

-------------------------------------------------------------------------
-----
```

Appendix E: Simulated Water Surface Elevations and Velocities

The elevations presented in these figures are relative to an arbitrary benchmark with a given elevation of 100 feet. Distances are from the left bank headpin looking upstream, in feet. Velocities are in feet per second. Green-lined plots were simulated with three flow regression, blue-lined plots were simulated with Manning's Equation.

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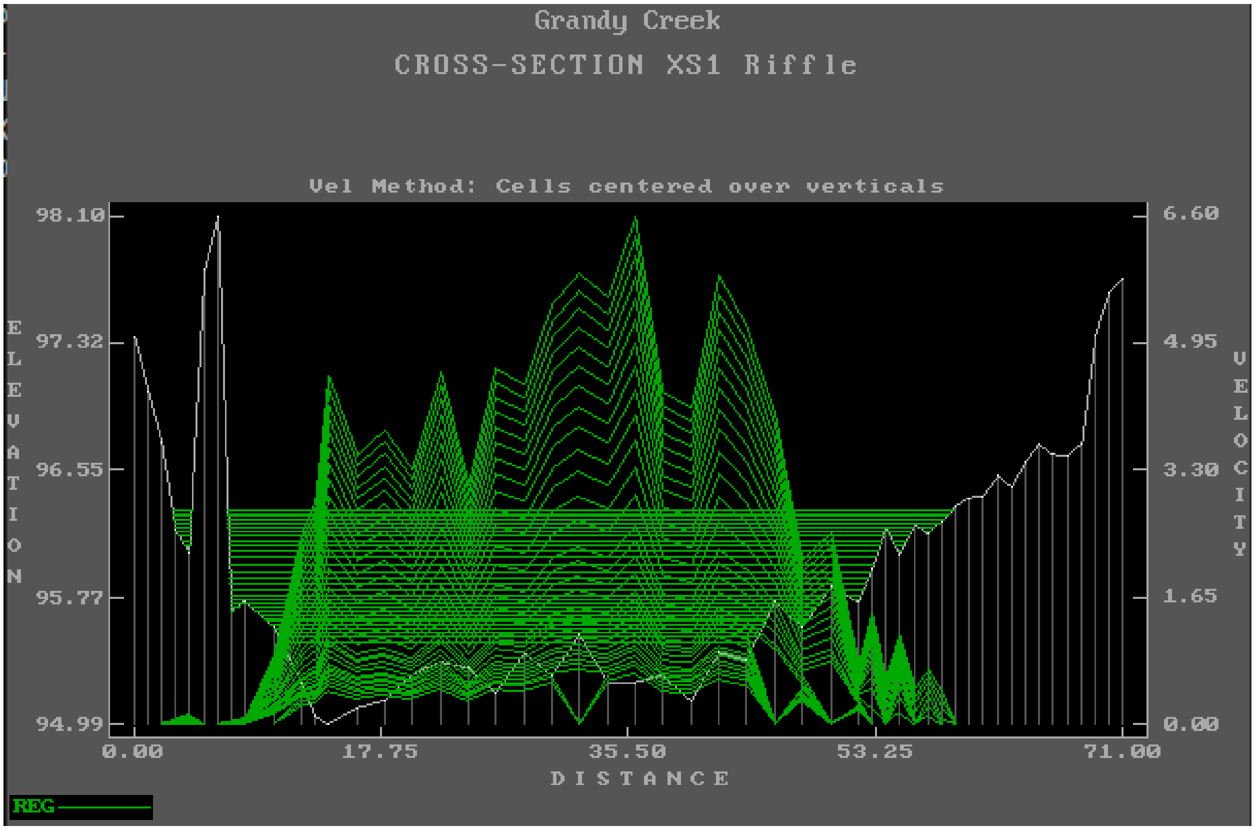

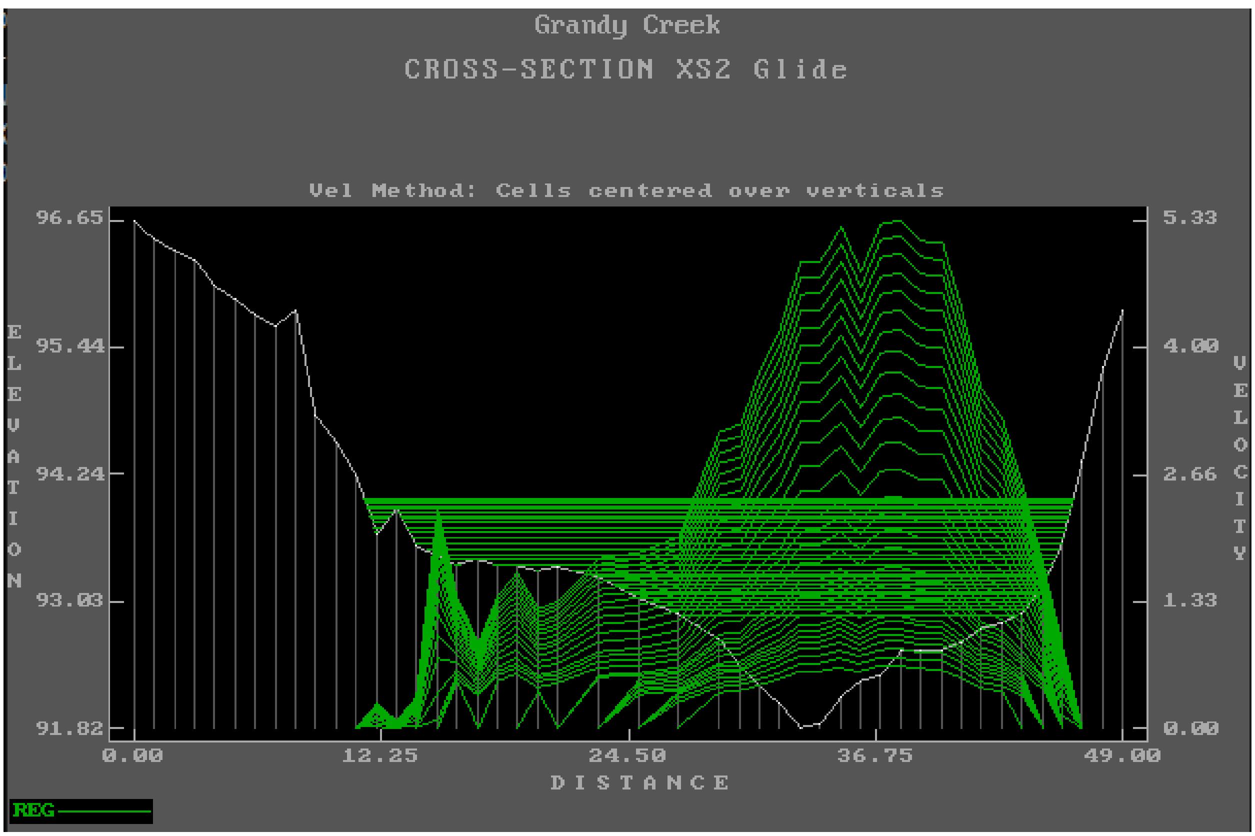

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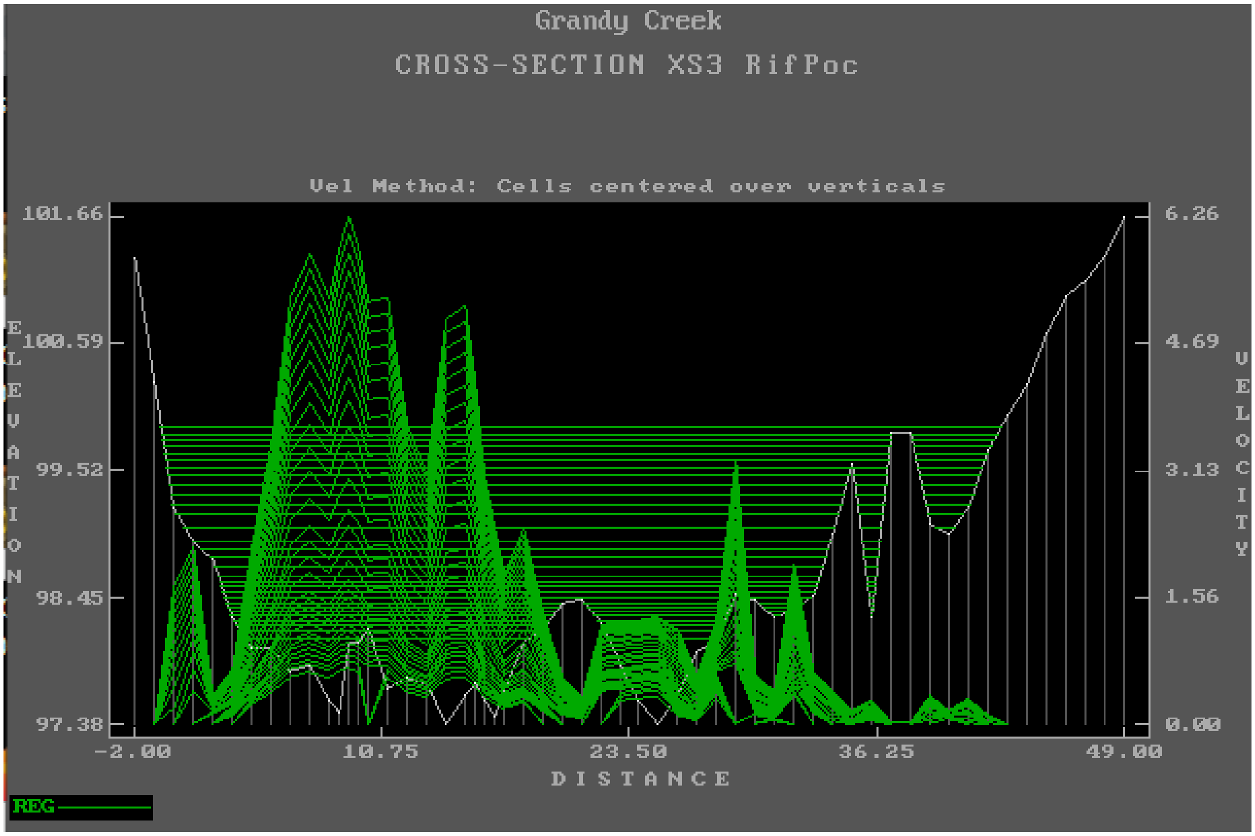

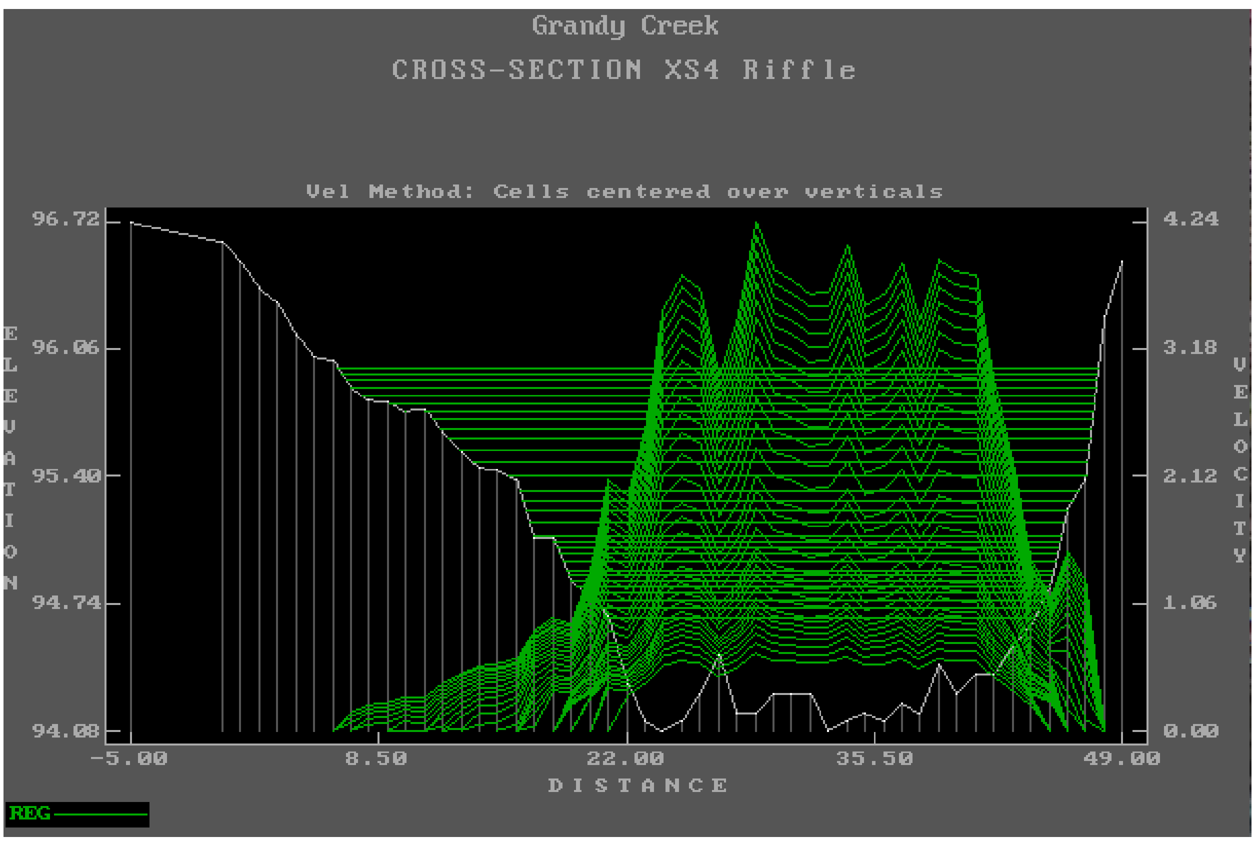

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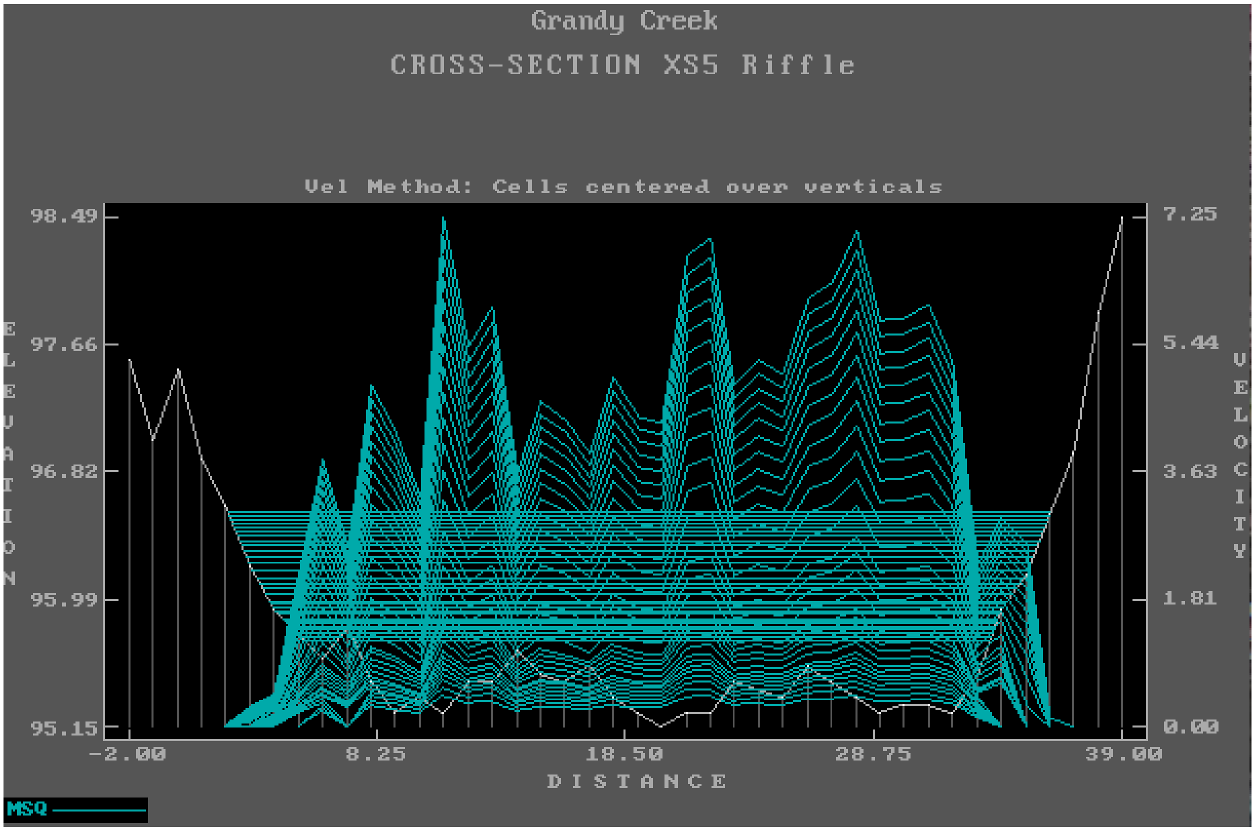

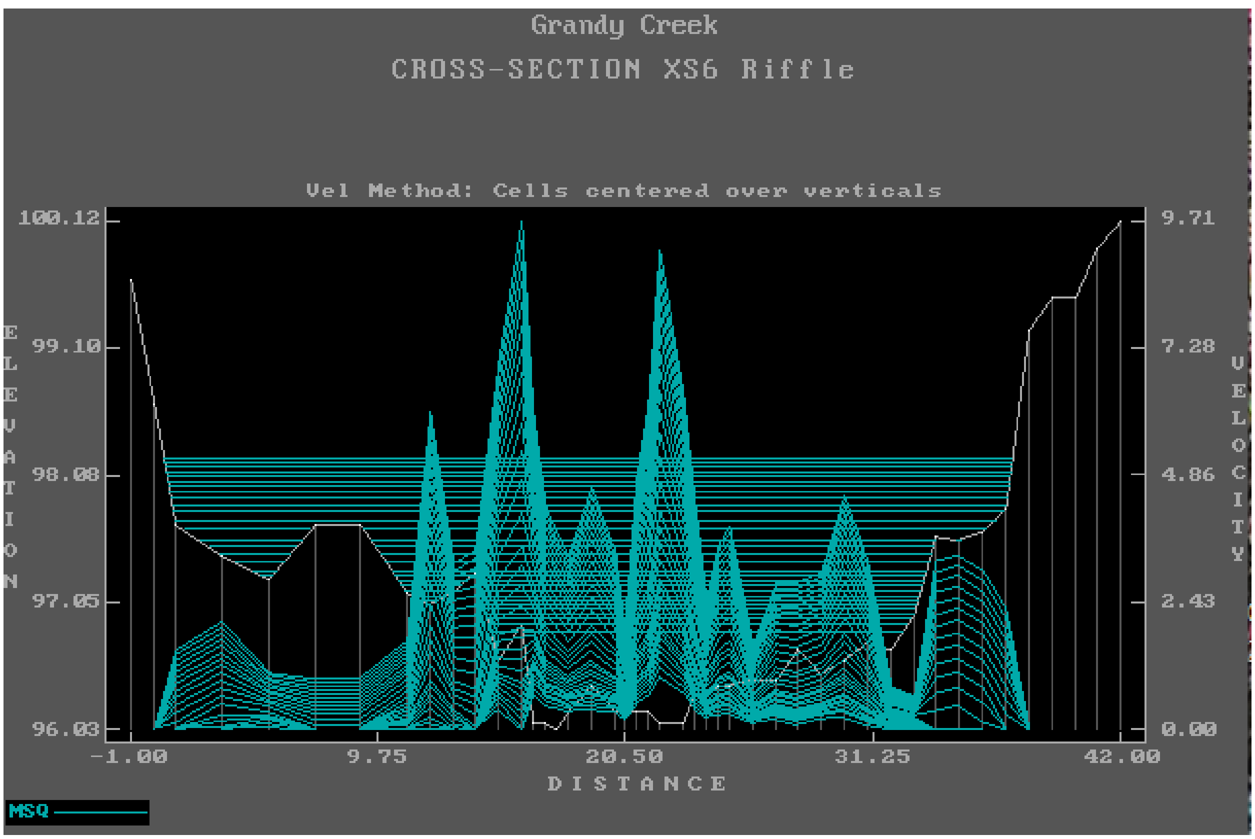

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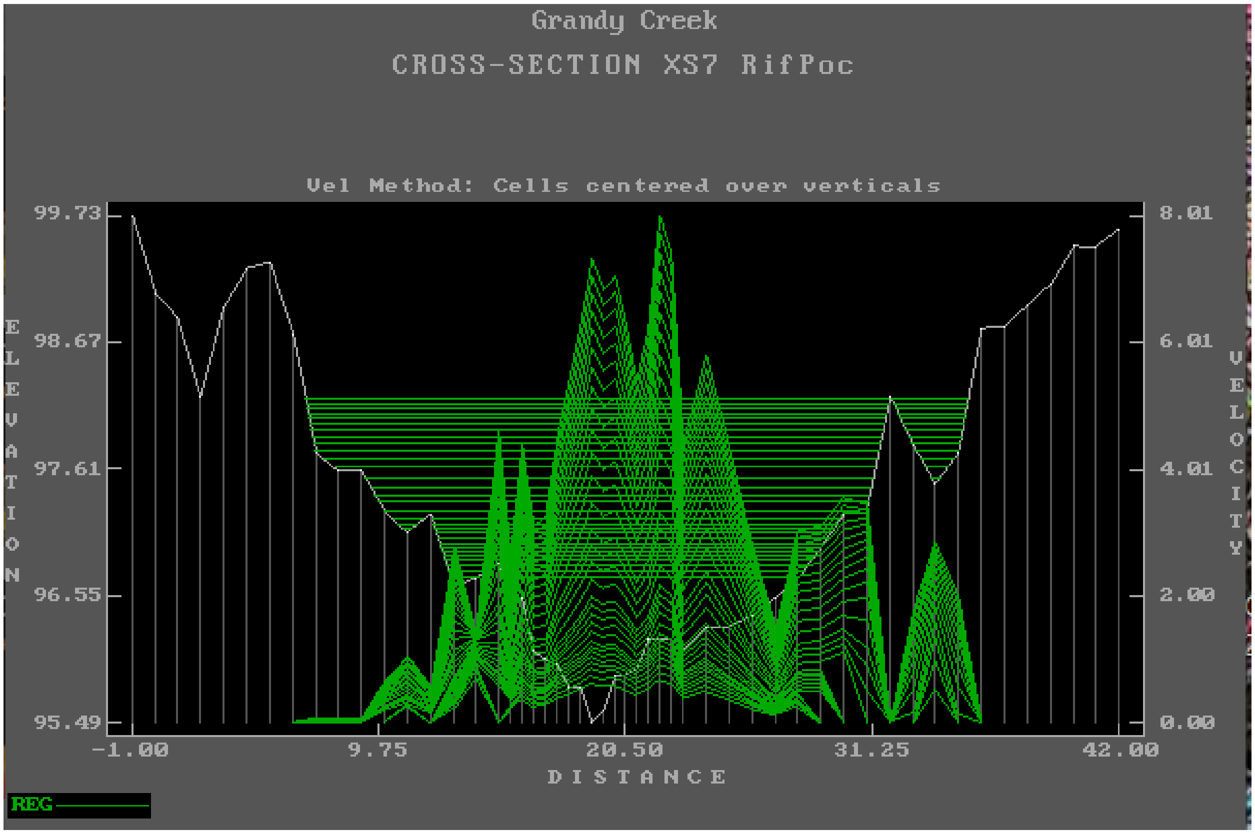

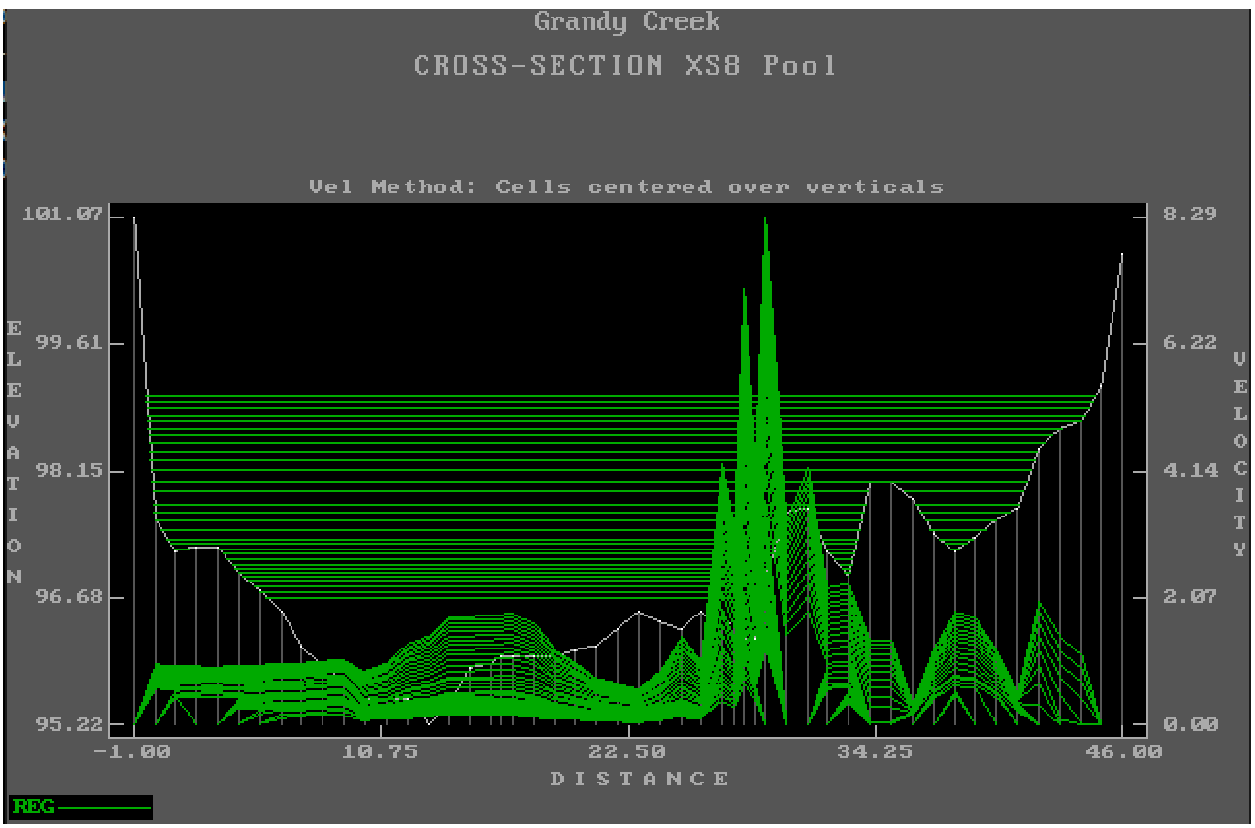

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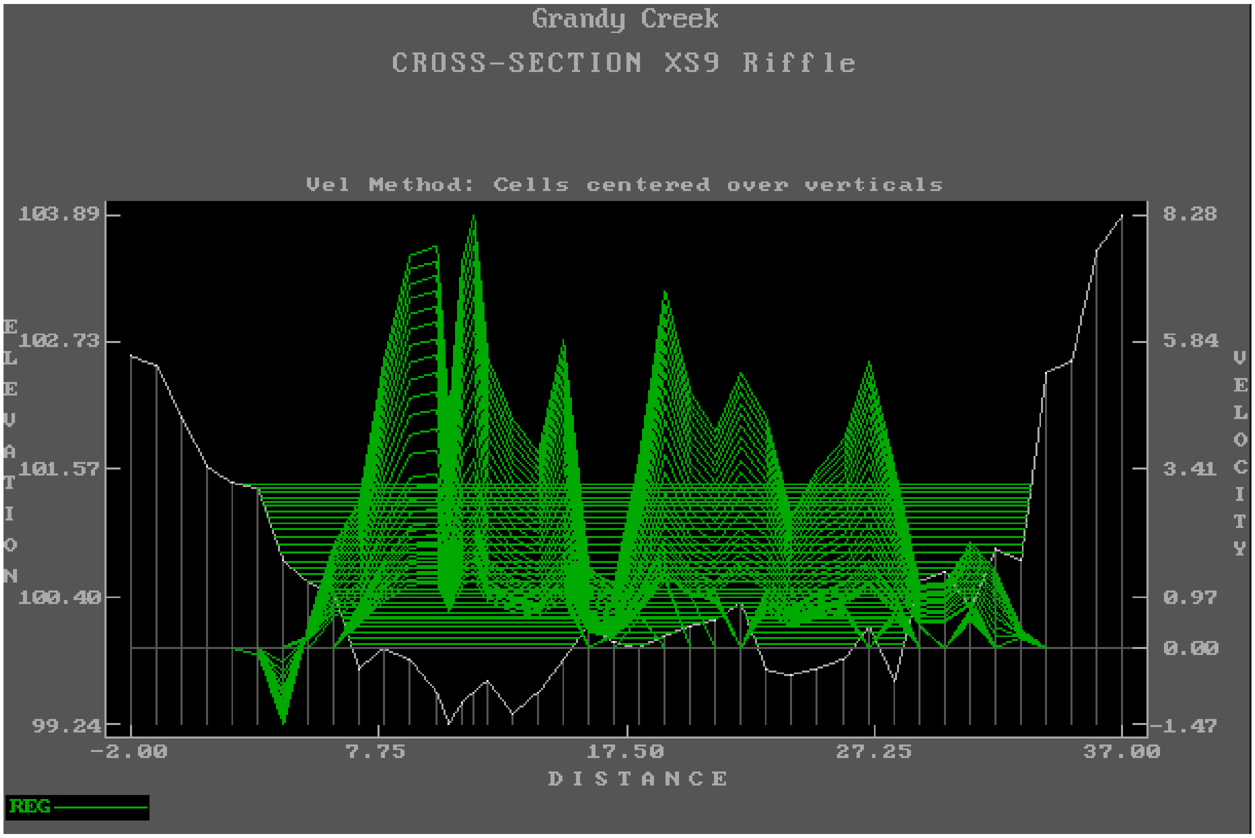

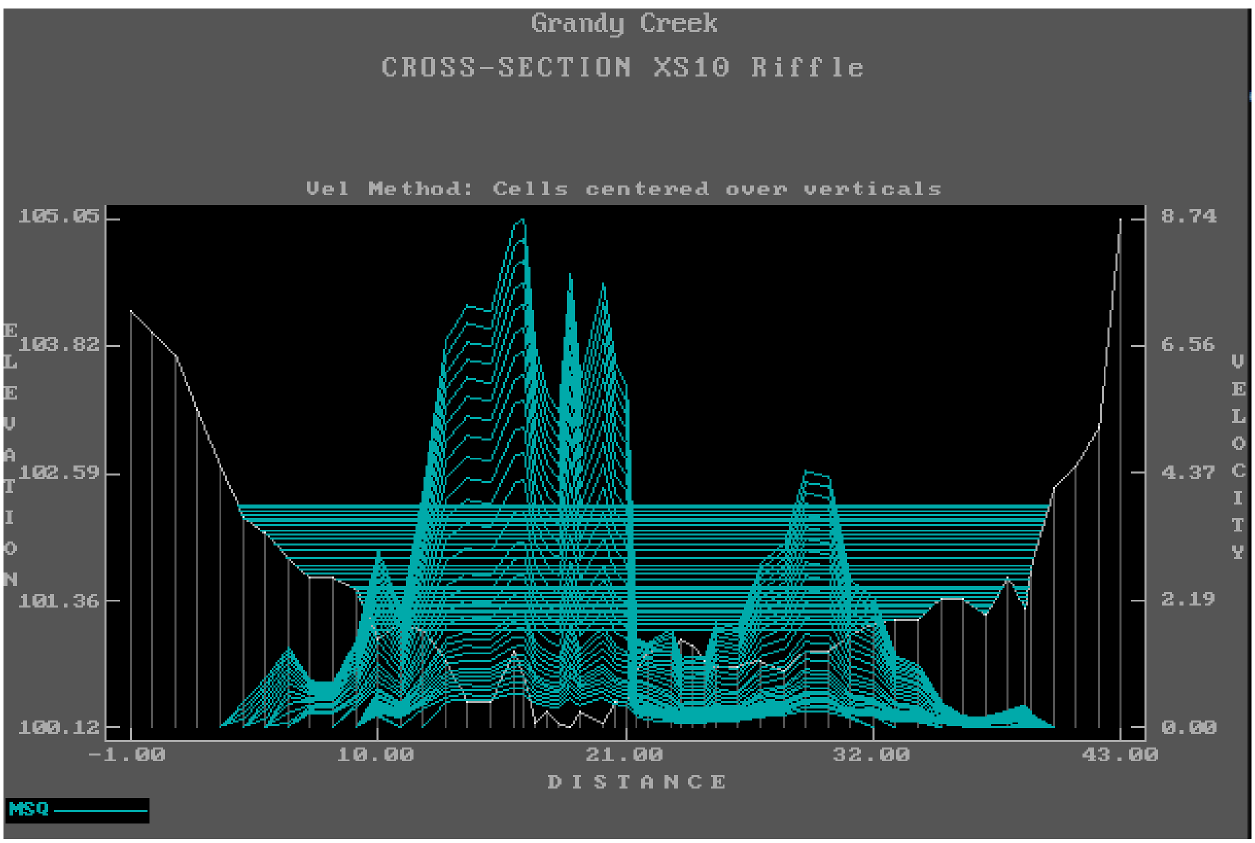

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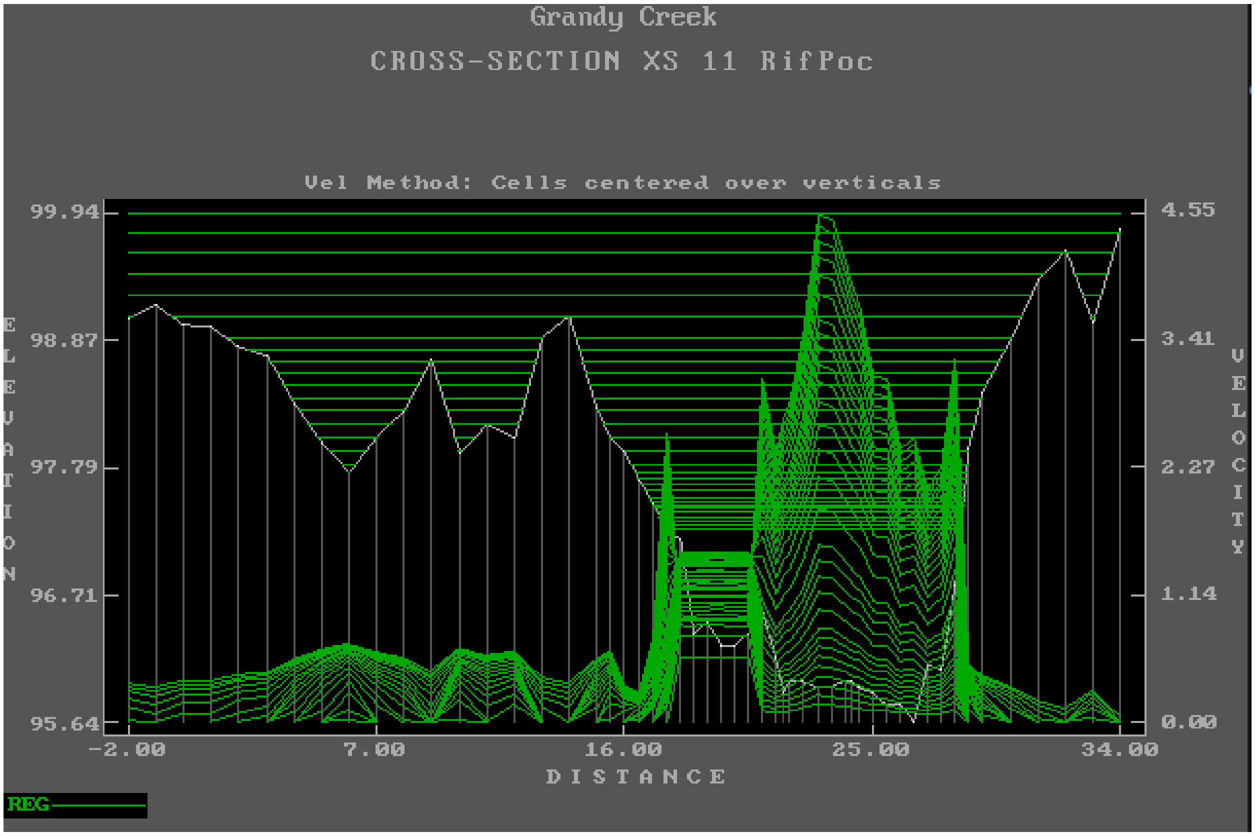

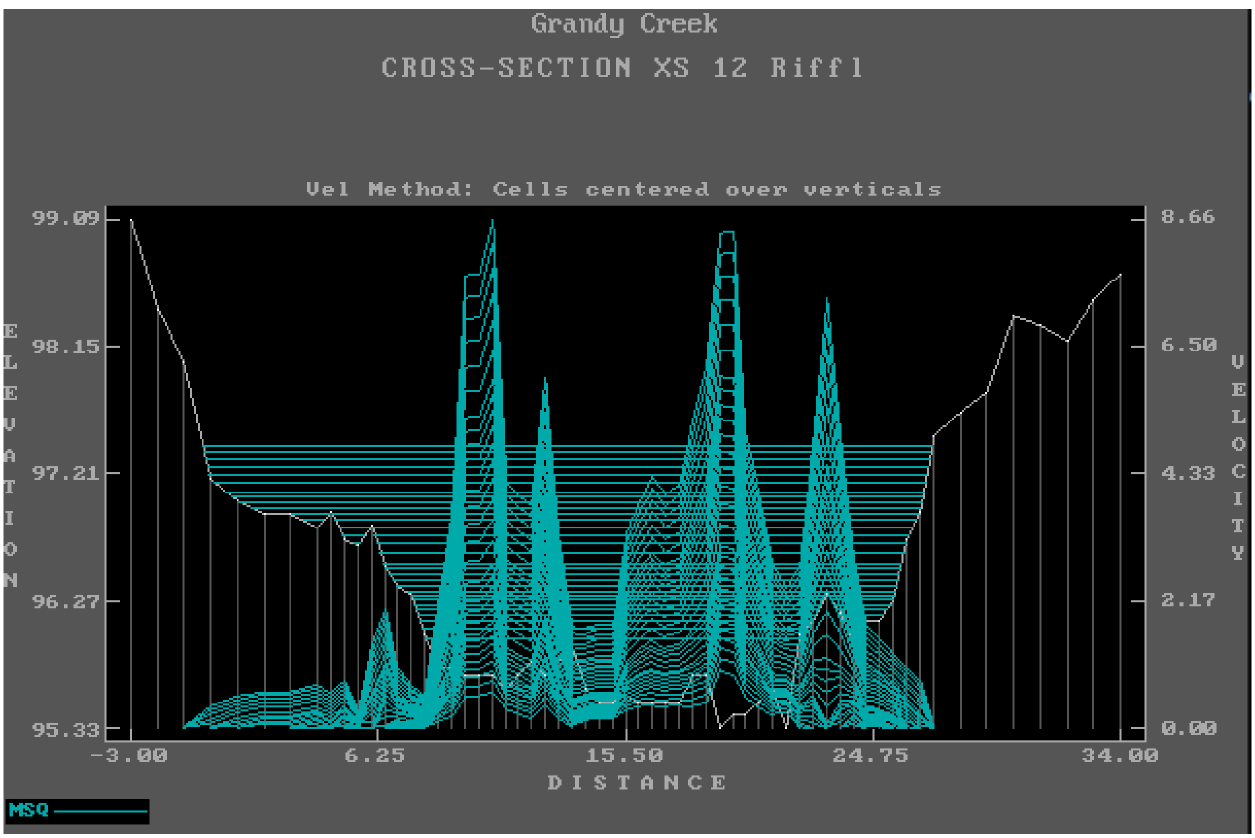

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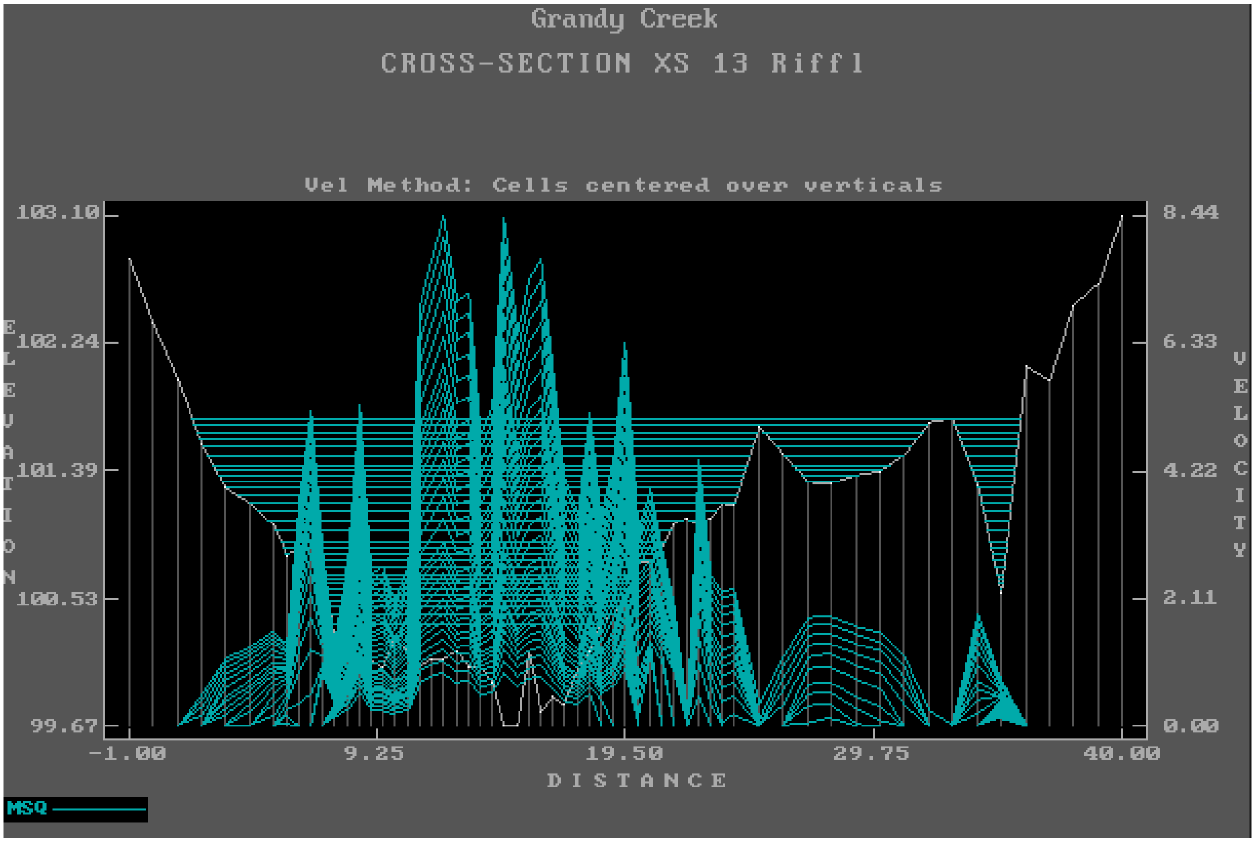

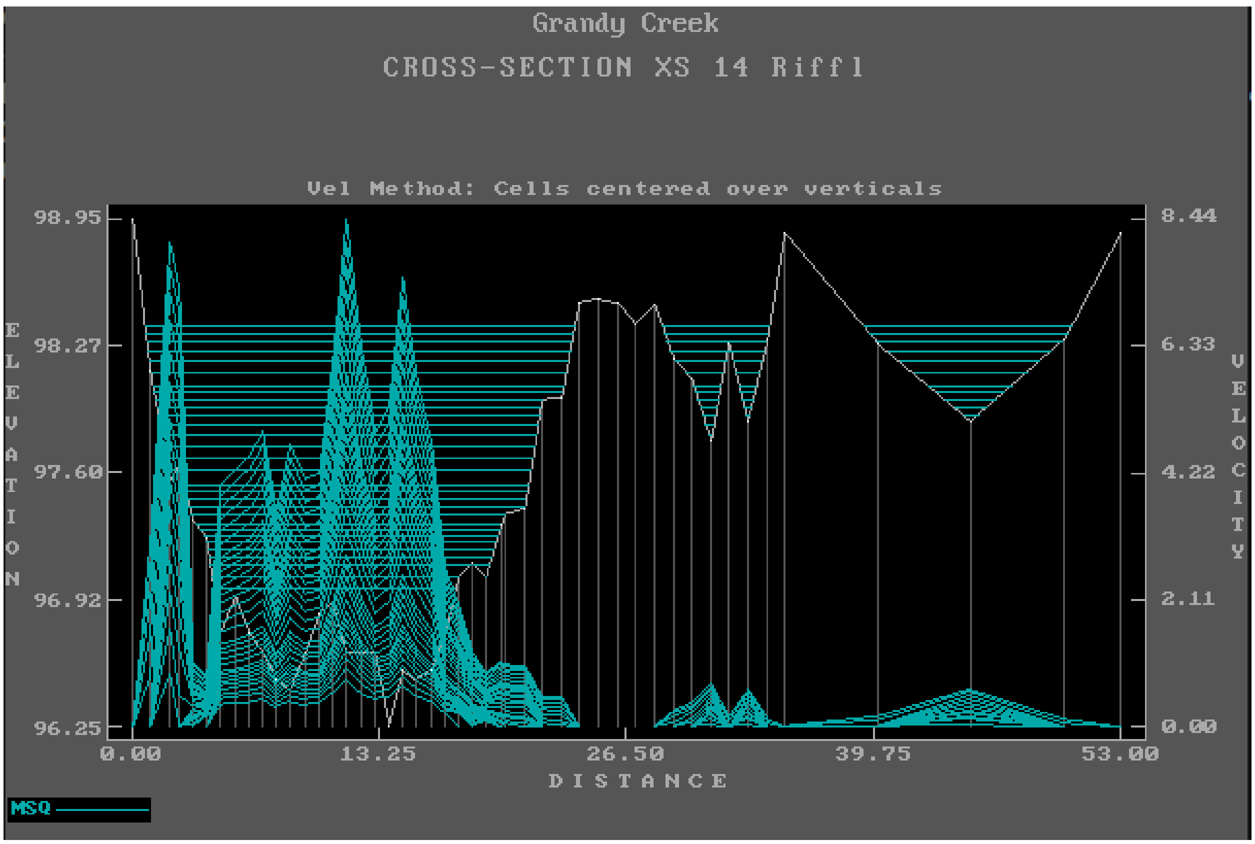

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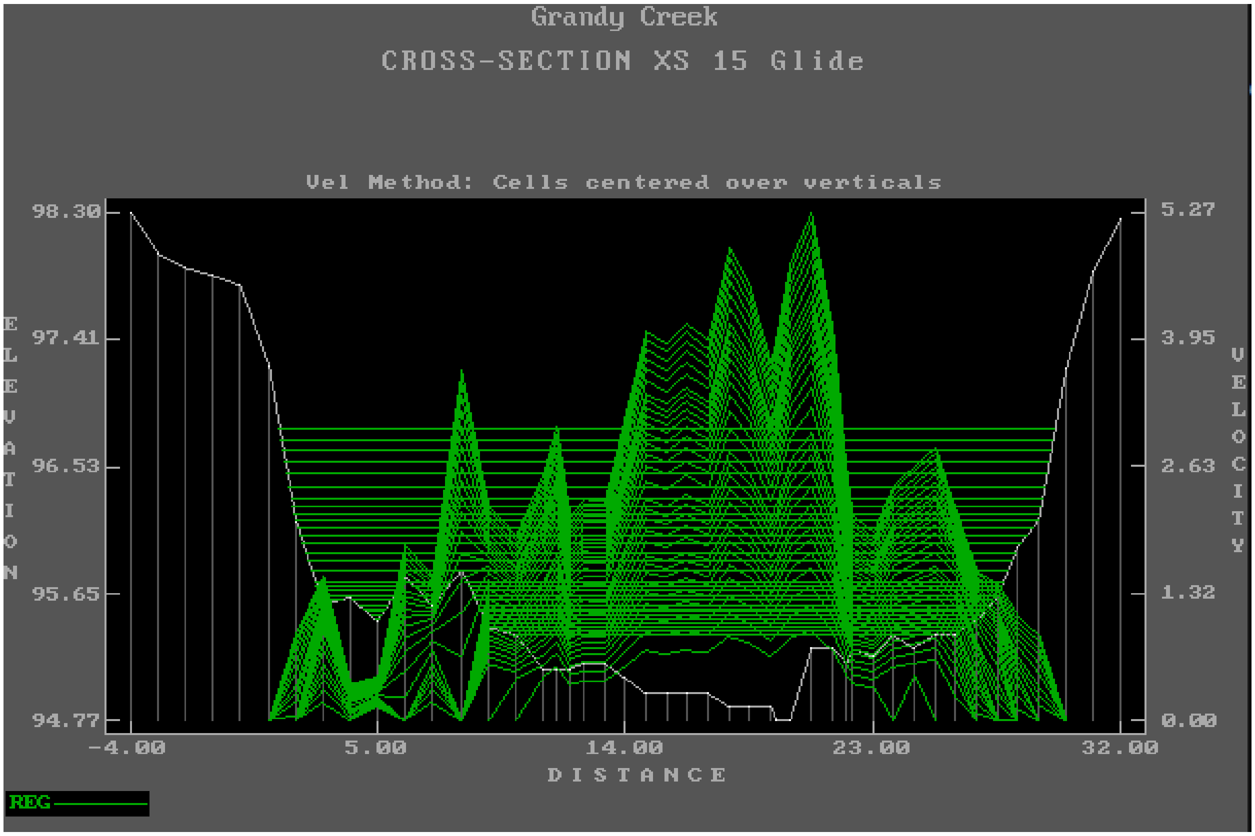

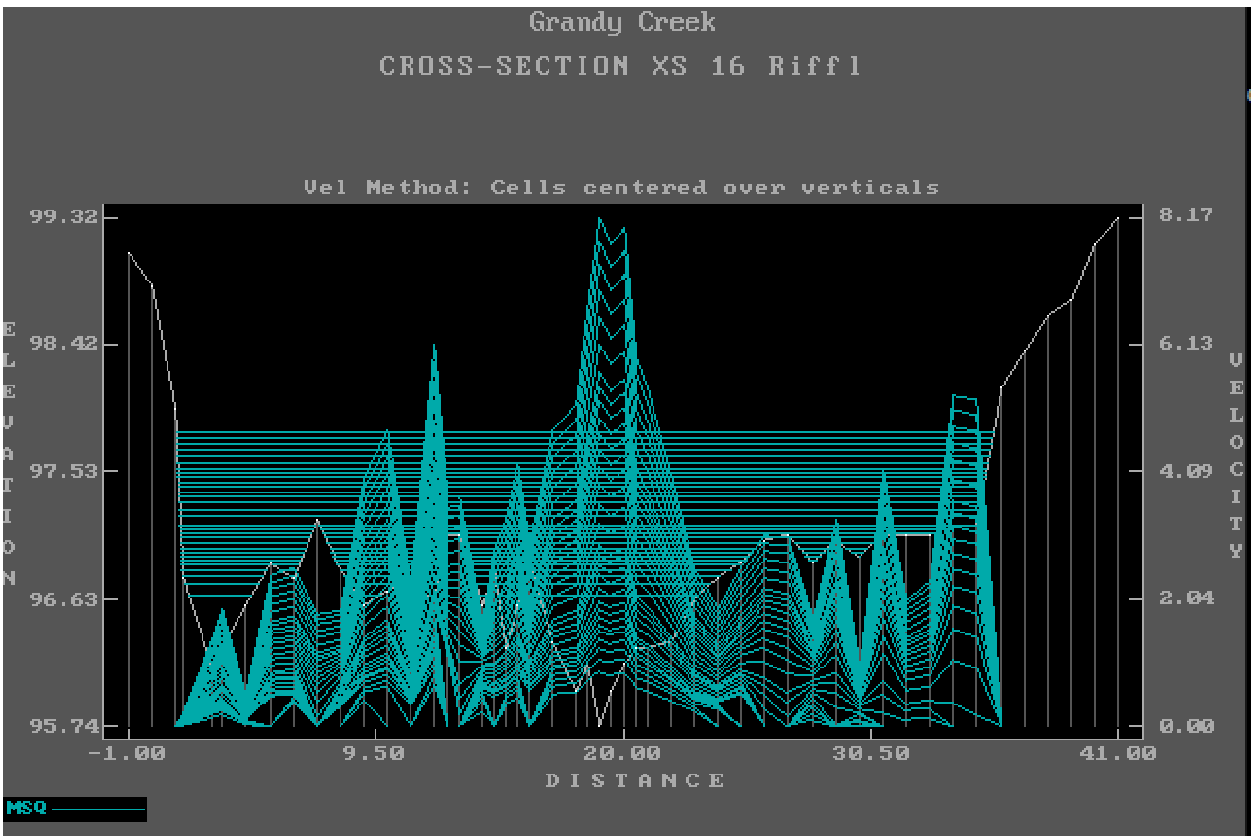

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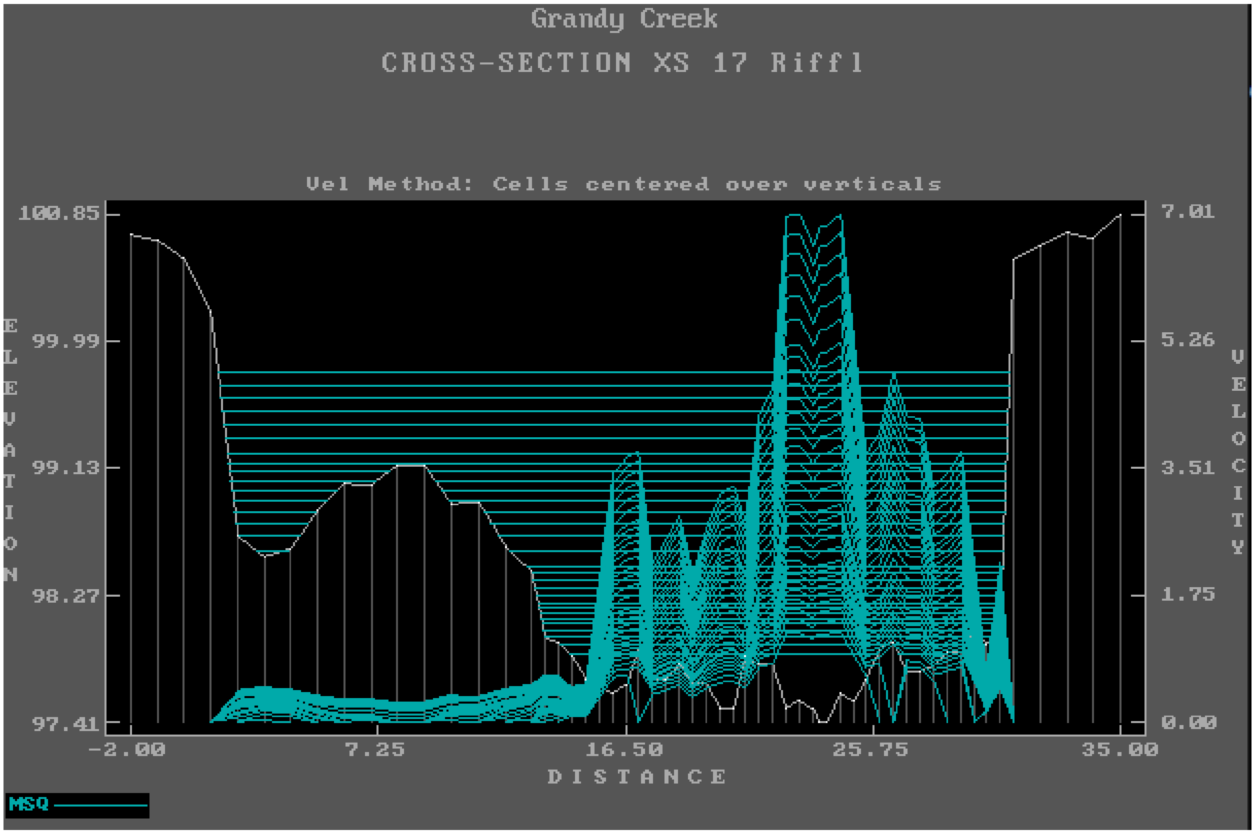

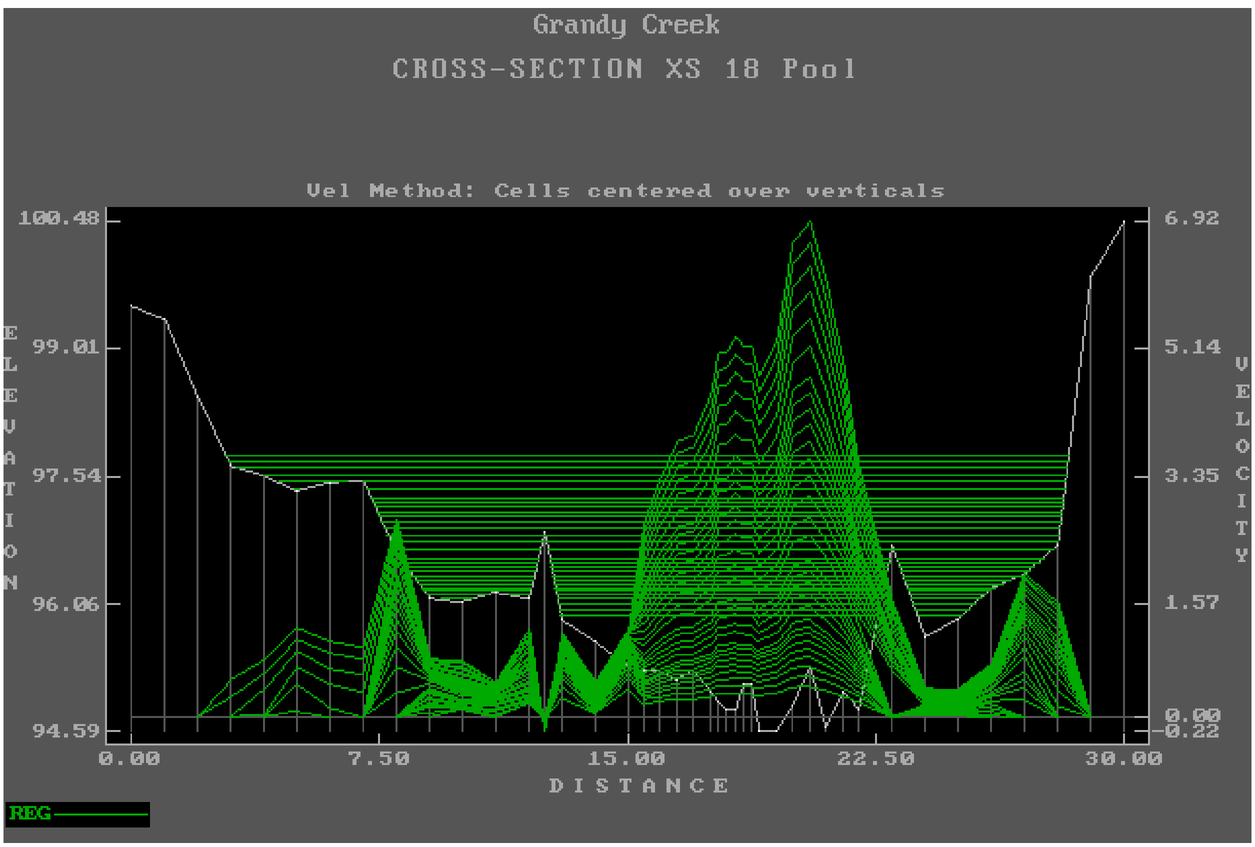

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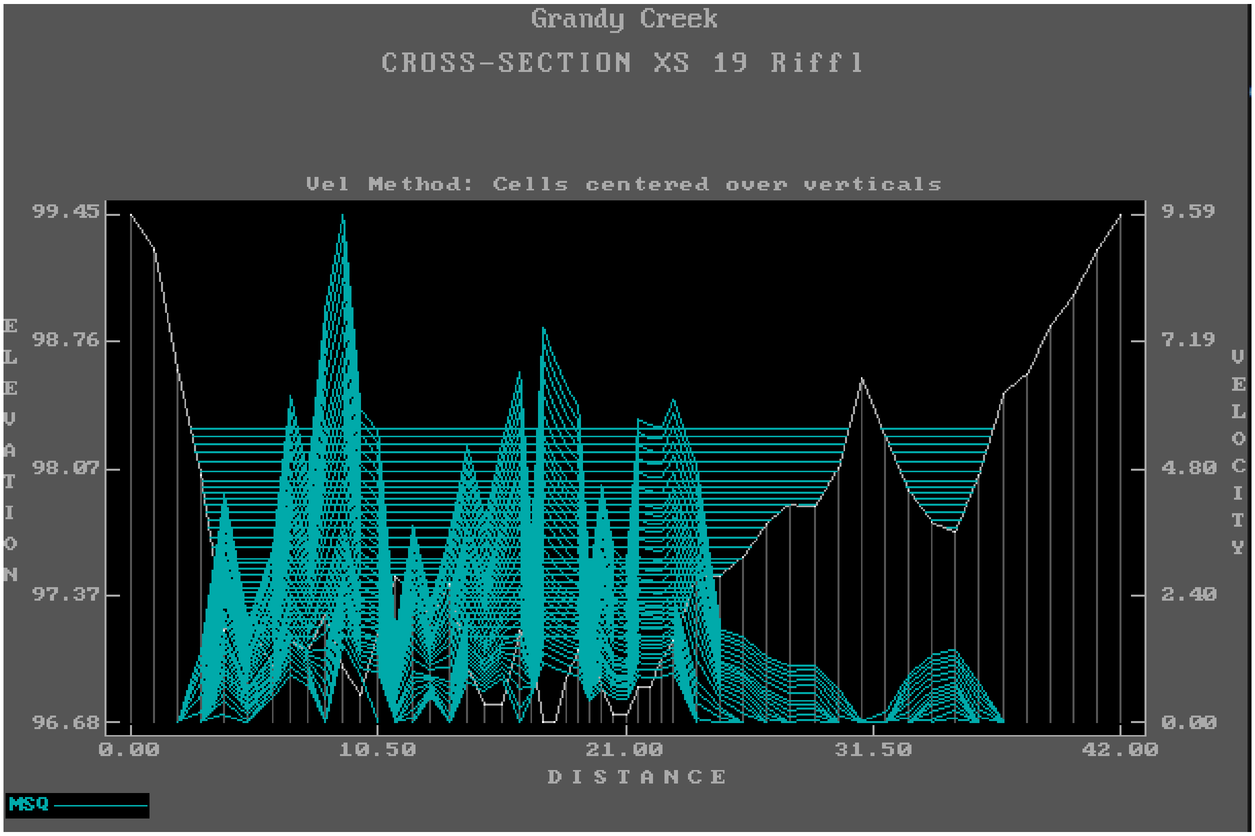

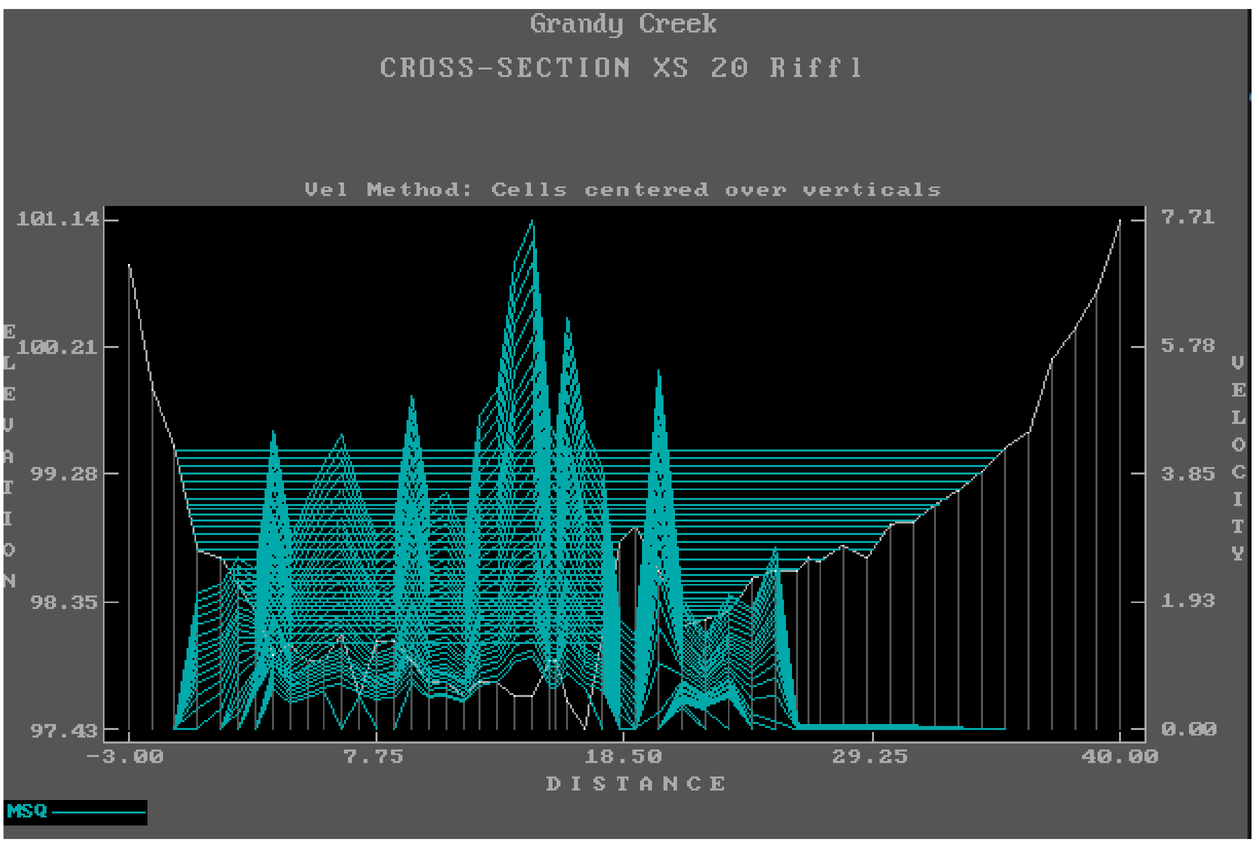

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Appendix F: Tabular AWS Values

Lower Reach AWS

		COHO						CHINOOK						STEELHEAD					
DISCHARGE	AREA	SPAWNING		FRY REARING		JUVENILE REARING		SPAWNING		FRY REARING		JUVENILE REARING		SPAWNING		FRY REARING		JUVENILE REARING	
cfs	ft2/1000ft	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT
3	21.03558	1.9149	9.1	0	0	0	0	0.03899	0.19	0.01017	0.05	0	0	0.03565	0.17	0.02157	0.1	0	0
4	22.11114	2.4763	11.2	0	0	0	0	0.0966	0.44	0.02145	0.1	0	0	0.05387	0.24	0.04845	0.22	0	0
5	22.82903	2.99757	13.13	0.00319	0.01	0.00468	0.02	0.15508	0.68	0.03249	0.14	0	0	0.0771	0.34	0.07699	0.34	0	0
6	23.45521	3.48586	14.86	0.01364	0.06	0.01261	0.05	0.21276	0.91	0.04312	0.18	0	0	0.10433	0.44	0.10448	0.45	0.00012	0
7	23.97387	3.95111	16.48	0.02352	0.1	0.01838	0.08	0.27272	1.14	0.0532	0.22	0	0	0.14289	0.6	0.13369	0.56	0.00115	0
8	24.50784	4.4039	17.97	0.03287	0.13	0.02258	0.09	0.3405	1.39	0.06443	0.26	0	0	0.19138	0.78	0.16267	0.66	0.00236	0.01
9	24.96096	4.84079	19.39	0.04095	0.16	0.02534	0.1	0.41843	1.68	0.07592	0.3	0	0	0.25351	1.02	0.19234	0.77	0.00351	0.01
10	25.38674	5.25997	20.72	0.048	0.19	0.02567	0.1	0.50569	1.99	0.08758	0.34	0	0	0.32351	1.27	0.22187	0.87	0.00461	0.02
12	26.24519	6.02998	22.98	0.06528	0.25	0.0292	0.11	0.69704	2.66	0.10919	0.42	0	0	0.48601	1.85	0.27943	1.06	0.00669	0.03
14	26.97506	6.6877	24.79	0.08139	0.3	0.03226	0.12	0.9196	3.41	0.12644	0.47	0	0	0.67145	2.49	0.31814	1.18	0.0089	0.03
16	27.46729	7.25664	26.42	0.09679	0.35	0.03763	0.14	1.18052	4.3	0.14095	0.51	0	0	0.8915	3.25	0.35811	1.3	0.01149	0.04
18	28.00305	7.72165	27.57	0.11588	0.41	0.04616	0.16	1.46112	5.22	0.16128	0.58	0.0009	0	1.13222	4.04	0.39454	1.41	0.01446	0.05
20	28.59252	8.12576	28.42	0.13228	0.46	0.05265	0.18	1.755	6.14	0.18005	0.63	0.00315	0.01	1.3529	4.73	0.42904	1.5	0.01813	0.06
25	29.8577	8.94062	29.94	0.16284	0.55	0.06194	0.21	2.51727	8.43	0.22081	0.74	0.01114	0.04	1.82662	6.12	0.49947	1.67	0.02665	0.09
30	30.80263	9.50812	30.87	0.19295	0.63	0.08157	0.26	3.28916	10.68	0.25587	0.83	0.01856	0.06	2.24023	7.27	0.53927	1.75	0.03622	0.12
35	31.32095	9.89616	31.6	0.21691	0.69	0.09951	0.32	4.02135	12.84	0.29	0.93	0.02629	0.08	2.59492	8.28	0.5751	1.84	0.04916	0.16
40	31.79113	10.18293	32.03	0.24439	0.77	0.12804	0.4	4.68071	14.72	0.32217	1.01	0.03693	0.12	2.91445	9.17	0.61575	1.94	0.06338	0.2
50	32.91098	10.51836	31.96	0.29581	0.9	0.16438	0.5	5.62919	17.1	0.39047	1.19	0.05926	0.18	3.45357	10.49	0.71579	2.17	0.09306	0.28
60	34.10605	10.69199	31.35	0.33712	0.99	0.18657	0.55	6.27407	18.4	0.44877	1.32	0.07829	0.23	3.808	11.17	0.80912	2.37	0.12217	0.36
70	34.63072	10.72819	30.98	0.38057	1.1	0.22021	0.64	6.49933	18.77	0.48956	1.41	0.10102	0.29	4.02835	11.63	0.89552	2.59	0.15209	0.44
80	35.0852	10.66913	30.41	0.43232	1.23	0.24011	0.68	6.5331	18.62	0.51643	1.47	0.12264	0.35	4.03621	11.5	0.92918	2.65	0.18222	0.52
90	35.44192	10.51708	29.67	0.4688	1.32	0.26068	0.74	6.38312	18.01	0.53168	1.5	0.14228	0.4	3.98621	11.25	0.94663	2.67	0.21125	0.6
100	35.77726	10.28017	28.73	0.49774	1.39	0.28327	0.79	6.07894	16.99	0.54273	1.52	0.16574	0.46	3.97599	11.11	0.96651	2.7	0.24144	0.67
110	36.13533	9.99865	27.67	0.51054	1.41	0.30223	0.84	5.83563	16.15	0.56349	1.56	0.19012	0.53	3.87052	10.71	0.9837	2.72	0.26669	0.74
120	36.67733	9.6533	26.32	0.52357	1.43	0.32024	0.87	5.64292	15.39	0.58306	1.59	0.21215	0.58	3.684	10.04	0.98656	2.69	0.2917	0.8
130	37.131	9.24474	24.9	0.549	1.48	0.33296	0.9	5.39662	14.53	0.60038	1.62	0.23163	0.62	3.53913	9.53	0.98276	2.65	0.31534	0.85

DISCHARGE	AREA	COHO SPAWNING		COHO FRY REARING		COHO JUVENILE REARING		CHINOOK SPAWNING		CHINOOK FRY REARING		CHINOOK JUVENILE REARING		STEELHEAD SPAWNING		STEELHEAD FRY REARING		STEELHEAD JUVENILE REARING	
cfs	ft2/1000ft	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT
140	37.38013	8.8942	23.79	0.57319	1.53	0.34129	0.91	5.04625	13.5	0.61845	1.65	0.24908	0.67	3.39697	9.09	0.97492	2.61	0.33757	0.9
150	37.56482	8.59639	22.88	0.59348	1.58	0.34701	0.92	4.81041	12.81	0.63416	1.69	0.26626	0.71	3.26335	8.69	0.96312	2.56	0.36034	0.96
160	37.74025	8.31938	22.04	0.61558	1.63	0.35557	0.94	4.62047	12.24	0.6446	1.71	0.28233	0.75	3.13042	8.29	0.95838	2.54	0.38068	1.01
170	38.06334	8.02256	21.08	0.63507	1.67	0.36282	0.95	4.38906	11.53	0.65862	1.73	0.30021	0.79	3.03557	7.98	0.96646	2.54	0.39877	1.05

Upper AWS

DISCHARGE	AREA	COHO SPAWNING		COHO FRY REARING		COHO JUVENILE REARING		CHINOOK SPAWNING		CHINOOK FRY REARING		CHINOOK JUVENILE REARING		STEELHEAD SPAWNING		STEELHEAD FRY REARING		STEELHEAD JUVENILE REARING	
cfs	ft2/1000ft	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT
2	12842.5	0.71404	5.56	0.0643	0.5	0.04919	0.38	0.01402	0.11	0.10747	0.84	0	0	0	0	0.15903	1.24	0.00453	0.04
3	14096.51	1.08288	7.68	0.08674	0.62	0.05752	0.41	0.03786	0.27	0.12657	0.9	0.00031	0	0	0	0.17367	1.23	0.00636	0.05
4	15059.45	1.44885	9.62	0.10455	0.69	0.0651	0.43	0.07721	0.51	0.14306	0.95	0.00163	0.01	0.00835	0.06	0.1909	1.27	0.00801	0.05
5	15729.05	1.79669	11.42	0.11996	0.76	0.06967	0.44	0.13299	0.85	0.15482	0.98	0.00349	0.02	0.0191	0.12	0.20733	1.32	0.00956	0.06
6	16230.65	2.11097	13.01	0.13323	0.82	0.07281	0.45	0.20089	1.24	0.16024	0.99	0.00532	0.03	0.03173	0.2	0.22152	1.36	0.01094	0.07
7	16622.71	2.39437	14.4	0.14836	0.89	0.07682	0.46	0.28261	1.7	0.16247	0.98	0.00702	0.04	0.04764	0.29	0.23523	1.42	0.01216	0.07
8	16942.28	2.65762	15.69	0.16179	0.95	0.07768	0.46	0.37987	2.24	0.16256	0.96	0.00877	0.05	0.06743	0.4	0.24696	1.46	0.01431	0.08
9	17290.68	2.89822	16.76	0.17134	0.99	0.07568	0.44	0.4843	2.8	0.16228	0.94	0.01054	0.06	0.09708	0.56	0.25588	1.48	0.01676	0.1
10	17620.14	3.11967	17.71	0.17981	1.02	0.07504	0.43	0.59991	3.4	0.16226	0.92	0.01233	0.07	0.13091	0.74	0.26248	1.49	0.01942	0.11
12	18365.67	3.51254	19.13	0.19102	1.04	0.07202	0.39	0.83884	4.57	0.16442	0.9	0.0159	0.09	0.21708	1.18	0.27448	1.49	0.02535	0.14
14	19155.67	3.85152	20.11	0.196	1.02	0.06916	0.36	1.07081	5.59	0.16752	0.87	0.01926	0.1	0.35764	1.87	0.28045	1.46	0.03079	0.16
16	19841.08	4.14089	20.87	0.19641	0.99	0.06804	0.34	1.30476	6.58	0.17128	0.86	0.0221	0.11	0.51147	2.58	0.28357	1.43	0.03584	0.18
18	20298.96	4.38983	21.63	0.19678	0.97	0.07253	0.36	1.52463	7.51	0.17503	0.86	0.02515	0.12	0.64362	3.17	0.28665	1.41	0.04058	0.2
20	20921.27	4.58824	21.93	0.19767	0.94	0.07733	0.37	1.72944	8.27	0.18077	0.86	0.02862	0.14	0.77354	3.7	0.29257	1.4	0.04535	0.22
25	21804.24	4.95897	22.74	0.20596	0.94	0.08809	0.4	2.18094	10	0.18872	0.87	0.03756	0.17	1.08001	4.95	0.30794	1.41	0.05656	0.26
30	22866.96	5.20567	22.77	0.21434	0.94	0.09195	0.4	2.54403	11.13	0.19216	0.84	0.04543	0.2	1.31517	5.75	0.32233	1.41	0.0672	0.29
35	23720.44	5.38916	22.72	0.22074	0.93	0.09641	0.41	2.76018	11.64	0.19569	0.82	0.05276	0.22	1.50314	6.34	0.3389	1.43	0.07799	0.33
40	24431.51	5.52777	22.63	0.2279	0.93	0.09986	0.41	2.93088	12	0.19748	0.81	0.06097	0.25	1.67197	6.84	0.34579	1.42	0.08935	0.37

		COHO						CHINOOK						STEELHEAD					
DISCHARGE	AREA	SPAWNING		FRY REARING		JUVENILE REARING		SPAWNING		FRY REARING		JUVENILE REARING		SPAWNING		FRY REARING		JUVENILE REARING	
cfs	ft2/1000ft	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT	AWS	PERCENT
45	25160.08	5.60269	22.27	0.23953	0.95	0.10308	0.41	3.04318	12.1	0.19881	0.79	0.0688	0.27	1.77308	7.05	0.35035	1.39	0.10014	0.4
50	25950.86	5.61921	21.65	0.24879	0.96	0.10596	0.41	3.16877	12.21	0.20069	0.77	0.07655	0.29	1.81993	7.01	0.35031	1.35	0.11006	0.42
55	26948.41	5.61201	20.83	0.25615	0.95	0.10952	0.41	3.22496	11.97	0.21096	0.78	0.085	0.32	1.87118	6.94	0.36276	1.35	0.11962	0.44
60	27598.21	5.59636	20.28	0.25922	0.94	0.11422	0.41	3.2688	11.84	0.22604	0.82	0.09403	0.34	1.89482	6.87	0.38574	1.4	0.12921	0.47
65	28432.88	5.58243	19.63	0.26145	0.92	0.11403	0.4	3.30184	11.61	0.24213	0.85	0.10305	0.36	1.91294	6.73	0.41996	1.48	0.13821	0.49
70	28910.02	5.57168	19.27	0.26514	0.92	0.11317	0.39	3.31427	11.46	0.256	0.89	0.11125	0.38	1.94149	6.72	0.45941	1.59	0.14568	0.5
80	29985.08	5.53956	18.47	0.30306	1.01	0.14314	0.48	3.31256	11.05	0.28216	0.94	0.12672	0.42	2.02362	6.75	0.54183	1.81	0.15911	0.53
90	30846.21	5.49887	17.83	0.34945	1.13	0.15295	0.5	3.29846	10.69	0.30861	1	0.13852	0.45	2.12051	6.87	0.62919	2.04	0.17551	0.57
100	31429.85	5.47347	17.41	0.3747	1.19	0.14677	0.47	3.23575	10.3	0.33414	1.06	0.15045	0.48	2.18563	6.95	0.71616	2.28	0.19091	0.61
110	31991.79	5.43743	17	0.38424	1.2	0.14728	0.46	3.16819	9.9	0.36878	1.15	0.16124	0.5	2.22706	6.96	0.80673	2.52	0.20544	0.64
120	32348.42	5.37985	16.63	0.40334	1.25	0.17196	0.53	3.0917	9.56	0.41268	1.28	0.1691	0.52	2.23163	6.9	0.8693	2.69	0.21899	0.68
130	32702.07	5.29838	16.2	0.43046	1.32	0.20945	0.64	3.06417	9.37	0.44779	1.37	0.17709	0.54	2.24073	6.85	0.94624	2.89	0.23415	0.72

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Appendix G: Habitat Duration Curves

The habitat duration curves for each species and life-stage compare the AWS percent exceedance for the baseline habitat to each of the climate and population adjusted scenarios.

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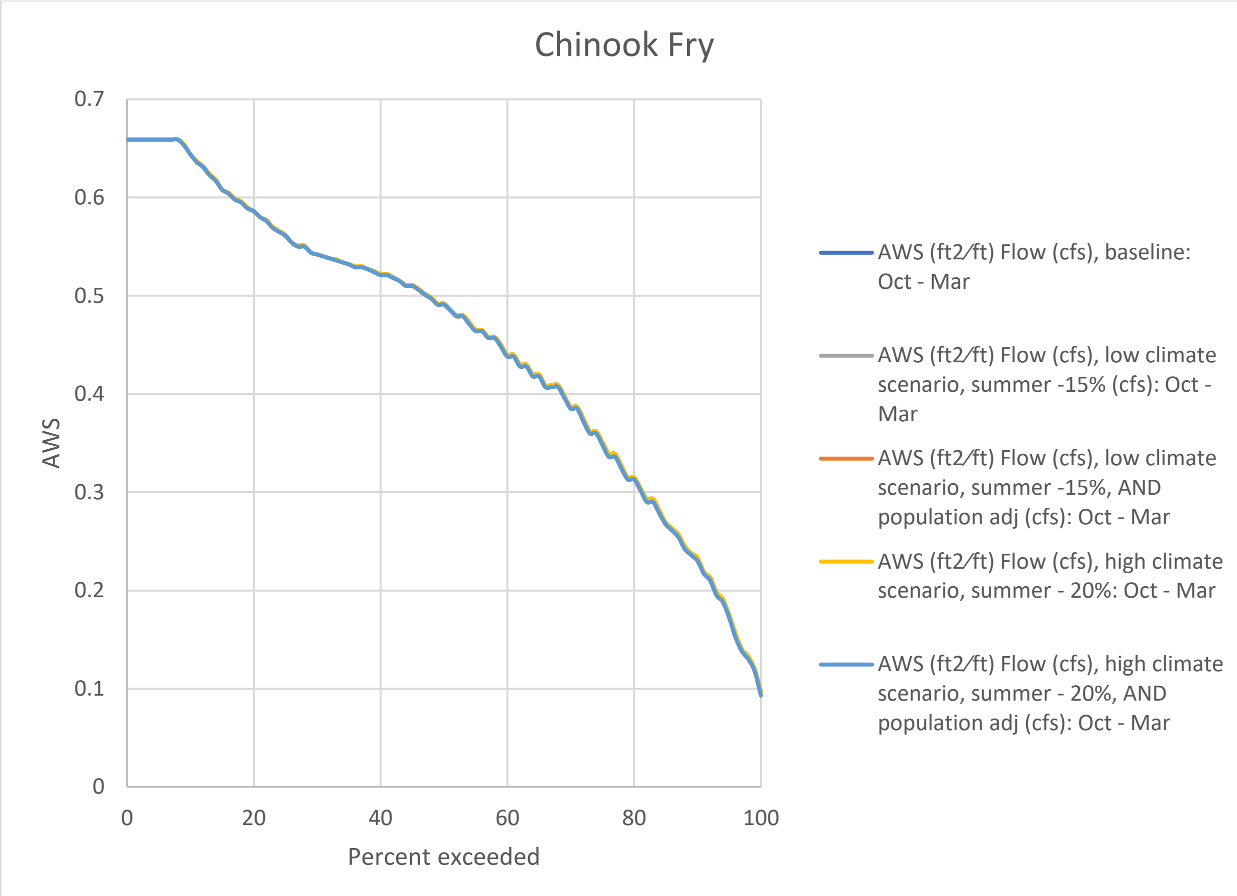
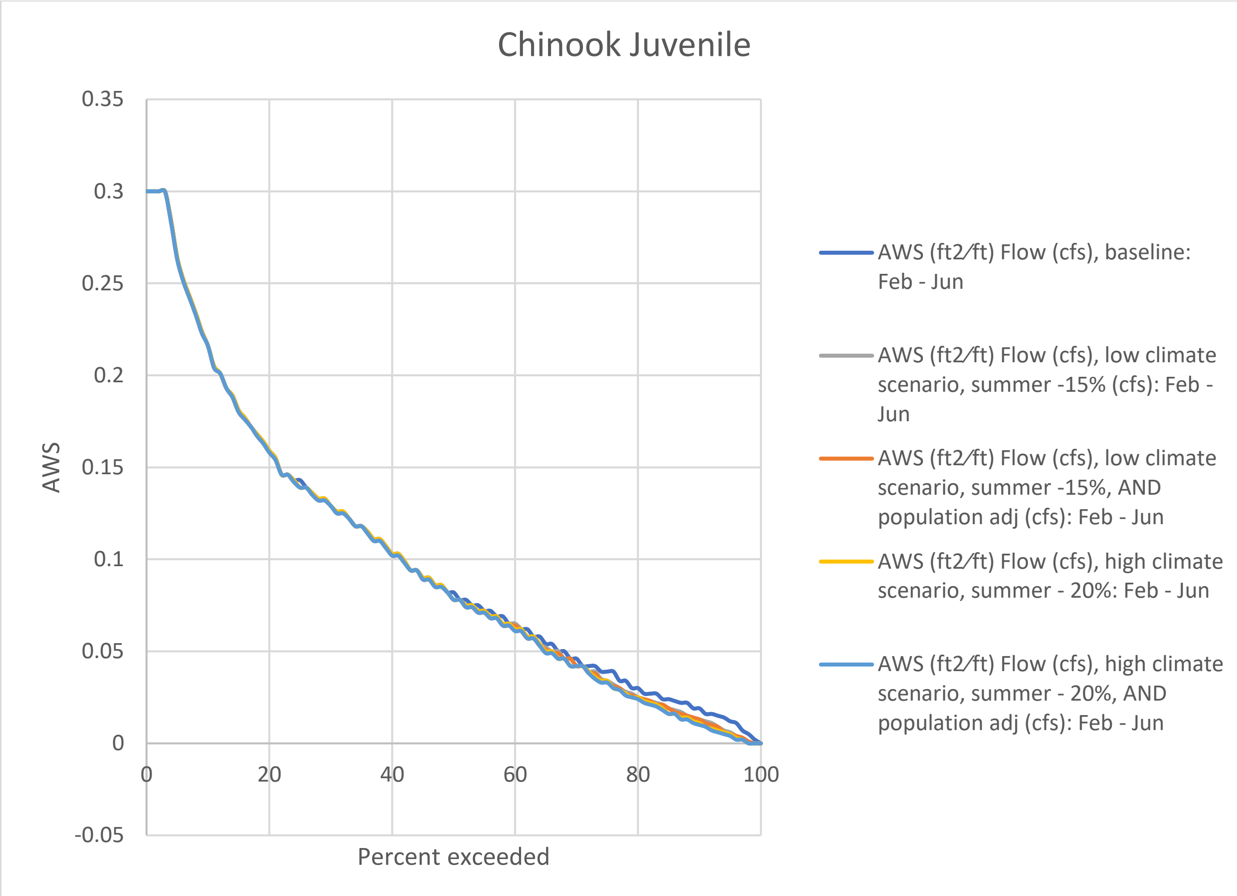
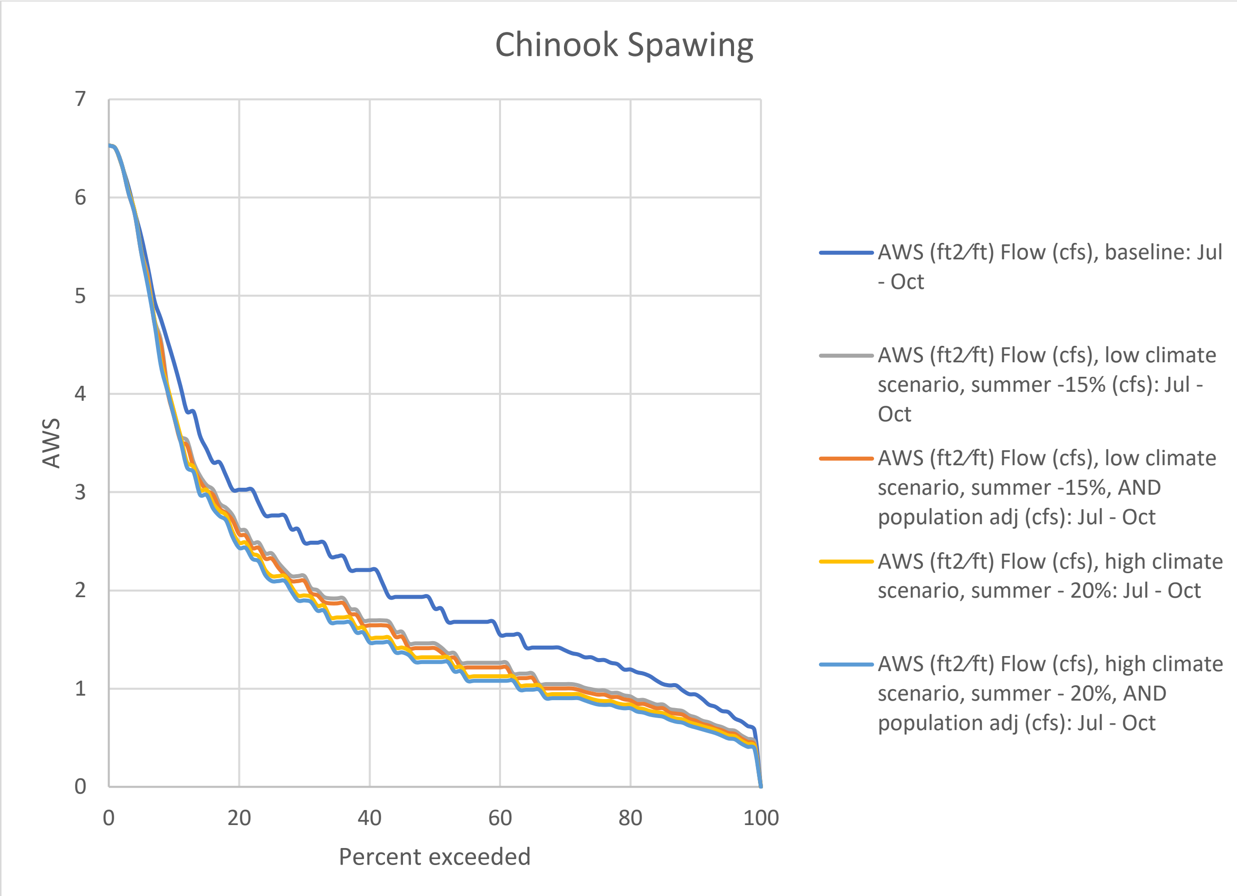
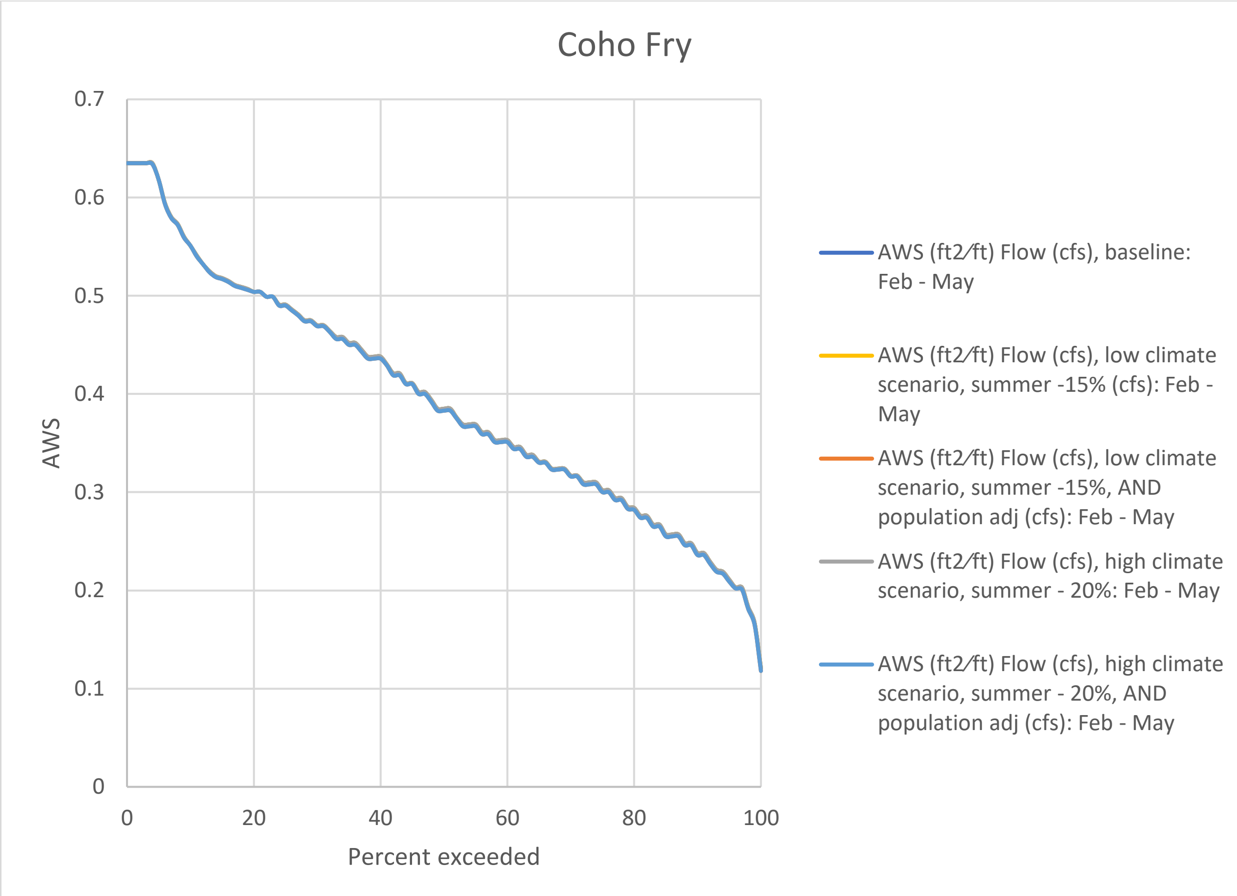
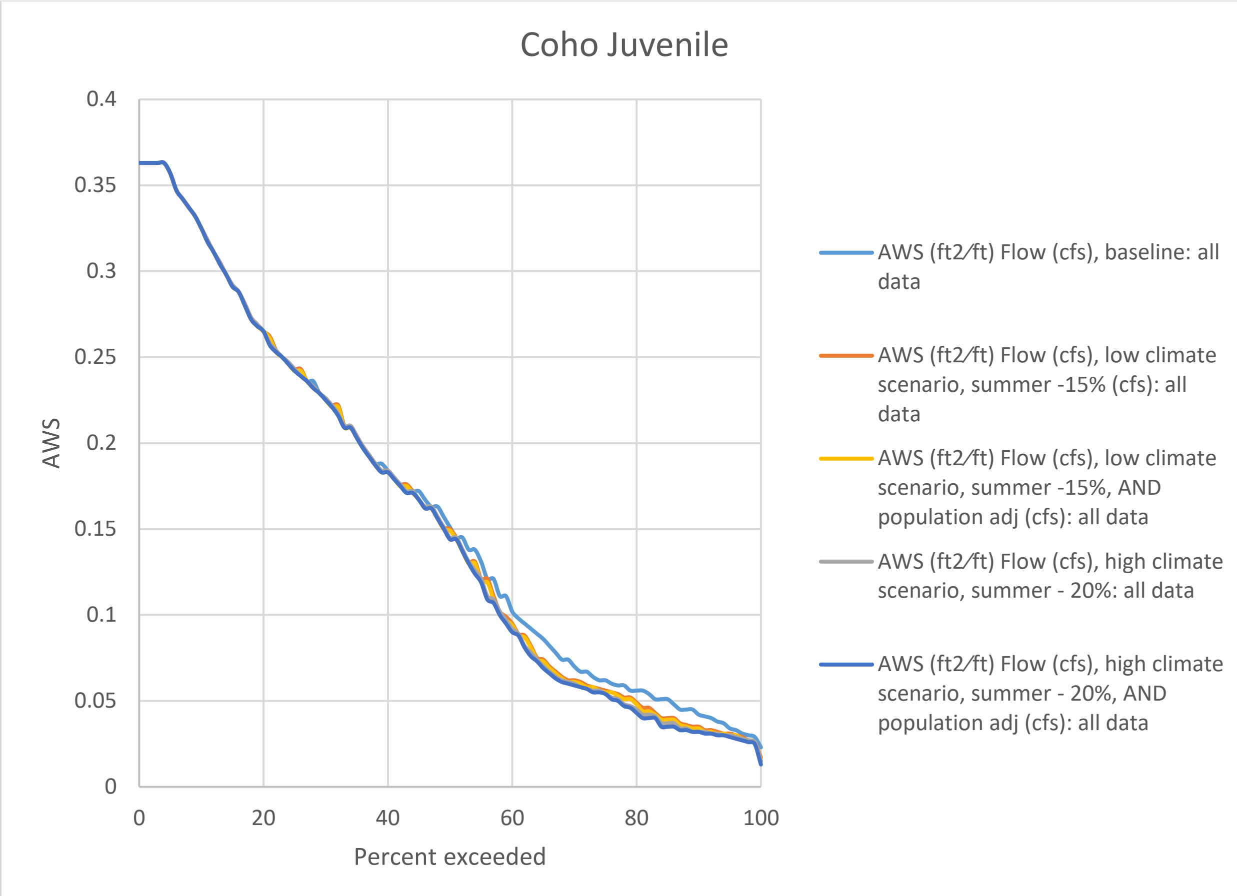
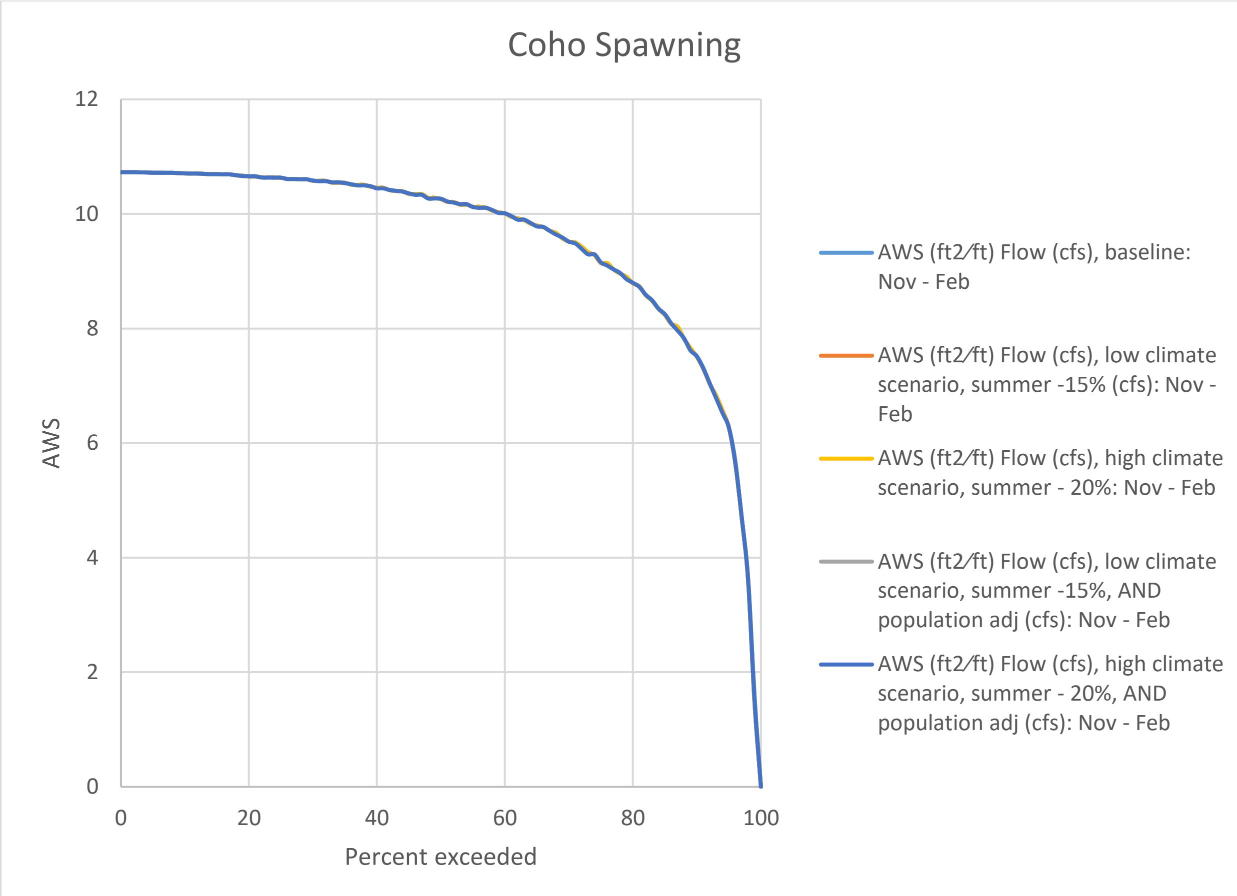

Chinook Fry
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AWS
0
20
40
60
80
100
Percent exceeded
AWS (ft2/ft) Flow (cfs), baseline: Oct - Mar
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15% (cfs): Oct - Mar
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): Oct - Mar
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%: Oct - Mar
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): Oct - Mar

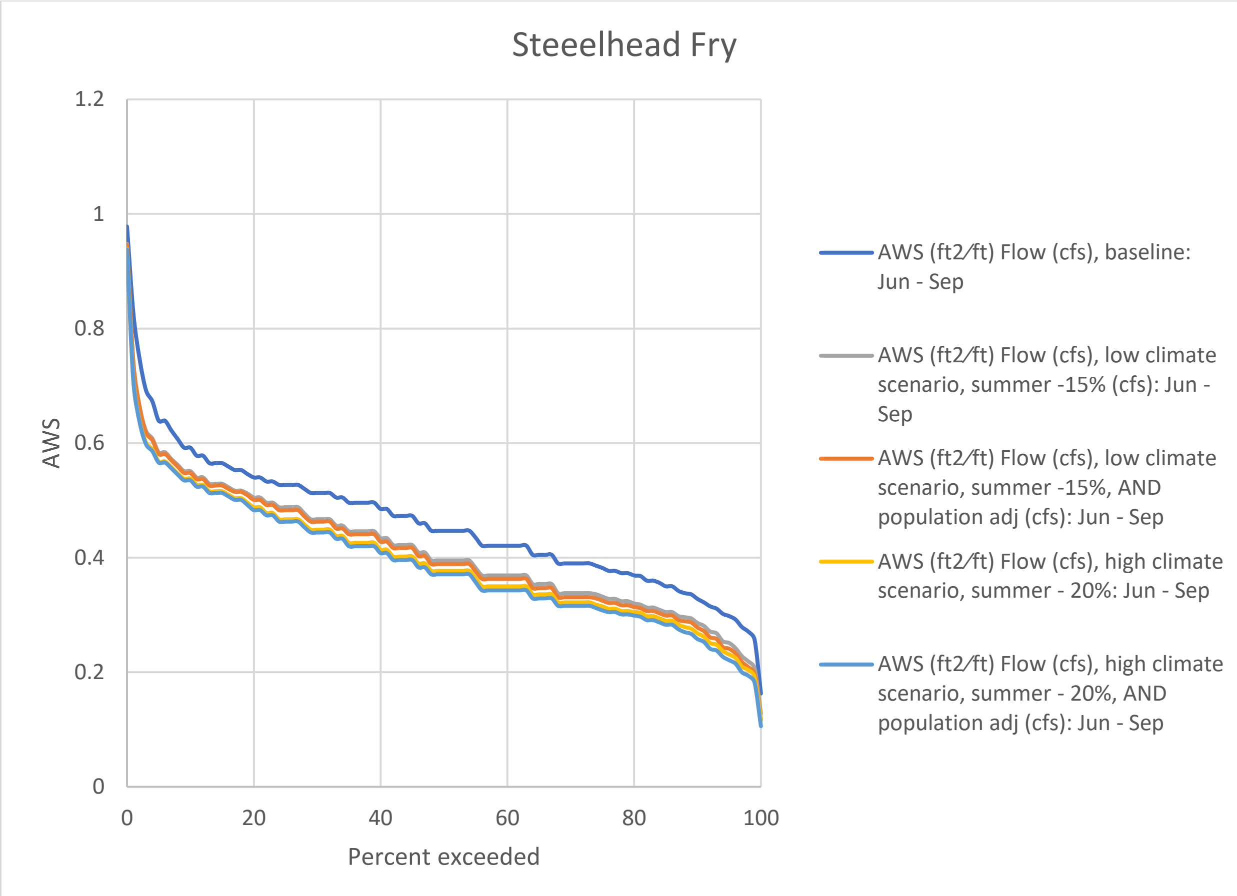

Chinook Juvenile
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
AWS
0
20
40
60
80
100
Percent exceeded
AWS (ft2/ft) Flow (cfs), baseline: Feb - Jun
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15% (cfs): Feb - Jun
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): Feb - Jun
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%: Feb - Jun
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): Feb - Jun

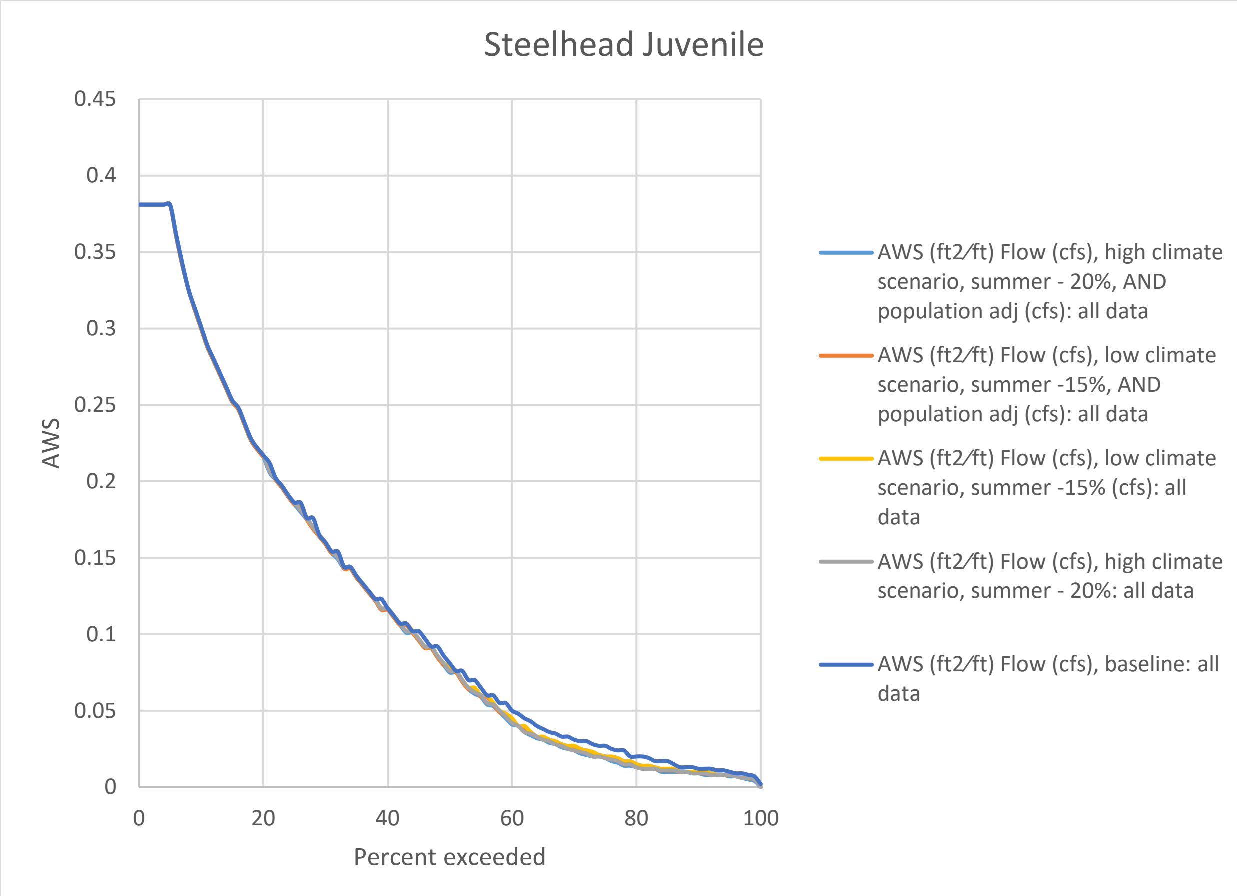

Chinook Spawing
AWS
Percent exceeded
0
1
2
3
4
5
6
7
0
20
40
60
80
100
AWS (ft2/ft) Flow (cfs), baseline: Jul - Oct
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15% (cfs): Jul - Oct
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): Jul - Oct
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%: Jul - Oct
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): Jul - Oct

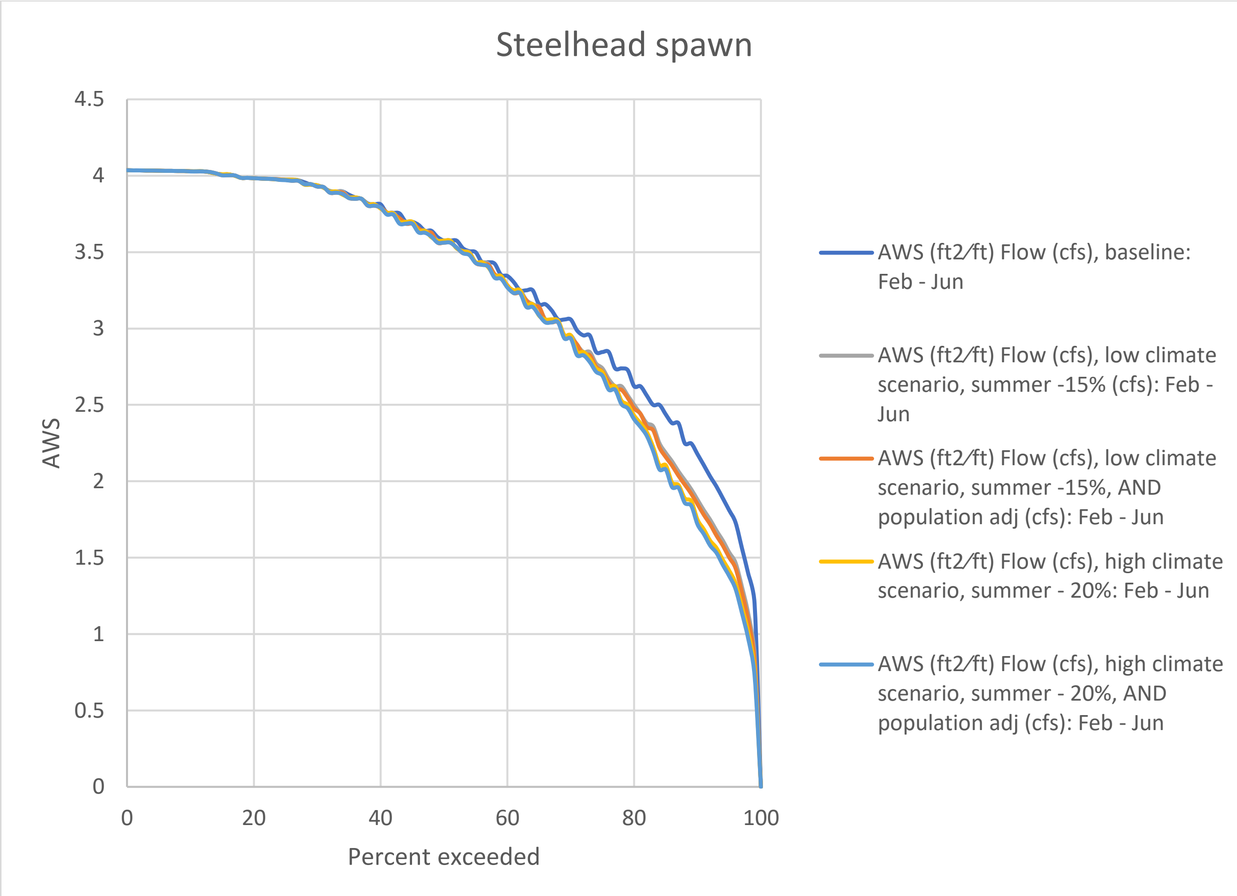

Coho Fry
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AWS
0
20
40
60
80
100
Percent exceeded
AWS (ft2/ft) Flow (cfs), baseline: Feb - May
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15% (cfs): Feb - May
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): Feb - May
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%: Feb - May
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): Feb - May


Coho Juvenile
AWS
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
Percent exceeded
AWS (ft2/ft) Flow (cfs), baseline: all data
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15% (cfs): all data
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): all data
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%: all data
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): all data


Coho Spawning
AWS
12
10
8
6
4
2
0
0
20
40
60
80
100
Percent exceeded
AWS (ft2/ft) Flow (cfs), baseline: Nov - Feb
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15% (cfs): Nov - Feb
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%: Nov - Feb
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): Nov - Feb
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): Nov - Feb


Steeelhead Fry
1.2
1
0.8
0.6
0.4
0.2
0
AWS
0
20
40
60
80
100
Percent exceeded
AWS (ft2/ft) Flow (cfs), baseline: Jun - Sep
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15% (cfs): Jun - Sep
AWS (ft2/ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): Jun - Sep
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%: Jun - Sep
AWS (ft2/ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): Jun - Sep


Steelhead Juvenile
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
AWS
0
20
40
60
80
100
Percent exceeded
AWS (ft2⁄ft) Flow (cfs), high climate scenario, summer - 20%, AND population adj (cfs): all data
AWS (ft2⁄ft) Flow (cfs), low climate scenario, summer -15%, AND population adj (cfs): all data
AWS (ft2⁄ft) Flow (cfs), low climate scenario, summer -15% (cfs): all data
AWS (ft2⁄ft) Flow (cfs), high climate scenario, summer - 20%: all data
AWS (ft2⁄ft) Flow (cfs), baseline: all data



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Appendix H: Habitat Raster Plots

The habitat raster plots depict the habitat index (AWS) throughout the time series period for each species and life-stage. An additional plot depicts the change in AWS between baseline and the population adjusted high climate scenario. All plots are based on the calendar year.

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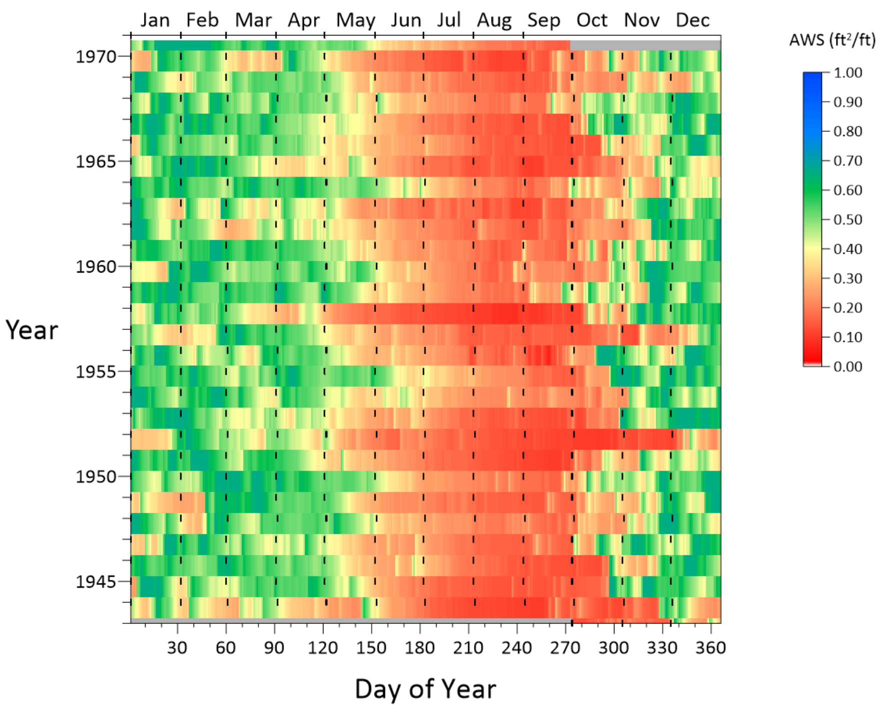
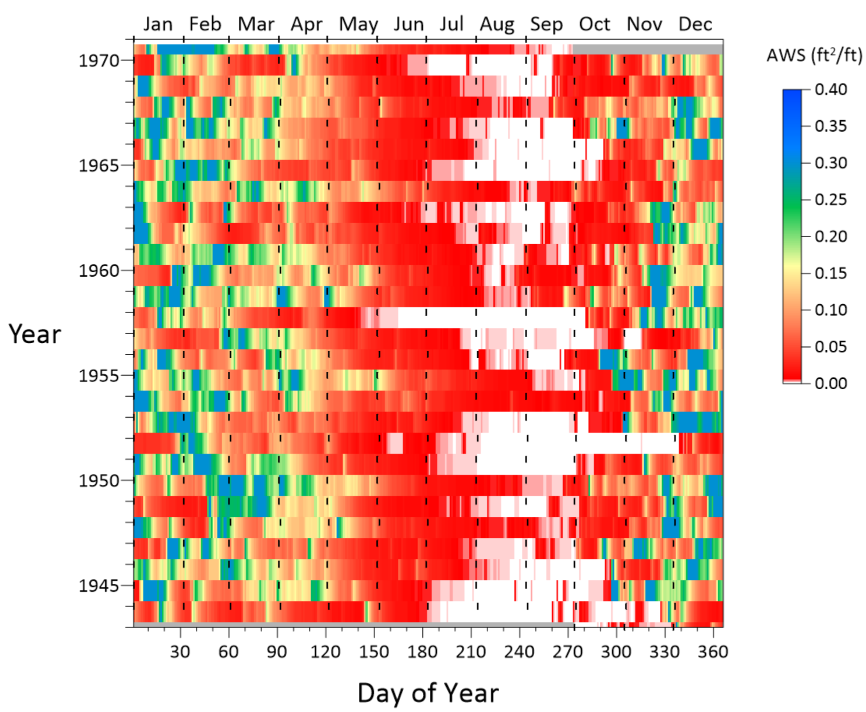
Chinook fry baseline



Chinook juvenile baseline



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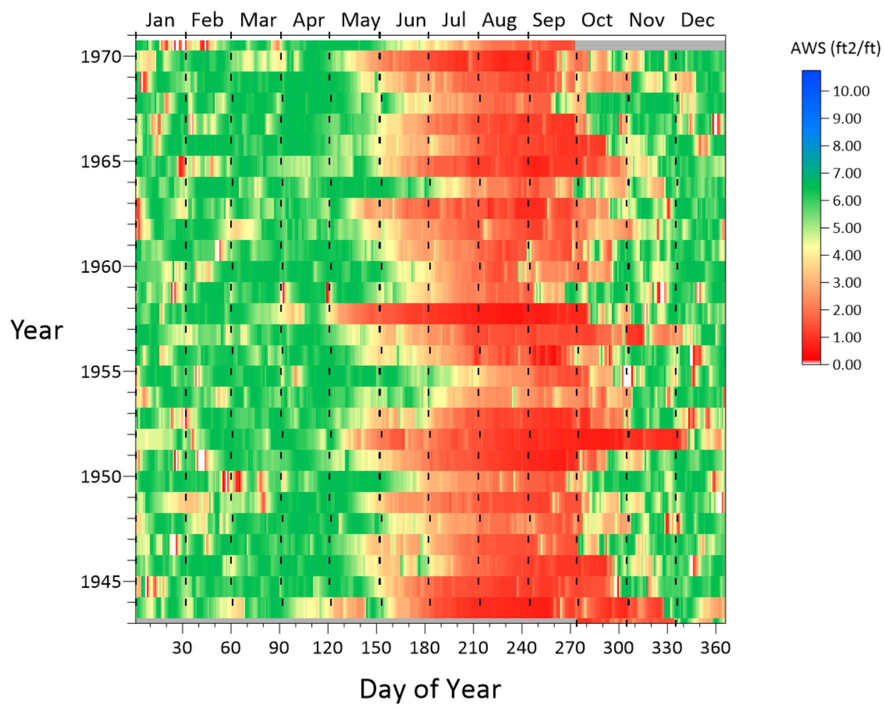
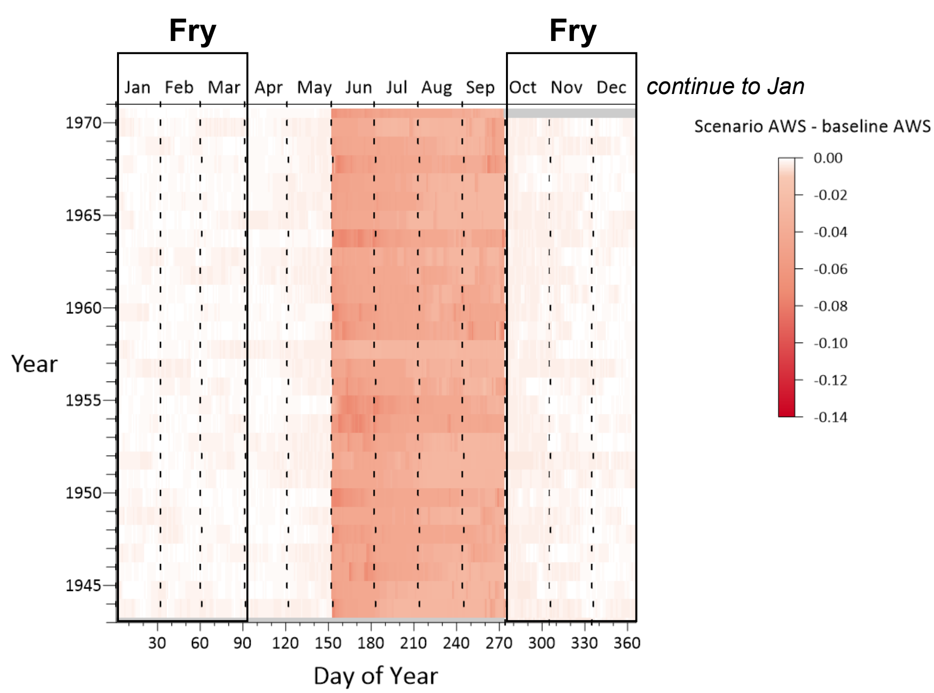
Chinook spawn baseline



Chinook high climate scenario, summer -20%, AND population adj (cfs) AWS minus baseline AWS



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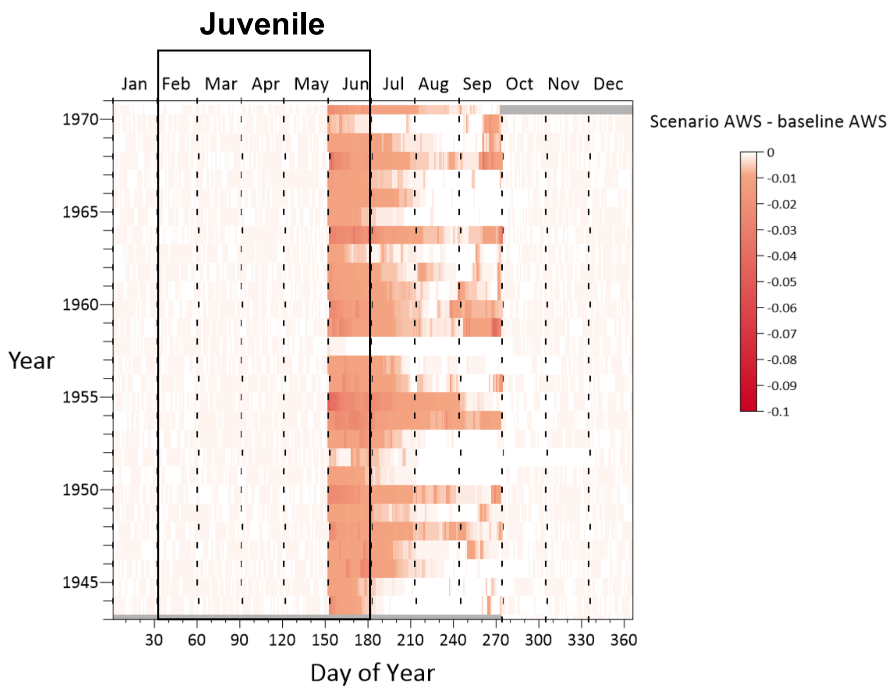
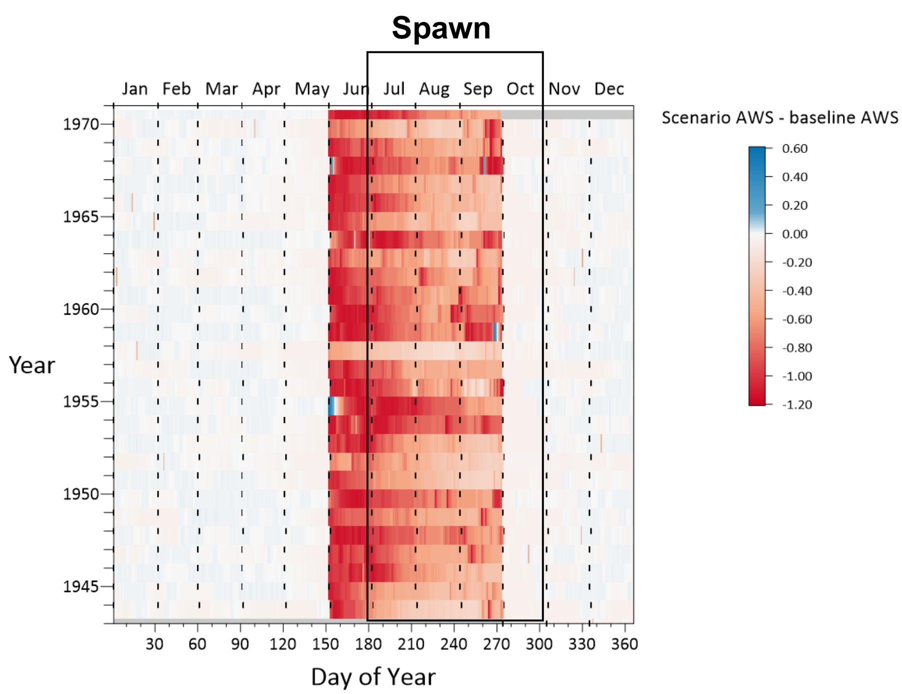
Chinook
high climate scenario, summer - 20%, AND population adj (cfs) AWS minus baseline AWS



Chinook
high climate scenario, summer - 20%, AND population adj (cfs) AWS minus baseline AWS



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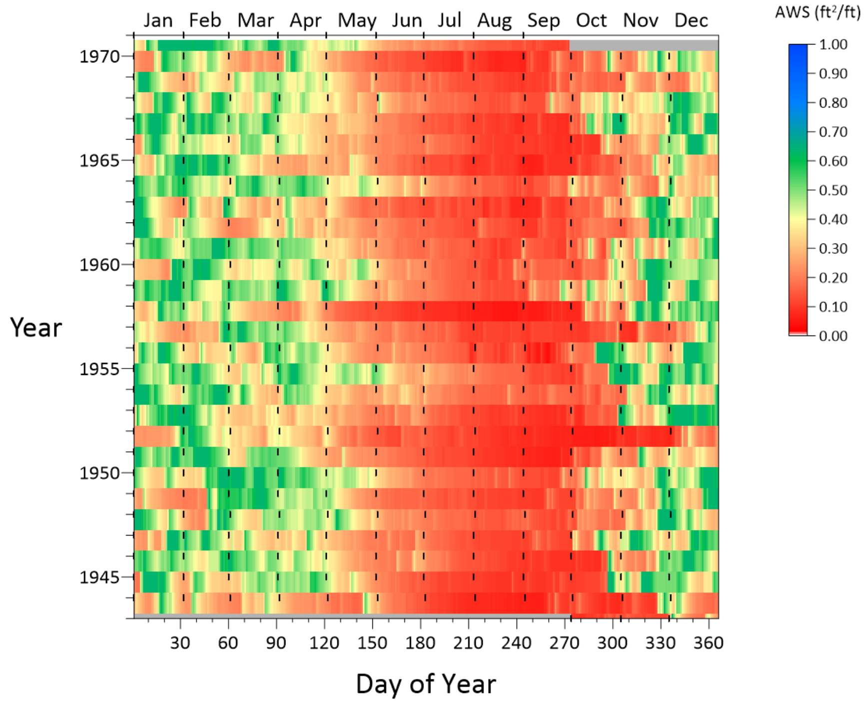
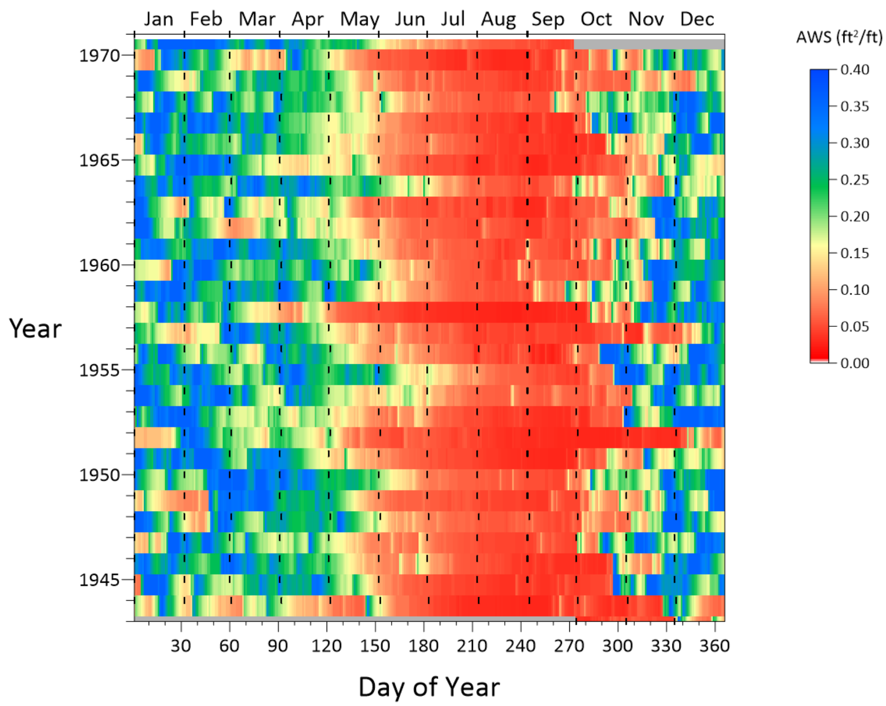
Coho fry baseline



Coho juvenile baseline



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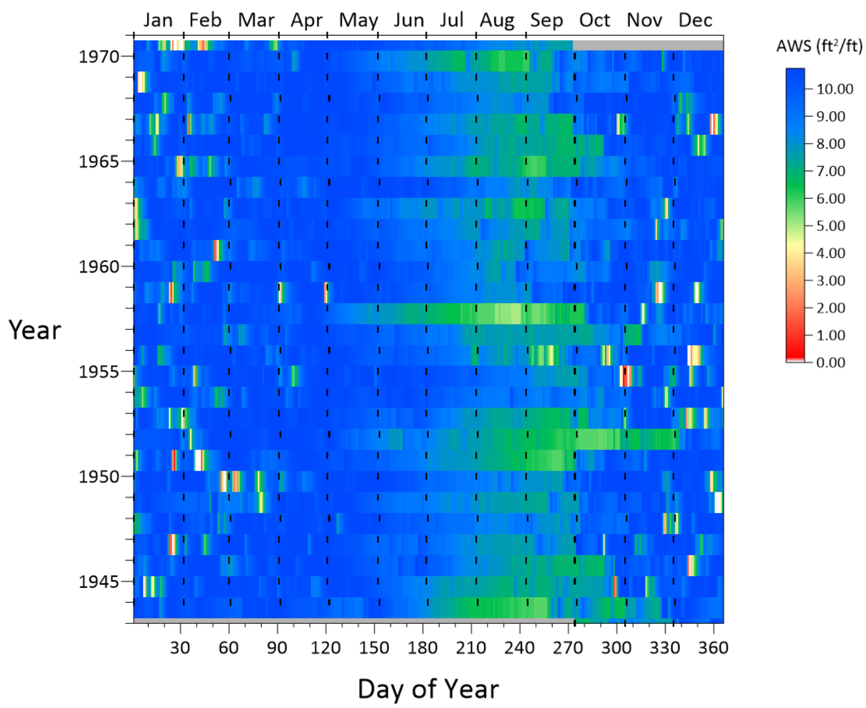
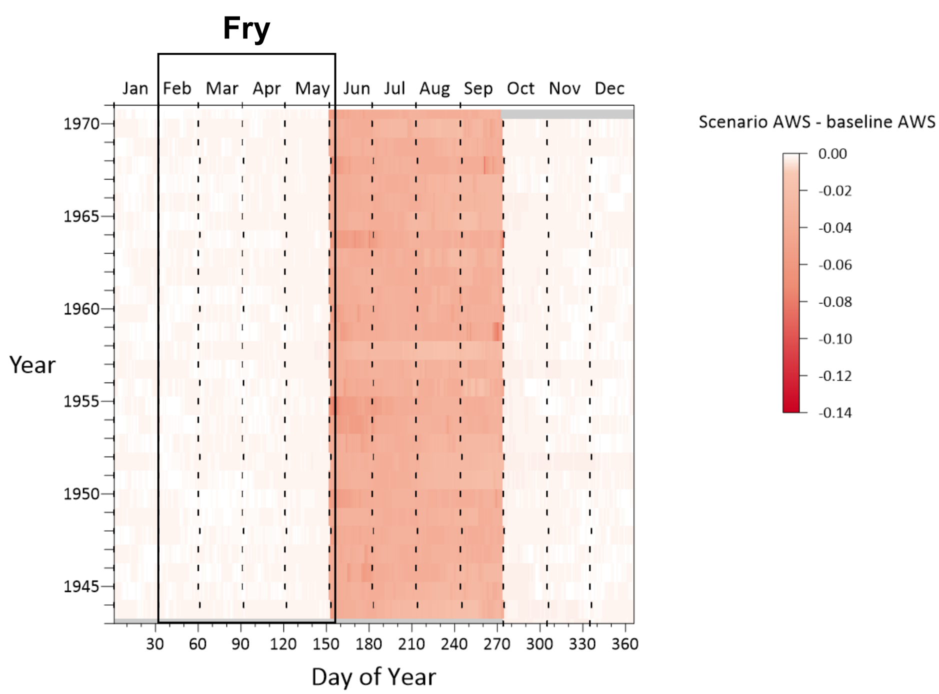
Coho spawn baseline



Coho high climate scenario, summer -20%, AND population adj (cfs) AWS minus baseline AWS



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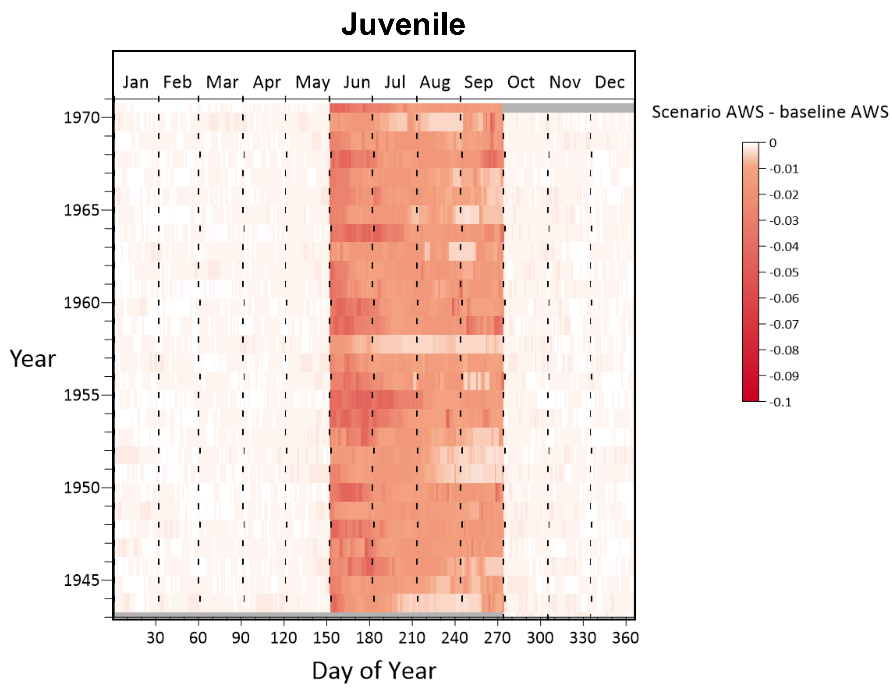
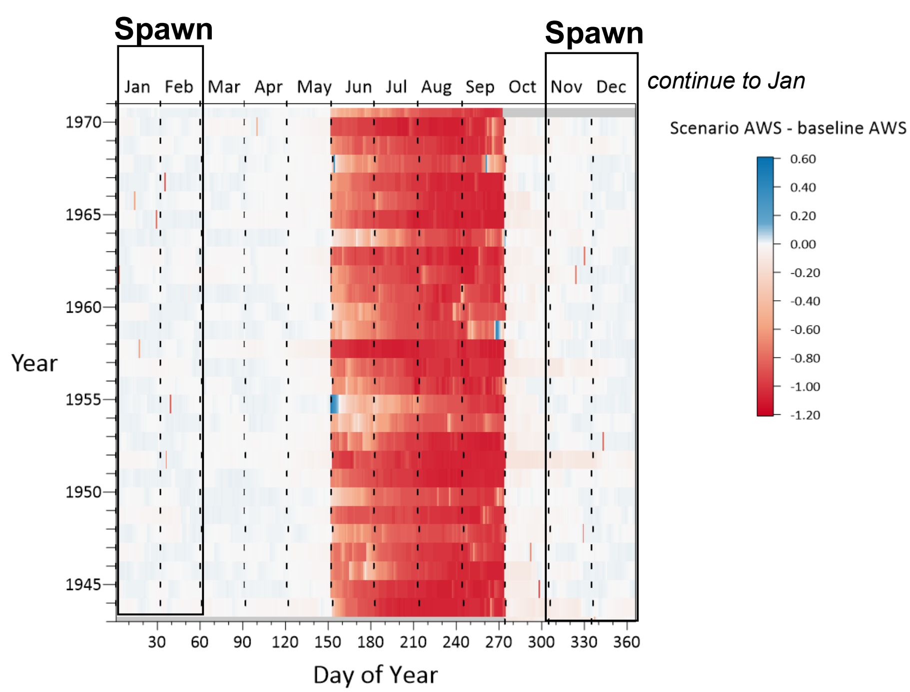
Coho
high climate scenario, summer - 20%, AND population adj (cfs) AWS minus baseline AWS



Coho
high climate scenario, summer - 20%, AND population adj (cfs) AWS minus baseline AWS



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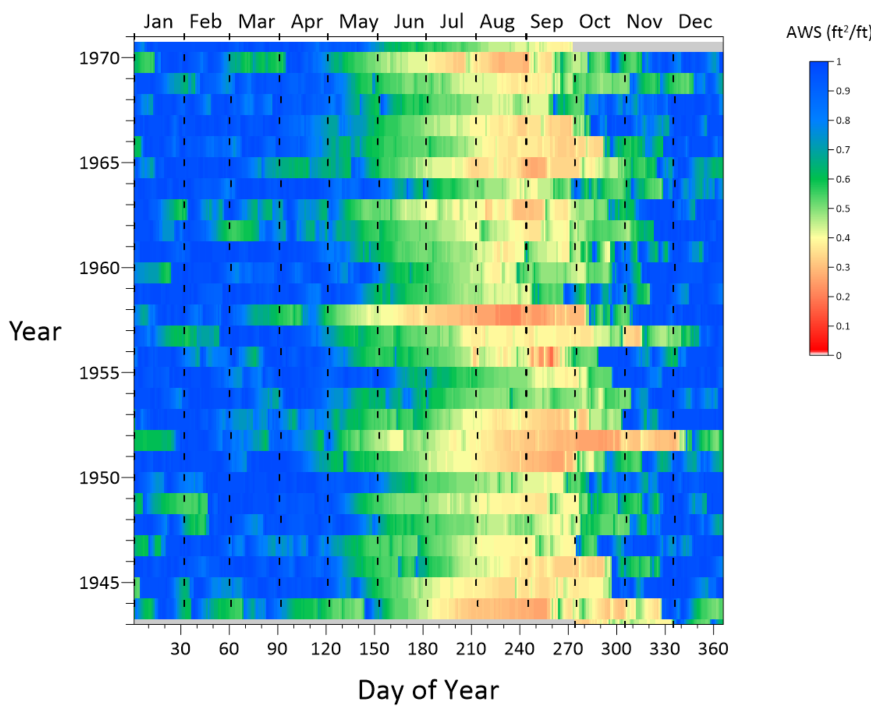
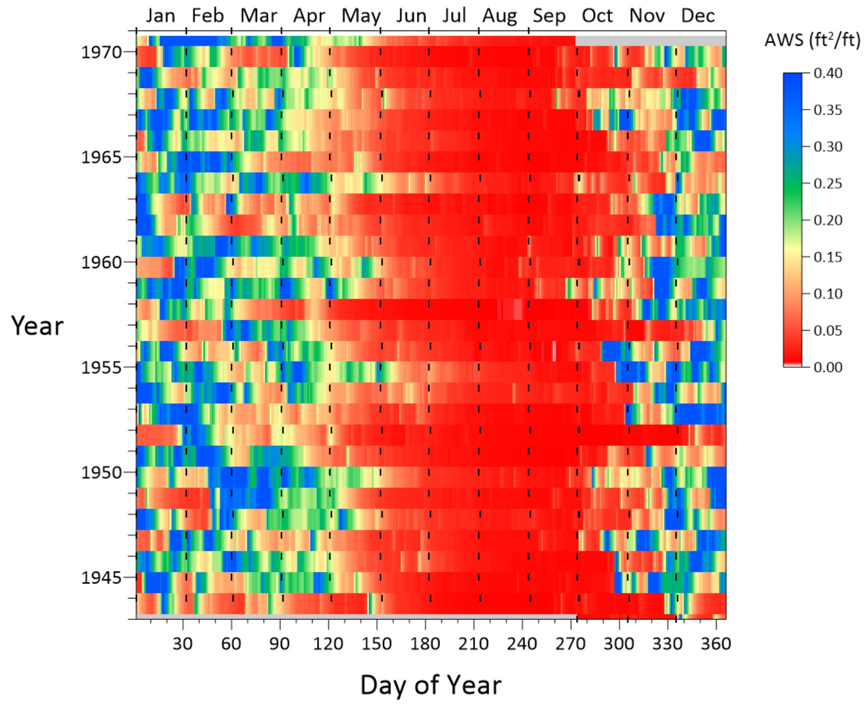
Steelhead fry baseline



Steelhead juvenile baseline



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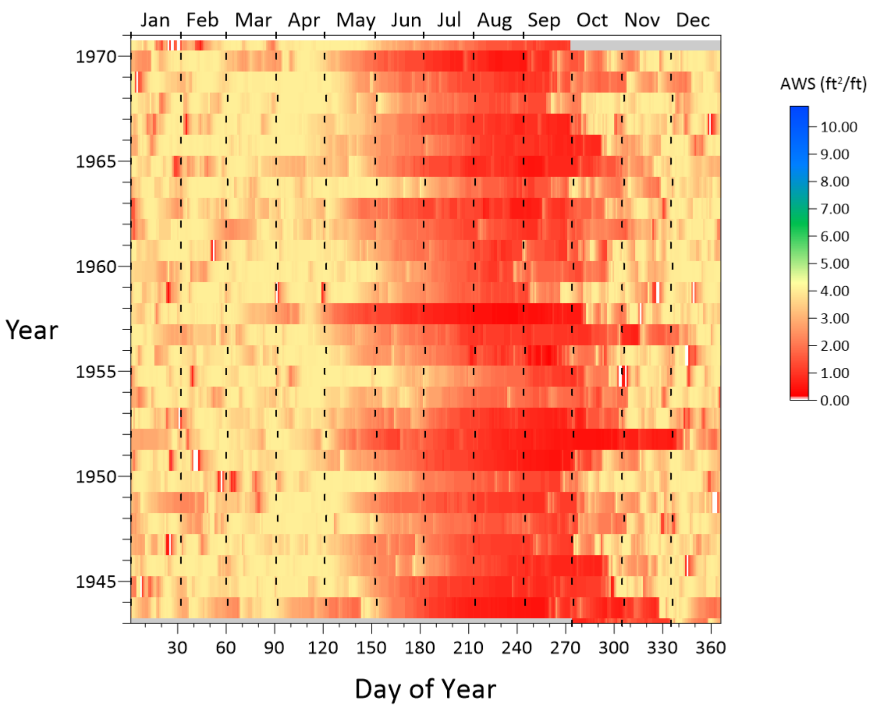
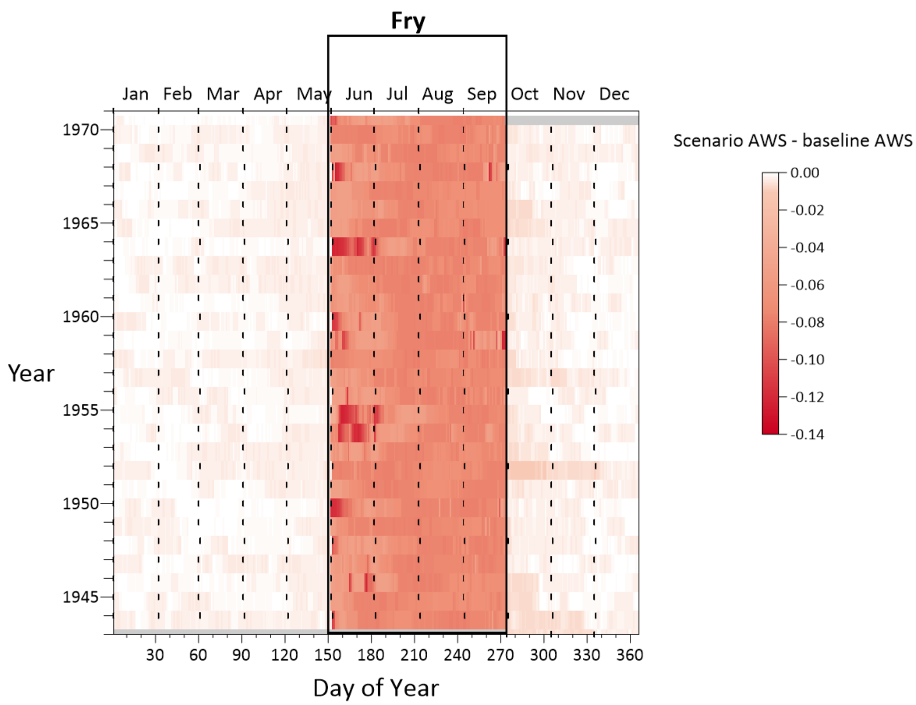
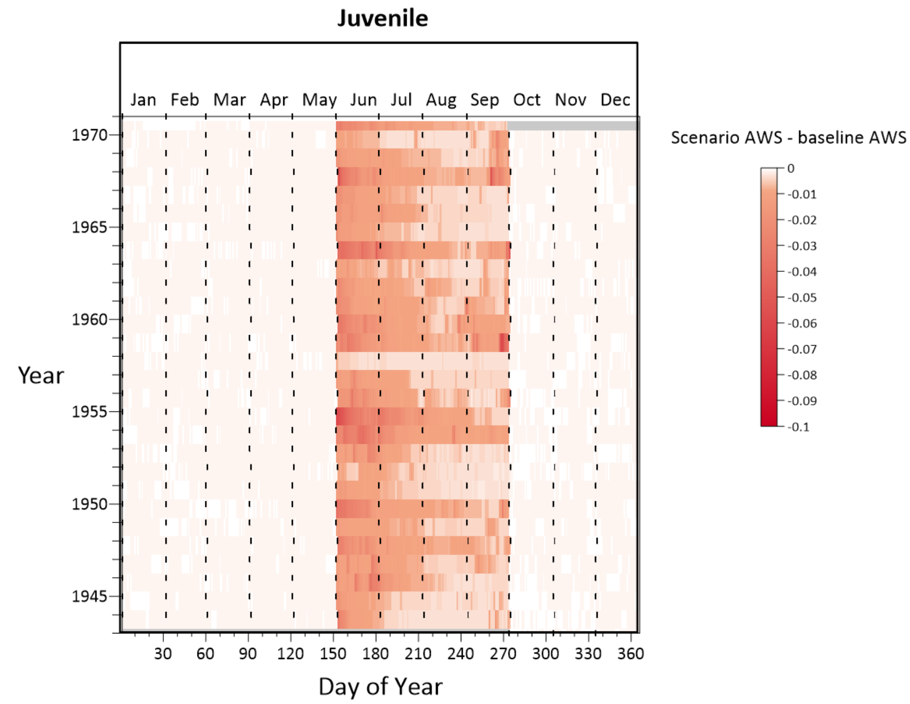
Steelhead spawning baseline



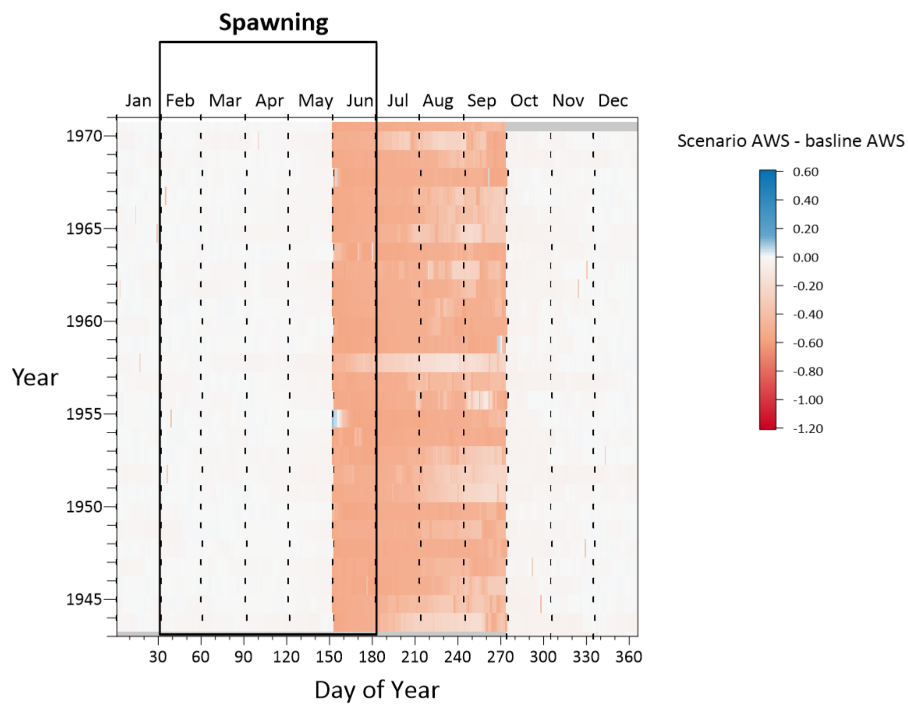
Steelhead high climate scenario, summer - 20%, AND population adj (cfs) AWS minus baseline AWS



Steelhead high climate scenario, summer - 20%, AND population adj (cfs) AWS minus baseline AWS



Steelhead high climate scenario, summer - 20%, AND population adj (cfs) AWS minus baseline AWS



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Appendix I: Peer review of the draft report on the "Skagit River Tributary Instream Flow Habitat Assessment" itemized comments, responses, and actions.

The Washington State Department of Ecology ("Department") asked the Washington State Academy of Sciences ("WSAS") to provide a peer review of the Tributaries Study, one of three studies commissioned by the Department at the direction of the Washington Joint Legislative Task Force on Water Supply ("Task Force") through the Washington State Water Research Center at Washington State University. WSAS convened a panel of four reviewers, chaired by WSAS Board Member Michael F. Goodchild, to conduct the peer review. Reviewers were chosen for their expertise in areas covered by the study, and in the Skagit Basin generally. WSAS asked reviewers to provide written commentaries on the study in response to guiding questions and convened reviewers for a virtual discussion on March 3, 2025. The comments, responses, and actions are itemized in Table 1.

Many thanks to the four reviewers who spent their time reviewing this document. The report is better for their comments.

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Table 1. Peer review of the draft report on the "Skagit River Tributary Instream Flow Habitat Assessment" itemized comments, responses, and actions.

Comments	Response	Action
Reviewer 1		
1. Grammar errors – subject-verb agreement X2; para 1 and para 2 Methodology; P. 9 Water Surface Elevation "Data was…" should be "Data were" as was expressed appropriately in other parts of the report. P. 12 Water Surface Prediction para. 2 subject-verb disagreement X2. P. 14, Table 3 "Incubtaion" is misspelled. P. 42, para. 3, "Developers may bypass this" should be "these."		Corrected
2. P. 8 PHABSIM Is the second sentence correct? I think percent contribution of a given habitat would be based on area of habitat, reflected by its length (width) as a proportion of the width of the transect. This may have been clarified on P. 12, Transect Weighting.	The habitat weighting and stratification in PHABSIM are done by habitat lengths, not by area.	
3. P. 13, para. 2: The selection of the HSC, also found in HSC-TM where it is presented as having used an arithmetic mean, should be substantiated here with respect to the options presented to the stakeholders and the salient points of discussion that caused them to agree on using the mean.		Added text summarizing the process and selection of the HSC.
4. Table 3. Poorly formatted table.		Added page break to prevent the table from being presented on two pages.
5. Figures 3 through 10. These figures do not appear to correspond to those presented in the HSC-TM document. Also, these seem somewhat rough. For example, Figure 11 shows a velocity curve that dips from near 0.8 at 0.1 for a small range of intermediate velocities with higher HSC values on either side of it. Figure 9 shows several dips between high HSC values. Also, the meanings of values used on the horizontal axes are not provided.	The HSC plots are directly from the RHABSIM software. They are certainly not as good graphically as what can be done in software today; however, they depict the exact HSC that was used in the model. They are the same curves as those presented in the HSC Technical Memo. The X-axis is labeled "Value" because it is either depth, velocity, substrate code, or cover code, depending on the curve.	Added sentence to clarify the X-axis.
6. Figure 13. "Exceededance" is misspelled in the flow chart.		Fixed
7. Table 4. Poorly formatted table. Provide the N size so the reader understands the math that total length equals mean length of habitat units multiplied by number of habitats within a type. Remove "total length surveyed" values from the first two columns. Also, does "NA" mean not measured or not present? Add % represented by each habitat to correspond with Figure 15.	The N size is provided in Table 5. Table 4 gives the average habitat unit length and the total lengths as surveyed. The mean length in the first two columns is the mean length of all the habitat units.	Added page break to prevent the table from being presented on two pages. Added "NA indicates that no habitat units of that type were encountered."

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Comments	Response	Action
8. P. 27. I do not see the channel changes between Fig. 17 and Fig. 18 caused by pink salmon spawning.	The channel changes between Figures 17 and 18 were caused by the high flow event. Redds and carcasses are also seen in Figure 18.	Clarified that the redds and carcasses could be seen in Figure 18.
9. P. 28. How much were the rating curves degraded by this? Is this reflected on P. 32 by the statement: "all but two transects had a mean error less than 5 percent"?	We do not know how much the rating curves were degraded by the pink spawning; however, the statement on p. 32 indicates that the rating curves were acceptable.	
10. P. 35. Upper Reach and Fig. 20. Interpretation of the shape of the ratings curves is subjective – it decreased 2 AWS from the peak which is about 30%. Also, the perception of flatness can be a function of how long the x-axis is in relation to the y-axis. Similar caveats for Figs. 21 and 22.	Interpretation of curve shape can be subjective; however, the fry and juvenile curves are low and flat indicating that instream cover is lacking.	
11. P. 38. Refers to "locations" of the USGS gage stations in the plural. I think Alder Creek had the only gage.		Changed sentence to read "The location of the USGS gage station and the mouth of Grandy Creek were used to determine the drainage area for the two basins."
12. P. 43. Para. 2. The peaks were in water years 1949, 1950 and 1970, not 1950, 1951, and 1971, according to Fig. 27.	The years referred to are calendar years.	
13. Figures 30 and 31. I am not clear on the value of these figures. Figure 30 is challenging to see the correspondence between high flows and suitable Chinook spawning habitat availability, and this is not much clarified in Figure 31. I discern in general that more habitat may be available at higher water levels, but I am not sure the figures present that in the clearest light.	The lines plots and habitat duration curves are traditional methods of presenting the AWS time series results, and are presented here. The authors developed the raster plot method of presenting AWS time-series data, and prefer that method.	
14. Figure 33. The Y-axis appears to be calendar year, which causes the top and bottom margins of the horizontal rasters to misalign with year.	That particular plot uses calendar year since the x-axis starts in January.	
15. P. 47. The statement: "Chinook fry do not rear in the summer months and juveniles only rear in the one summer month of June." is contrary to previous statements. See Table 3. Also, this gets at the life history differences between stream-type and ocean-type Chinook. Given the protracted release of this draft, I recommend the authors consult last year's publication by O'Neal et al. about stream-type Chinook in the Skagit watershed (see reference and description below).	We could not find any reference to stream type Chinook rearing in Grandy Creek.	Added text to p.12: "Chinook salmon in the Skagit watershed exhibit both ocean-type (sub yearling outmigration) and stream-type (yearling outmigration) life histories. Ocean- type represent over 90% of the total freshwater production of Chinook (Zimmerman and Kinsel 2015). Stream-type juveniles are mostly associated with the snowmelt dominated watersheds (Kudo et al 2017, Beechie 2006). Grandy Creek is a rain dominated watershed. For this study, the periodicity of the ocean-type life history was used."
16. Figure 37. While I applaud the innovative application of heat maps to characterize stream climate, I find that the portrayal intending to contrast the two scenarios portrayed	No comment.	

Comments	Response	Action
in Figure 37 is not evident. Showing them as differences as in Figures 38, 39 and 40 is much clearer.		
17. Discussion. This is probably the weakest part of the report. My opinion is that it does not qualify as a discussion in the usual sense because it does not provide meaning and context with reference to the abundance of other studies that are included in the bibliographies. I recommend re-framing it as Conclusions and bolstering it with overviews of the evidence that has been provided.	The Discussion is not intended to be same as a Discussion in a journal article. It is intended to interpret the results of the PHABSIM study, and include professional observations relevant to utilizing the results to manage the stream.	
a. Paragraph 1. Although the lack of pool habitat is evident, this paragraph provides no comparison as to what expectations of the pool to riffle habitat should be. I expect it is not just number of pools but area of pools that lacking. Given that the principal methods used for this study are derived from a California document that has the main purpose of guiding restoration (Flosi et al 2010), and, incidentally, is not included in any of the lists of literature in the report, I would suggest looking there first. Also, at the higher level of hierarchy it may prove more useful to characterize habitats as either fast water or slow water so that the reader can better envision types of habitats that could be restored to function as “pools.”	In a PHABSIM study, the object of stratifying the habitat(habitat typing) is to assist in the placement of transects and weighting of the suitability. The observation that Grandy Creek lacks in pool habitat is a professional observation. Bovee et al., 1998 is a better reference for principal methods. Flosi et al., 2010 pertains mostly to the habitat typing.	Added text p.50, "Whereas, Flosi et al (2010) suggest that pool habitat should comprise 40% of the total length, Grandy Creek has 4% pool habitat in the Lower Reach and 7% in the Upper Reach."
b. Paragraph 2. This paragraph presents results that I do not recall from the report, and a brief statement of methods. This observation would be most useful if a standard barrier assessment had been conducted so that the reader could know whether the feasibility of providing fish passage should even be considered. It would also be useful to know if the cascade is natural or the result of human activities.	The falls are natural, but it was not within our scope of work to conduct a barrier analysis of the falls.	
c. Paragraph 3. Similar to the first paragraph, this paragraph also lacks context as to expectations of how much AWS would meet at least a minimum criterion to function as rearing habitat. The statement: “Instream cover, where present, is mostly restricted to the margins, creating only a narrow strip of rearing habitat along each stream bank.” This is clearly a result statement, although I do not recall analysis that addresses this in the report.	The results of the PHABSIM study are the AWS curves. The statement pertaining to the cause of the shape of the AWS curve is a professional observation explaining why the AWS curves are low and flat.	

Comments	Response	Action
d. Paragraph 4. The first sentence is a well-stated conclusion. The second and third sentences build on this, but may contain errors. I would expect that coho fry and stream-type Chinook fry and juveniles may be impacted.	Coho fry are expected to become juveniles before the summer period, and steam-type Chinook were not expected to rear in Grandy Creek, and were not included in the analysis.	
e. I think that in the context of this study, the question of "What is the best flow?" should be addressed with respect to biological needs since this was a fish habitat study. I also think that while the needs of individual species may vary among seasons, the single-most evident need is for more slow water, likely as pools.	Unfortunately PHABSIM results are often misinterpreted. PHABSIM is only one aspect of IFIM. This caveat is used to encourage the reader to consider the other aspects of IFIM. The lack of pool habitat is a problem, but is not a conclusion from the PHABSIM study which relates flow to habitat.	
HSC-TM Habitat Suitability (Criteria Attachment 2)		
1. Selection of appropriate HSC criteria appears to have undergone rigorous evaluation.		
2. Provide detailed information for the criteria used to exclude and include HSCs from other studies. Current language is: "…filtered to only include HSC that met several criteria, including…" Perhaps the list of criteria that were used is comprehensive; if so, language should be edited to reflect that.	From p.1: The Normandeau HSC database was filtered to only include HSC that met several criteria, including HSC based on actual field data collected in the western U.S. (HSC based on subjective decisions were excluded), HSC based on adequate sample size (generally datasets containing 100 or more observations), HSC accounting for habitat availability (by sampling design, adjusting habitat use by habitat availability, or other method), and HSC collected from similar channel sizes (HSC based on large rivers were excluded).	
3. Rationale should be provided for selection of the "averaging methodology."	From p. 2: The new HSC curves used to represent habitat selectivity for salmon and steelhead fry were developed by utilizing an averaging methodology intended to characterize the central tendency of the existing HSC curves.	
4. Include language reflecting interpretation of the HSC scores that were used (0, 1, 0.5, and 0.2)	Suitability is expressed from zero (none) to one (perfect).	
Hydrologic Analysis: Grandy Creek Watershed (Attachment 3)		
1. The application of the hydrologic information from adjacent Alder Creek to the Grandy Creek watershed is well justified and appears appropriate.		
2. In the introduction describe what a water year is. The terms "water year" and "calendar year" occur in different sections of the report.		added text to introduction: The term "water year" refers to the period from October 1 to September 30, and is assigned the year number of the last day of the water year. Between October 1 and December 31, the year number of the water year is the calendar year number plus one.

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Comments	Response	Action
3. Clarify Figure 3 x-axis label. The text states “Day of Water Year” and the label states “Day of Year.”	The x-axis is labeled as "Water Year".	
4. Table 2, lower right. I am not familiar with the five statistics listed below “Interquartile Range.” But I am not a hydrologist, so these may be commonly recognized.	No comment	
5. Figure 6. Figure caption stats are a bit misleading in that 1950 is not especially extraordinary if one considers that the decade is 10 of the 28 years (36%), and the categories of 10 driest and 10 wettest each make up 36% of the total – but probably moot to the report. Language in the caption should indicate that these are water years – driest and wettest water years. Figure 7 is a better portrayal of the “wet” 1950s with 7 of its 10 years above the median rank of 14.5.	No comment	
6. Figure 7. Wow.	No comment	
7. P. 17, para 2. The second to last sentence provides future scenarios for mean winter stream flow ratio to mean spring stream flow. It does not provide current or past ratios for context. Also, Chegwidden et al. 2017 define the months of winter and of spring differently than presented in Table 4 caption of this analysis.		Changed text to read: “Alder Creek, which has been used as a surrogate gaged watershed near Grandy Creek, has a ratio of 2.0 and is expected to increase to 2.1 under a higher climate change scenario, respectively. This indicates that under these two climate scenarios, average winter streamflow is approximately 2 times greater than average spring streamflow and is expected to increase approximately to 2.1 in the 2050’s time period.”
8. Figure 12. I am unclear on what the numbers next to the blue circles represent. Are these 1.08 X (+8%) actual peak flow on those dates?	That is correct, +8% and +12%.	
Additional thought: A barrier assessment is an essential component of fish habitat assessment, and most habitat assessment guidance includes a protocol for how to assess the many aspects of a barrier. In this case Grandy Creek crosses under an SR20 bridge. Flosi et al. 2010 include a section on assessment of fish passage at stream crossings. Was one conducted?	A barrier analysis was not within the scope of work for this study.	
Appendix C. Transect Profiles, and Calibration Flow Velocities and Water Surface Elevations		
Recommendations:		

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Comments	Response	Action
1. Provide context in figure captions for locations and dates on pages 2 through 11.		Added map and table of WSEL, discharge, and dates. Added text: "The calibration flows were measured at each transect. The Figure A1 depicts the transect locations and the Tables A1 and A2 itemizes the average water surface elevation (WSEL), measured discharge, and date of measurements. Values are in feet and feet/second."
2. Add units to all axis labels	The RHABSIM software is not capable of adding units to the axis labels.	
3. The difference between lines representing velocity and those of water surface elevation are not distinguishable by what appears to be a slight change in color density, such that VELx looks like WSLx in the various graphs.	These are RHABSIM generated plots.	
Appendix D: PHABSIM Calibration Summaries		
Recommendations:		
Spell out the habitat type for each cross-section. For example, Cross-section #3 XS3 indicates "RifPoc." What habitat type is that? Also, Cross-section #8 XS8 indicates "Pool." What is a pool	This is RHABSIM output that is common to include in a PHABSIM report. RHABSIM does not allow sufficient characters to spell out the names. More detail on the habitat typing is provided in Attachment 1.	
Appendix E: Simulate Water Surface Elevations and Velocities		
Recommendations:		
1. Provide context in figure captions for locations and dates on pages 2 through 11.		Added explanation of units at beginning, "The elevations presented in these figures are relative to an arbitrary benchmark with a given elevation of 100 feet. Distances are from the left bank headpin looking upstream, in feet. Velocities are in feet per second. "
2. Add units to all axis labels.	RHABSIM has limited formatting ability for the plots.	
3. The difference between lines representing water surface elevation and velocity are only distinguishable by shape because the same color is used for both. Also, the lines in some graphs are green and in others they are turquoise – why?	RHABSIM has limited formatting ability for the plots.	Added text, "Green-lined plots were simulated with three flow regression, blue-lined plots were simulated with Manning's Equation."
Appendix F: Tabular AWS Values		
Recommendations:		

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Comments	Response	Action
1. Without knowing the purpose of providing a tabular set of data in pdf format, rather than as a spreadsheet, I am uncertain of its purpose. However, if one wished to copy these data and paste them into a spreadsheet, then having the headings left-justified over the appropriate columns would greatly facilitate interpretation.	We try to keep the report and appendices in pdf format. I can open the table in Excel from Adobe Acrobat with only minor issues with the merged headers.	
Appendix G: Habitat Duration Curves		
Recommendations:		
1. These lack appropriate figure captions for reference and to provide context for "Percent exceeded."		Added introductory text, "The habitat duration curves for each species and life-stage compare the AWS percent exceedance for the baseline habitat to each of the climate and population adjusted scenarios. "
2. Page G-2 appears to have all five scenarios overlain. A caption, or even a set of general statements before presentation of the graphs could indicate if this is the case.		Added introductory text, "The habitat duration curves for each species and life-stage compare the AWS percent exceedance for the baseline habitat to each of the climate and population adjusted scenarios. "
3. The vertical scale in all of the graphs portrays the change in AWS in ft2/ft. From a restoration perspective, the % increase in AWS may be useful for identifying reaches where a given amount of restoration may result higher amounts of AWS from baseline for a given change in exceedance. This is speculative on my part.	That is correct. This study is focused on stream flow impacts to fish habitat from climate change and population growth.	
Appendix H: Habitat Raster Plots		
Recommendations:		
1. Clearly indicate that the axes of these plots are based on calendar years and calendar day of the year rather than water years because water years were used in other portions of the report.		Added introductory text: "The habitat raster plots depict the habitat index (AWS) throughout the time series period for each species and life-stage. An additional plot depicts the change in AWS between baseline and the population adjusted high climate scenario. All plots are based on the calendar year."
2. The Chinook juvenile baseline raster plot shows areas with no color fill. Provide the explanation in the key.	White is near zero habitat.	
The "Scenario AWS – baseline AWS" is an especially useful portrayal of changes in habitat area under the various scenarios.		
Reviewer 2		
General Comments		

Comments	Response	Action
1. Comprehensive redd and carcass surveys were not part of this study, interpretation about the distribution of spawning, and the possible role of a falls, is not supported and seems out of place in the discussion.	That is correct that the carcass and passage observations were not part of this study; however, the professional observations are important and inform the interpretation of the results.	
2. Morhardt et al. 1983 and Bovee et al. 1998 are obscure or inaccessible, the authors need to describe the different mesohabitat types and their characteristics in the methods section	These references describe the PHABSIM methodology that was integral to the scope of work for this study.	
3. It is unclear if length and width for each habitat unit was taken. It appears length was, but without width, it is unclear how the cell-based assessments of habitat suitability developed in RHABSIM are translated into area for fish habitat.	Habitat typing is conducted by measuring length and used to stratify the transect selection. Width is accounted for in the PHABSIM model by the transects.	
4. Why was temperature not recorded as a measure of habitat?	See comment #8.	
5. Specifics about what constituted spawning gravel was not described in the methods. In many of the site pictures, predominant substrate appears to be larger, cobble-sized material. Different species of salmon prefer different sizes of gravel, so knowing the size class of gravel is important.	The substrate was coded on each transect. The spawning habitat suitability curves depict the substrate size suitability for each species.	
6. Additional explanation for how the habitat simulation was completed is needed. Methods described on Page 19 are incomplete. Cell size is not explained, flow ranges are not described (they are mentioned as mandatory or seasonally minimum, but we are not informed what these flow levels are). How the cells are distributed is not made clear. Is this only cells along the transects? Or is the entire overall score across the transect then associated with that specific habitat type? Where there are multiple samples of that habitat type (as in riffles), how are these values summarized? There is a general lack of explanation for how work was completed in enough detail to fully understand how the habitat simulations for each transect were translated into habitat suitability in areas that were not in the transect.	We are not attempting to fully describe nor justify the PHABSIM methodology.	
7. Different species of salmon might be expected to spawn or rear in different locations along Grandy Creek. This preference for different locations in the network is indirectly captured by the velocity and depth preferences in the RHABSIM model, but not fully.	That is correct.	

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Comments	Response	Action
8. Temp was also not part of the RHABSIM models. Only velocity, depth, and variously substrate and cover were included in the models. Temperature is a key habitat metric at all life stages. During summer, stress from high temperatures can affect rearing fish and delay the onset of spawning. Both of these outcomes could change under future climate conditions, and are not represented in this study.	That is correct; however, a water temperature model was not part of the scope of work for this study.	
9. In table 3, citations 1 and 2 mostly speak to juvenile Chinook salmon life stage needs, and only peripherally refer to the spawning life stage. Is there a more specific citation that can be identified for Chinook spawning timing and life stage changes that could be referenced here?	Current work in the Skagit Watershed could refine the periodicity.	
10. By clustering transects (as displayed in Figure 16 and described in the methods), the study design demonstrates pseudo-replication for riffle habitat types. There are essentially four study areas. While multiple riffle habitats in reaches 1 and 2 were sampled, they are so close together they are likely spatially autocorrelated, yet measurements are treated as independent samples across all riffle habitat types. However, it was never clearly described how the transect measurements were turned into habitat suitability scores more broadly. Pseudo-replication could possibly be controlled, but it is unclear how the transects were translated into habitat scores, to see how that might be done.	These are standard methods when collecting data for the PHABSIM model.	
11. Field surveys water surface elevation and discharge were completed in fall 2022 through fall 2023. Were the flow levels that were measured characteristic of Grandy Creek? Was there a daily flow time series installed at Grandy Creek? Was a comparison to the modeled historic flow regime at Grandy Creek created?	No level logger was installed on Grandy Creek for this study. The original time line for this study was very short (Fall of 2022). No level logger was scoped do to the short turnaround time.	
12. There appears to be no consideration that mesohabitat types change with different flow levels. Riffles can become pools, and pools can become glides or riffles at different flow levels. Was a winter survey of habitats considered, to evaluate whether habitat types changed?	In a PHABSIM study, the object of stratifying the habitat(habitat typing) is to assist in the placement of transects.	
13. More information about the staff gages is necessary in the text. How were they installed and monitored? That is not described.	Temporary staff gauges were used to monitor the streamflow during calibration flow measurements. They were removed when each calibration flow reach measurements were complete.	

Comments	Response	Action
14. Why was a pressure transducer not installed anywhere on Grandy Creek at least for the duration of this study? The transects and development of ratings curves described in the study could have been leveraged to describe actual flow conditions if a gage had been installed.	See comment 11.	
15. Why was Grandy Creek selected for this study, when the historic gage is at Alder Creek? Throughout the document, the historic flow attributed to Grandy Creek needs to be referenced as “modeled” or “interpolated”, or something of that nature. This is needed in all figures, tables, and captions as well as in the text (of the main document, and all attachments). Otherwise, it appears that these measurements are from Grandy Creek, when they are from neighboring Alder Creek. The use of Alder Creek gage data in this way to capture some of the potential variability over time that could have been experienced by Grandy Creek is likely adequate for this study.	The hydrology for the time-series analysis was synthesized from the historic Alder Creek Gage data; however, all measurements were conducted on Grandy Creek	Added text to methodology p. 19: "Historic gauge data from adjacent Alder Creek were used to develop a synthetic hydrograph for Grandy Creek."
16. the climate change scenarios and future water demands for development were not described in the methods. They were discussed starting on Page 40. There is no justification for why these particular scenarios were selected. Much of the content on Pages 40-42 likely belongs in the methods.	These scenarios were considered to be low and high climate change scenarios with and without increased consumption.	
17. The simple methods used to evaluate future habitat conditions may not adequately represent future climate change. Temperature is absent from the habitat suitability mapping, and from assessments of future effects of environmental conditions on life stages of fish. It follows that without considering thermal effects, the only season showing significant vulnerability to future climate is summer, with lower flow conditions. This lower flow may also result in higher temperatures, which is not represented in the possible future effects of climate scenarios on life stages of fish.	A temperature model was not part of the scope of work for this study.	
Detailed Comments		
1. Page 1 Last sentence first paragraph, what “resource is being referred to? presumably water? Or is it fish?		Changed to "Grandy Creek".
2. Page 1 Second paragraph. Define WSU.		Added definition of WSU
3. Page 1 First sentence second paragraph – instream flow doesn’t become “habitat value”. How was habitat value calculated?	The result of the instream flow study is the relationship between AWS and discharge.	

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Comments	Response	Action
4. Page 2 Last paragraph of executive summary, what does this mean? “compare the resulting habitat value to the baseline habitat value”		changed "resulting" to "climate change and population adjusted ".
5. Page 4 A lake is mentioned. Are there sockeye here?	No references were found to sockeye inhabiting the lake.	
6. Page 5 On the Grandy Creek map, where does the study section start and end? Where is the lake referenced in the study area?		Updated Figure 1
7. Page 6 What does “within the framework” mean? In the PHABSIM framework?		Changed to "Instream Flow Incremental Methodologies (IFIM) and PHABSIM framework ".
8. Page 6 Define IFIM		Changed to "Instream Flow Incremental Methodologies (IFIM) and PHABSIM framework ".
9. Page 7 Using cotton thread for length measurements can result in accidental ensnarement of birds.	We remove as much as possible.	
10. Page 7 Why are “feet” used for measurement and not the metric system?	"feet" are still more commonly understood in the US than metric units.	
11. Page 7 “entire study area or within designated reaches”. Reaches have never been described or mapped.		Added text to previous paragraph: "The mapping information was used to determine reach boundaries".
12. Page 7 No dates given in methods for habitat typing field work.	Dates are included in the Results section.	
13. Page 9 are “study segment[s]” the same as reaches?	Yes	
14. Page 9 what does this mean? “Several units were be selected by random number.”		deleted "be"
15. Page 9 No dates for the calibration flows data collection given.	Dates are presented in the Results section.	
16. Page 10 define IFG.		Changed to "Instream Flow Group (IFG)"
17. Page 11 Staff gages? How were they monitored? How were they established? What was a significant change to require re-measurement of water surface elevation.	The temporary staff gauges were steel rulers stuck in the stream bottom.	Added: "Temporary".
18. Page 11 What instrument is being referred to here: “Upon establishment of headpin and tailpin elevations, a level loop was shot to check the auto-level instrument for accuracy.”		Changed text to: "Upon establishment of headpin and tailpin elevations, a level loop was shot to verify the elevations established with the auto-level.".
19. Page 13 refers to Annex B which is actually Attachment 2.		Changed to: "Attachment 2".
20. Page 19 these methods need illustration.	Figures 12 and 13 are our illustrations.	

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Comments	Response	Action
21. Page 20 the hydrologic analysis evaluated interpolated historic hydrologic conditions in Grandy Creek. Data came from the smaller, neighboring Alder Creek, as described in Attachment 3. However, Throughout the report document and attachment 3, the Grandy Creek historical analysis is presented as if the data was collected at Grandy Creek. Through this study, Grandy Creek historical analysis needs to be referred to as "Grandy Creek modeled historical analysis". This includes graphs and tables.	The method for establishing the baseline and climate change/population growth hydrologic scenarios is typical an ungauged stream and clearly described in Attachment 3.	
22. Page 22 remove "undoubtably". There are ways to measure whether this is a barrier. Replace with "may".		Changed to: "may".
23. Page 32 You say modifications were made to roughness and Manning's N to account for "unrealistic" simulated velocities. Please define this. Remove "excessively" when describing edge effects and justify how much higher or lower adjacent flows needed to be to justify adjustments.	"Unrealistic" is a determination made by the modeler. It means the simulated flow pattern does not match the flow pattern that would be characteristic at the simulated flow.	
24. Page 32 "ate" to "are"		Changed "ate" to "are".
25. Page 52 – adult holding habitat is generally associated with spring-run Chinook.		Re-wrote first paragraph, "The habitat typing indicated that there is a lack of pool habitat. Whereas, Flosi et al (2010) suggest that pool habitat should comprise 40% of the total length, Grandy Creek has 4% pool habitat in the Lower Reach and 7% in the Upper Reach. While there is ample spawning habitat in the lower reach, adult holding habitat is also essential for spawning success. Adult holding habitat was not modeled; however, the small number of pools indicates that is could be limiting."
Tables		
1. Table 2, were the cover codes quantified? How much undercut bank? How many rootwads?	Codes were for cover type presence.	
Figures		
1. Figures 3 - 11 need more explanation. What is "Value" on the x axis? Why are the axis values for spawning, juveniles and fry so different?	The Bovee substrate code ranges from 0-100, whereas the cover code ranges from 0-1.	Added text: "The X-axis in each figure is labeled "Value", and is either depth, velocity, substrate code, or cover code, depending on the suitability curve."
2. Figure 30 seems to be cut off on the top. It's unclear what this time series is meant to represent.	Figure 30 is not cut off, the top is the maximum available, limited by suitable substrate area. Each flow in the time-series has an associated AWS value. The top plot is the flow, the bottom the AWS.	
3. Figure 31 AWS seems to be cut off on the top. Why was this time period selected? What is this meant to show?	Figure 31 is an expanded subset of Figure 30 to depict more detail.	

Comments	Response	Action
4. Figure 32 what is this meant to show?	Figure 32 is a Habitat Duration curve.	
5. Figure 33 is confusing. In Table 3, authors identified Chinook spawn timing from July through October. Why are other months represented here?		Added box to identify Chinook spawning timing.
6. Figure 38, 39, 40. The authors need to explain why June – September have such strong differences compared to the rest of the year.	The summer differences are explained in the Discussion.	
Attachments		
1. Appendix A – is spawn gravel % the percent of substrate as gravel? Or percent of gravel substrate that is spawning gravel? And is this spawning gravel for what species of salmonid?	The percent spawning gravel is percent of total area for any of the target species.	
2. Attachment 2 – what does Fallback mean?	Fallback means that the HSC curves can be used when no site-specific curves are available.	
3. Attachment 3 – in the conclusion, these two sentences are contradictory: "A climate change summary was compiled based on multiple sources that predicted little change in total annual precipitation and streamflow timing due to the rain-dominant nature of Grandy Creek watershed. Summer streamflow is expected to decrease between 15 and 20% in the 2050's, depending on climate change scenario."	The timing and the type of precipitation changes, not the total amount.	
Reviewer 3		
General Comments		
The writers need to reorganize their work to clearly articulate the overall goals of the study and how the work undertaken reaches those goals	This is the standard presentation of a PHABSIM study.	
If some goals were not met, the writing should articulate why these goals were not met and what future efforts might be needed.	The study was conducted according to the scope of work and the results presented.	
The executive summary should be readable and informative as a stand-alone document, as should the primary report PDF	No comment.	
The primary report PDF should properly reference the supplementary material and appendices, with clear descriptions of how these were used to support the conclusion in the primary report.	Reorganized the Report and Appendices into a single document.	
As written, acronyms and methodology are not well explained. In its current state, it is not clear what the reader should or could learn from the material presented.	No comment.	

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Comments	Response	Action
Detailed Comments		
1. The grammar of the first sentence of the executive summary is wrong (subject verb agreement, two periods).		Re-wrote text: "This instream flow study established the relationship between an index of fish habitat suitability (Area Weighted Suitability, AWS) and stream flow in the Skagit River tributary, Grandy Creek. "
2. What does PHABSIM stand for? The methodology is not well explained.	PHABSIM stands for Physical Habitat Simulation, a common method for establishing the relationship between flow and habitat suitability.	
3. P 7 first paragraph doesn't make sense, what does the biodegradable cotton thread on a hip chain do? "habitat unit lengths were measured using hip-chain" – what does that mean?	Hip chain is a common instrument for surveying and does not need further definition.	
4. Why was a river chosen that isn't actually gauged or measured?	Most streams are not gauged.	
5. P 14, 15, what do these graphs represent? They are hard to see and hard to interpret.	These figures are RHABSIM output graphics depicting the HSC.	
6. Figure 13 is meant to explain processes, but it is hard to follow.	No comment.	
7. It appears there were just 3 days in Sept 2022 for surveying? Why then? Fish have life stages all year round.	The habitat typing is only done once for a PHABSIM study.	
8. I don't understand what the AWS curves (ft2/ft) actually mean. This is not well explained in the document.	The AWS is the habitat suitability of each flow.	
9. The use of the neighboring creek for a timeseries is a good idea, but it is unclear why the study did not focus on the creek with a discharge gauge to start with.	Most streams are not gauged.	
10. The provided link to climate change scenarios does not work. It is imperative that references be available to people reading the report. It is not clear or justified why the climate change scenario is predicting a decline in summer flow of 20%. This is a very specific value in a field with immense uncertainty. I would guess they are predicting more ET with warmer temperatures, but this is not discussed or explained in the report.	Many climate-related links no longer work. The link was removed.	
11. If the goal is to understand climate impacts on the Skagit as a whole, it would make more sense to focus on a snow-dominated headwater watershed, which would be affected by climate change regardless of which climate change scenario or model one picks.	The goal was to focus on an area that was not developed, but could be in the future.	

Comments	Response	Action
12. P 42, states there's development restrictions on this creek – it would be helpful to put this in context and to explain from the beginning why we're looking at this.	The goal was to focus on an area that was not developed, but could be in the future.	
13. There are waterfalls between lower and upper reach, would they be more passable at lower flows (e.g., if lower reach didn't' have enough water to spawn, could salmon get to the upper reach, or never?) This would be helpful to know.	A passage assessment was not part of the scope of this study.	
14. The discussion section at the end is interesting, but it seems unrelated to the data presented in the rest of the report. They state that changes in flow don't really matter anyway, and that there's low habitat suitability in rearing in all reaches for all reasonable flows. Is this a conclusion that the work done was not relevant for the initial questions asked? It would be helpful to put this section in context and to support the claims made here with data.	The results are presented in the results section. The discussion is intended to discuss limitations of the results and other professional observations that influence the results and are not included in the Results Section.	
Reviewer 4		
General Comments		
1. Report was presented in a folder rather than as a document. There should be a pdf that links all the various sections with consistently used naming convention throughout such that information is connected and accessible to the reader.	Created a single PDF file for the report and appendices.	
2. Regarding the concluding statement: "The results of this instream flow study provide….." the document needs organization and clarity such that the proposed tools and methods can be reproducible by others.	The results are presented such that others with sufficient knowledge can reproduce and utilize the results.	
3. It would be good to provide a statement on Grandy Creek's selection, given it has no streamflow record and fish cannot access upper reaches. Why was work done on the upper reach? Is there a plan to develop passage to upper reach.	Most streams are not gauged. It is unknown if adult salmonids can access the Upper Reach; however, whereas redds, adults, and carcasses were observed in the Lower Reach during this study, none were observed in the Upper Reach. While we collected data and ran the PHABSIM analysis for the Upper Reach, we did not conduct the time-series analysis on the Upper Reach due to the likelihood of the falls being a partial or full barrier to upstream migration.	
Does the work reflect the best of scientific methods?		
1. There should be a methods section that more clearly describes the methods with citations and reasoning. The connections between various empirical methods to infer	We are not attempting to fully describe nor justify the PHABSIM methodology.	

Comments	Response	Action
flow properties (Dual SDR log/log regression, MANSQ) and the model RHABSIM are not described.		
2. Is Manning's roughness fixed in RHABSIM, which it seems to be.	No, Manning's N can be changed.	
3. Some examples of model inputs and output results should have been presented for reviewers' assessment.	Appendices A, B, and C are model inputs and Appendices D, E, and F are PHABSIM model outputs.	
Hydrology Report		
1. How does the hydrology report connect with RHABSIM modeling?	Since there was no gauge on Grandy Creek, we had to model the hydrology. The report also explains the climate and population adjusted scenarios.	
2. What is the elevation range of Alder creek?	Mean elevation Grandy Creek is 1970 ft (Max 4770ft), Alder Creek 1330 (Max 3430 ft)	
3. Is there a period where limited data from Grandy overlap with Alder Creek to compare.	No, Alder Creek Gauge was discontinued.	
4. Are there any differences in soils--can be checked with digital soil datasets.	The watersheds are adjacent.	
5. The report should indicate why all these flow analysis (extreme value, daily change, flow duration curves) were conducted. Are all these pieces of information used in the habitat assessment? For example in the main report under Habitat Simulation, Ci equation is given, there it says the hydraulic model is used. How are those hydrologic analyses used in the hydraulic model, or is it just the reconstructed streamflow used? Is this model run at each site separately with rescaled streamflow from the outlet or does the hydraulic model run connect the various reaches from up to downstream direction? Logically shouldn't this Ci be an integrated value using the flow duration curve or the entire annual hydrograph, could this be more clearly articulated and explained? How is AWS related to Ci, the equations don't show that. Figure 13 of the main report seem to describe the "time series process", what does that mean? It is not clear if the flow duration curve or the hydrograph (or both) are used and how do these feed the model? How does the daily habitat time series relate to Ci described above. In Ci you need Q to force the model, how does this time series section use Q and the model, are all those related to serve for getting the multiplier for Ci	The hydrologic analysis was done to synthesize the baseline and altered flow time-series for Grandy Creek. The hydraulic model is a component of PHABSIM used to simulate depths and velocities. The Ci is calculated for each cell and expanded to entire reach for each simulated flow (for each specie/life-stage) in the habitat component of the PHABSIM model. The AWS is the resulting habitat/flow relationship. The AWS is integrated with the flow time-series from the hydrologic analysis, producing the habitat time-series. The habitat duration curves are one way of presenting the habitat time-series.	

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Comments	Response	Action
6. What is Appendix F that relates Q to AWS, where do those numbers come from? How relevant? How does AWS relate to habitat quality and suitability?	Appendix F is the main output of the PHABSIM model. (AWS is the same habitat index as WUA, with a different name (Payne and Jowett, 2013)).	
7. The suitability curves seem to have a lot of uncertainty, shouldn't those need to be considered in the various AWS-flow relations?	HSC curves are very important to the modeling. Mark Allen, Normandeau, Inc., was the technical lead for developing the HSC and presenting the curves for discussion during the initial stakeholder meeting. No site-specific curves were developed and the curves best representing Grandy Creek were chosen.	
8. Fig 2-24—what AWS values indicate suitable habitats and how much time the watershed spend at those values, and how do the values correspond to different stages of salmon life cycle? Was the hydrograph seasonality factored in the assessment?	The habitat duration curves are imperfect representations of the time-series results, which is why we developed the raster habitat time series plots to better understand the annual and seasonal variability of the habitat.	
Are the conclusions justified based on the evidence presented?		
1. Presentation of evidence for data quality check before running the model simulations were missing.	All data (stationing, depth profiles, velocities, substrate/cover codes) were entered into the RHABSIM computer files. Internal data graphing routines were then used to review the bottom and velocity profiles for each transect separately and in context with others for quality control purposes. All data gaps (e.g., missing velocities) or discrepancies (e.g., conflicting records) were identified and corrected using available sources, such as field notes, photographs, or adjacent data points. (from the Quality Assurance and Quality Control Section)	
2. From a hydrologic perspective I cannot assess the quality of the habitat model. Conclusions were also limited, stating that this is the report that may be used at other sites.	No comment	
Are there any revisions you would suggest or recommend?		
Please aim to create a document that is reproducible by others.	The results are presented such that others with sufficient knowledge can reproduce and utilize the results.	

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Attachment 1: Habitat Mapping Technical Memo and Associated GIS, Excel, and Photo files

Provided in a separate zipped file.

Habitat Suitability Criteria

Habitat Suitability Criteria (HSC) are models representing a target species and life-stage's selectivity for specific habitat attributes (Bovee 1986). For aquatic species, the habitat attributes typically modeled include water depth, mean column water velocity, and substrate or cover. HSC are essential and influential biological components of the 1-D hydraulic modeling approach. Following discussions with WDFW and Ecology, the following target species and life-stages were selected for assessing the flow-habitat relationships in the project reach:

1. Chinook Salmon (*Oncorhynchus tshawytscha*)
    a. Spawning, fry rearing, juvenile rearing
2. Coho salmon (*Oncorhynchus kisutch)*
    a. Spawning, fry rearing, juvenile rearing
3. Steelhead (*Oncorhynchus mykiss*)
    a. Spawning, fry rearing, juvenile rearing

For each of the species and life-stages listed above, HSC were drawn from the Washington Department of Fish and Wildlife and Washington Department of Ecology's "Fallback" curves (WDFW & WDE 2022). However, the 2022 HSC update did not include any HSC representing salmonid fry, and the 2022 update did not include HSC for coho juveniles. Consequently, we developed new HSC curves for salmon and steelhead fry and referred to the WDFW/WDE's 2004 update for coho juvenile curves.

To provide context for the Washington HSC curves, additional HSC curves were drawn from an HSC database managed by Normandeau Associates to compare with the Washington curves. Additional existing HSC were provided by Dudley Reiser of Kleinschmidt (previously of R2 Resource Consultants), and John Blum. These comparisons were used to identify any areas of Washington's depth or velocity suitability values that were divergent from other available HSC data. The Normandeau HSC database was filtered to only include HSC that met several criteria, including HSC based on actual field data collected in the western U.S. (HSC based on subjective decisions were excluded), HSC based on adequate sample size (generally datasets containing 100 or more observations), HSC accounting for habitat availability (by sampling design, adjusting habitat use by habitat availability, or other method), and HSC collected from similar channel sizes (HSC based on large rivers were excluded). These filtering criteria were relaxed for coho salmon due to the relative paucity of HSC describing habitat selectivity for that species; in which case almost all available HSC for coho in the Normandeau database or provided from other sources were included for comparison with the Fallback curves.

The new HSC curves used to represent habitat selectivity for salmon and steelhead fry were developed by utilizing an averaging methodology intended to characterize the central tendency of the existing HSC curves. This process calculated the average velocity or depth at which HSC values created a new five-point or six-point curve. For velocity, each existing curve was individually assessed to determine the HSC value at a velocity of 0.0 or where the HSC velocity curve began at a suitability of 0.0 (the first point). The curve was then assessed to determine where the curve first reached a suitability of 1.0 (the second point). The third point was the maximum velocity where suitability was last equal to 1.0 (this was the same as the second point for HSC having a single peak at 1.0). The curve was then assessed to determine the velocity where suitability descended to 0.5 (the fourth point) and again at suitabilities of 0.2 (fifth point) and 0.0 (sixth point).

This process was repeated for all existing velocity and depth curves for a given species fry life-stage and the average of all values at each given suitability point was used to define the new HSC curve, and is illustrated in Figure 1 for Chinook salmon fry velocity HSC based on the calculated mean values listed in Table 1.

Substrate HSC for all spawning life-stages utilized the Fallback data (Table 2). Likewise, the Fallback HSC for cover (Table 3) was used to represent all fry rearing and juvenile rearing life-stages. Table 4 includes the metadata for the existing HSC curve sets, with the final Fallback HSC and (for fry) the average curve points listed in Table 5. Each of the existing HSC curves along with the Fallback curves or fry average curves are portrayed in Figures 2 through 10.

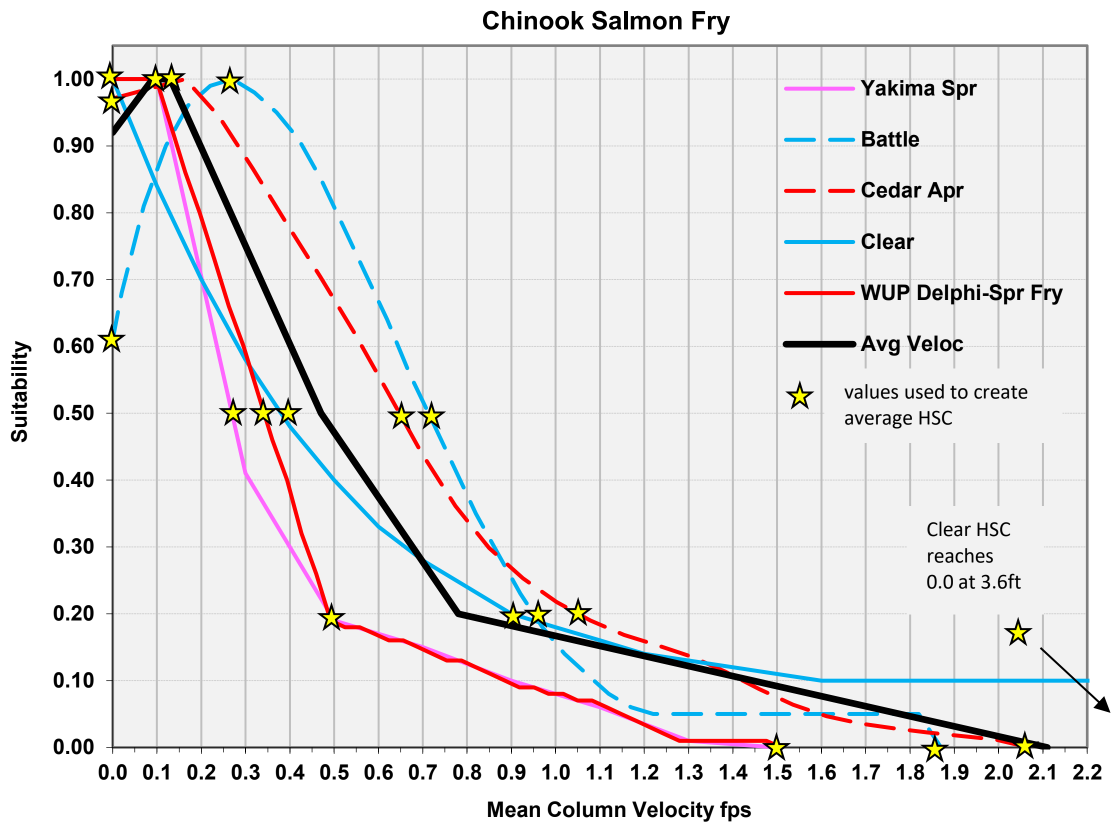

Figure 1. Example fry curve showing calculation of average HSC curve (see Table 1 for values).

Table 1. Calculation of average velocities and depths used to crease average HSC curve.

	Velocity where HSC equals:					
HSC	y-axis	1.00	1.00	0.50	0.20	0.00
Yakima	1.00	0.00	0.10	0.26	0.50	1.50
Battle	0.61	0.27	0.27	0.71	0.95	1.87
Cedar	0.97	0.16	0.16	0.65	1.05	2.07
Clear	1.00	0.00	0.00	0.38	0.90	3.60
WUP	1.00	0.00	0.10	0.34	0.49	1.51
Avgs	0.92	0.09	0.13	0.47	0.78	2.11

Avg Veloc	Vel HSC
0.00	0.92
0.09	1.00
0.13	1.00
0.47	0.50
0.78	0.20
2.11	0.00

	Depth where HSC equals:					
HSC	0.00	1.00	1.00	0.50	0.20	0.00
Yakima	0.00	0.30	0.30	0.75	1.30	4.70
Battle	0.00	1.05	1.05	2.10	2.55	3.55
Cedar	0.00	1.20	1.20	1.90	2.80	5.60
Clear	0.00	0.10	0.10	1.05	1.95	4.10
WUP	0.00	0.10	0.40	0.75	1.30	4.60
Avgs	0.00	0.55	0.61	1.31	1.98	4.51

Avg Depth	Depth HSC
0.00	0.00
0.55	1.00
0.61	1.00
1.31	0.50
1.98	0.20
4.51	0.00

Table 2. Substrate definitions used for Fallback spawning HSC.

code	*Substrate*	*inches*
1	silt,clay, organics	-
2	sand	<0.1
3	small gravel	0.1-0.5
4	medium gravel	0.5-1.5
5	larg gravel	1.5-3.0
6	small cobble	3.0-6.0
7	large cobble	6.0-12.0
8	boulder	>12.0
9	bedrock	-

Table 3. Cover definitions used for Fallback fry and juvenile rearing HSC.

code	*Cover*
00.1	undercut bank
00.2	overhanging veg near or touching water (incl branches) <3ft above SZF WSE
00.3	rootwad
00.4	log jam/submerged brush
00.5	log parallel to bank
00.6	aquatic veg
00.7	short grass <1ft
00.8	tall dense grass >3ft
00.9	veg >3ft above SZF WSE

Table 4. Metadata for existing HSC curves used for comparison with Fallback HSC.

Species	Curve Name	Life-stage	Length cm	No. HSC Obs	State	River	Streamflow cfs Low	High	Site - Specific?	Curve Type	Reference
Chinook	Bovee Fall	spwning	-	-	OR,ID	various	250 avg		N	Cat I	Bovee 1978
	Yakima2	spwning	-	118	WA	Yakima/American			Y	Cat II	Stempel 1984
	TrinityU	spwning	-	311	CA	Trinity	300	450	Y	Cat II	Hampton 1997
	Battle nose	spwning	-	216	CA	Battle			Y	Cat II?	Vogel 1982
	Eel	spwning	-	399	CA	Eel	20	285	Y	Cat II	Steiner 1990
	Oregon Fall	spwning	-	107	OR	various			Y	Cat II	Sams & Pearson 1963
	Panther	spwning	-	150	ID	Panther			Y	Cat I/II	Reiser 1985
	WDF-riv/strm	spwning	-	-	WA	various	"Stream" HSC		N	Cat I	WDFW 2022
	Butte	spwning	-	792	CA	Butte	45	135	Y	Cat IV?	USFWS 2003
	Mokelumne	spwning	-	-	CA	Mokelumne			Y	Cat II?	from Beak 1988
	Clear Fall	spwning	-	442	CA	Clear			Y	Cat III ?	USFWS 2011
	WUP Delphi	spwning	-	-	-	-			N	Cat I	R2 spreadsheet data
	Hood	spwning	-	-	OR	MF/WF Hood			N	Cat I	WPN 2012
	Yakima Spr	fry	2-4	345	WA	Yakima, Cle Elum	132	483	Y	Cat II	Allen 2000
	Trinity	fry	5	345	CA	Trinity			Y	Cat II	Hampton 1997
	Battle	fry	4	353	CA	Battle	268	823	Y	Cat II	TRPA 1998
	Stanislaus	fry	<5	417	CA	Stanislaus	125	1,250	Y	Cat III ?	Aceituno 1990
	Cedar Apr	fry+juv	-	1510	WA	Cedar	300	800	Y	Cat III	Peters & Levy no date
	WUP Delphi	fry	-	-	-				N	Cat I	R2 spreadsheet data
	Clear	fry	80	202	CA	Clear	89	378	Y	Cat III ?	USFWS 2011
	Bovee	juv	-	-	OR,ID	various			N	Cat I	Bovee 1978
	Idaho	juv	-	179	ID	2 small streams	20-26 avg		Y	density	Rubin et al 1991
	Yakima Sum	juv	5-12	403	WA	Yakima, Naches	810	2360	Y	Cat II	Allen 2000
	TrinityU	juv	-	251	CA	Trinity			Y	Cat II	Hampton 1997
	Battle	juv	6-8	155	CA	Battle	268	823	Y	Cat II	TRPA 1998
	Stanislaus	juv	5-15	434	CA	Stanislaus	125	1,250	Y	Cat III ?	Aceituno 1990
	WA Fallback	juv	-	5615	WA	9 rivers			N	Cat III?	WDFW 2022
	Cedar June	juv	-	256	WA	Cedar	300	300	Y	Cat III	Peters & Levy no date
	Clear	juv	80	191	CA	Clear	89	378	Y	Cat III ?	USFWS 2011
	Hood	juv	-	-	OR	MF/WF Hood			N	Cat I	WPN 2012
Coho	Bovee	spwning	-		OR	various			N	Cat I	Bovee 1978
	TrinityU	spwning	-	107	CA	Trinity	300	450	Y	Cat II	Hampton 1997
	WA Fallback	spwning	-	30	WA	4 streams			N	Cat I	WDFW 2022
	Oregon	spwning	-		OR	various			Y	Cat II	Sams & Pearson 1963
	Terror	spwning	-		AK	Terror			Y	Cat II	AEIDC 1981
	Sanford	spwning	-		OR,WA	various			N	Cat II ?	Sanford 1984
	Susitna	spwning	-		AK	Susitna			Y	Cat II ?	Vincent-Lang et al 1984
	Falls	spwning	-	-	AK	Falls Creek			N	Cat I	R2 2001
	Sawmill	spwning	-	-	AK	Sawmill			N	Cat I	City 2005
	WUP Delphi	spwning	-	-	-	-			N	Cat I	R2 spreadsheet data
	Hood	spwning	-	-	OR	MF/WF Hood			N	Cat I	WPN 2012
	Bovee	fry+juv	-		OR,ID	various			N	Cat I	Bovee 1978
	TrinityU	fry	50	131	CA	Trinity	300	450	Y	Cat II	Hampton 1997
	KlamathENV	fry	-		CA	various			N	Cat I	Hardy & Addley 2001
	Indian	fry	-	367	AK	Indian	51-220 simulated		Y ?	Cat III	Nadeau & Lyons 1987
	Terror	fry	-		AK	Terror			Y	Cat II	AEIDC 1981
	Sanford	fry	-		OR,WA	various			N	Cat II?	Sanford 1984
	TrinityP	fry	50	130	CA	Trinity	300	450	Y	Cat III	Hampton 1988
	Falls	fry	-	-	AK	Falls Creek			N	Cat I	R2 2001
	Sawmill	fry	-	-	AK	Sawmill			N	Cat I	City 2005
	WUP Delphi	fry	-	-	-	-			N	Cat I	R2 spreadsheet data
	Hollow Tree	fry	3-5	568	CA	Hollow Tree	5	22.5	Y	Cat II/III	Gephart et al 2020
	TrinityU 97	juv	-	82	CA	Trinity	300	450	Y	Cat II	Hampton 1997
	KlamathENV	juv	-		CA	various			N	Cat I	Hardy & Addley 2001
	Indian	juv	-	22	AL	Indian ?	51-220 simulated		Y ?	Cat I ?	Nadeau & Lyons 1987
	WA Fallback	juv	-	451	WA	3 rivers			N	Cat III?	WDFW 2004
	Ontario	juv	51-114	86	NY	3 streams	15-20 avg		Y	Cat II	Sheppard & Johnson 1985
	Terror	juv	-		AK	Terror			Y	Cat II	AEIDC 1981
	Susitna1	juv	-		AK	Susitna			Y	Cat II	Suchanek et al 1984b
	Susitna2	juv	-		AK	Susitna (lower?)			Y	Cat II	Suchanek et al 1984
	TrinityP	juv	-	81	CA	Trinity	300	450	Y	Cat III	Hampton 1988
	TrinityU 88	juv	-	81	CA	Trinity	300	450	Y	Cat II	Hampton 1988
	Hood	juv	-	-	OR	MF/WF Hood			N	Cat I	WPN 2012
	Falls	juv	-	-	AK	Falls Creek			N	Cat I	R2 2001
	Sawmill	juv	-	-	AK	Sawmill			N	Cat I	City 2005
	Hollow Tree	juv	-	217	CA	Hollow Tree	5	22.5	Y	Cat II/III	Gephart et al 2020

Species	Curve Name	Life-stage	Length cm	No. HSC Obs	State	River	Streamflow cfs Low	High	Site - Specific?	Curve Type	Reference
Steelhead	Bovee	spwning	-		OR,ID	various			N	Cat I	Bovee 1978
	TrinityU	spwning	-	88	CA	Trinity	300	450	Y	Cat II	Hampton 1997
	Panther	spwning	-	84	ID	various ID			N	Cat I	Reiser 1985
	Oregon 1	spwning	-	49	OR	Mollalla,N Santiam			Y	Cat II	Sams & Pearson 1963
	Oregon 2	spwning	-		OR	various			Y	Cat II	Smith 1973
	WA Fallback	spwning	-	108	WA	4 streams			N	Cat III ?	WDFW 2022
	Carmel	spwning	-	142	CA	Carmel	150	230	Y	Cat II	Dettman & Kelley 1986
	Clear	spwning	-	212	CA	Clear			Y	pres-abs	USFWS 2007
	Sawmill	spwning	-	-	AK	Sawmill			N	Cat I	City 2005
	WUP Delphi	spwning	-	-	-	-			N	Cat I	R2 spreadsheet data
	Hood	spwning	-	-	OR	MF/WF Hood			N	Cat I	WPN 2012
	Bovee	fry	-	-	OR,ID	various			N	Cat I	Bovee 1978
	Idaho	fry	4-5	258	ID	Camas,Cape Horn	20-26 avg		Y	density	Rubin et al 1991
	TrinityU	fry	<5	80	CA	Trinity	300	450	Y	Cat II	Hampton 1997
	Sanford	fry	-	?	OR,ID,WA	various			N	Cat II	Sanford 1984
	Clear	fry	<4-7	774	CA	Clear	89	378	Y	Cat III ?	USFWS 2011
	Big Sur	fry	5	3921	CA	Big Sur	35	51	Y	Cat II	Holmes et al 2015
	Sawmill	fry	-	-	AK	Sawmill			N	Cat I	City 2005
	WUP Delphi	fry	-	-	-	-			N	Cat I	R2 spreadsheet data
	Hollow Tree	fry	3-5	120	CA	Hollow Tree	5	22.5	Y	Cat II/III	Gephart et al 2020
	Bovee	juv	-	-	OR,ID	various			N	Cat I	Bovee 1978
	Trinity S	juv	>5	185	CA	Trinity	300	450	Y	Cat II	Hampton 1997
	WA Fallback	juv	-	1954	WA	32 studies			N	Cat III	WDFW 2022
	Sanford	juv	-		OR,ID,WA	various			Y	Cat III ?	Sanford 1984
	Panther	juv	-		OR,ID	various			Y	Cat II	Reiser 1986
	Clear	juv	8	191	CA	Clear	89	378	Y	Cat III ?	USFWS 2011
	Hood	juv	-	-	OR	MF/WF Hood			N	Cat I	WPN 2012
	Big Sur 6-9	juv sml	6-9	914	CA	Big Sur	31	62	Y	Cat II	Holmes et al 2015
	Big Sur 10-15	juv lrg	10-15	1179	CA	Big Sur	23	62	Y	Cat II	Holmes et al 2015
	Sawmill	juv	-	-	AK	Sawmill			N	Cat I	City 2005
	WUP Delphi	juv	-	-	-	-			N	Cat I	R2 spreadsheet data
	Hollow Tree	juv	6-15	326	CA	Hollow Tree	5	22.5	Y	Cat II/III	Gephart et al 2020

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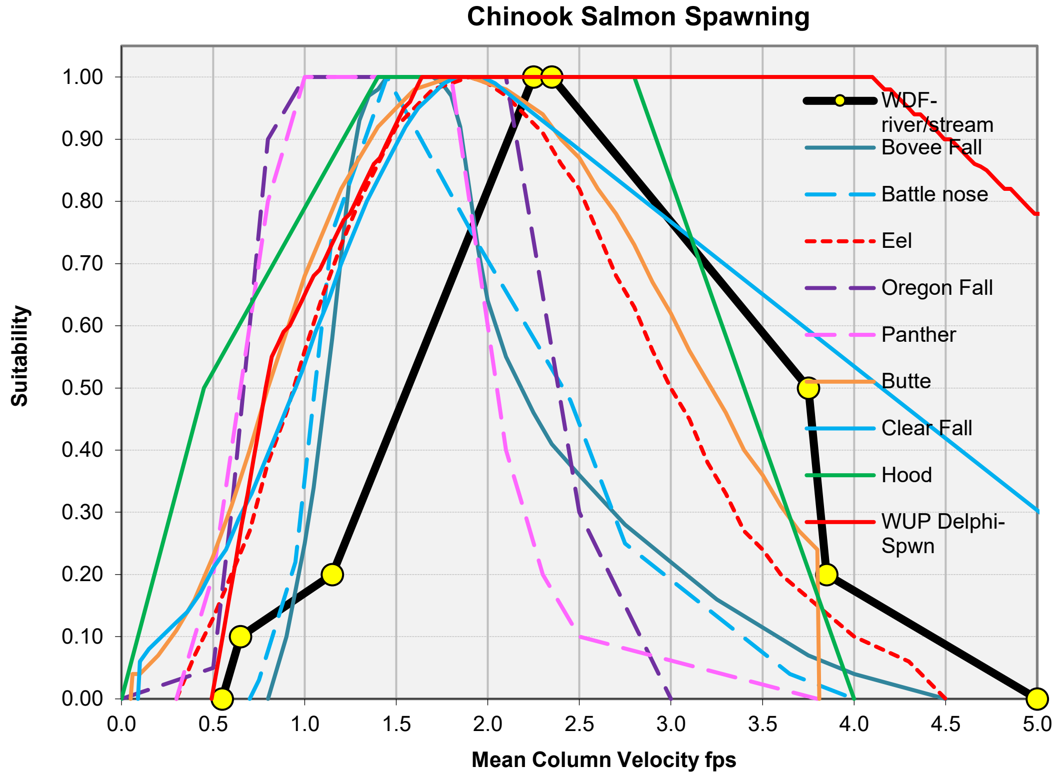
Table 5. Final Fallback and average HSC curves used for flow modeling. See the 2022 update for full spawning substrate HSC.

Species	Life-Stage	Velocity fps	HSC	Depth ft	HSC	Substrate	HSC	Cover	HSC	Source
Chinook	Spawning	0.55	0.00	0.35	0.00	1	0.00	n/a	n/a	WDF-river/stream '22
		0.65	0.10	0.95	0.80	2	0.00			
		1.15	0.20	1.25	0.94	3	0.30			
		2.25	1.00	1.75	1.00	4	1.00			
		2.35	1.00	2.75	0.40	5	1.00			
		3.75	0.50	99.00	0.40	6	1.00			
		3.85	0.20			7	0.50			
		5.00	0.00			8	0.00			
						9	0.00			
Chinook	Fry	0.00	0.92	0.00	0.00	n/a	n/a	00.1	1.00	"Average" HSC
		0.09	1.00	0.55	1.00			00.2	1.00	w juvenile cover
		0.13	1.00	0.61	1.00			00.3	1.00	
		0.47	0.50	1.31	0.50			00.4	1.00	
		0.78	0.20	1.98	0.20			00.5	0.80	
		2.11	0.00	4.51	0.00			00.6	0.80	
								00.7	0.10	
								00.8	0.70	
								00.9	0.20	
Chinook	Juvenile	0.00	0.24	0.45	0.00	n/a	n/a	00.1	1.00	WA Fallback '22
		0.15	0.30	1.05	0.30			00.2	1.00	
		0.55	0.85	1.65	0.85			00.3	1.00	
		0.95	1.00	2.05	0.95			00.4	1.00	
		1.05	1.00	2.45	1.00			00.5	0.80	
		1.85	0.45	7.40	1.00			00.6	0.80	
		3.65	0.00	99.00	1.00			00.7	0.10	
								00.8	0.70	
								00.9	0.20	
Coho	Spawning	0.00	0.00	0.00	0.00	1	0.00	n/a	n/a	WA Fallback '22
		0.45	0.53	0.15	0.00	2	0.00			
		1.25	1.00	0.55	0.65	3	0.30			
		1.45	1.00	0.85	1.00	4	1.00			
		4.25	0.62	1.15	1.00	5	1.00			
		5.00	0.00	1.55	0.90	6	1.00			
				1.95	0.53	7	0.50			
				2.75	0.35	8	0.00			
				99.00	0.35	9	0.00			
Coho	Fry	0.00	0.78	0.11	0.00	n/a	n/a	00.1	1.00	"Average" HSC
		0.17	1.00	0.74	1.00			00.2	1.00	w juvenile cover
		0.41	1.00	1.63	1.00			00.3	1.00	
		0.69	0.50	2.95	0.50			00.4	1.00	
		0.95	0.20	3.46	0.20			00.5	0.80	
		1.98	0.00	4.23	0.00			00.6	0.80	
								00.7	0.10	
								00.8	0.70	
								00.9	0.20	
Coho	Juvenile	0.00	0.78	0.10	0.00	n/a	n/a	00.1	1.00	WA Fallback '04
		0.15	1.00	0.25	0.25			00.2	1.00	
		0.30	0.96	1.55	0.90			00.3	1.00	
		0.45	0.31	2.50	1.00			00.4	1.00	
		0.60	0.20	3.25	1.00			00.5	0.80	
		1.20	0.16	3.90	0.90			00.6	0.80	
		2.00	0.00	4.00	0.27			00.7	0.10	
				6.00	0.27			00.8	0.70	
				99.00	0.27			00.9	0.20	
Steelhead	Spawning	0.25	0.00	0.65	0.00	1	0.00	n/a	n/a	WA Fallback '22
		0.35	0.10	0.75	0.25	2	0.00			
		1.05	0.30	1.25	0.68	3	0.50			
		1.35	0.88	1.85	1.00	4	1.00			
		1.55	1.00	2.35	1.00	5	1.00			
		1.95	1.00	2.75	0.34	6	1.00			
		3.25	0.62	99.00	0.34	7	0.30			
		3.45	0.28			8	0.00			
		5.00	0.00			9	0.00			

Species	Life-Stage	Velocity fps	HSC	Depth ft	HSC	Substrate	HSC	Cover	HSC	Source
Steelhead	Fry	0.00	0.69	0.00	0.01	n/a	n/a	00.1	1.00	"Average" HSC
		0.22	1.00	0.32	1.00			00.2	1.00	cover from WA FB '04
		0.29	1.00	0.67	1.00			00.3	1.00	
		1.02	0.50	1.51	0.50			00.4	1.00	
		1.46	0.20	2.12	0.20			00.5	0.30	
		2.76	0.00	4.45	0.00			00.6	0.10	
								00.7	0.40	
								00.8	0.70	
								00.9	0.20	
Steelhead	Juvenile	0.00	0.55	0.15	0.00	n/a	n/a	00.1	1.00	WA Fallback '22
		0.75	1.00	0.65	0.10			00.2	1.00	
		0.95	1.00	1.35	0.63			00.3	1.00	
		1.15	0.87	2.65	1.00			00.4	1.00	
		1.55	0.78	99.00	1.00			00.5	0.80	
		1.85	0.54					00.6	0.80	
		3.15	0.30					00.7	0.10	
		3.85	0.07					00.8	0.70	
		5.00	0.00					00.9	0.20	

Chinook Salmon Spawning



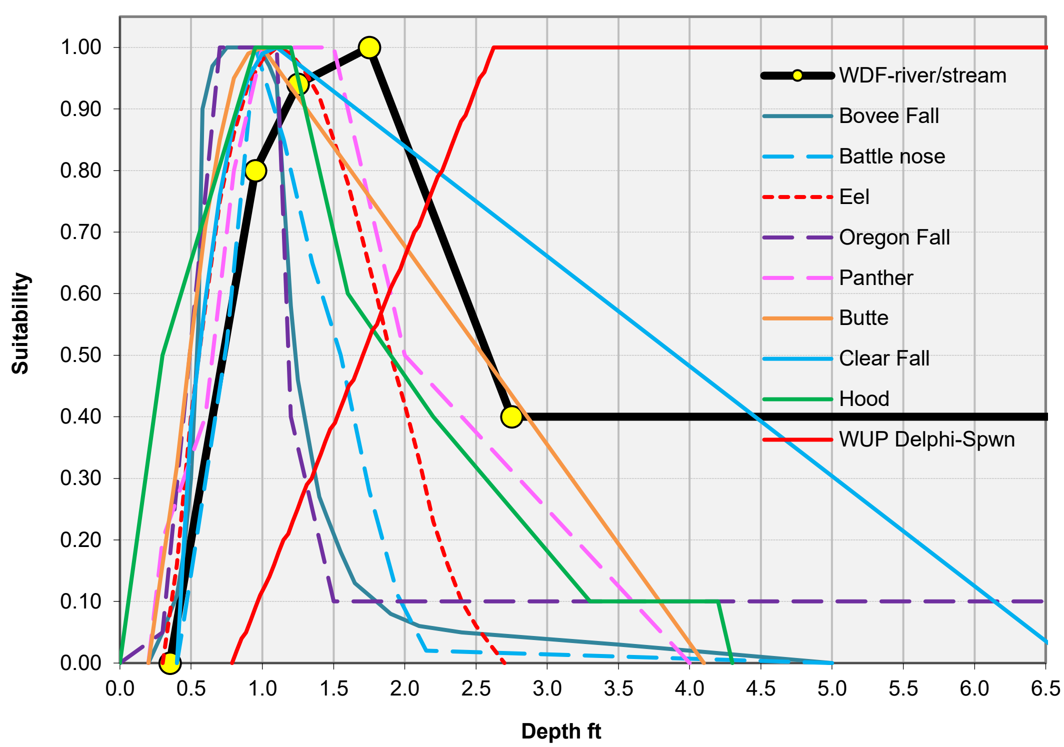
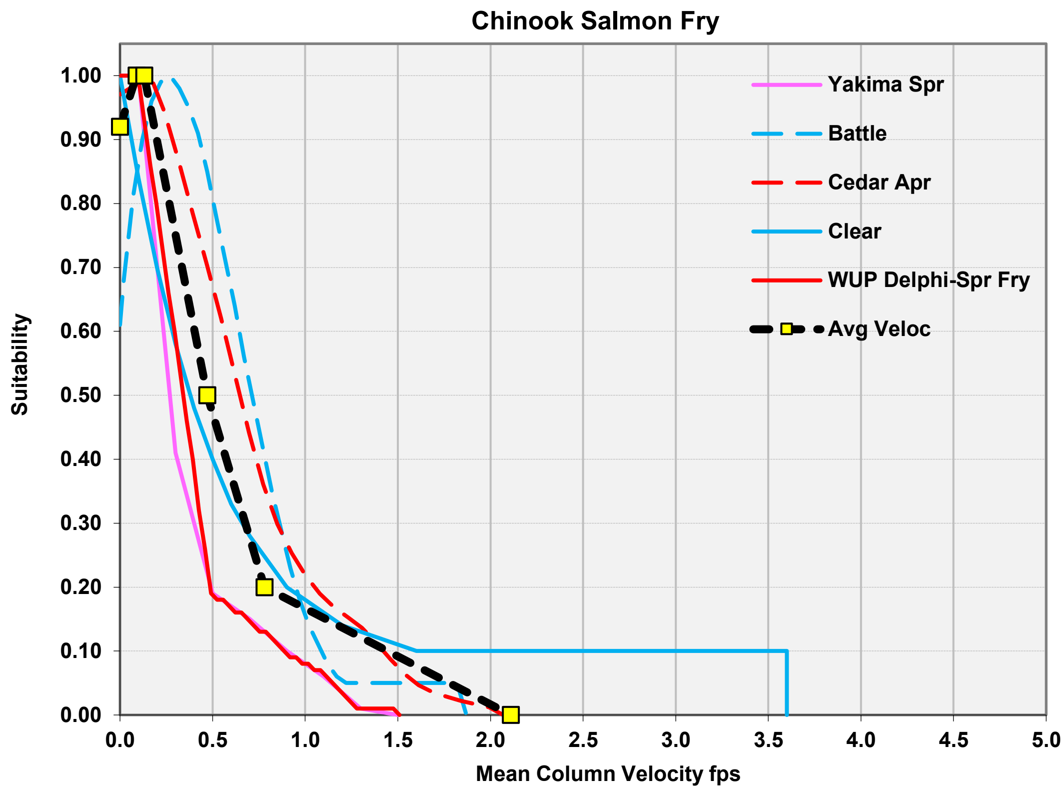


Figure 2. HSC for Chinook salmon spawning velocity (top figure) and depth (bottom figure).



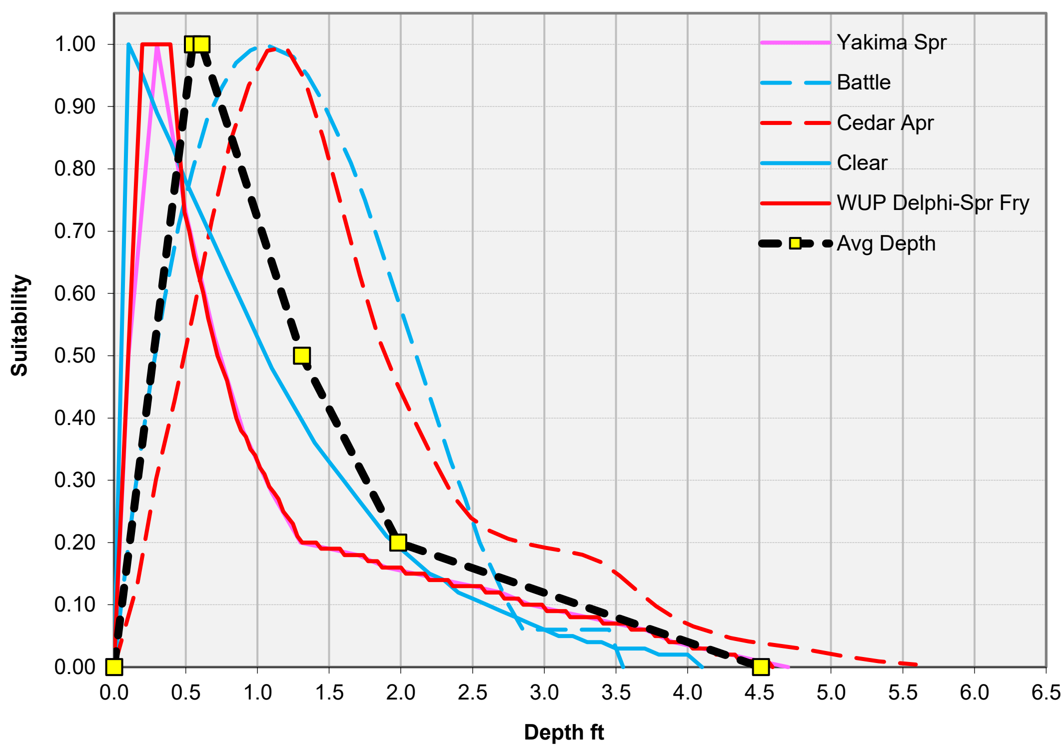
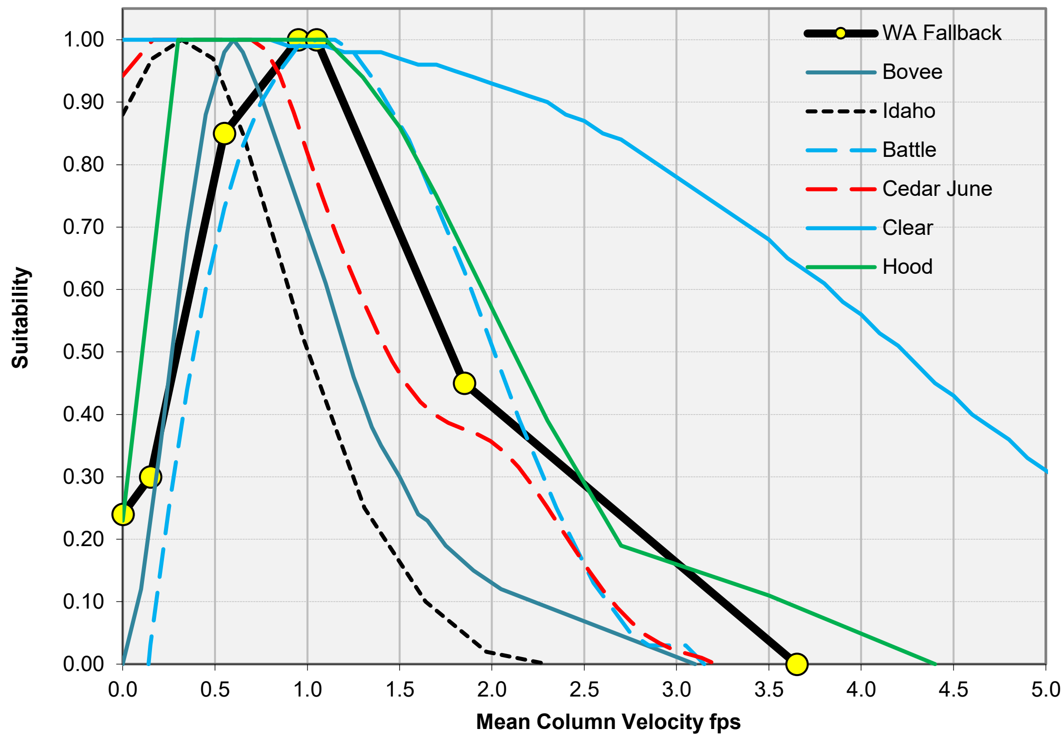


Figure 3. HSC for Chinook salmon fry rearing velocity (top figure) and depth (bottom figure).

Chinook Salmon Juvenile



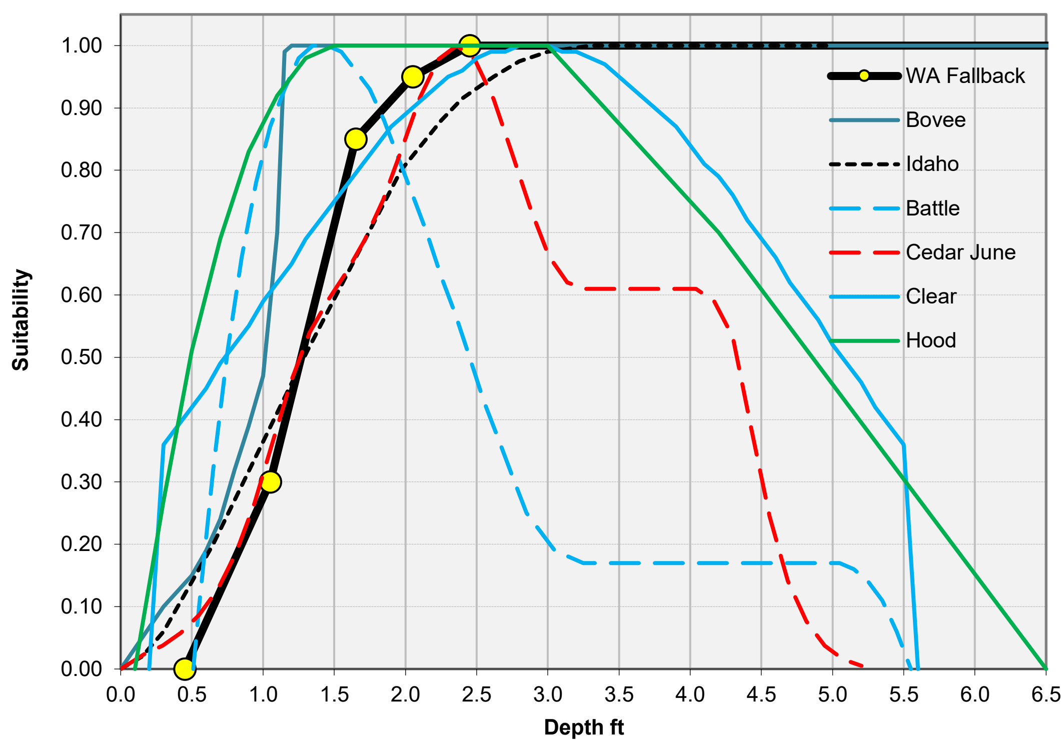
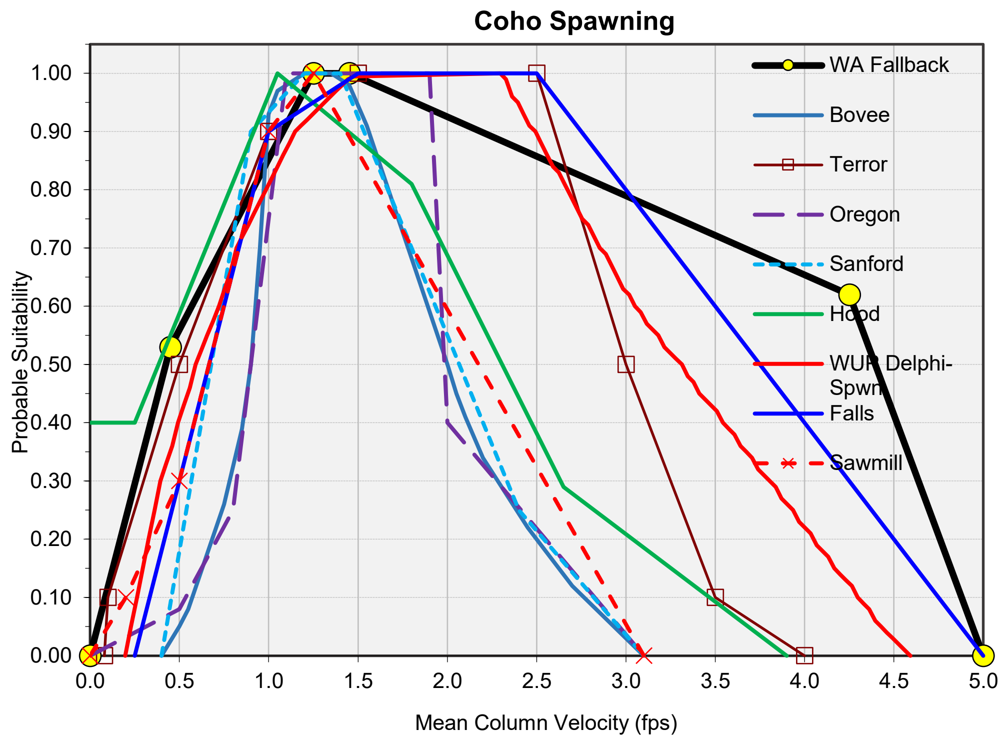


Figure 4. HSC for Chinook salmon juvenile rearing velocity (top figure) and depth (bottom figure).



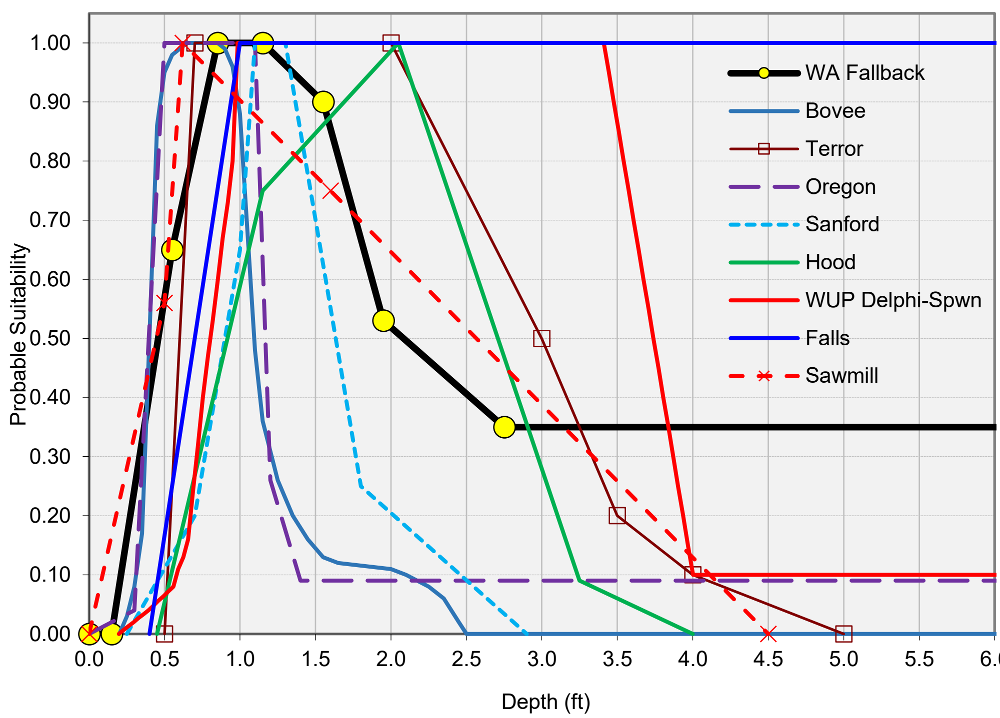
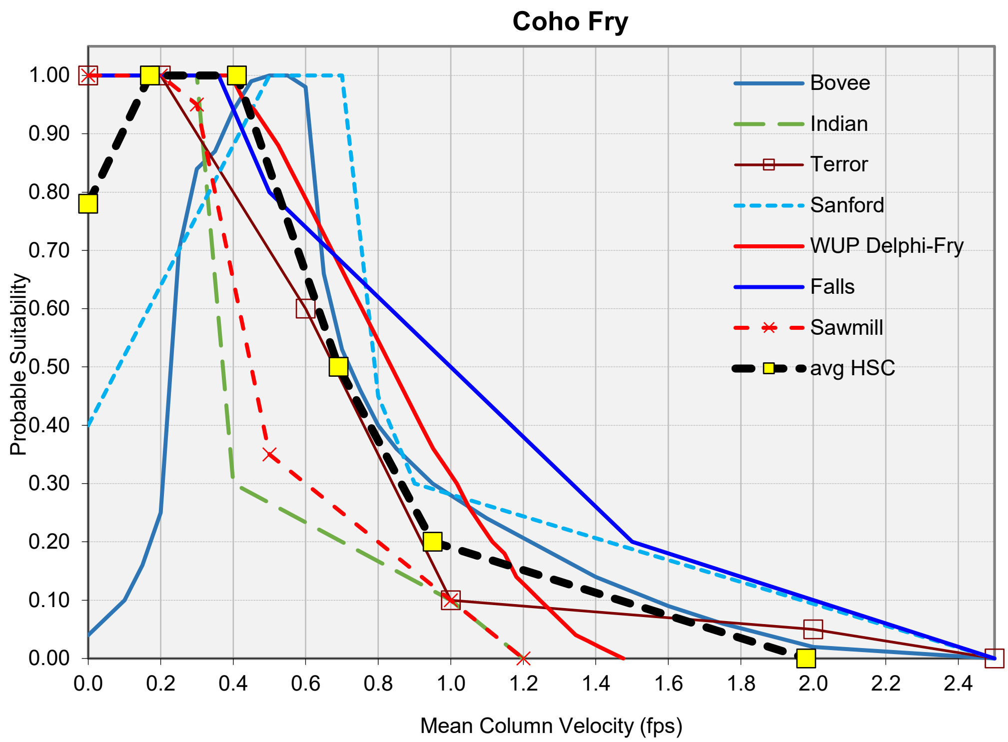


Figure 5. HSC for coho salmon spawning velocity (top figure) and depth (bottom figure).



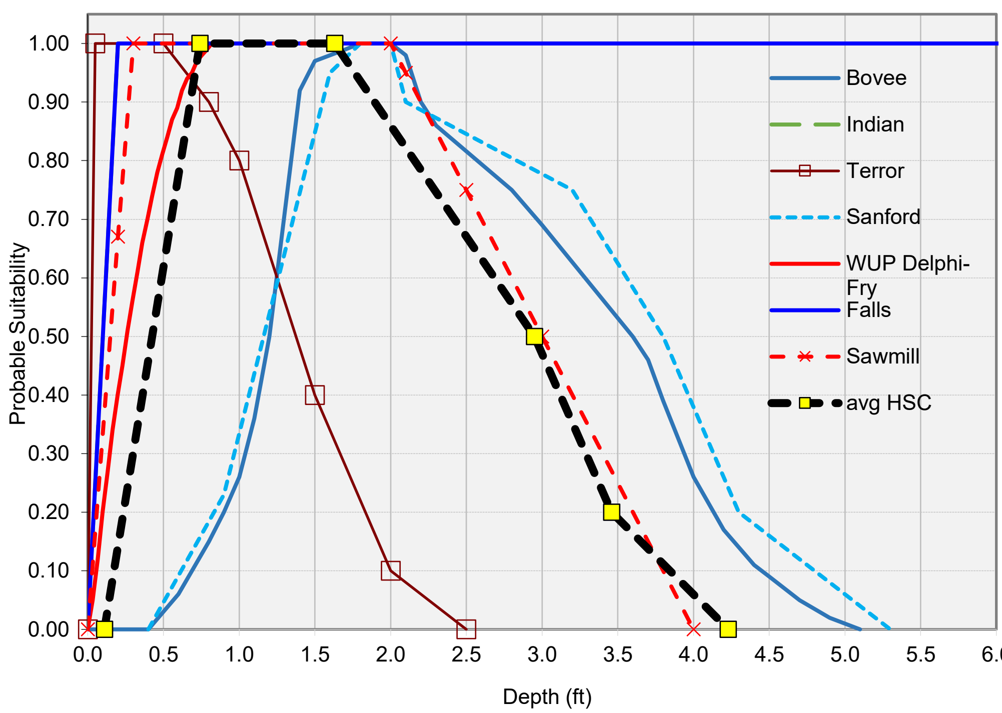
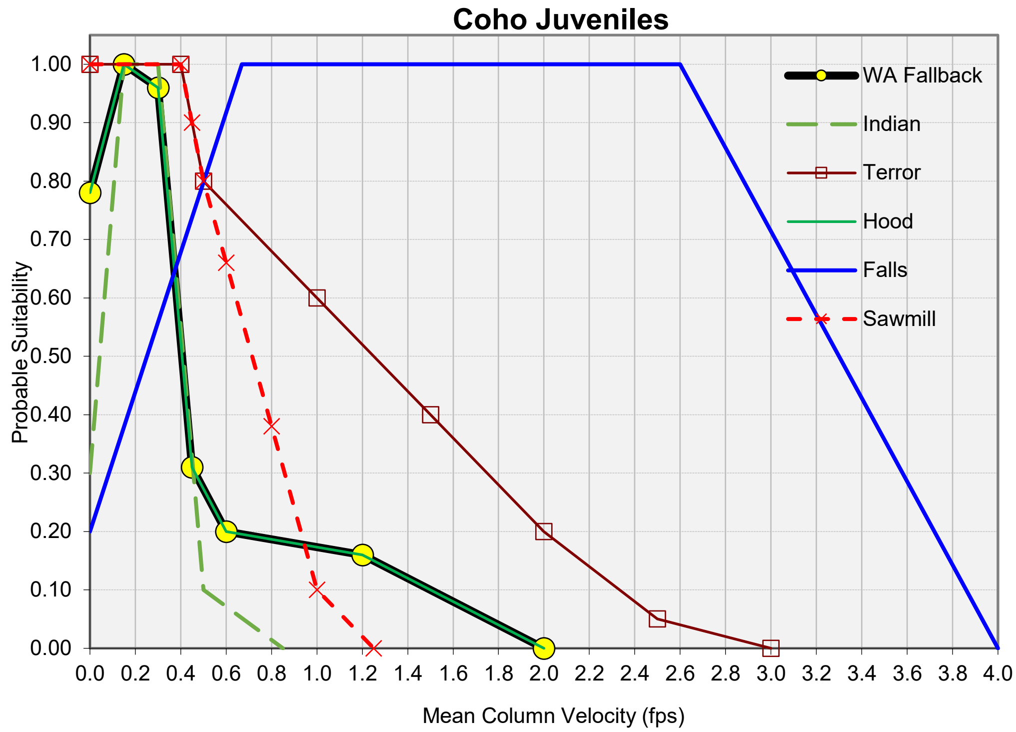


Figure 6. HSC for coho salmon fry rearing velocity (top figure) and depth (bottom figure).



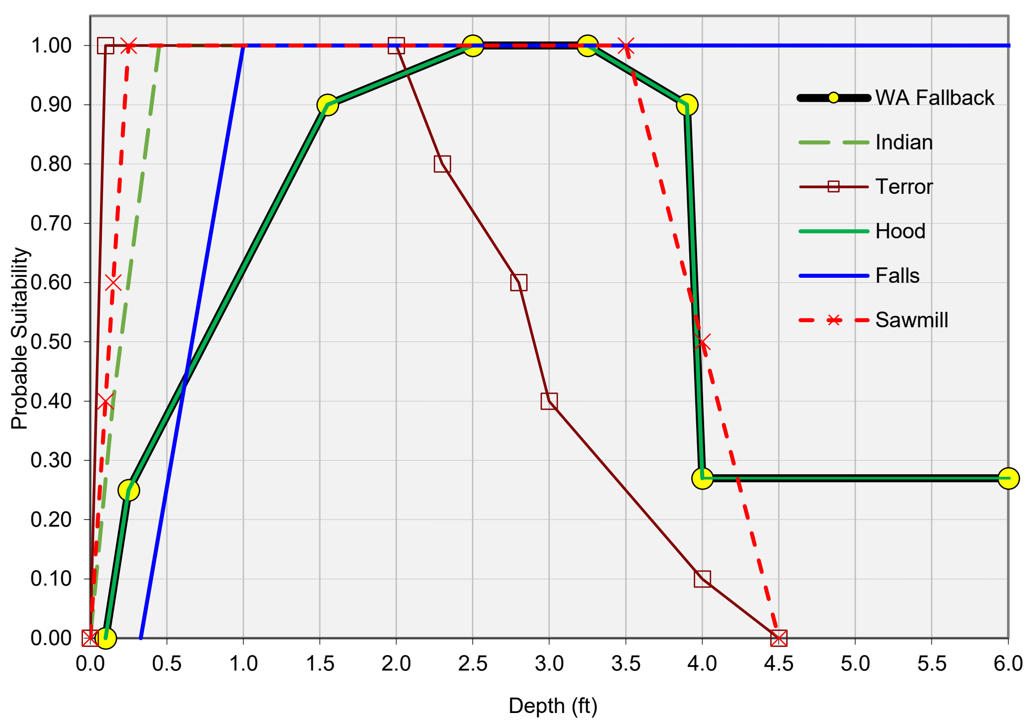
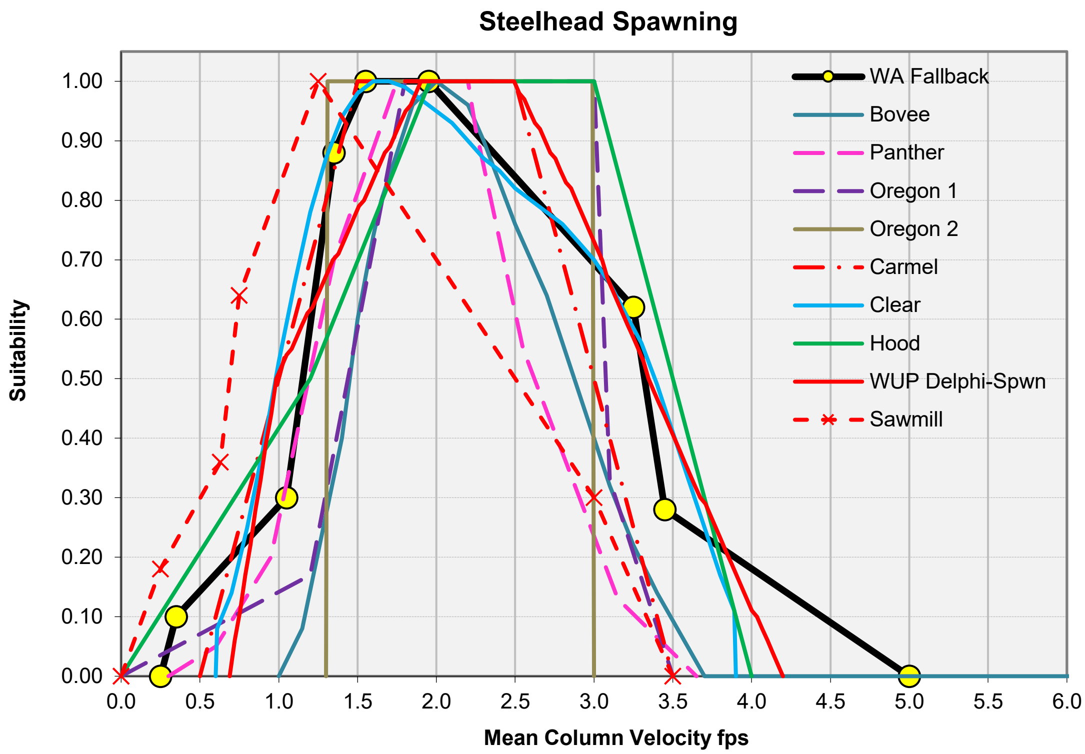


Figure 7. HSC for coho salmon juvenile rearing velocity (top figure) and depth (bottom figure).



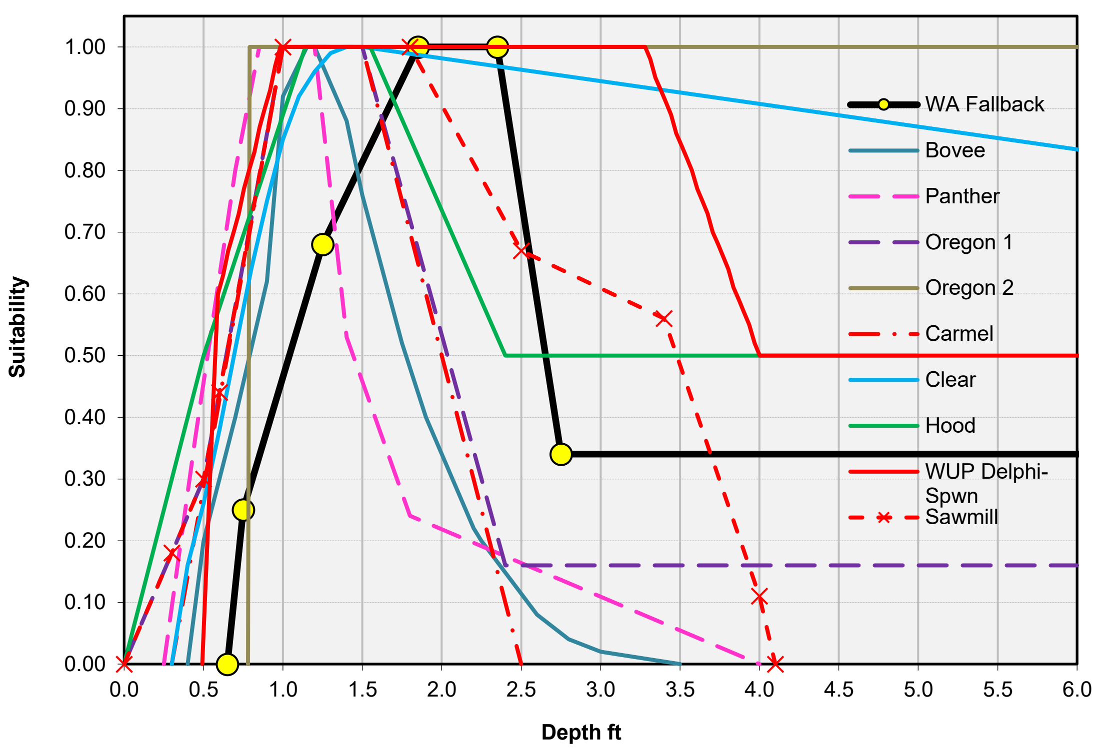


Figure 8. HSC for steelhead spawning velocity (top figure) and depth (bottom figure).

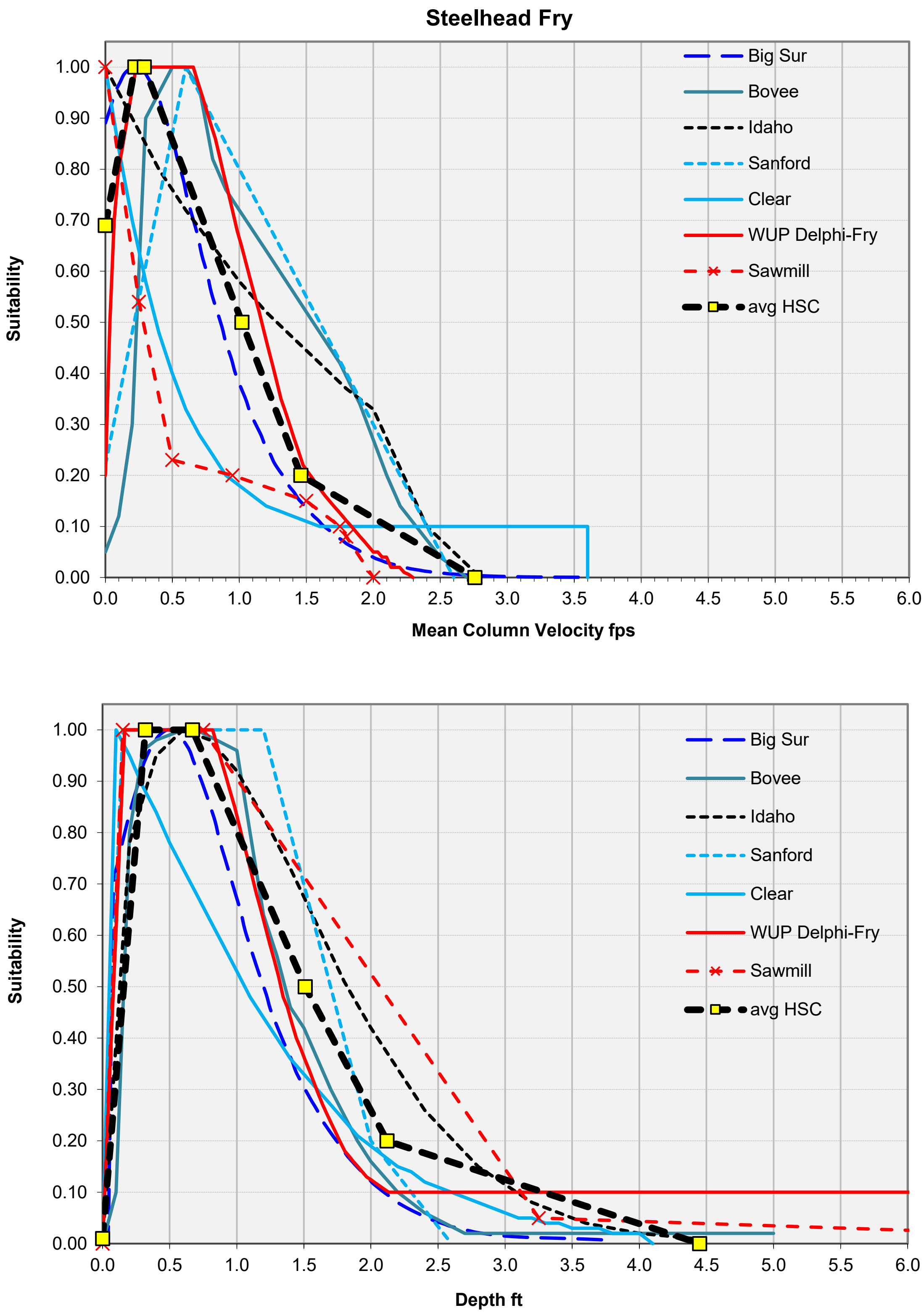
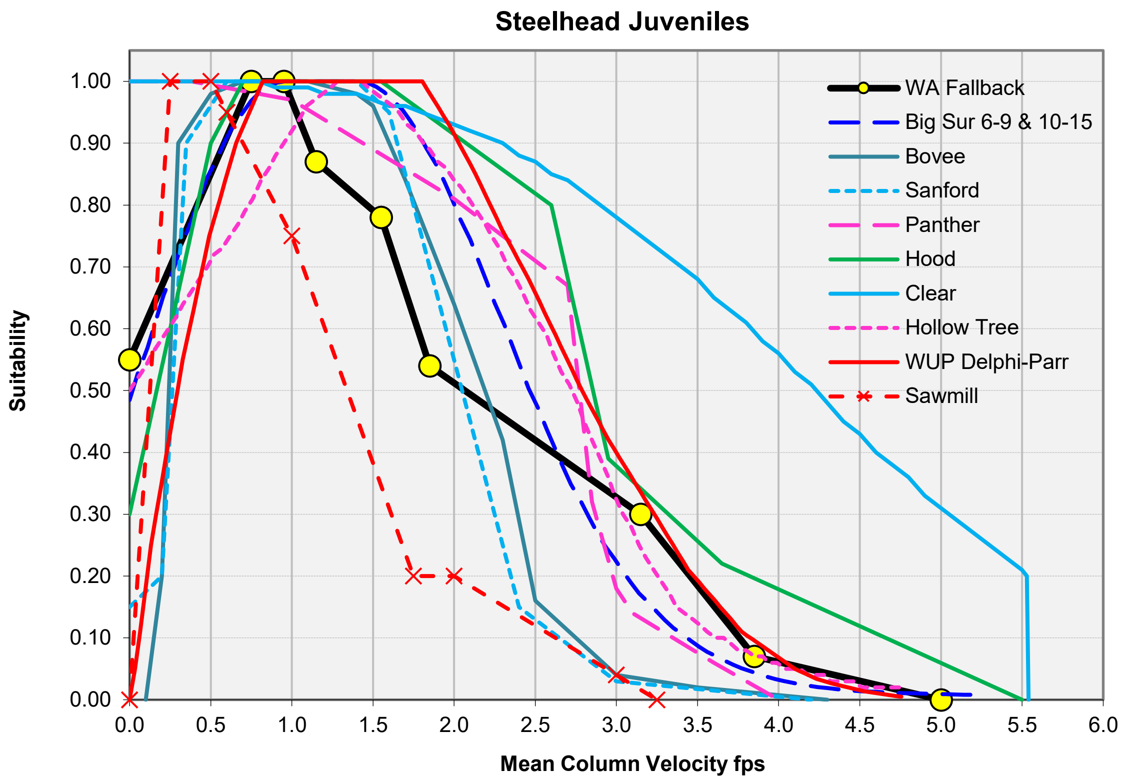


Figure 9. HSC for steelhead fry rearing velocity (top figure) and depth (bottom figure).



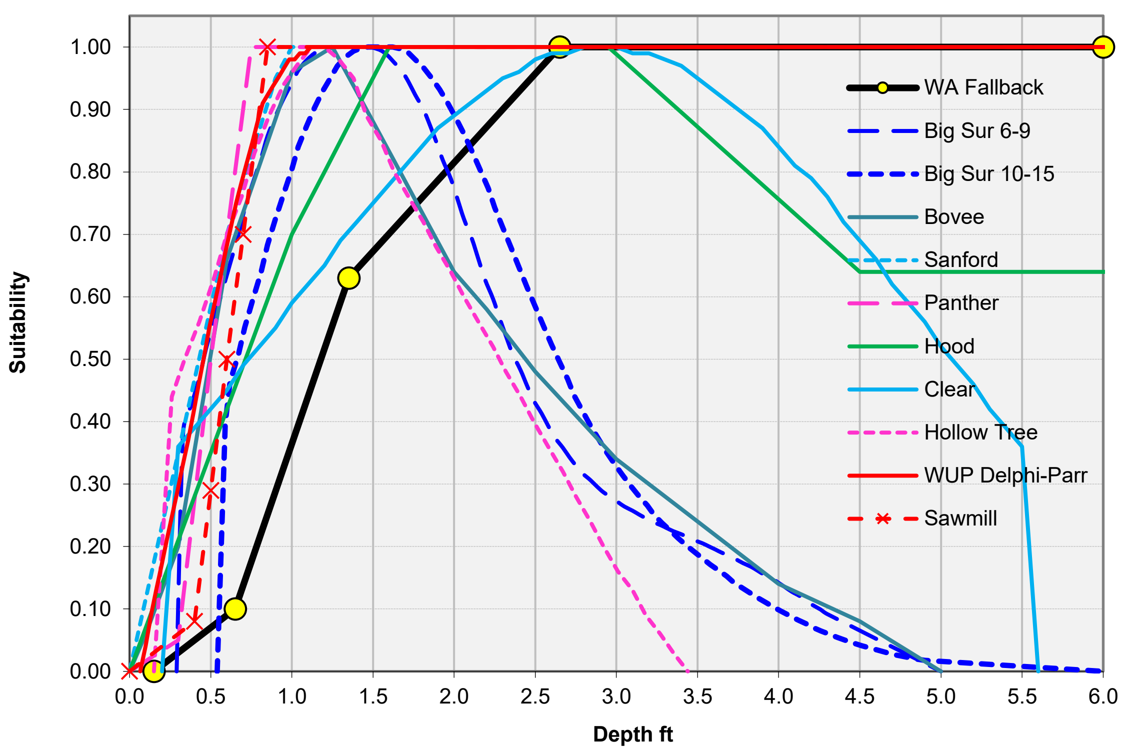


Figure 10. HSC for steelhead juvenile rearing velocity (top figure) and depth (bottom figure).

Comparison of Fallback HSC with Other Existing HSC

Chinook Salmon

The Fallback HSC for Chinook salmon spawning (Figure 2, Table 5) generally falls within the range of other existing HSC. The most notable difference is the very narrow peak of maximum suitability (from 2.25 to 2.35 fps), and the location of the Fallback peak at the faster end of the suite of HSC curves, most of which peak at slower velocities 1.0 fps and 2.5 fps. The spawning depth HSC is a closer match to the existing HSC although the Fallback's peak is slightly deeper (by ~0.5 ft) than most of the other HSC, most of which peak at depths of 1.0 to 1.5 ft.

For Chinook fry rearing, the average HSC curve falls well within the other existing curves (Figure 3), although the range of peak velocity is narrower than some of the other curves. The fry depth HSC appears to split the difference between shallower curves (Clear Creek, Yakima River spring-run, and the WUP Delphi curves) and the deeper curves from Battle Creek and the Cedar River spring curve.

Not unexpectedly the Chinook juvenile HSC curves (Figure 4) show wider variation than did the fry curves, however the Fallback HSC fit well within the other existing curves for both velocity and depth. As noted for spawning, the juvenile Fallback curve suggests a very narrow range of maximum suitability (0.95-1.05 fps), whereas several of the existing curves show a broader range of high suitability, with the Clear Creek curve appearing as an outlier. The Fallback juvenile depth curve like the Bovee and the Idaho curves give maximum suitability into deeper water, whereas the other curves show declining suitability for depths ranging from two ft (Battle Creek) to four ft (Hood River and Clear Creek).

Coho Salmon

The Fallback HSC curve for coho salmon spawning velocity essentially brackets the other existing curves (Figure 5, Table 5), except several curves (Oregon, Terror, WUP, and Falls) suggest that peak suitability extends into velocities over 2.0 fps. The Fallback spawning depth HSC likewise mirrors several of the existing curves but also stops the range of maximum suitability at a lower level than do some of the curves. For example, the Fallback curve gives maximum suitability for depths less than 1.5 ft, whereas several curves maintain maximum suitability to over 2.0 ft.

Washington does not propose a Fallback curve for coho fry rearing, so an average fry curve was developed based on the central tendency of seven existing HSC curves (Figure 6). The average curve for velocity captures the trends in the existing curves, although several curves give maximum suitability for zero velocity, whereas other curves (Sanford and Bovee) give low to moderate suitability in the absence of velocity. Likewise, the average depth curve for fry rearing is intermediate between three shallower curves (Falls, Terror and Indian) and two deeper curves (Bovee and Sanford), but overall appears to capture the general trend in suitabilities.

Washington does not propose a Fallback curve for juvenile coho in their 2022 update, therefore an earlier Fallback curve from 2004 was plotted against other available HSC curves (Figure 7). The 2004 Fallback curve for velocity was similar to other slow curves, such as the Indian and Sawmill curves, but showed lower suitability for intermediate velocities (e.g., 1.0-2.0 fps) than did the Terror curve. The Falls HSC curve appears as an outlier showing little resemblance to any of the other juvenile velocity curves. For depth, the 2004 Fallback curve was generally inclusive of most of the existing HSC curves, except it gave low to intermediate suitability for depths less than 1.5 ft, whereas the Indian and Sawmill curves suggested shallow depths were highly suitable for juvenile coho rearing.

Steelhead

Existing HSC curves for steelhead spawning, fry rearing, and juvenile rearing were relatively abundant in comparison to HSC for coho salmon (Table 5). For spawning velocity, the Fallback HSC captured the other existing curves fairly well, although as discussed above the Fallback curve gave maximum suitability for a relatively short range of velocities (~0.5 fps) in comparison to several other curves (Figure 8). Likewise, the Fallback HSC for spawning depth gave maximum suitability for depths from 1.85-2.75 fps, and gave intermediate suitability for depths from 0.5 ft to 1.5 ft, whereas most other HSC curves showed high suitability starting at about 1.0 fps.

HSC for steelhead fry velocity rearing is represented by the average curve (Figure 9), which appears to capture the central tendency of the other curves, although the existing curves were variable in terms of suitability at zero velocity, with some curves giving low suitability at 0.0 fps (Bovee, Sanford, and WUP), whereas other curves gave maximum suitability at zero velocity (Sawmill, Clear, Idaho). Consequently, the average HSC gave intermediate suitability at 0.0 fps. For depth, the average curve matched the other existing curves very well.

The Fallback HSC for juvenile steelhead rearing was similar to the overall trend in other HSC velocity curves (Figure 10), though several curves extended maximum suitability into faster velocities (1.5-2.0 fps) than did the Fallback curve, which again had a very narrow range (less than 0.5 fps) in peak suitability. The Fallback curve for juvenile depth rearing was notably deeper in character than most other curves, only reaching maximum suitability at over 2.5 ft (similar to the Clear curve), whereas all other HSC curves showed peak or near peak suitability at a depth of just one foot.

Conclusions

Overall the Fallback HSC for spawning and juvenile rearing generally represented the other available HSC, although the Fallback HSC often showed a very narrow range of maximum suitability. Because no Fallback HSC were available to represent fry rearing, average HSC curves were developed to capture the central tendency of the other existing curves. The average curves did appear to represent other HSC data, although the average curves were by nature intermediate in character due to the averaging process used to develop the curves.

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HYDROLOGIC ANALYSIS:
GRANDY CREEK WATERSHED

Date:	9/25/2023
Project:	Skagit Tributary Instream Flow Study
Prepared For:	Skagit Basin Water Task Force Work Group
Prepared By:	Thomas Gast & Associates Environmental Consultants P.O. Box 1137 Arcata, CA 95518 Visual Data Analytics, LLC Erie, CO
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afy	Acre-feet per year
DEM	Digital Elevation Model
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
PDO	Pacific Decadal Oscillation
PHDI	Palmer Hydrologic Drought Index
POR	Period of Record
RCP	Representative Concentration Pathways
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WRIA	Water Resource Inventory Area

1. Introduction and Purpose

Salmonids in the Skagit River watershed use tributary streams to spawn and rear. Population growth and climate change will alter the amount and timing of streamflow and will impact salmonid spawning and rearing habitat in the Skagit River tributaries. As part of the greater Skagit River Tributary Instream Flow Habitat Assessment project, this report summarizes the hydrologic analysis of Grandy Creek. The following report evaluates historic hydrologic conditions in Grandy Creek and models future conditions assuming two scenarios of climate change and population growth in the watershed to best understand the impacts to spawning and rearing salmonids.

The term "water year" refers to the period from October 1 to September 30, and is assigned the year number of the last day of the water year. Between October 1 and December 31, the year number of the water year is the calendar year number plus one.

2. Watershed Description

Grandy Creek has a drainage area of approximately 18.9 square miles and elevations ranging from 123 feet to 4770 feet (Table 1). The mean basin slope, as computed by 30-meter DEM, is 29.3%. Approximately 50% of the basin area is composed of steep slopes (>30%).

Table 1: Basin Characteristics for Grandy Creek near Concrete, WA

Parameter	**Value**
Drainage Area (square miles)	18.9
Mean Basin Slope (%)	29.3
Mean Basin Elevation (ft)	1970
Maximum Basin Elevation (ft)	4770
Minimum Basin Elevation (ft)	123
Mean Annual Precipitation (inches)	71.3
Relief (Maximum – Minimum Elevation, feet)	4650
Percent Area with Slopes >30%	48.4

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3. Hydrologic Assessment for Streamflow Properties

a. Background

Discharge patterns across multiple temporal scales are important factors influencing the physical and ecological properties of a stream. Identifying these discharge patterns is important in understanding and protecting the water supply and aquatic habitat of a watershed.

Streamflow can be considered as the “master variable” limiting the distribution and abundance of riverine species (Poff et al. 1996). The physical attributes of the hydrologic regime include the magnitude, frequency, duration, timing, and rate-of-change, also known as “flashiness”. This report section identifies, quantifies, and visualizes these properties for Grandy Creek.

b. Data Generation

This assessment is best conducted with a daily streamflow record at the site. However, no daily record exists for Grandy Creek. A review of existing data shows the USGS station for Grandy Creek (12195000) lists 11 individual field measurements between August 16, 1951 and September 18, 2001. These measurements were made during summer (late-May to mid-September) with widely-spaced timing, with the largest gap in measurements being 30 years (1971 to 2001). As such, the nearby USGS streamgage at Alder Creek near Hamilton, WA (station 12196000) is used to generate the daily discharge dataset for Grandy Creek.

The US Army Corps of Engineers conducted a flood risk assessment of the Skagit River which included an estimate of the local flow between Concrete, WA and Sedro Woolley, WA. The area includes both Alder Creek and Grandy Creek (USACE, 2013). The authors note that tributary streamgage records on the lower Skagit River basin are limited. For their study, they used the Alder Creek streamgage which has data from September 1, 1943 through September 29, 1971.

The flood risk study found that the longer record of Alder Creek gage provided higher confidence in estimating local inflows from tributaries along the north bank of the Skagit River below Concrete, WA. The authors point out that most of the tributaries along the northern bank are aligned in the north to south direction and all have similar sized drainage areas (i.e., less than 20 square miles). The study estimated a combined runoff from all tributaries based on a total local tributary area of 69.8 mi^2.

To estimate the daily flow for Grandy Creek, data from the Alder Creek streamgage was modified by an adjustment factor based on the drainage areas of Alder Creek and Grandy Creek watersheds. The locations of the USGS gage station were used to determine the drainage area for the two basins.

$$\text{Adjustment factor} = \text{Grandy Creek Drainage Area} / \text{Alder Creek Drainage Area} \qquad (1)$$

$$\text{Adjustment factor} = 18.9\ mi^2 / 10.7\ mi^2 = 1.77 \qquad (2)$$

Two advantages for using the Alder Creek location are 1) the USGS quality controlled and approved daily discharge records for Alder Creek and 2) the close proximity of the two watersheds (Figure 1). Because the two watersheds adjoin, this analysis assumes that both

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watersheds experience the same storms during the period of record. A traditional hydrograph for the generated Grandy Creek discharge is shown in Figure 2.

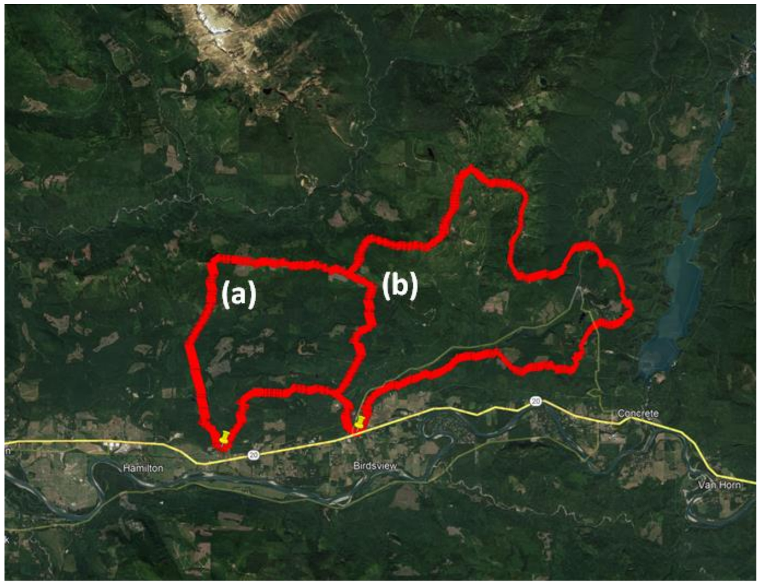

Figure 1. Relative locations of Alder Creek (a) and Grandy Creek (b) watersheds.

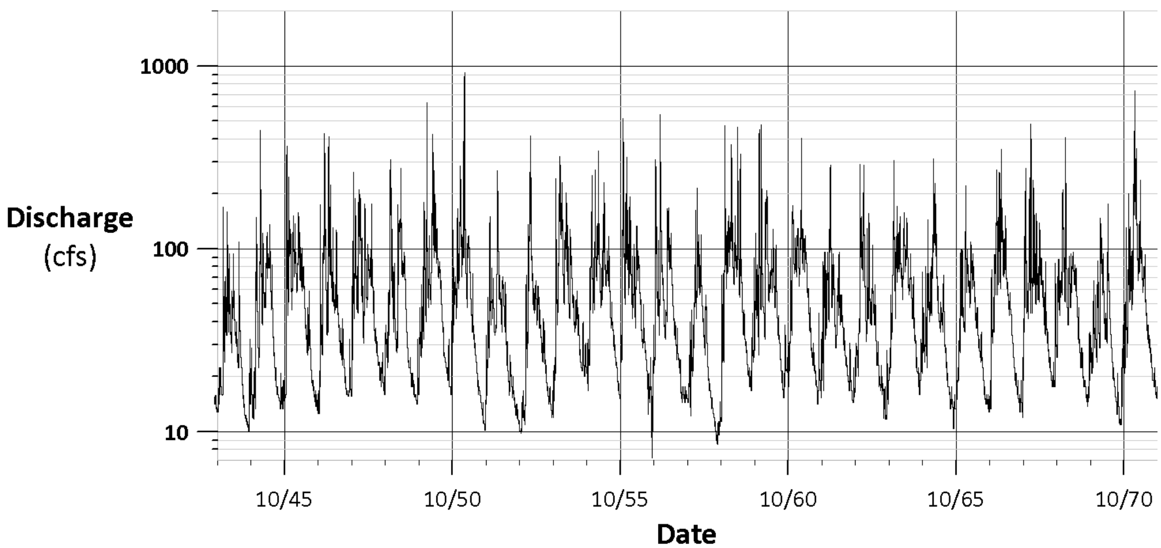

Figure 2. Daily mean flow hydrograph, Grandy Creek (water years 1944 to 1971).

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An alternate discharge plot, a raster hydrograph, presents more details than a traditional hydrograph (Figure 3). This uses a "heat map" method where the x-axis is "Day of Water Year", the y-axis is "Water Year", and discharge is represented by color. Three extreme low flows are shown in September 1956, in 1958 with an extended drought with associated lower flows, and in 1970 where the annual daily maximum occurred in April. Such details are difficult to identify in a traditional hydrograph.

Other observations in Figure 3 include individual storms (blue), recessions (smeared green/yellow), and drought periods (deep red/white). The absence of patterns is also important to identify. Snowmelt runoff would be seen as increased discharge during the May to July timeframe; the lack of such a pattern indicates that there is little snowpack runoff in Grandy Creek.

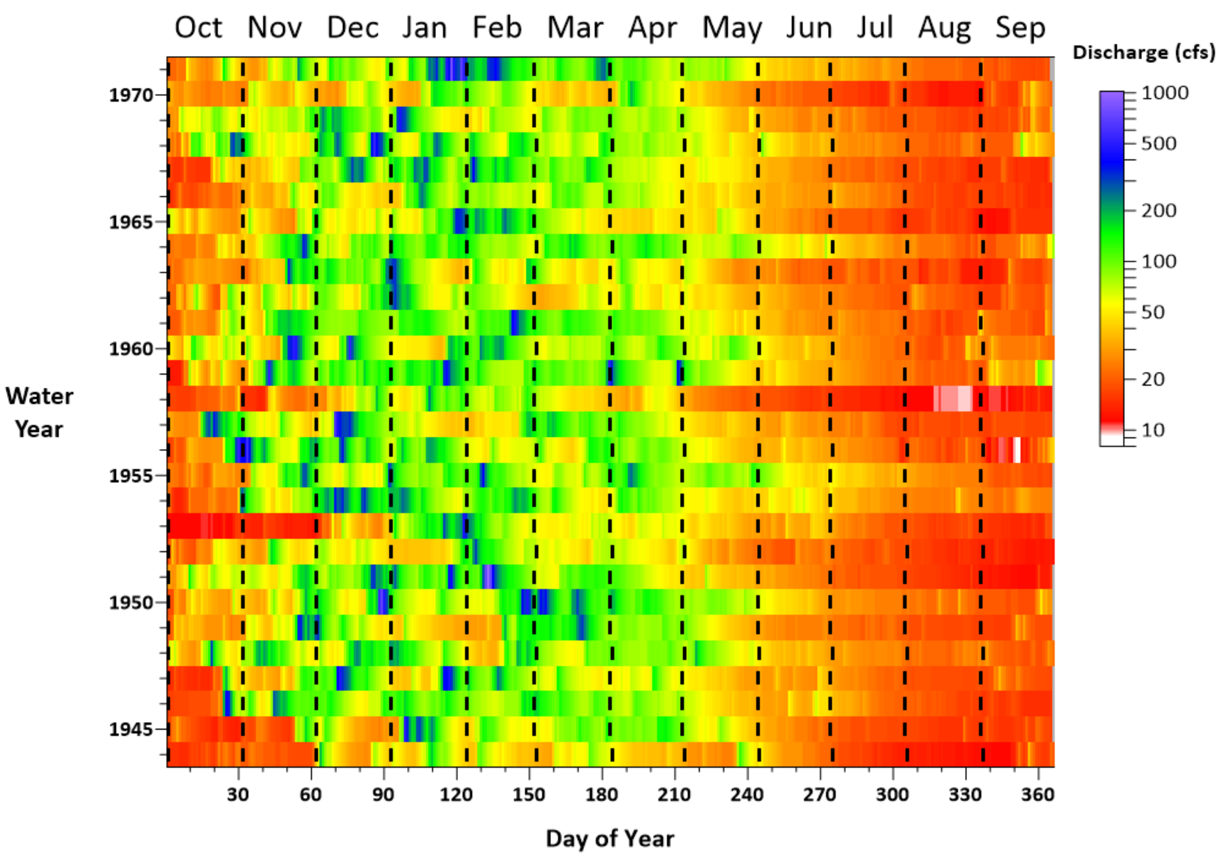

Figure 3. Daily mean flow raster hydrograph, Grandy Creek (water years 1944 to 1971).

c. Statistical Summary, Flood Frequency Analysis

A detailed summary of discharge statistics for Grandy Creek is listed below (Table 2). Table 3 shows the annual maximum daily flows along with date of occurrence. Table 4 and Figure 4 show the period of record and the season-based number of days for different flow categories.

Table 2. Statistical summary for Grandy Creek discharge (water years 1944 to 1971).

Metric		units
Count	10226	*days*
Start	10/1/1943	
End	9/29/1971	
Minimum	8.0	*cfs*
Maximum	1021.3	*cfs*
Range	1013.3	*cfs*
Mean	62.8	*cfs*
Median	46.0	*cfs*
Geometric Mean	46.2	*cfs*
Harmonic Mean	35.3	*cfs*
Root Mean Square	86.0	*cfs*
Standard Error	0.581	*cfs*
Variance	3454.7	*cfs* ^{2}
Std Dev:	58.8	*cfs*
Coef. of Variation:	0.937	*none*
Skewness:	3.645	*none*
Kurtosis:	29.296	*none*

Metric		units
Percent exceedance		
99%	11.9	*cfs*
95%	14.9	*cfs*
90%	17.0	*cfs*
75%	24.8	*cfs*
50%	46.0	*cfs*
25%	81.4	*cfs*
10%	123.9	*cfs*
5%	161.1	*cfs*
1%	299.1	*cfs*
Interquartile Range	56.6	*cfs*
Mean Diff.	53.4	*cfs*
Median Abs. Dev.	24.8	*cfs*
Average Abs. Dev.	36.8	*cfs*
Quartile Disp.	0.5	*cfs*
Relative Mean Diff.	0.9	*cfs*

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Table 3. Annual maximum daily mean flow, Grandy Creek (Water years 1944 to 1971).

WY year	Flow (cfs)	Date
1944	187.6	3-Dec-1943
1945	492.1	7-Jan-1945
1946	403.6	25-Oct-1945
1947	474.4	11-Dec-1946
1948	292.1	19-Oct-1947
1949	341.6	24-Nov-1948
1950	700.9	28-Dec-1949
1951	1021.3	10-Feb-1951
1952	297.4	5-Feb-1952
1953	460.2	31-Jan-1953
1954	355.8	9-Dec-1953
1955	380.6	8-Feb-1955
1956	575.3	3-Nov-1955
1957	601.8	9-Dec-1956
1958	239.0	17-Jan-1958
1959	525.7	12-Nov-1958
1960	531.0	15-Dec-1959
1961	447.8	21-Feb-1961
1962	318.6	3-Jan-1962
1963	322.1	20-Nov-1962
1964	336.3	26-Nov-1963
1965	343.4	29-Jan-1965
1966	244.3	14-Jan-1966
1967	387.6	4-Feb-1967
1968	532.8	25-Dec-1967
1969	453.1	5-Jan-1969
1970	194.7	10-Apr-1970
1971	814.2	26-Jan-1971

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Table 4. Flow days for the period of record and seasonal breakout (water years 1944 to 1971). Winter (Dec, Jan, Feb), Spring (Mar, Apr, May), Summer (Jun, Jul, Aug), Fall (Sept, Oct, Nov).

Log flow	Flow category (cfs)	Total days	Winter days	Spring days	Summer days	Fall days
0.9	7.9	2	0	0	0	2
1	10	90	0	0	29	61
1.1	13	357	2	0	141	214
1.2	16	922	1	0	453	468
1.3	20	885	2	18	574	291
1.4	25	1107	31	55	663	358
1.5	32	848	80	139	394	235
1.6	40	842	168	316	191	167
1.7	50	909	255	384	90	180
1.8	63	1168	382	550	32	204
1.9	79	971	411	446	4	110
2	100	855	373	395	5	82
2.1	126	602	351	178	0	73
2.2	158	315	201	55	0	59
2.3	200	182	127	21	0	34
2.4	251	81	56	10	0	15
2.5	316	67	49	5	0	13
2.6	398	26	17	3	0	6
2.7	501	18	13	1	0	4
2.8	631	5	4	0	0	1
2.9	794	3	3	0	0	0
3	1000	1	1	0	0	0

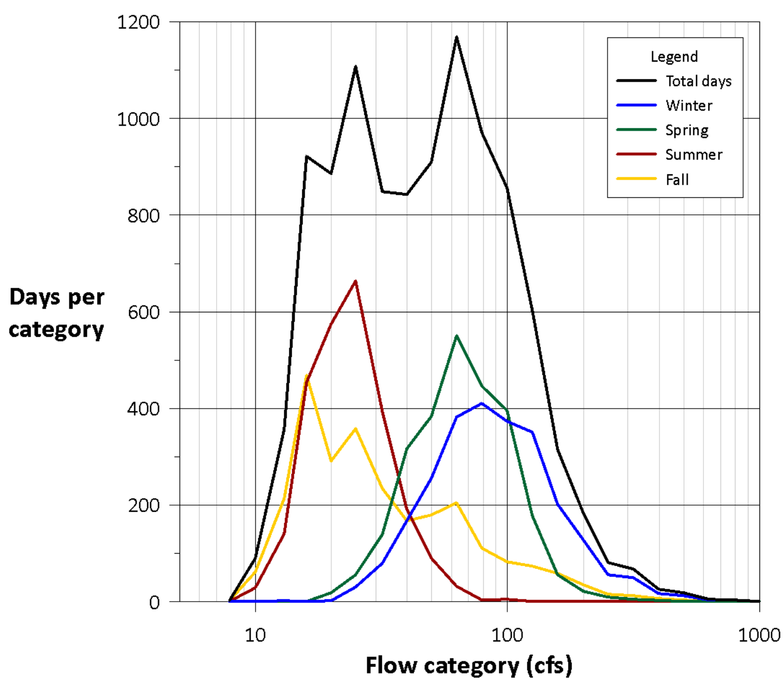

Figure 4. Distribution of flow days, Grandy Creek discharge (water years 1944 to 1971).

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The highest flows occur during late fall, winter, and early spring as seen in Figure 3, Table 4 and in Figure 4. There is a bi-modal distribution for the total flow days with peaks at 25 and 63 cfs. This reflects the dry summer/early fall season and the rainy late/fall/winter/early spring season. The lack of snowmelt is also apparent in these distributions.

To find the recurrence intervals, the maximum mean daily discharge values from Table 4 were used. A Weibull empirical distribution was employed and the results are presented in Table 5.

$$p = (100 \text{ x rank})/(n+1) \qquad (1)$$

$$\text{Return interval} = 1/p \qquad (2)$$

where:
p = annual probability of occurrence
rank = order of magnitude, largest (1) to smallest (28)
n = number of years

Table 5. Prob. of occurrence, recurrence intervals, and associated discharges in Grandy Creek.

Probability, p	1/p	Discharge (cfs)
0.5	2	396
0.2	5	532
0.1	10	700
0.05	20	918
0.02	50	1100*
0.01	100	n/a

* = extrapolated
n/a = record too short to determine

d. Flow-Duration Curve

The flow-duration curve is a cumulative frequency that shows the percentage of time specified discharges were equaled or exceeded during a given period. Figure 5 shows overall and seasonal flow duration curves that match the flow days discussed earlier. Overlaid are the period of record (POR) and seasonal curves. The minimum, maximum, and median values for each curve are listed in the inset table.

Distinct discharge periods are evident where the higher flows occur during parts of spring, winter, and parts of late fall. The lower discharge period occurs during summer and parts of early fall. Fall is a transition period where early rainy season storms can happen in October or November, while any late start to the rainy season storms causes the low summer flows to continue into the fall months.

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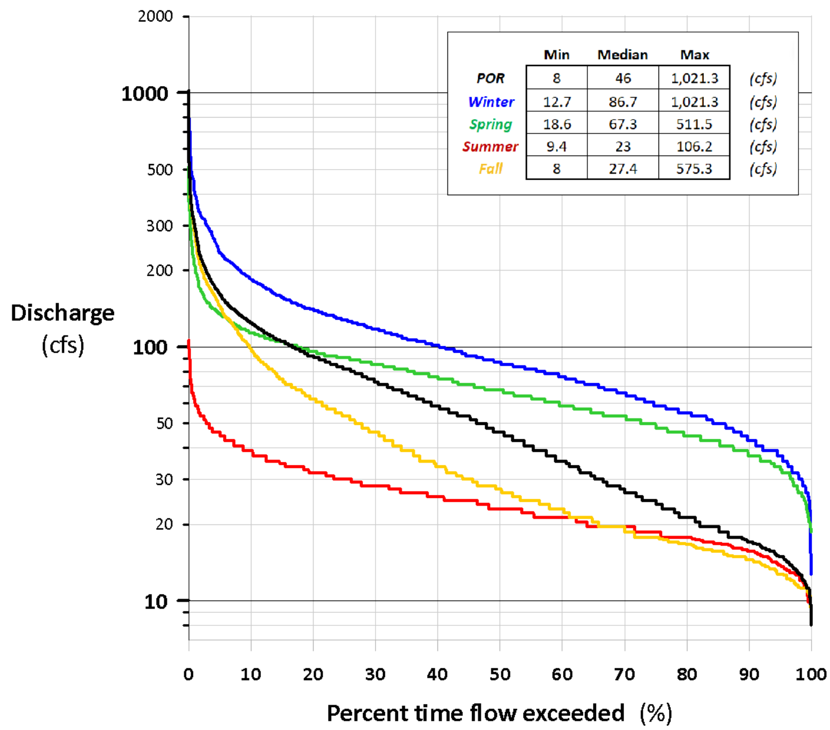

Figure 5. Flow duration curves, Grandy Creek (water years 1944 to 1971).

4. Alternate Hydrologic Assessment for Streamflow Properties

a. Water Volume Ranking

A variation of the raster hydrograph approach allows for additional ways to examine discharge data. By summing all daily discharges for each water year, an annual runoff value can be determined (Table 6). Additionally, the rank from the highest ("wettest") to the lowest ("driest") volume years are included. Water year 1971 was ranked first while water year 1944 was ranked last.

This ranking provides a different way to display the data in the raster format. Instead of using the water year as the y-axis coordinate, rank can be used instead. Figure 6 is a "dot plot" that provides a way to view both rank and water year.

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Table 6. Annual discharge volume, Grandy Creek (water years 1944 to 1971).

WY year	Annual vol. (ac-ft)	Rank
1944	25,456	28
1945	38,790	21
1946	48,609	13
1947	44,375	17
1948	50,621	12
1949	43,823	18
1950	57,787	3
1951	55,426	4
1952	32,196	25
1953	33,605	24
1954	55,311	5
1955	51,751	10
1956	52,888	7
1957	48,377	14
1958	27,251	27
1959	58,690	2
1960	52,337	9
1961	51,026	11
1962	37,760	22
1963	38,911	20
1964	52,724	8
1965	39,926	19
1966	35,835	23
1967	48,220	15
1968	53,974	6
1969	44,977	16
1970	30,842	26
1971	61,503	1

Figure 6 shows the annual volume variability. An example is the decade of the 1950s. Five of those years were in the ten wettest years, while three years were listed in the ten driest years. Abrupt changes are also seen as 1958, the second driest year was followed by 1959, the second wettest year.

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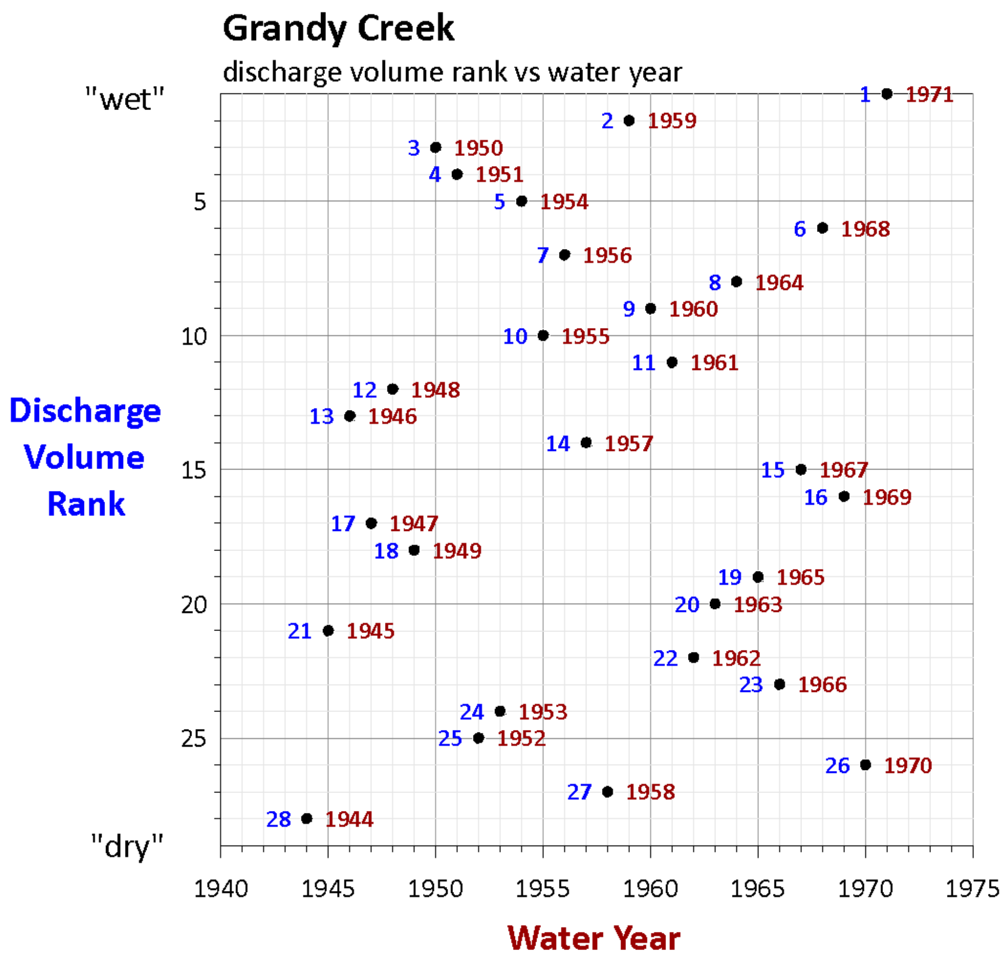

Figure 6. Water Year – Volume Rank comparison plot, Grandy Creek.

b. Wet Season Baseflow Conditions

A raster hydrograph based on rank can show additional properties (Figure 7). This figure has a contour overlay to provide additional interpretation of the hydrologic system and allows for a visualization of baseflow for Grandy Creek.

A 40-cfs contour provides a useful demarcation between wet season and dry season periods. For wet years (ranks 1 to 10), the contour generally begins from mid-October to the start of November and lasts until early to mid-June although exceptions do occur.

For the driest years, the 40-cfs discharge can start as late as mid-December, though some dry years start at the beginning of November. The driest year, 1944, has the 40-cfs level ending at the beginning of May with one storm occurring in late May. In general, the wetter years have a longer period of 40 cfs or greater discharge levels, up to 3 to 4 months, than the driest years.

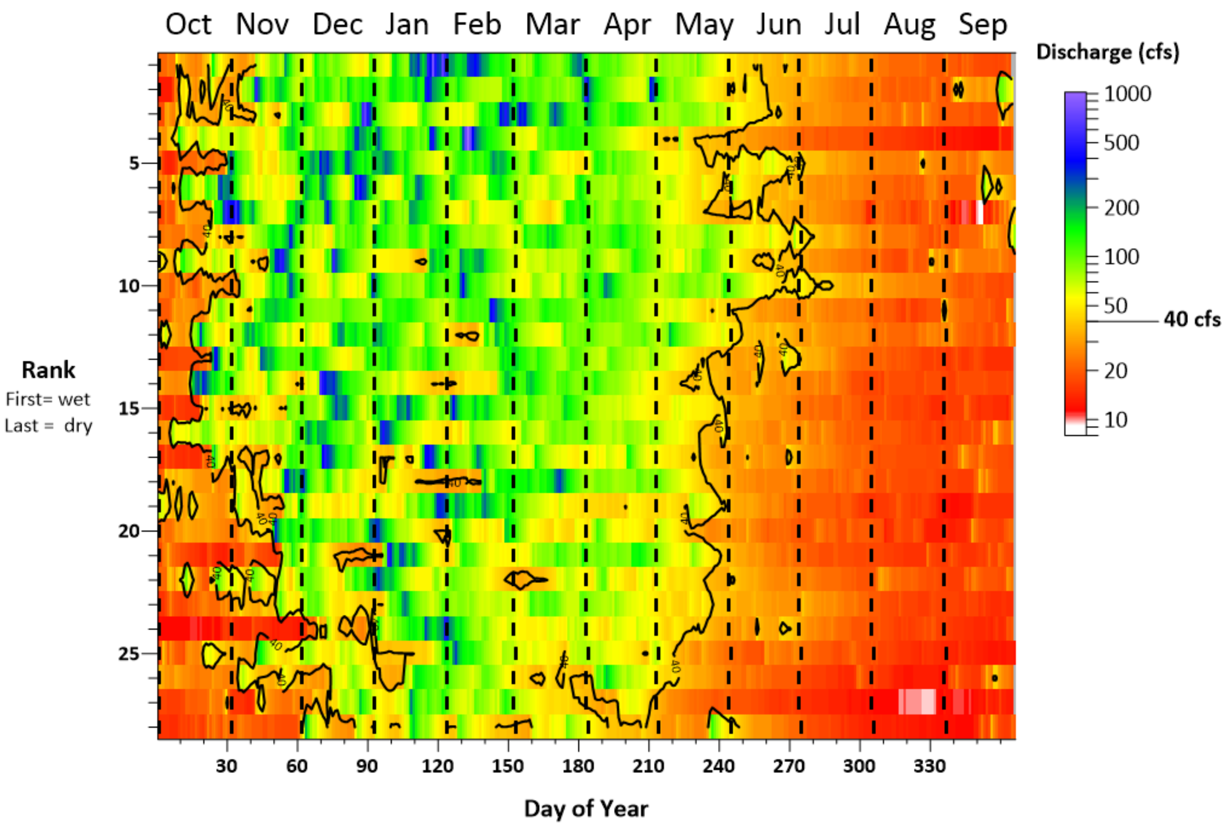

Figure 7. Grandy Creek ranked-based raster hydrograph with 40 cfs contour overlay.

c. Change-in-Flow Plots

Discharge information presented thus far has been general. Properties of timing and change in flow typically have the fewest metrics to describe the hydrologic regime (Olden and Poff, 2003). To overcome this, an alternative technique is used to quantify the discharge magnitude, frequency, duration, timing, change-in-flow and temporal configuration by specific discharge levels.

A change-in-flow technique examines the discharge record in daily pairs, with the first day (time "t") as the x-coordinate value (Q_t) and the following day (time "t+1") as the y coordinate value (Q_{t+1}). This is the same approach used for temporal autocorrelation "lag(1)" scatterplots. Autocorrelation, or serial correlation, is a measure of the degree of similarity for a time-series when compared to itself. An example of data preparation for the change-in-flow technique is shown in Table 7.

An advantage with this approach is that data becomes self-sorting where values of increasing or decreasing discharge naturally cluster on the scatterplot. This is different than a traditional line hydrograph where data points of increasing or decreasing discharge will stretch across the entire length of the record, becoming highly dispersed and making it difficult to visualize collective streamflow properties.

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Table 7. Example of the daily change-in-flow analysis

Date	$x = Q_t$ (cfs)	$y = Q_{t+1}$ (cfs)
1-Dec-1943	37.2	58.4
2-Dec-1943	58.4	187.6
3-Dec-1943	187.6	115.1
4-Dec-1943	115.1	81.4
5-Dec-1943	81.4	67.3
6-Dec-1943	67.3	69
7-Dec-1943	69	56.6
8-Dec-1943	56.6	49.6
9-Dec-1943	49.6	46

When displayed as a $\log_{10}$-$\log_{10}$ scatterplot (Fig 8), the diagonal line of y = 1x ($Q_{t+1} = Q_t$) indicates there is no change in discharge from first day to second day. Points above this line indicate increasing flow conditions (y > x or $Q_{t+1} > Q_t$). Similarly, points below this line indicate decreasing flow conditions (y < x or $Q_{t+1} < Q_t$). Additional reference lines of y=2x and y=1/2x are included to help determine the degree of change and number of occurrences.

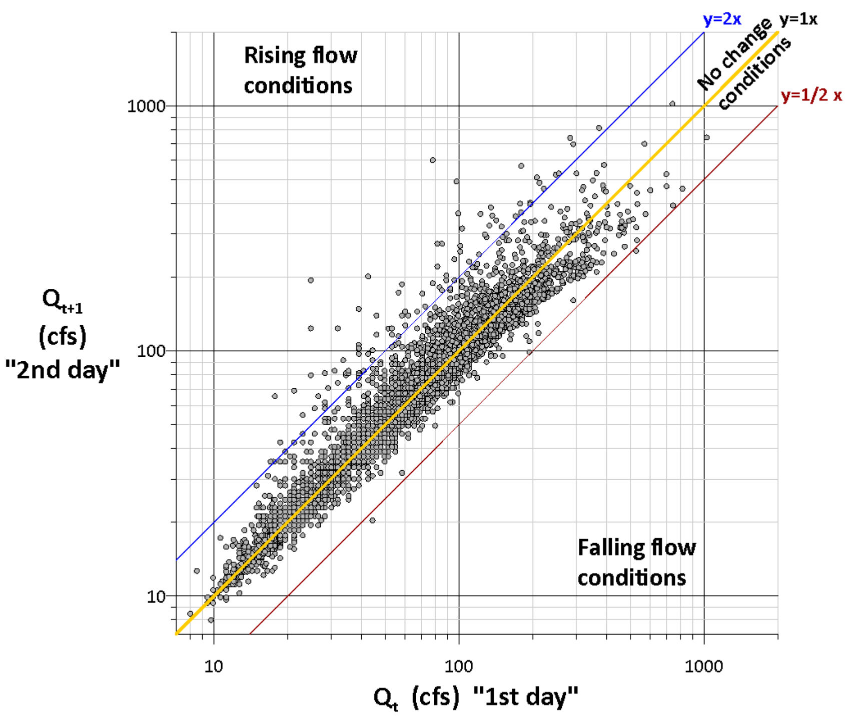

Figure 8. Change-in-flow scatterplot for Grandy Creek (water years 1944 to 1971).

As each point has an associated date, a breakout of each season is possible. Figure 9 shows a change-in-flow scatterplot for winter (blue), spring (green), summer (red), and fall (gold). These

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plots show the discharge magnitude (x-axis scale), duration (each point is one day), frequency (the number of points in a region of interest), timing (each plot represents a season), and change-in-flow (point position on the plot).

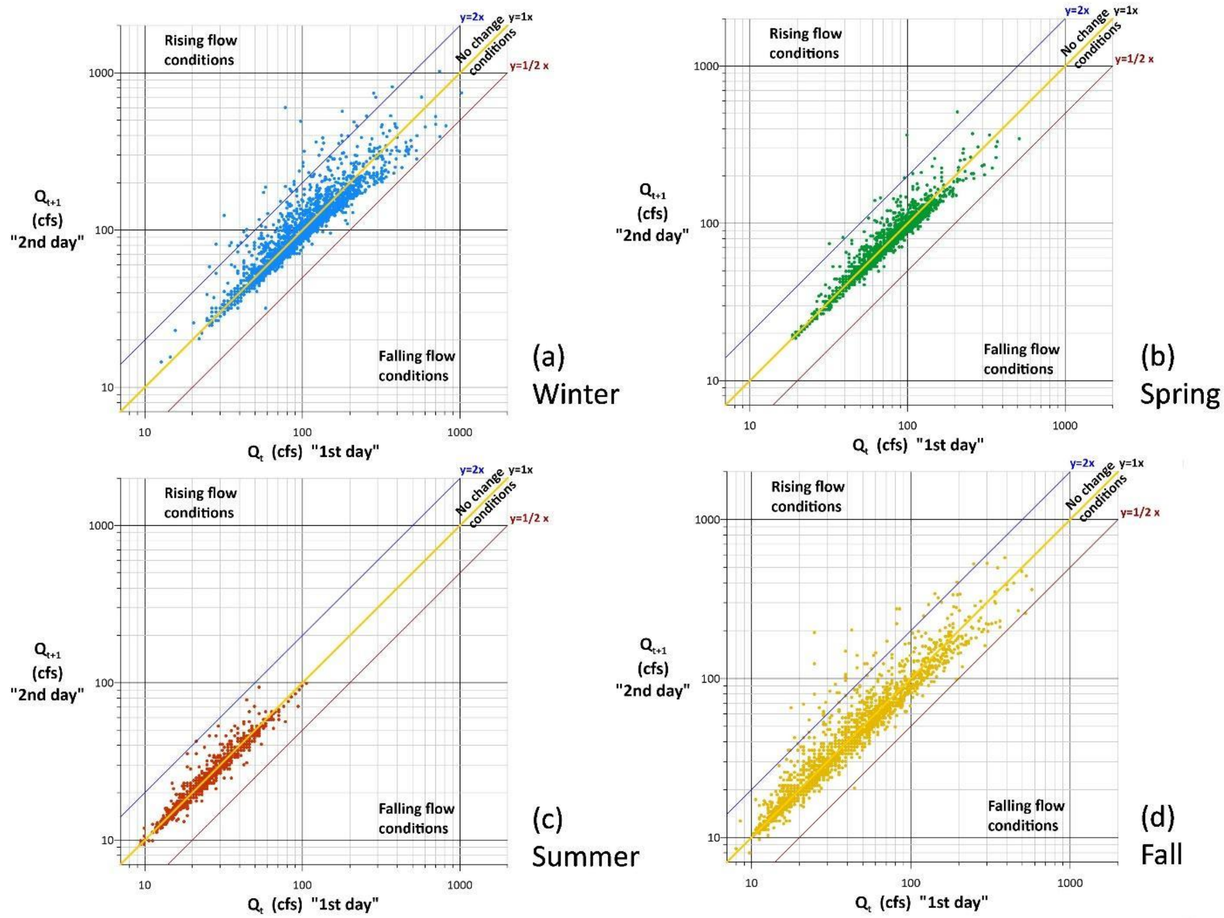

Figure 9. Change-in-flow scatterplots for (a) winter, (b) spring, (c) summer, (d) fall.

When discharges are categorized, data can be quantified. This allows for consistent comparisons. Three steps were taken to compile the data into a format suitable for plotting and are outlined in Figure 10:

Step 1 (Figure 10a) shows that daily data pairings are summarized. For consistency, categorized flows are the same as used in Figure 3. All possible discharge combinations are examined and, if present in the data, are summarized in tabular form.

Step 2 (Figure 10b) uses (Q_t, Q_{t+1}) coordinates to plot results.

Step 3 (Figure 10c) shows the process repeating for all categories, creating a summary matrix.

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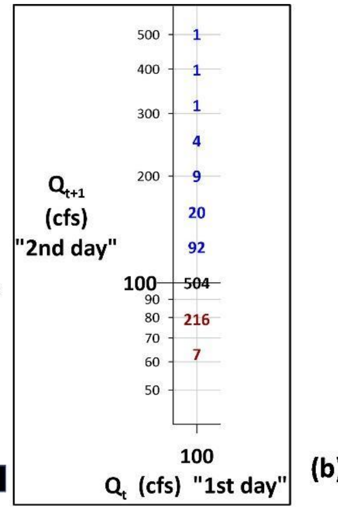
X	Y		
Q_t (cfs)	Q_{t+1} (cfs)	no. of days	*type of change*
100	501	1	*Increase*
100	398	1	*Increase*
100	316	1	*Increase*
100	251	4	*Increase*
100	200	9	*Increase*
100	158	20	*Increase*
100	126	92	*Increase*
100	100	504	*no change*
100	79	216	*decrease*
100	63	7	*decrease*

(a)



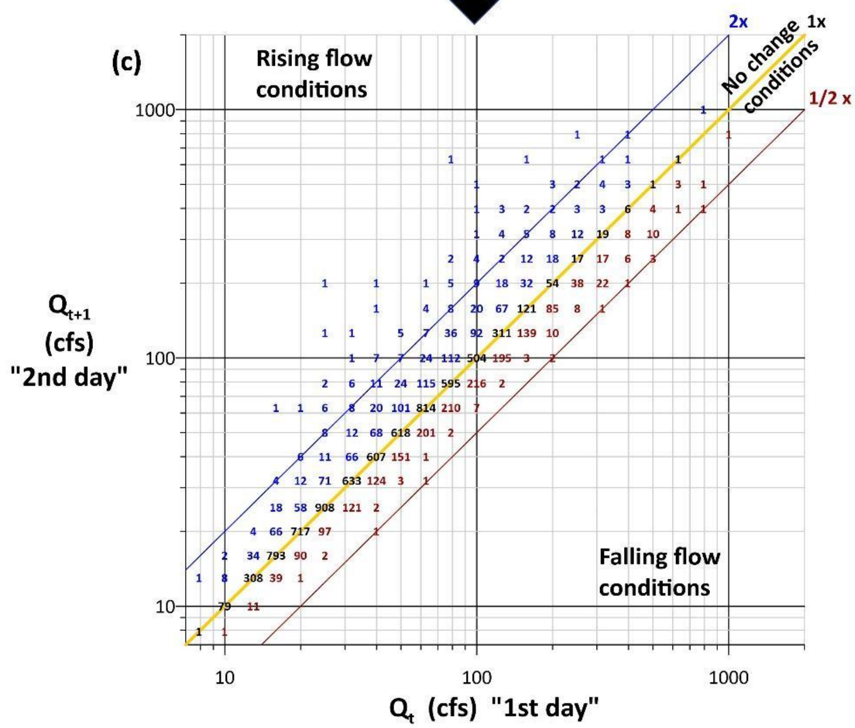


Figure 10. Steps for compiling Grandy Creek data. (a) data tabulation, (b) plotting for one flow category (example, Q_t = 100 cfs), (c) matrix for all flow categories for the period of record.

Highly detailed streamflow information is revealed, which is not possible with existing techniques. For example, the traditional flow duration curve (Fig 5), shows flows exceeded 100 cfs 15 percent of the time but there is no context information between adjacent days. In other words, there is no way of knowing for a specific day with a discharge of 100 cfs if there was an increase, decrease, or no change for the next day. However, using Figure 10, it is possible to see that for 100 cfs, there was only 1 day when the discharge increased to 501 cfs, a total of 504 days

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when discharge stayed the same, and a total of 216 days when discharge decreased to 79 cfs over the entire period of record.

5. Climate Change

Representative concentration pathways (RCP) describe possible future global greenhouse gas and aerosol emissions scenarios. One scenario used for this report, RCP 4.5, is described by the Intergovernmental Panel on Climate Change (IPCC) as a moderate scenario in which emissions peak around year 2040 and then decline. The other scenario, RCP 8.5, is the highest baseline emissions scenario where emissions continue to rise until year 2100. Climate change projected under RCP 8.5 can be assumed to be more severe than RCP 4.5 (Cal-adapt, 2023).

The Climate Mapping for a Resilient Washington is a webtool which summarizes compiled data relating to predicted changes in streamflow, precipitation, and other climate indicators under varying future climate projections (link, retrieved March, 2023). This tool is intended for state agencies, local governments, and communities in Washington to explore expected changes in the climate. The RCP 4.5 and RCP 8.5 greenhouse gas scenarios were used in this analysis to examine climate change impacts to Grandy Creek. Changes in climate summarized by the webtool are provided for 30-year future time periods. The time period evaluated in this report is the 2050's (2040 – 2069). The webtool climate conditions and changes listed for Alder Creek were applied directly to Grandy Creek without adjustment.

The Climate Mapping for a Resilient Washington webtool shows that Grandy Creek would have a 5.5% increase in annual precipitation under the higher emissions scenario (Figure 11). Annual precipitation is not predicted under the lower emissions scenario.

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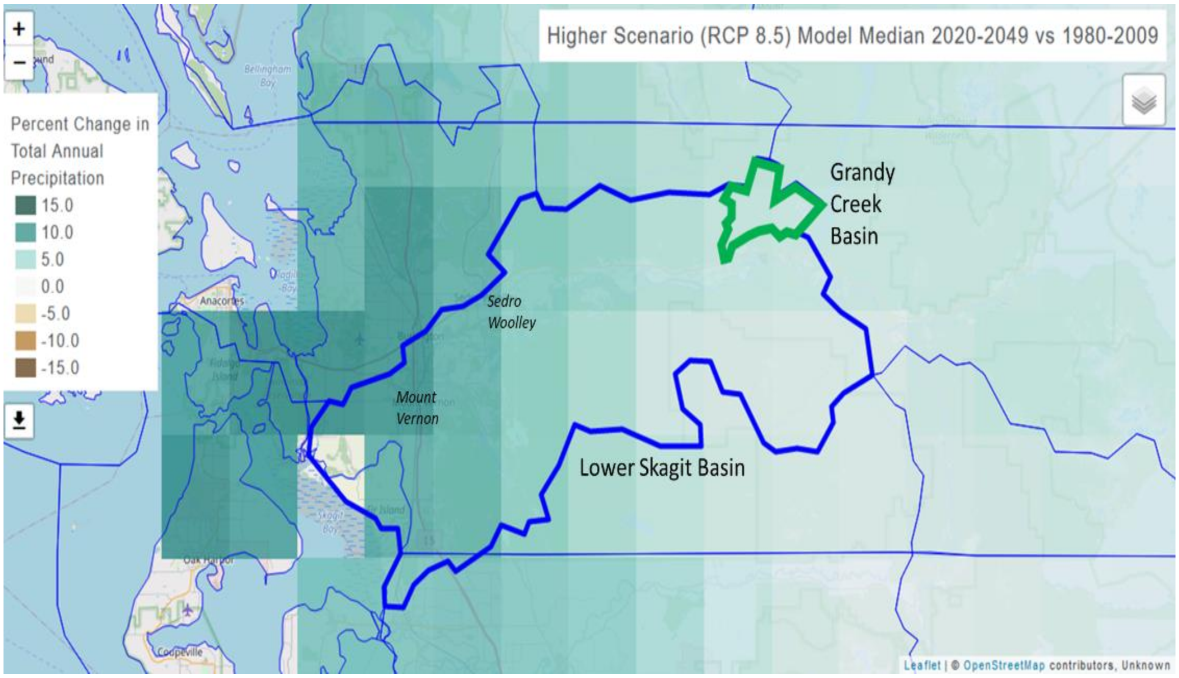
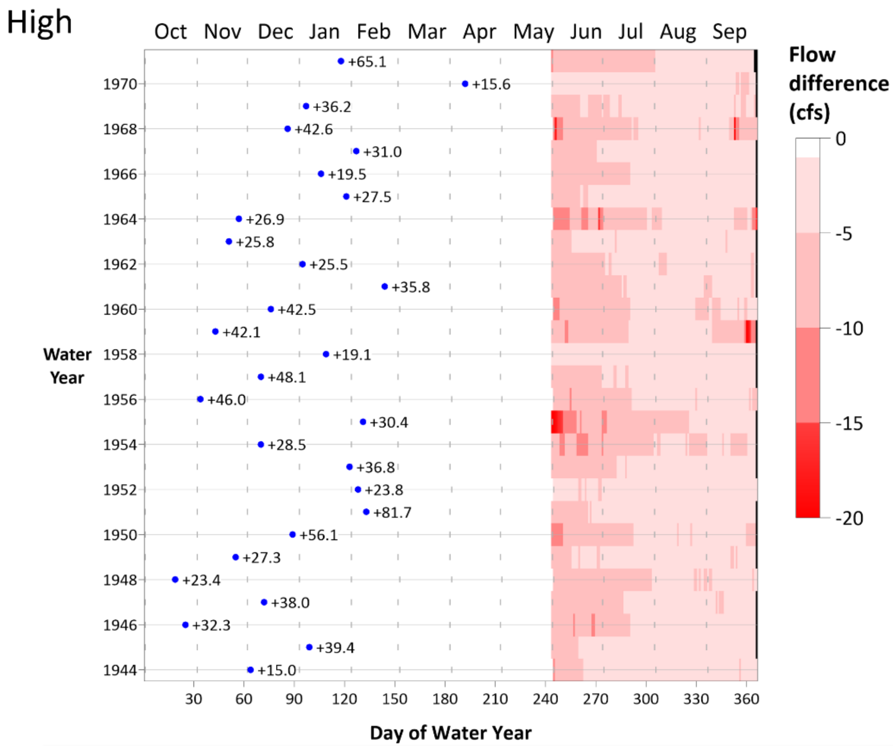


Figure 11. Percent change in annual precipitation for the Lower Skagit basin under a "high emissions scenario" (RCP 8.5) for the 2050's time period. (Source: Climate Mapping for a Resilient Washington, link)

Recent studies examining climate change for the Skagit River watershed have focused on rising temperatures and the effect this has on snowpack and glaciers. However, the Grandy Creek watershed is classified as a rain-dominated basin (Dalton et al., 2013). Dalton et al. state that "rain-dominant watersheds could experience higher winter streamflows if winter precipitation increases, but little change in streamflow timing". Se-Yeun and Hamlet (2011) put this change into context; they disclose that in terms of climate change effects on rain-dominant basins, [streamflow] changes are not very significant, since the dominant portion of the basin experiences conditions above freezing already.

Another recent study, however, indicates a predicted shift in streamflow under climate change scenarios (Chegwidden et al., 2017). Data retrieved from the Climate Mapping for a Resilient Washington webtool indicate that Grandy Creek may experience a higher ratio of winter streamflow to spring streamflow under both a lower and higher climate change scenario. This "Streamflow Timing" ratio represents the ratio of winter (Nov. – Feb.) streamflow to spring (Mar. – June) streamflow. Alder Creek, which has been used as a surrogate gaged watershed near Grandy Creek, has a ratio of 2.0 and is expected to increase to 2.1 under a higher climate change scenario, respectively. This indicates that under these two climate scenarios, average winter streamflow is approximately 2 times greater than average spring streamflow and is expected to increase approximately to 2.1 in the 2050's time period.

Peak flows are predicted to increase by 12% in Grandy Creek under the lower emissions scenario. Under the high emissions scenario, peak flows are expected to increase by 8% for the evaluated 2050's time period. The resulting raster time-series plots are displayed in Figure 12.

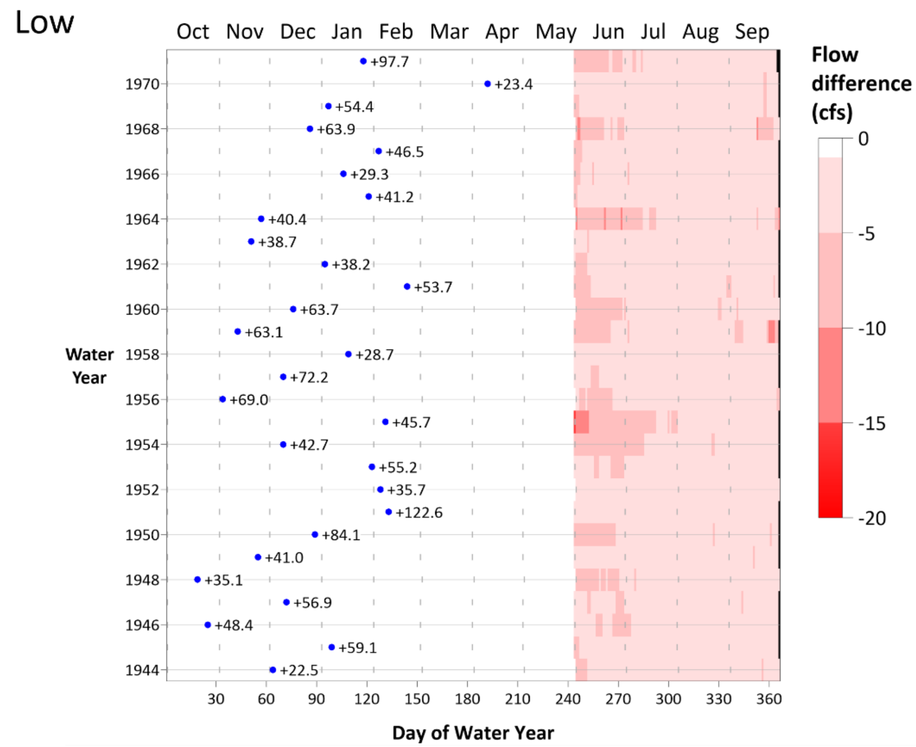


Peak flows

Higher Scenario (RCP 8.5), 2040 to 2069, Peak Streamflow, +8%. Only the annual maximum Grandy Creek flow was increased by +8%. All other values unchanged.

Summer daily flows

High Scenario (RCP 8.5), 2040 to 2069, Summer Streamflow, -20%. All Grandy Creek June, July, August, and September flows reduced by 20%



Peak flows

Lower Scenario (RCP 4.5), 2040 to 2069, Peak Streamflow, +12%. Only the annual maximum Grandy Creek flow was increased by +12%. All other values unchanged.

Summer daily flows

Low Scenario (RCP 4.5), 2040 to 2069, Summer Streamflow, -15%. All Grandy Creek June, July, August, and September flows reduced by 15%

Figure 12: High (RCP 8.5) and low (RCP 4.5) climate scenario adjustments to historic winter peak flows and summer daily flows.

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Streamflow during the summer season is critical in maintaining fisheries habitat. The change in summer streamflow (June – Sept.) is predicted under two climate scenarios relative to the 1980 – 2009 time period (Chegwidden et al., 2017; accessed via link). Summer streamflow in Grandy Creek is predicted to decrease by 15% under the lower emissions scenario. Under the higher scenario, the summer streamflow is expected to decrease 20%. These predicted changes in streamflow were applied to the Grandy Creek summer streamflow record and are presented in Figure 13.

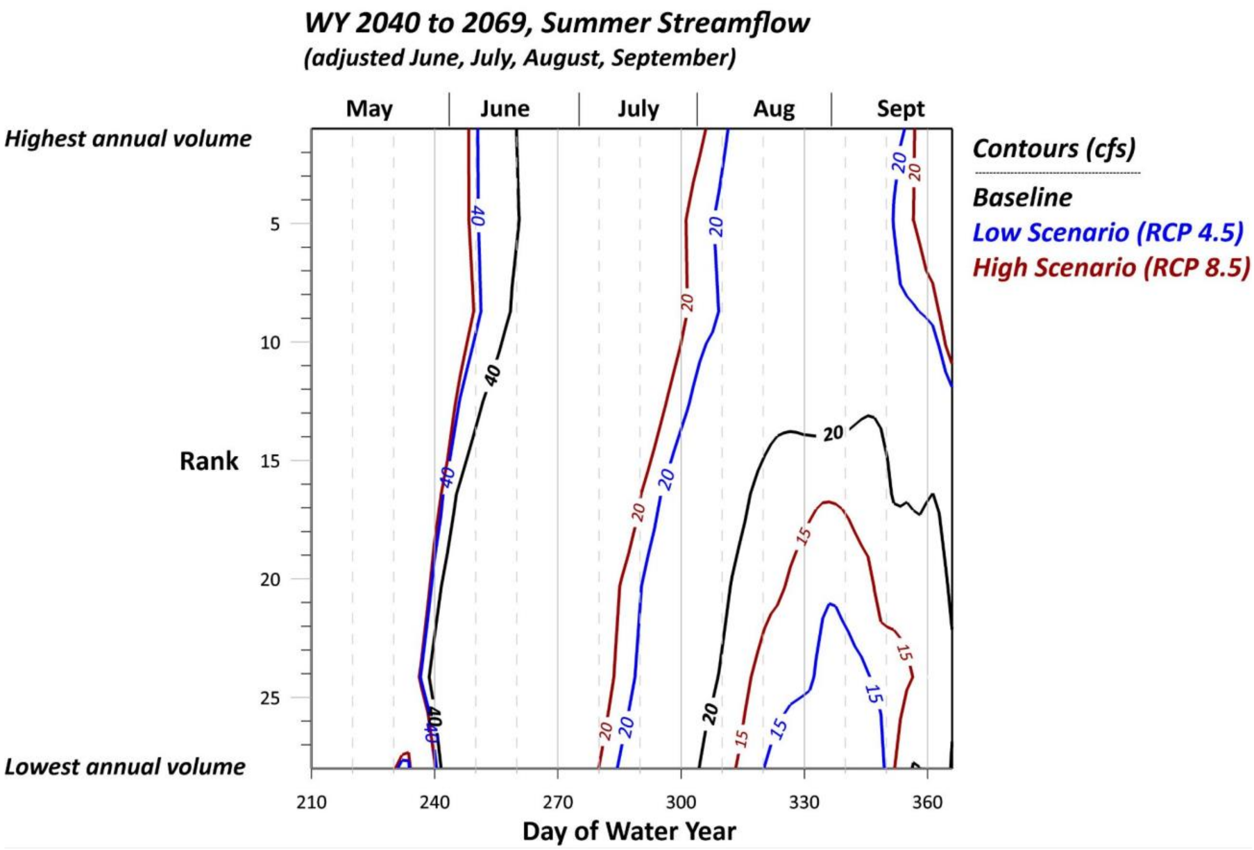

Figure 13. Summer Streamflow (adjusted Grandy Creek June, July, August, September discharges). Climate change scenarios for the time period between 2040 and 2069 (2050's). Baseline, Low Scenario (RCP 4.5), High Scenario (RCP 8.5).

The framework for Figure 13 is based on Figures 6 and 7 where ranked wet and dry yearly flows are grouped together. A highly smoothed option was used to plot the contour levels, which decreased high frequency variability, similar to a low pass filter, and produced a better representation of overall conditions.

Figure 13 also displays both climate change effects (contours line separation) as well as wet and drought effects (vertical placement of contour lines). Under wet conditions (top of graph), 40 cfs flow conditions for high and low climate scenarios occur 10 days earlier than for the baseline.

Also notable are that for water year ranks 1 to 15 (wet to average years), baseline flows are above 20 cfs while under both scenarios flow drop below 20 cfs.

Under dry conditions, the 40 cfs baseline contour is 20 days sooner than wet conditions and the climate change scenarios are 10 days earlier. The 20 cfs contour for both low and high scenarios are 20 days earlier (mid-July) than the baseline (late July). Finally, the lowest flows occur late August to early September with the high scenario having the lowest flows.

a. Drought

Although climate scenarios show little change for annual precipitation, there is still a need to examine Grandy Creek for possible future stress conditions. Lee and Hamlet (2011) and Mote et al. (2003) discuss that since 1900, five of the six extreme multi-year droughts occurred during the warm phase of the Pacific Decadal Oscillation (PDO) and four of the five highest flow years happened during the cool phase of the PDO. However, climate change reports do not provide much specific information on drought for the Grandy Creek area.

To address this gap, an analysis was undertaken to understand drought factors that influence the annual volume in Grandy Creek. Specifically, three factors were examined; regional drought conditions, the number of runoff events per year, and annual maximum mean daily flow.

For the regional perspective, the Palmer Hydrologic Drought Index (PHDI) is used because it measures hydrological impacts of drought. This long-term index was developed to quantify such effects (NOAA, 2023). PHDI information is produced by the National Drought Center and NOAA's National Centers for Environmental Information. Washington state is divided into different climate divisions, each with a specific set of PHDI monthly values. The Skagit River project area is within Division 4, East Olympic Cascade Foothills. The relationship between monthly PHDI value and drought condition is shown in Table 8.

Table 8. PHDI classifications

Index value	Condition
4.00 or greater	Extremely Wet
3.00 to 3.99	Very Wet
2.00 to 2.99	Moderately Wet
1.00 to 1.99	Slightly Wet
0.50 to 0.99	Incipient Wet period
0.49 to - 0.49	Near Normal
-0.50 to -0.99	Incipient Dry period
-1.00 to -1.99	Mild Drought
-2.00 to -2.99	Moderate Drought
-3.00 to -3.99	Severe Drought
-4.00 or less	Extreme Drought

Figure 14 shows the location of climate divisions and Figure 15 displays the monthly PHDI values for Division 4. Positive values are green and represent wetter conditions. Negative values are orange and represent drier conditions.

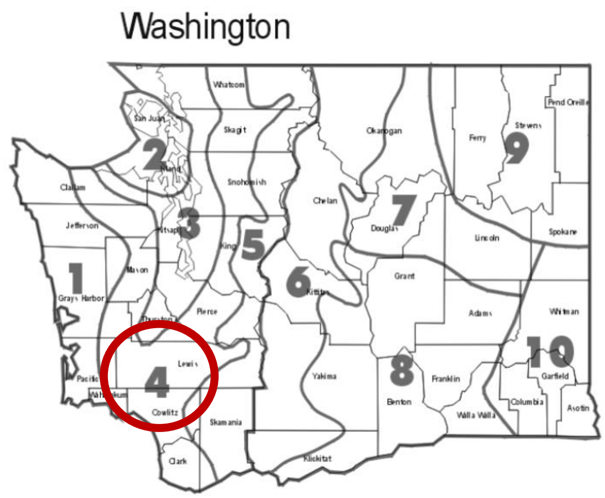

Figure 14. Washington State climate divisions (source: NOAA).

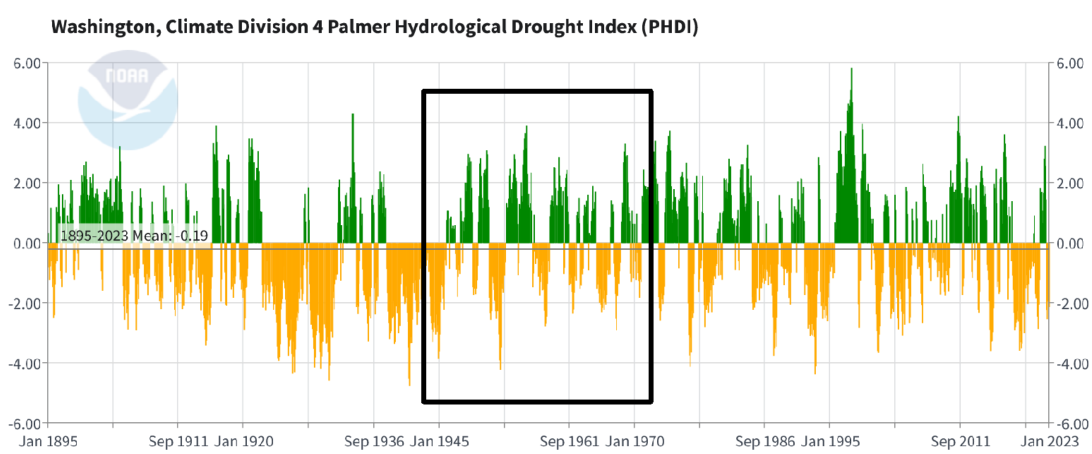

Figure 15. Line plot - Monthly values for Washington state Climate Division 4. Grandy Creek discharge period shown by rectangle (source: NOAA).

During the period of record for Grandy Creek, years 1944, 1945, 1952, and 1953 experienced severe to extreme drought (PHDI ≤ -3.00). Figures 16 (a) and (b) show the averaged PHDI monthly values for each year with the annual runoff volume. The general pattern of annual runoff volumes and PHDI are similar, as would be expected. Some years show the delay between the two timelines. Figure 17 shows the regression results of these two factors.

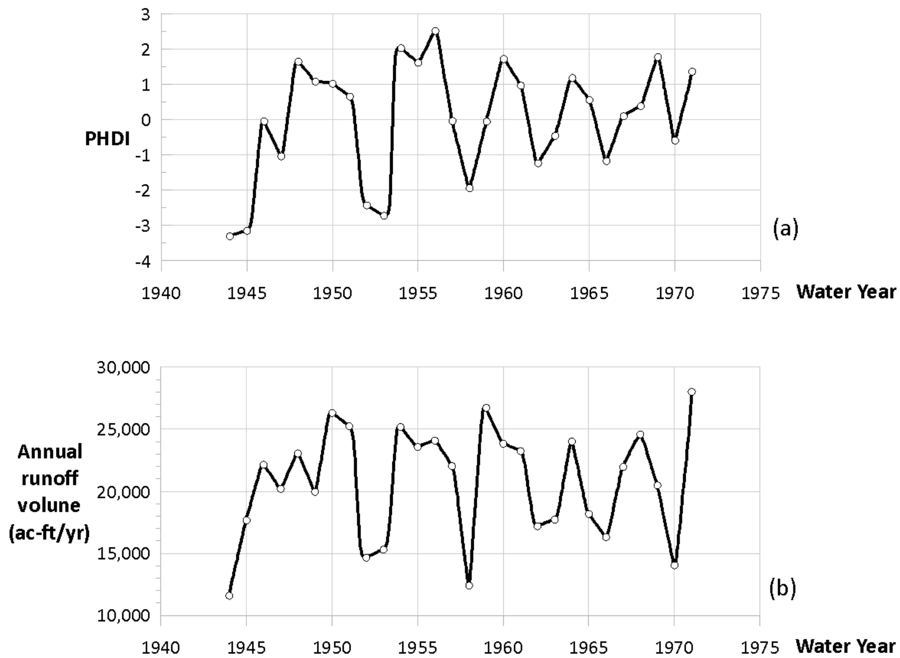

Figure 16. Yearly comparison plot between PHDI (a) and annual runoff volume (b).

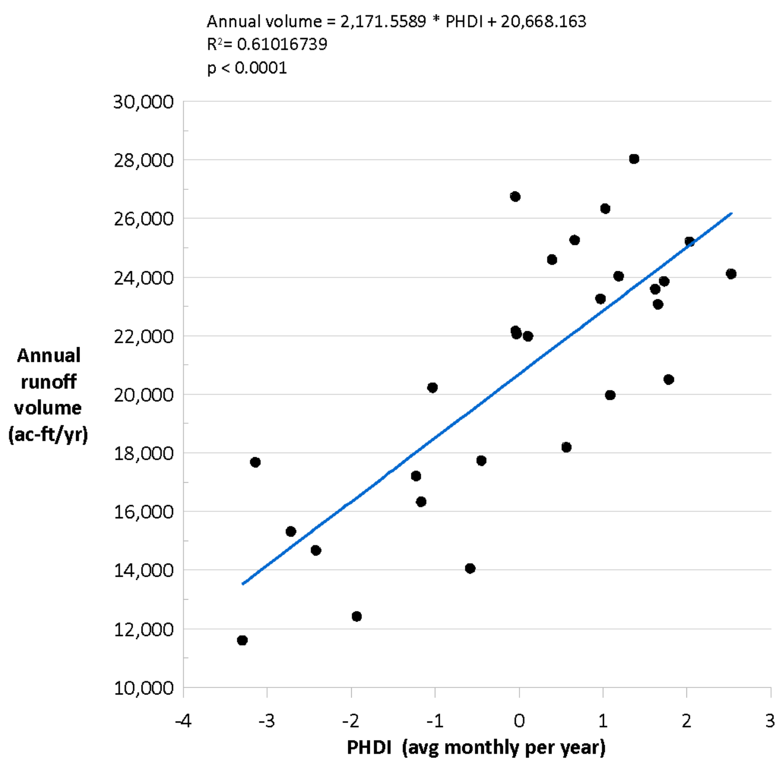

Figure 17. Regression of average monthly PHDI value per year and annual runoff volumes.

The regression line shows a correlation between these two variables (R-squared = 0.61). When higher PHDI values exist, annual runoff volumes tend to be higher as well. The p-value of less than 0.0001 indicates the relation between these factors is highly significant.

b. Events per Year

For this study, a daily discharge increase of 15 cfs was used to identify runoff events, as this threshold correlated best with the annual runoff volume (Table 9). Once this threshold was identified, the number of events for each water year could be determined (Table 10). Results are shown below for several threshold levels.

Table 9. Threshold rise, avg events per year, and coefficient of determination, R^2

Threshold rise (cfs)	Avg events/year	r^2
1	43.6	0.38
5	29.8	0.61
10	20.8	0.68
15	16.7	0.79
20	13.1	0.70
25	10.6	0.71
30	9.9	0.65
50	5.0	0.42

Table 10. Number of runoff events, 15 cfs threshold, Grandy Creek.

WY year	total events	winter	spring	summer	fall
1944	9	5	3	0	1
1945	13	6	5	0	2
1946	19	9	4	2	4
1947	16	8	3	1	4
1948	22	10	2	0	10
1949	16	6	5	0	5
1950	22	9	7	0	6
1951	21	12	3	0	6
1952	10	5	1	0	4
1953	14	12	1	1	0
1954	22	14	3	1	4
1955	16	6	6	0	4
1956	17	6	4	0	7
1957	15	4	6	0	5
1958	9	7	0	0	2
1959	26	13	3	0	10
1960	20	7	5	1	7
1961	15	5	2	1	7
1962	17	7	2	0	8
1963	12	7	3	0	2
1964	23	9	7	2	5
1965	15	10	2	0	3
1966	10	6	3	0	1
1967	19	14	2	0	3
1968	20	8	4	1	7
1969	15	5	3	0	7
1970	12	7	2	0	3
1971	22	11	6	0	5

drought

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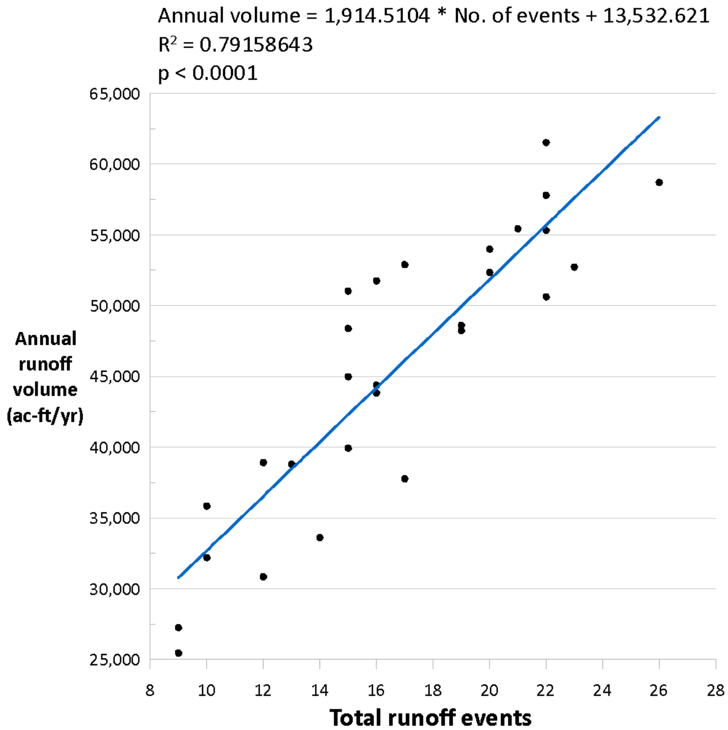

Figure 18. Total runoff events vs annual runoff volume, Grandy Creek (water years 1944 to 1971).

Figure 18 displays the relationship between total runoff events in a water year and the annual runoff volume. The regression line in Figure 18 shows a strong correlation between these two variables (R-squared = 0.79). With a greater number of events, the annual runoff volumes are greater as well. The p-value of less than 0.0001 indicates the relation between these factors is highly significant.

c. Annual Maximum Daily Mean Discharge

Finally, an analysis between the annual maximum daily mean discharge and annual runoff volume was performed and regression results are shown in Figure 19. The regression line shows a positive correlation between these two variables, though the R^2 value is not as large as the two previous regressions (R-squared = 0.46). Regardless, the p-value of less than 0.0001 indicates the relation between these factors is significant.

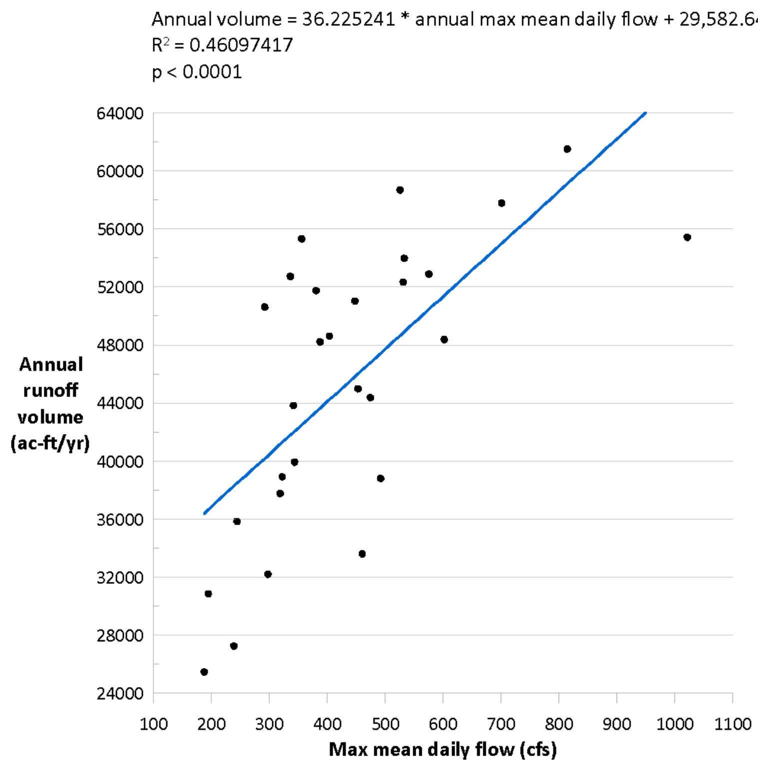

Figure 19. Annual maximum daily mean discharge vs annual runoff volume, Grandy Creek (water years 1944 to 1971).

d. Multivariate Analysis

When PHDI, number of events, and annual maximum mean daily flow are used in a multivariate regression with the annual runoff volume, the summary shows that 91.5% of the data variation is explained by these variables (Table 11). The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< 0.01) indicates rejection of the null hypothesis and acceptance that the variables and coefficients are both highly significant.

Table 11. Multivariate analysis results

Regression Statistics		*Varaible*	*Coefficients*	*P-value*
Multiple R	0.961	Intercept	20487.49	8.6E-08
R^2	0.924	PHDI avg	2179.02	6.7E-05
Adjusted R^2	0.915	Max annual flow	16.91	2.4E-04
Standard Error	2904.2	No. of events	1091.14	2.1E-06
Observations	28			

ANOVA	*df*	*F, Signif F*
Regression	3	97.43
Residual	24	1.42E-13
Total	27	

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The practical implication of these results is that all of these variables play important roles in local hydrology. Specifically, a more severe drought PHDI index means lower runoff volumes, fewer storms, and smaller annual maximum flows for Grandy Creek.

The monthly PHDI record for Washington Climate Division 4 (1895 to 2023) shows that for 43% of the time, the division experienced mild to severe drought. The most severe drought conditions (PHDI index of -5 or less) occurred in 1930 and 1952. The wettest conditions (PHDI index of 5 or greater) occurred in 1933, 1934, and 1997. Table 12 summarizes the PHDI wettest and driest years in the streamflow record used for Grandy Creek. While water year 1944 was in drought conditions the entire year, water year 1971 was a transition period going from dry to wet conditions.

Table 12. PHDI and runoff volume values for water years 1944 and 1971, Grandy Creek

WY year	Runoff vol (ac-ft/yr)	PHDI avg	PHDI max	PHDI min
1944	25,456	-3.30	-1.41	-4.22
1971	61,503	1.37	2.67	-1.23

A review of the existing discharge record helps put the multivariate variables into context. Water years 1944 and 1971 represent the smallest and largest runoff volumes for Grandy Creek. Examining the distribution of discharges of these years aid in future planning of climatic extremes. The total and seasonal number of events for these two extreme years are listed below (Table 13).

Table 13. Events per year and events per season for water years 1944 and 1971.

WY year	total events	winter	spring	summer	fall
1944	9	5	3	0	1
1971	22	11	6	0	5

6. Water Demands and Future Development

Grandy Creek watershed contains 19 state-issued water rights that provide use for domestic, municipal, irrigation, and recreational purposes. Water right holders diverting and/or storing surface water from Grandy Creek include Lake Tyee, Creekside Camping, and Grandy Creek Resort public water systems. Table 14 summarizes the annual allotted water for each purpose of use in Grandy Creek. Irrigation primarily consists of watering grass/hay, gardens, and lawns. In addition to existing surface water rights, there are 98 permit-exempt wells in Grandy Creek watershed whose water diversions are not monitored or accounted for in this study.

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Table 14: Water rights in Grandy Creek watershed and total possible volumes allotted for consumption in acre-feet per year (afy). Table modified from 2019 WRIA 4 Water Use Study.

Purpose of Use	Allotted Volume (afy)	Estimated Use (afy)	Percent Used
Municipal	141.0	62.4	44%
Domestic Multiple	29.0	16.2	56%
Domestic Single	2.0	0.4	20%
Irrigation	82.0	1.0	1%
Recreation - Beautification	343.2	151.0	44%

Municipal water use is expected to increase by 7% by 2040 in the Water Resource Inventory Area (WRIA) 4, which Grandy Creek falls within (Yoder et al., 2021). Total irrigation water demand in this region is minimal relative to the Lower Skagit (WRIA 3) and there are no known reports indicating the expansion of irrigated lands in Grandy Creek watershed.

Although the municipal water use is predicted to increase, streamflow in Grandy Creek is protected under the Instream Resources Protection Program rule (WAC 173-503) which may impact the ability to develop property in the Grandy Creek basin. Under this rule, new exempt wells for single-family residences are limited and must be approved by Skagit County. Any applicant for a residential building permit must demonstrate legal and adequate water availability for their parcel in order to attain a permit from the County. This Instream Flow rule does not impact existing water rights, such as those listed in Table 14 above.

In addition, Skagit County designated Grandy Creek as a "Low Flow Stream," indicating that it is a limited surface water source under Skagit County Code Critical Areas Ordinance Title 14.24.340 Subsection (3)(c) (Skagit County iMap). Developers may bypass these water right limitations by connecting to a public water supply, mitigating impacts to instream flows, or being eligible for the Skagit River Basin Mitigation Program, which offers a limited quantity of water to landowners within a specified zone. However, majority of land parcels surrounding Grandy Creek fall outside this Mitigation Program zone (Skagit River Basin Mitigation Map).

7. Conclusion

This hydrologic analysis quantifies the discharge magnitude, frequency, duration, timing and change in flow properties of Grandy Creek, Washington, a tributary to the Skagit River. Due to limited discharge data, the data from the USGS streamgage station on Alder Creek near Hamilton, Washington, was modified based on a watershed area ratio approach.

The resulting daily time series dataset was evaluated with traditional methods such as line hydrographs, descriptive statistics, flow duration curves, and an empirical flood frequency

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analysis. An alternative evaluation was also conducted using raster hydrographs, seasonal change-in-flow scatterplots and matrices.

A climate change summary was compiled based on multiple sources that predicted little change in total annual precipitation and streamflow timing due to the rain-dominant nature of Grandy Creek watershed. Summer streamflow is expected to decrease between 15 and 20% in the 2050's, depending on climate change scenario. A drought analysis was conducted exploring the relationship of the annual runoff volume to the Palmer Hydrologic Drought Index, the number of runoff events per year, and the annual maximum mean daily discharge value. Results show for drier, drought conditions, as indicated by PHDI values, fewer runoff events and smaller annual maximum discharges are expected. A historic summary was compiled using observed discharge records and change-in-flow scatterplots to illustrate how the Grandy Creek hydrologic regime behaves under severe drought and moderately wet conditions.

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Attachment 4: High Flow Transect Photographs

Provided in a separate zipped folder.

Attachment 5: Transect Installation Photographs

Provided in a separate zipped folder.

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