UPPER GRANDE RONDE INSTREAM FLOW INCREMENTAL METHOD STUDY

Prepared for:

Upper Grande Ronde River Watershed Partnership

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EXECUTIVE SUMMARY

The Upper Grande Ronde River Watershed (UGRRW) Partnership in Union County, Oregon has completed an Instream Flow Incremental Methods (IFIM) study on the Upper Grande Ronde River to evaluate streamflow targets for ESA-listed Chinook (*Oncorhynchus tschawytscha*) and summer steelhead (*Oncorhynchus mykiss*) at the juvenile rearing, spawning, and adult life stages. The study area includes the Upper Grande Ronde River from its confluence with Five Points Creek near River Mile (RM) 118.55 to its confluence with the East Fork Grande Ronde River at RM 145.45. This study follows technical guidance provided by OAR 635-400 *Instream Water Right Rules* and the requirements of the Oregon Water Resources Department (OWRD) and Oregon Department of Fish and Wildlife (ODFW) including OWRD *Draft Guidelines: A Tool for Conducting Place-Based Integrated Water Resources Planning in Oregon* (OWRD 2015), *Oregon's Integrated Water Resources Strategy* (Mucken and Bateman 2017), the Storage-Specific Study Requirements (OWRD 2023). The study field data collection, methodology, and analyses were completed in collaboration with local, state, and federal project partners.

An IFIM study is used to evaluate the relationship between streamflow and fish habitat for species at relevant life stages using the best available science to relate environmental parameters such as depth, velocity, substrate, and cover to relative suitability for the target species-life stage combination. A combination of field survey, remote sensing, and hydraulic modeling data is used to supply environmental parameter information across a range of streamflow conditions based on analysis of existing hydrologic data. The result of these analyses is a flow-habitat relationship curve for each Biologically Significant Reach (BSR), which can be integrated with species periodicity and hydrology to determine the streamflow needed for the "*conservation, maintenance and enhancement of aquatic and fish life, wildlife, and fish and wildlife habitat*" (OAR 635-400).

Results of this study indicate that water conservation is critical to sustaining aquatic habitat for all life stages for Chinook and summer steelhead. For all species-life stage combinations, aquatic habitat availability demonstrated a positive relationship with streamflow (though spawning life histories exhibit additional local maxima). This indicates that water availability is a primary limiting factor for the species considered based on the environmental parameters included in the study. However, there may be additional limiting factors that influence habitat availability including temperature, fine sediment, hydraulic conductivity, fish passage, competition, predation, and others. Results from this study can be used to guide streamflow and aquatic habitat restoration efforts by integrating optimal streamflow conditions for relevant species. Ultimately, deviations from the natural hydrology of the Upper Grande Ronde River require careful consideration as the aquatic species present are adapted to local conditions. Therefore, modifications outside of the standard deviation of the mean annual hydrograph have the potential for detrimental impacts to aquatic habitat. Additionally, instream flow recommendations based on these results should consider the impact of projected climate change on streamflow and temperature in water resources planning.

ACKNOWLEDGEMENTS

We would like to thank all collaborators on this study for providing expertise, review, access to data, and guidance throughout the project duration.

Table 1. Names and individuals and organizations collaborating on this study.

Name	Organization	Role/Responsibility
Anton Chiono	Confederated Tribes of the Umatilla Indian Reservation	Review
Cole Hendrickson	Oregon Department of Environmental Quality	Review
Dana Kurtz	Anderson Perry and Associates	Project Management, Data Provision
Donna Beverage	Union County	Review
Jesse Steele	Grande Ronde Model Watershed	Data Provision, Review
Jessica Humphries	Trout Unlimited	Review
Jim Morrow	National Oceanic and Atmospheric Administration	Review
Joseph Lemanski	Oregon Department of Fish and Wildlife	Review
Spencer Sawaske	Oregon Department of Fish and Wildlife	Review
Upper Grande Ronde River Watershed Partnership		Review, Collaboration

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1. INTRODUCTION

Cramer Fish Sciences (CFS) was retained by Anderson Perry and Associates (Anderson Perry) on behalf of the Upper Grande Ronde Watershed (UGRRW) Partnership to perform professional services relevant to the Instream Flow Incremental (IFIM) study for the Upper Grande Ronde (UGR) subbasin, located in Union County, Oregon.

Figure 1 Photograph taken by CFS during field data collection in June 2023.

1.1 Purpose and Scope

The purpose of this study is to develop instream flow targets for the Upper Grande Ronde River using the IFIM study methodology. The development of instream flow targets is directed by the Instream Water Rights Act of 1987 (OARS 537.332 – 537.360). Water rights are regulated by the Oregon Department of Water Resources (OWRD) filed through Oregon Department of Fish and Wildlife (ODFW), consistent with *Oregon's Integrated Water Resources Strategy* (Mucken and Bateman 2017). Additionally, this study is designed to meet the standards mandated by the Storage-Specific Study Requirements (OWRD 2023) consistent with OAR 690-600. This study follows technical guidance provided by OAR 635-400 *Instream Water Right Rules* to produce instream flow targets for ESA-listed Chinook and summer steelhead for juvenile rearing, spawning, and migration life stages in the Upper Grande Ronde River. The study area includes the Upper Grande Ronde River from its confluence with Five Points Creek near River Mile (RM) 118.55 to its confluence with the EF Grande Ronde River at RM 145.45 (Figure 2).

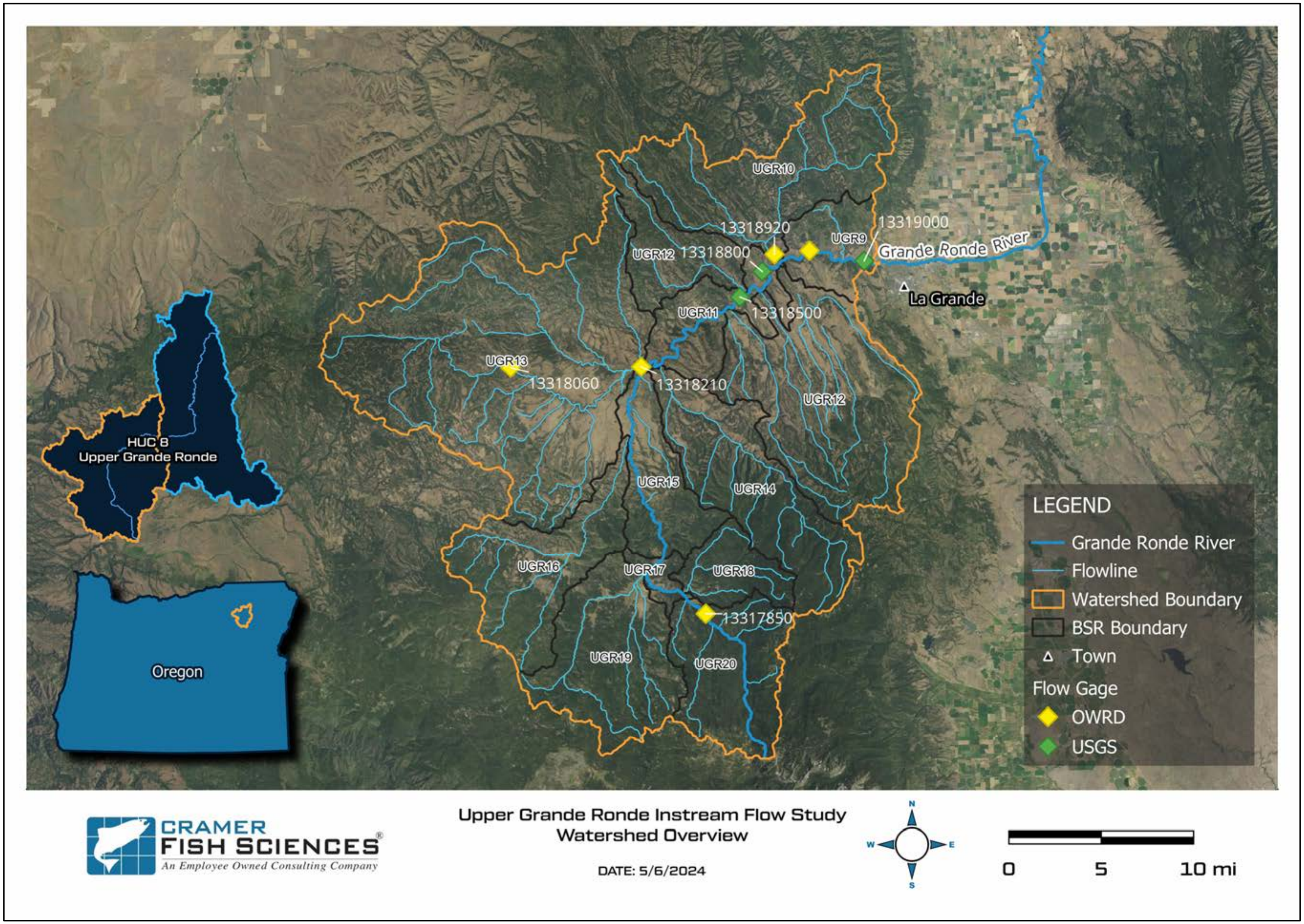


Figure 2. Upper Grande Ronde River watershed overview map.

In addition to target instream flow development, this study also includes development of annual peak flushing flow targets as well as habitat-forming flow targets consistent with ODFW (2007) and OWRD (2023), as summarized in Table 2.

Table 2 Analysis of Ecological Flows (reprinted from OWRD 2023).

Type of Ecological Flow	Definition	Acceptable Assessment Methods
By-pass flows	By-pass flows, a type of minimum flow, are flows that a project should pass to maintain the minimum habitat needs within a river system downstream of the impoundment (Robison 2007). Generally, by-pass flows refer to flows equal to the 50% exceedance flow (approximately the average flow) or less. *Ecological function*: submergence (water level) of the minimum habitat required to maintain populations of present species	Generally minimum habitat needs for bypass flows are studied in the same manner as baseflows. ODFW currently recommends assessing baseflow needs of a stream system for spawning, incubation, rearing, and passage using the Instream Flow Incremental Methodology (IFIM). In many cases, the Physical Habitat Simulation (PHABSIM) model can be used to determine necessary baseflows, though other conditions (e.g., whether a project will impact water quality) may necessitate a more in-depth assessment (ODFW 2016).
Optimum peak flows	Optimum peak flows are flows that occur less frequently, but at a greater volume than the average flow. Optimum peak flow functions can be divided up between ecological triggering flows that trigger key behaviors such as migration or spawning and geomorphic maintenance flows which help build and maintain overall ecological habitat (Robison, 2007). *Ecological function*: maintenance of key habitat and biologically triggering flows	Ecological triggering flows are best defined through biological investigation and observation and typically the expertise and knowledge of the local fish/aquatic biologists. This provides specific information about fish and other aquatic organisms' behaviors and how they respond to differing stream flows (Robison, 2007). Geomorphic maintenance flows can best be assessed using standard hydrologic and fluvial geomorphic analysis (e.g., identification of effective discharge – Wolmon and Miller, 1959).
Flushing flows	Flushing flows are a subset of optimum peak flows that specifically address the moving of existing streambeds and gravels allowing for "cleaning" of gravels intruded with fines. They improve spawning habitat and foods sources in the medium and long-term by providing higher quality macro invertebrate habitat (ODFW 2007). *Ecological function:* maintenance of key habitat	In the analysis of this subset of optimum peak flows, focus on the initiation and movement of gravels and suspension of fines from those gravels. Similar to optimum peak flows, flushing flows can best be assessed using standard hydrologic and fluvial geomorphic analysis.

[1] NOTE: If the applicant/grantee intends to apply for Water Project Grants and Loans, OWRD will determine if the aforementioned analysis will be used in the assessment of Seasonally Varying Flows or if additional analysis will be needed.

This study proposes the following selected methods to meet the study objectives:

Table 3. Summary of selected assessment methods for each type of ecological flow.

Type of Ecological Flow	Selected Assessment Method
By-pass (Instream)	Instream Flow Incremental Methodology (IFIM)
Optimum Peak Flows (Habitat-Forming Flows)	Hydrologic and fluvial geomorphologic analysis
Flushing Flows	Hydrologic and fluvial geomorphologic analysis

1.2 Consultation

Consultation meetings were held with study participants (Table 1) to solicit feedback and input on study objectives, methods, and results. A study kickoff meeting was held on December 12, 2022, to establish study objectives. The first methodology meeting was held on March 6, 2023, to establish target flows for field data collection and transect selection. The second methodology meeting was held on October 10, 2023, to establish habitat suitability criteria and determine ecological flow methods.

2. HYDROLOGIC ANALYSIS

2.1 Datasets Used for Hydrologic Analysis

The Grande Ronde Model Watershed, in cooperation with Oregon Water Resources Department, operates and maintains four stream-flow gauges in the Upper Grande Ronde Basin. The gauges are funded by Bonneville Power Administration, Oregon Watershed Enhancement Board, and the U.S. Forest Service (USFS). Additionally, the U.S. Geological Survey (USGS) operated three historical gages applicable to the project. Observed flow, stage, and temperature data was obtained from the OWRD website (OWRD, 2022) for current gages within the Upper Grande Ronde Watershed, including the period of record through Water Year (WY) 2022. Discontinued gage data was also obtained from the National Water Information System (NWIS) maintained by USGS. The U.S. Army Corps of Engineers (USACE), Hydrologic Engineering Center's (HEC) Data Storage System (HEC-DSS) was used for data storage and analysis. This software allows users to perform statistical analyses of hydrologic data. A graphic representation of the mean annual hydrograph at the two primary gage locations is shown in Figure 3 and Figure 4.

Table 4. Summary of gage data used for hydrologic analysis.

Station Number	Name	Agency	River Mile	Drainage Area (mi^2)	Start Year	End Year	15-Minute Data	Daily Mean Data	% Missing
13319000	Grande Ronde R at La Grande, OR	USGS	113.5	686	1903	1989	Yes	Yes	5.75
13318960	Grande Ronde R near Perry, OR	OWRD	116.9	677	1997	Current	Yes	yes	4.27
13318920	Five Points Cr at Hilgard, OR	OWRD	118.6[1]	72	1992	Current	Yes	Yes	2.93
13318800	Grande Ronde R at Hilgard, OR	USGS	119.9	555	1966	1981	No	Yes	0
13318500	Grande Ronde R near Hilgard, OR	USGS	123.1	505	1937	1956	No	Yes	0
13318210	Meadow Cr below Dark Canyon Cr near Starkey, OR	OWRD	130.9	181	1992	Current	Yes	Yes	7.49
13318060	Meadow Cr above Bear Cr near Starkey, OR	OWRD	130.9	48	1997	Current	Yes	Yes	2.36
13317850	Grande Ronde R below Clear Cr near Starkey, OR	OWRD	147.3	39	1992	Current	Yes	Yes	4.25

[1]River mile at tributary confluence

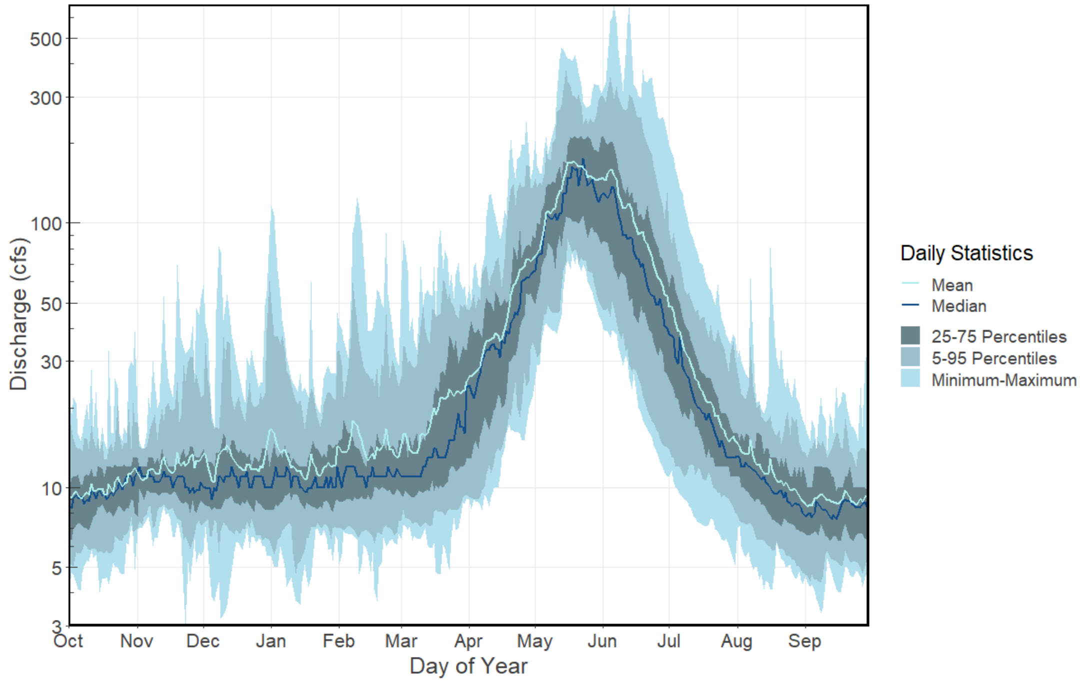


Figure 3. Mean annual hydrograph from OWRD Gage: 13317850 Grande Ronde River below Clear Creek near Starkey, OR.

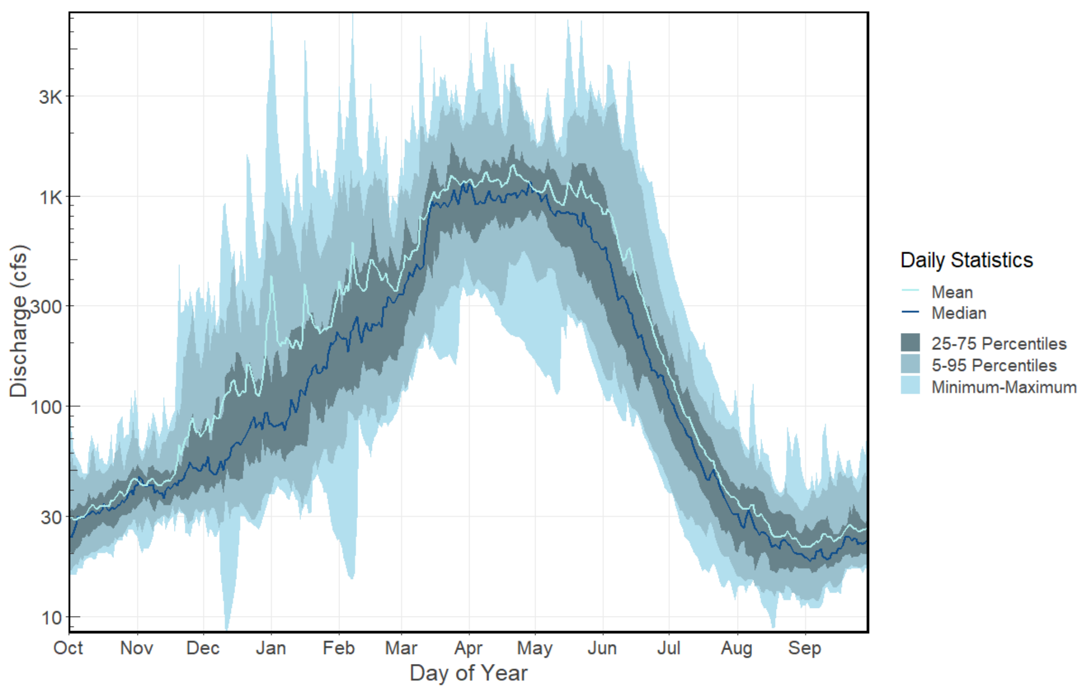


Figure 4. Mean annual hydrograph from OWRD Gage: 13318960 Grande Ronde River near Perry, OR.

2.2 Hydrologic Grouping and Subbasin Delineation

Because the Upper Grande Ronde River varies in drainage basin area, channel type, confinement, slope, as well as other geomorphological, hydraulic, and hydrologic characteristics, it is necessary to separate the river into hydrologic reaches. Reach breaks were delineated at each hydrologic unit code (HUC) 12 tributary confluence, as well as at Biologically Significant Reach (BSR) breaks. To assess and determine target instream flows, annual peak flushing flows, and channel forming flows for each of these reaches, the watershed characteristics, such as drainage area, average slope, elevation, mean annual precipitation, and others were calculated to determine flood frequency and flow duration method applicability. Reach and tributary watershed characteristics are shown in Table 5.

Table 5. Summary of mainstem reaches.

HUC Reach Name (BSR)	River Mile Start	River Mile End	Tributaries	Interior Drainage Area (mi^2)	Cumulative Drainage Area
Haywire Canyon (UGR9)	112.60	118.55	Five Points Cr	20.89	689.22
Coleman Ridge (UGR11)	118.55	130.95	Meadow Cr, Jordan Cr, Spring Cr, Whiskey Cr, Rock Cr	27.64	595.83
Warm Spring Creek (UGR15)	130.95	141.00	Fly Cr	30.76	208.97
Sheep Creek (UGR17)	141.00	145.85	Limber Jim Cr, Sheep Cr	5.95	126.10
Meadowbrook Creek (UGR20)	145.85	149.40	Tanner Gulch	21.34	45.16

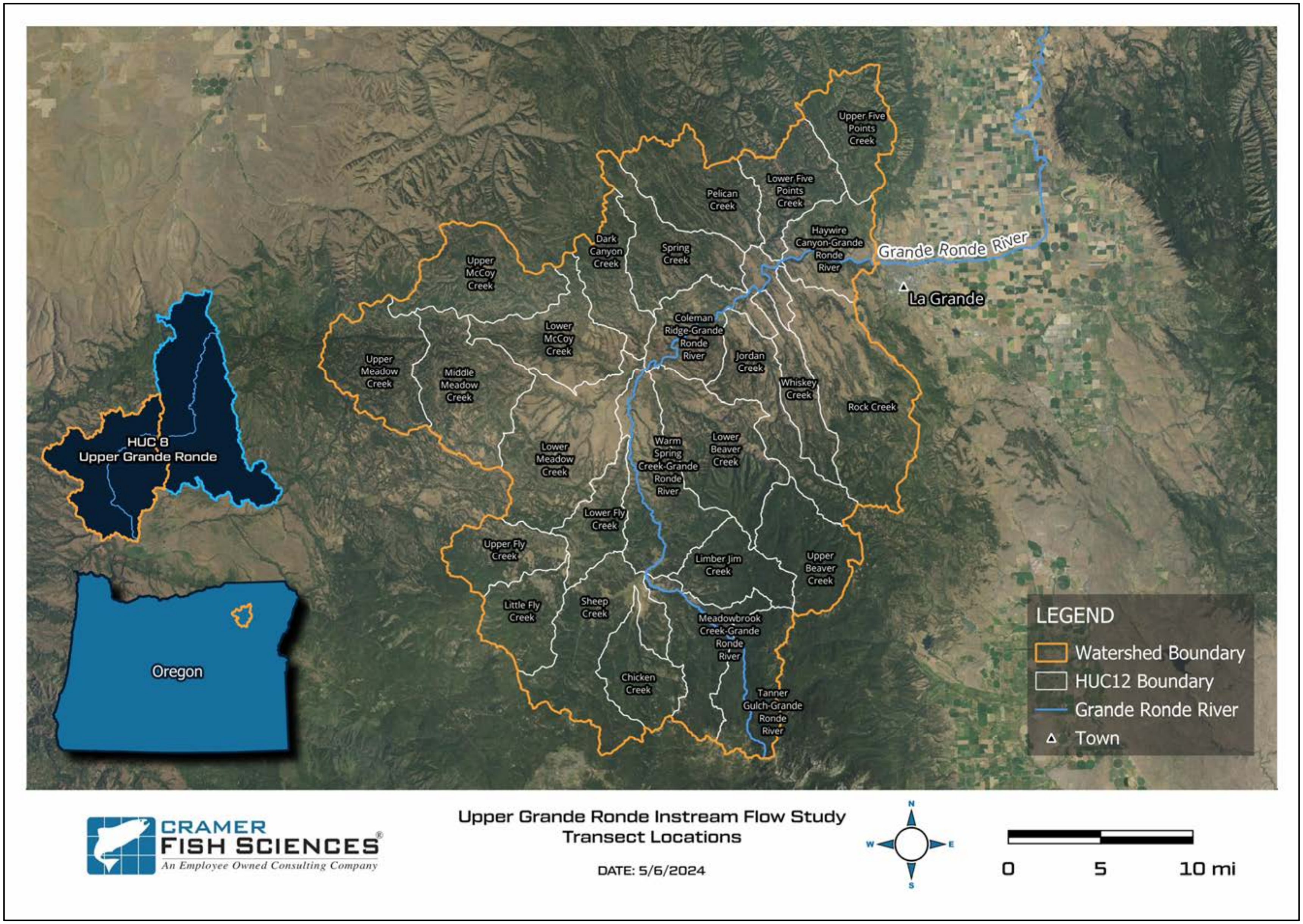


Figure 5. Map of HUC 12 tributaries.

Table 6. Summary of HUC 12 tributaries.

HUC Reach Name (BSR)	Included HUC 12 subbasins	Confluence River Mile	Drainage Area (mi^2)	Mean Annual Precipitation
Five Points Creek (UGR10)	Upper Five Points Cr, Lower Five Points Cr, and Pelican Cr	118.55	72.50	30.1
Rock Creek (UGR12)	Rock Cr	118.85	50.60	25.4
Whiskey Creek (UGR12)	Whiskey Cr	121.25	14.99	24.2
Spring Creek (UGR12)	Spring Cr	122.15	26.56	27.3
Jordan Creek (UGR12)	Jordan Cr	123.35	25.59	26.1
Beaver Creek (UGR14)	Upper Beaver Cr, Lower Beaver Cr	129.65	60.26	28.8
Meadow Creek (UGR13)	Dark Canyon Cr, Lower McCoy Cr, Upper McCoy Cr, Lower Meadow Cr, Middle Meadow Cr, Upper Meadow Cr	130.95	181.22	24.6
Fly Creek (UGR16)	Lower Fly Cr, Upper Fly Cr, Little Fly Cr	134.75	52.11	25
Sheep Creek (UGR19)	Sheep Cr, Chicken Cr	142.45	56.19	27
Limber Jim Creek (UGR18)	Limber Jim Cr	145.45	18.80	30.4
Tanner Gulch (UGR20)	Tanner Gulch	149.40	23.82	34.1

2.3 Flood Frequency Analysis

Flood frequency analysis was conducted using the USGS Bulletin 17C methodology (England et al. 2019) for each mainstem Grande Ronde River reach between HUC 12 boundaries and HUC 12 tributary inflows (Section 2.2). Approved peak discharges from 15-minute observed gages (Table 4) were used for flood frequency analysis at gage locations. Below is a list of the modification to the flow records to optimize flood frequency analysis:

- Grande Ronde River near Perry, OR: The gage record for the Grande Ronde River near Perry, OR, was modified by a) supplementing 15-minute peak discharge values for WY 2014 – 2022 at Station 13318960 Grande Ronde R near Perry, OR, with daily peak discharge values for WY 1997 – 2014 scaled by the mean ratio of overlapping peak gage records (1.142) and b) supplementing with peak discharge values from Station 13319000 Grande Ronde R near La Grande, OR, scaled by basin area (0.987). This resulted in a synthetic peak discharge record from 1903 – 2022 (106 record years, 14 missing years)
- Grande Ronde River near Hilgard, OR: Both gages near Hilgard, OR, are discontinued USGS gages. To create a longer synthetic peak flow record, Station 13318800 Grande Ronde R at Hilgard, OR, and Station 13318500 Grande Ronde R near Hilgard, OR, were scaled by basin area (0.974) and merged. This resulted in a synthetic peak discharge record from 1937 – 1981 (33 record years, 10 missing years).

At ungaged locations, the drainage-area ratio method was used to extrapolate discharges associated with discharge recurrence intervals. The drainage area associated with tributaries not explicitly included in the subbasin delineation was accounted for by lumping the area with the adjacent mainstem HUC 12 reach. The USACE Hydrologic Engineering Center's (HEC) Statistical Software Package (HEC-SSP) was used to perform statistical analyses of hydrologic data.

The results of the flood frequency analysis represent a flood frequency regime for each BSR, as well as between HUC 12 tributaries. Application of the drainage-area ratio method to Station 13318800 Grande Ronde R at Hilgard, OR, resulted in inconsistent hydrologic conditions compared to Station 13318960 Grande Ronde R near Perry, OR. This is likely because the discontinued gages reported mean daily data, or the data record does not incorporate the current climatic conditions. Therefore, only Station 13318960 Grande Ronde R near Perry, OR, (Index Station for Meadow Creek downstream) and Station 13317850 Grande Ronde R below Clear Cr near Starkey, OR, (Index Station for upstream of Meadow Creek) were used for flood frequency analysis. This resulted in the drainage-area ratio method being applied outside of typical limits. Installation and maintenance of a gage upstream and/or downstream of Meadow Creek is recommended to improve future hydrologic analysis of the Upper Grande Ronde basin. A summary of the flood frequency for each reach is shown in Table 7.

Table 7. Summary of flood frequency discharges for reaches and tributaries.

		Annual Exceedance Probability, in percent (Recurrence Interval)										
Start Location	End Location	0.2 (500-yr)	1 (100-yr)	2 (50-yr)	4 (25-yr)	10 (10-yr)	20 (5-yr)	50 (2-yr)	67 (1.5-yr)	83 (1.2-yr)	90 (1.1-yr)	99 (1.01-yr)
Five Points Creek	Study End	14829.7	12531.8	10924.7	9419.7	8005.6	6250.8	4980.2	3266.0	2637.1	2065.4	1773.5
Rock Creek	Five Points Creek	13051.7	11029.3	9614.9	8290.3	7045.8	5501.4	4383.1	2874.4	2320.9	1817.8	1560.9
Whiskey Creek	Rock Creek	11820.8	9989.2	8708.1	7508.5	6381.3	4982.5	3969.7	2603.3	2102.0	1646.3	1413.7
Spring Creek	Whiskey Creek	11469.0	9691.9	8449.0	7285.0	6191.4	4834.3	3851.6	2525.9	2039.5	1597.3	1371.6
Jordan Creek	Spring Creek	10845.6	9165.1	7989.7	6889.1	5854.9	4571.5	3642.3	2388.6	1928.6	1510.5	1297.0
Beaver Creek	Jordan Creek	10245.0	8657.5	7547.3	6507.6	5530.6	4318.3	3440.6	2256.3	1821.8	1426.9	1225.2
Meadow Creek	Beaver Creek	8830.7	7462.4	6505.4	5609.2	4767.1	3722.2	2965.6	1944.8	1570.3	1229.9	1056.1
Fly Creek	Meadow Creek	5072.3	4291.2	3743.9	3230.4	2747.0	2145.9	1709.7	1120.0	903.3	706.1	605.4
Sheep Creek	Fly Creek	3810.7	3225.8	2815.5	2430.2	2067.2	1615.3	1287.0	842.6	679.1	530.3	454.4
Limber Jim	Sheep Creek	2551.5	2162.4	1889.0	1631.7	1388.8	1085.7	865.0	565.7	455.4	354.9	303.7
EF Grande Ronde	Limber Jim	1555.8	1318.6	1151.8	994.9	846.8	662.0	527.4	345.0	277.7	216.4	185.2
Study Begin	EF Grande Ronde	820.6	695.5	607.5	524.8	446.7	349.2	278.2	181.9	146.5	114.2	97.7

2.4 Flow Duration Analysis

Flow duration analysis was conducted using the Risley et al. (2009) method for each mainstem Grande Ronde River reach between HUC 12 boundaries and HUC 12 tributary inflows (Section 2.2). Approved discharges from daily mean gage record (Table 4) were used for flow duration analysis at gage locations. At ungaged locations, the drainage-area ratio method and regression equation method were compared at each reach. Ultimately, the drainage-area ratio method was selected for establishing flow duration relationships because of a higher level of consistency between tributary and mainstem values. A summary of the flow duration discharges for each reach is shown in Table 8.

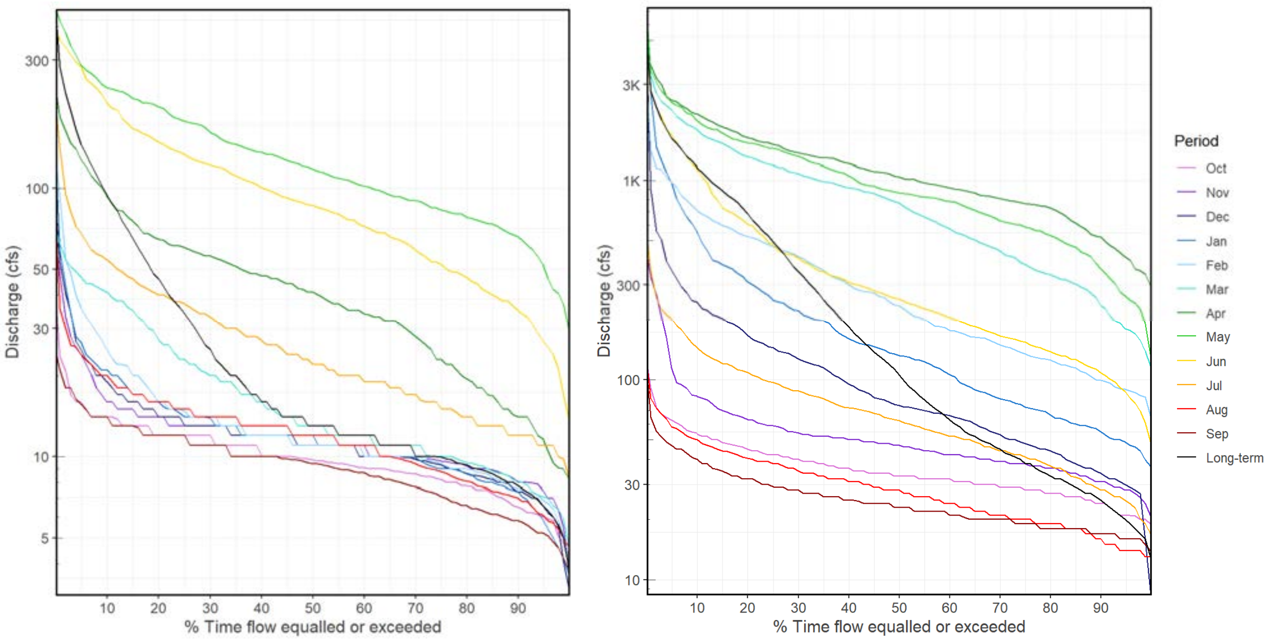


Figure 6. Flow duration curve from OWRD Gage: 13317850 Grande Ronde River below Clear Creek near Starkey, OR, (left) and OWRD Gage: 13318960 Grande Ronde River near Perry, OR (right).

Table 8. Summary of flow duration discharges for reaches at tributary junctions.

		Flow Duration, in percent (percentage of time that flow in a stream is likely to equal or exceed specified value)														
Start Location	End Location	99%	95%	90%	80%	75%	70%	60%	50%	40%	30%	25%	20%	10%	5%	1%
Five Points Creek	Study End	14.0	18.0	22.0	32.0	36.0	41.0	56.1	95.0	175.8	340.0	476.0	655.0	1122.0	1571.0	2750.2
Rock Creek	Five Points Creek	12.3	15.8	19.4	28.2	31.7	36.1	49.4	83.6	154.7	299.2	418.9	576.5	987.5	1382.6	2420.5
Whiskey Creek	Rock Creek	11.2	14.3	17.5	25.5	28.7	32.7	44.7	75.7	140.1	271.0	379.4	522.1	894.4	1252.3	1817.7
Spring Creek	Whiskey Creek	10.8	13.9	17.0	24.7	27.8	31.7	43.4	73.5	136.0	262.9	368.1	506.6	867.7	1215.0	1763.6
Jordan Creek	Spring Creek	10.2	13.2	16.1	23.4	26.3	30.0	41.0	69.5	128.6	248.7	348.1	479.0	820.6	1148.9	1667.8
Beaver Creek	Jordan Creek	9.7	12.4	15.2	22.1	24.9	28.3	38.8	65.6	121.5	234.9	328.8	452.5	775.1	1085.3	1575.4
Meadow Creek	Beaver Creek	8.3	10.7	13.1	19.1	21.4	24.4	33.4	56.6	104.7	202.5	283.4	390.0	668.1	935.5	1357.9
Fly Creek	Meadow Creek	6.5	8.2	9.8	14.1	15.5	17.2	22.5	35.9	61.0	111.8	154.4	210.5	289.9	358.2	454.3
Sheep Creek	Fly Creek	6.1	7.7	9.2	12.2	13.2	14.5	17.9	25.9	40.2	71.2	98.5	134.5	201.5	266.5	354.3
Limber Jim	Sheep Creek	5.7	7.4	8.6	10.7	11.4	12.2	14.0	17.8	23.1	37.8	52.5	71.9	128.6	190.9	271.9
EF Grande Ronde	Limber Jim	4.8	6.3	7.3	8.8	9.3	9.9	11.0	13.0	15.0	23.0	32.0	44.0	90.0	143.0	211.0
Study Begin	EF Grande Ronde	2.93	3.85	4.46	5.37	5.68	6.05	6.72	7.94	9.16	14.05	19.54	26.87	54.97	87.34	128.87

For flow duration analyses, consumptive use adjustments were made for water rights classified by the OWRD Water Rights Information System. There are 1,095 points of diversion within the study area: 30.1% of diversions are used for livestock, 20.6% for wildlife, 20% for instream flow, and fewer for other uses (Figure 7). However, most of the points of diversion were not for consumptive use, such as instream flow, recreational, power development, and others. These non-consumptive uses were not included in the hydrologic analysis. Additionally, many water rights rely on runoff, well water, reservoirs, or other non-instream sources. There are existing instream flow water rights on Bear Creek, Beaver Creek, Burnt Corral Creek, Chicken Creek, Clear Creek, Dark Canyon Creek, Five Points Creek, Fly Creek, Limber Jim Creek, Marley Creek, McCoy Creek, Meadow Creek, Pelican Creek, Rock Creek, Sheep Creek, Spring Creek, and West Chicken Creek. These sources were not considered in consumptive uses for the hydrologic analysis. Additionally, emergency or contingent uses such as fire protection or road construction were not considered consumptive uses for this hydrologic analysis. The resulting uses represent consumptive (or mostly consumptive) uses on water sources that have a direct impact on flow in the Upper Grande Ronde River. Consumptive water rights and points of diversion were aggregated by stream reach and are shown in Table 9.

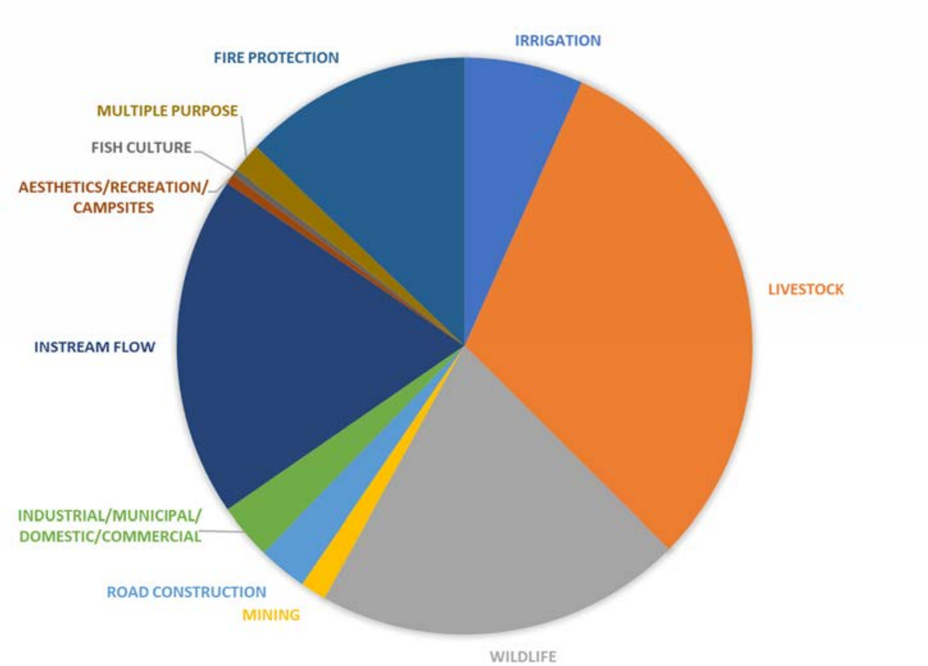


Figure 7 Summary of water right points of diversion use.

Table 9. Summary of water rights and points of consumptive use diversion within the Upper Grande Ronde basin.

Reach/Tributary	Type	Internal Basin Area (sq. mi.)	Cumulative Basin Area (sq. mi.)	Number of Points of Diversion	Total Diverted Flow (cfs)	Impacts Gage?
Five Points Creek	Tributary	72.5	689.22	5	1.513	Yes
Haywire Canyon	Reach	20.89	616.72	6	0.57	Yes
Rock Creek	Tributary	50.6	595.83	3	0.8522	No
Whiskey Creek	Tributary	14.99	545.23	1	2.91	No
Spring Creek	Tributary	26.56	530.24	1	0.275	No

Reach/Tributary	Type	Internal Basin Area (sq. mi.)	Cumulative Basin Area (sq. mi.)	Number of Points of Diversion	Total Diverted Flow (cfs)	Impacts Gage?
Five Points Creek	Tributary	72.5	689.22	5	1.513	Yes
Jordan Creek	Tributary	25.59	503.68	0	0	No
Beaver Creek	Tributary	60.26	478.09	3	7.002	No
Meadow Creek	Tributary	181.22	417.83	8	0.0426	Yes
Coleman Ridge	Reach	27.64	236.61	5	0.1934	Yes

The applicability of methodologies to determine flood frequency and flow duration, such as England et al. 2019, Risley et al. 2009, and Kelley and White (2016), primarily depend on the size of the drainage area and secondarily on mean annual precipitation, January maximum temperature, and drainage density (Kelley and White 2016). The Index Station (gaged tributaries, Table 4) used for drainage-area ration method used for each tributary and reach is shown in Table 10.

Table 10. Summary of Index Stations and drainage-area ratios for each reach and tributary within the study area.

Reach/Tributary Name	Drainage Area (mi^2)	Index Station	Drainage Area Ratio
Five Points Creek (UGR10)	72.50	13318920[1]	1.01
Rock Creek (UGR12)	50.60	13318920	0.70
Whiskey Creek (UGR12)	14.99	13318060	0.31[2]
Spring Creek (UGR12)	26.56	13318060	0.55
Jordan Creek (UGR12)	25.59	13318060	0.53
Beaver Creek (UGR14)	60.26	13318060	1.26
Meadow Creek (UGR13)	181.22	13318210[1]	1.00
Fly Creek (UGR16)	52.11	13318060	1.10
Sheep Creek (UGR19)	56.19	13317850	1.44
Limber Jim Creek (UGR18)	18.80	13317850	0.48[2]
Tanner Gulch (UGR20)	23.82	13317850[1]	0.61

[1]Index gages at these locations are represented by the actual gage.
[2]Outside the range of drainage-area ratio tolerances (Risley et al. 2009).

3. FIELD DATA COLLECTION

Three field data collection efforts occurred during the study period to gather hydrologic, hydraulic, and substrate observations at study transects to calibrate the hydraulic model and provide required data for the IFIM. All three efforts correspond to the range of flows or primary interest based on IFIM study methods, referred to as “Low,” “Moderate,” and “High” calibration discharges. Target field data collection flows were established through consultation with the study participants. The High calibration discharge field data collection occurred between May 30 and June 1, 2023, and targeted between 10-20% flow duration discharge. The Moderate calibration discharge field data collection occurred between June 27 and June 28, 2023, and targeted between the 40-60% flow duration. The Low calibration discharge occurred between September 6 and 7, 2023, and targeted between 90-99% flow duration discharge. A summary of field data collection efforts is included in Table 11, and a summary of each transect is provided in Appendix A.

Table 11. Summary of observed gage discharges related to daily flow duration during field data collection.

Gage Location	Calibration Discharge	Date	Daily Average Discharge (cfs)	Flow Duration
Grande Ronde River near Perry, OR	Low	Sep 6, 2023	25.1	92%
	Moderate	June 27, 2023	96.0	50%
	High	May 31, 2023	415.0	27.5%
Grande Ronde River near Stakey, OR	Low	Sep 7, 2023	7.2	90%
	Moderate	June 28, 2023	37.9	27.5%
	High	June 1, 2023	128.0	7.5%

3.1 Transect Surveys

The Instream Flow Incremental Method relies on gathering hydrologic, hydraulic, and habitat characteristics at study transects established throughout the study domain. Eight transects were established through consultation with study participants lettered A through H. One transect was added opportunistically during field data collection, denoted as Transect A1 (Figure 8 and Table 12).

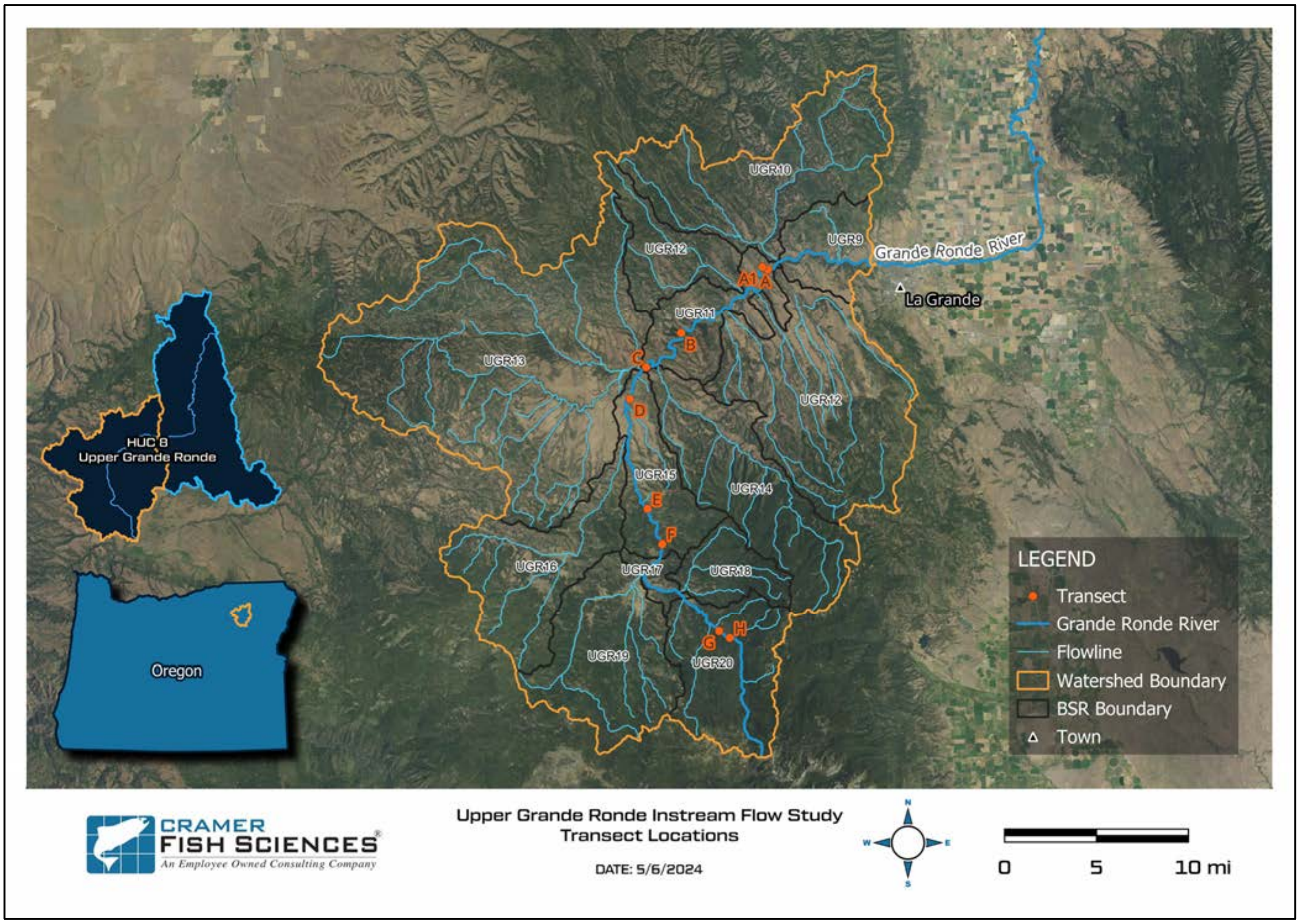


Figure 8 Transect locations for the Upper Grande Ronde IFIM study.

Table 12. Summary of transect properties and characteristics.

Transect	Biologically Significant Region (BSR)	River Mile (RM)	Slope (ft/ft)	Dominant Substrate	Primary Channel Unit Type	Description
A	11	119.2	0.5	Small Cobble	Glide	Head of riffle, rip rap along river right
A1	11	119.6	0.5	Small Cobble	Pool/Run	Mid-channel scour pool from bedrock outcrop
B	11	126.8	0.3	Very Coarse Gravel	Glide/Island	Head if island, inundated during higher flows, dry mid channel during low flows
C	11	130.7	0.6	Small Cobble	Glide	Eddy on river right, gradual transition to lateral bar river left
D[1]	15	132.5	1.5	Very Coarse Gravel	Fast Water/Side Channel	River left main channel with chute tail out to riffle, river right side channel slow water
E	15	138.1	1.5	Small Cobble	Riffle	Head of coarse riffle, pocket water
F	15	140.4	3.0	Large Cobble	Rapid	Rapid with large and variable substrate, complex flow path and velocity
G	20	148.7	0.6	Very Coarse Gravel	Glide	Plane bed channel

Transect	Biologically Significant Region (BSR)	River Mile (RM)	Slope (ft/ft)	Dominant Substrate	Primary Channel Unit Type	Description
H	20	149.4	0.5	Very Coarse Gravel	Riffle	Riffle upstream of vegetated flow split

[1]Transect Low calibration discharge field data was impacted by summer 2023 restoration projection construction (minor).

Figure 9 Photograph of CFS staff taken at Transect G during the Moderate discharge field data collection, showing a flagged tape strung across the transect location.

Depth and velocity measurements were taken across the wetted extent of each transect during each field data collection event. Depth and velocity measurements were collected with a SonTek M9 Acoustic Doppler Current Profiler (ADCP) using the Tethered Boat method described by the USGS (Mueller 2013) for transects that were not wadable during the High calibration discharge event. Measurements were collected with RTK-GPS mounted to the tethered boat to record the position and speed of the craft (Figure 10). A minimum of four passes were completed at each transect where discharge varied by less than 5%. Depth and velocity were recorded at a rate of 1 Hz. For Low and Moderate calibration discharges, as well as High calibration discharge transects where the transect was wadable, a SonTek FlowTracker2 handheld Acoustic Doppler Velocimeter (ADV) was used to collect depth and velocity measurements in accordance with USGS methodology (Turnipseed and Sauer 2010), as shown in Figure 11.

Figure 10 Photograph of CFS staff using the SonTek M9 to record depth, velocity, and discharge at Transect D during High calibration discharge field collection.

Figure 11 Photograph of CFS staff using the FlowTracker2 to record depth, velocity, and discharge at transect F during Low calibration discharge field collection.

During the Low calibration discharge dominant substrate observation were recorded at 1- or 2- foot increments using an RTK-GPS based on gravelometer measurements. The purpose of this field observation collection was a) to collect transect substrate data required in IFIM studies b) to collect observations to calibrate machine learning predictions for substrate mapping. At each measurement increment, a representative grain was sampled within the measurement increment and classified using a gravelometer similar to a Wolman pebble count. However, this measurement focuses on dominant substrate that is of primary concern for habitat suitability studies rather than for developing a grain size distribution.

3.2 Quality Control

CFS adhered to a rigorous quality assurance/quality control protocol for each type of field observation collected. Table 13 details the different types of QA/QC performed for this study.

Table 13. Summary of quality assurance/quality control protocol for each type of field observations collected.

Data Collection Type	Collection Protocol	Field QA/QC	Post-Processing QA/QC
SonTek M9 ADCP	Mueller (2013)	RiverSurveyor LIVE QA/QC	USGS QRev QA/QC
SonTek FlowTracker2 ADV	Turnipseed and Sauer (2010)	Review FlowTracker2 Quality Control parameters after each transect	SonTek FlowTracker2 Desktop Software
Substrate	Internal Protocol	Independent review after each transect	Independent review after each transect
RTK-GPS	NGS (2014), Internal Protocol	Independent review after each transect	OPUS-correction, Internal QA/QC protocol, Trimble Connect QA/QC

4. HABITAT SUITABILITY ANALYSIS

4.1 Instream Flow Incremental Methodology Overview

The methodology for determining instream flow is established by OAR 635-400-0015 and found in the *Oregon Department of Fish and Wildlife Guidelines for Instream Flow* (ODFW 1989). These guidelines require instream flow requirements to be based on one of three following methods: Instream Flow Incremental Method (IFIM), Oregon Method, or Forest Service Method. This study adheres to the IFIM (Bovee et al. 1998, Stalnacker et al. 1995). However, this study also aims to integrate the OWRD *Draft Guidelines: A Tool for Conducting Place-Based Integrated Water Resources Planning in Oregon* (OWRD 2015), which supports the *Oregon Integrated Water Resources Strategy* (adopted 2012, updated 2017).

The IFIM is regarded as the best available science for determining habitat and streamflow relationships. The methodology combines field-based observations with hydraulic modeling to determine habitat suitability based on four parameters: depth, velocity, cover, and/or substrate, depending on species in life stage. The field-based observations are used to calibrate and validate model parameters to extrapolate results over a greater area. The four parameters are all related to a Habitat Suitability Curve (Appendix C) that result in a suitability index (SI) for each parameter, which is combined to create a SI at the scale of the model resolution. The SI can be integrated over the study area to derive a Weighted Usable Area (WUA) for each simulated flow. Then the WUA can be compared over a range of flows to establish recommendations for instream flows.

Equation 1. Equations used to calculate SI, nWUA (normalized Weighted Usable Area), and WUA.

$$SI = (\Pi_i SI_{i,j})^{1/m} \ , \ \ nWUA = \frac{\sum_{i=1}^{p} SI_i A_i}{A_t} \ \ , \ \ WUA = \sum_{i=1}^{p} SI_i A_i$$

Where SI = suitability index, Π_i = weighting factor, SI = the suitability curve value, and A = the area of the cell, for habitat suitability parameters, i. OAR 635-400-0015 also dictates that site-specific studies may be needed to determine flows necessary for flushing of sediment deposits, gravel recruitment, stimulating upstream migration of fish species, maintaining passage for fish migration or other specific requirements. The methodology for recommending optimal peak (channel maintenance) and flushing flows is established based on *Calculating Channel Maintenance and Elevated Flows* (ODFW 2007). The hydrologic and/or fluvial geomorphic analysis method has been selected for the Upper Grande Ronde River. This method allows flows to be established based on recurrence interval analysis of gage streams and/or based on determination of incipient motion.

4.2 Target Species and Life Stages

4.2.1 Life Stage Periodicity

Target species life state periodicity was determined based on results of the *Catherine Creek and Upper Grande Ronde River Atlas* (Atlas Partners 2015), which provided detailed periodicity information separated by BSR (Appendix B). For BSRs 11, 15, 17, and 20 (in the mainstem Upper Grande Ronde River), the following are generally applicable:

Summer Steelhead

- Adult immigration and holding occur between March and May, with spawning between mid-April to mid-May.
- Incubation occurs primarily between April and June, with emergence between May and late June.
- Juvenile rearing occurs throughout the year.
- Juvenile emigration typically occurs between February and May.

Spring Chinook

- Adults immigrate to the system in June, holding throughout June and August.
- Spawning typically occurs in September.
- Incubation occurs from September through February with emergence between March and April.
- Juvenile rearing occurs throughout the year, depending on age class.
- Age 0 juveniles emigrate in October, whereas Age 1 juveniles emigrate between April and May.

4.2.2 Habitat Suitability Curves

Habitat suitability curves (HSC) were selected through consultation with study participants, in comparison to previous and concurrent studies, and professional judgement. The Washington State Department of Fish and Wildlife (WDFW) *Instream Flow Study Guidelines* (Beecher and Caldwell 2022) were determined to be the most applicable and consistent instream flow HSCs and, therefore, were used for this study (hereafter referred to as WDFW/Ecology 2022). Habitat suitability curves developed in Favrot et al. (2018) were also used as a comparison analysis for juvenile Chinook. A summary of HSCs can be found in Appendix C. The methodology for development of HSC input data is covered in Section 4.3 and 4.4.

4.3 Substrate and Cover

Substrate and cover data were developed to cover the study domain in spatial data layers derived from remote sensing products, previous studies, and field validation. Substrate and cover data are then related to HSCs to determine the relative preference of a given substrate or cover type for a species/life stage combination. Table 14 and Table 15 summarize substrate and cover classifications used in this study.

Table 14. Cover code, associated type of cover, and suitability preference (Beecher and Caldwell 2022).

Code	type of cover Note: Cover Codes are not used for spawning	Salmon & Trout Rearing juvenile & resident adult
00.1	undercut bank	1.00
00.2	overhanging vegetation near or touching water[2]	1.00
00.3	rootwad (including partly undercut)	1.00
00.4	log jam/submerged brush pile	1.00
00.5	log(s) parallel to bank	0.80
00.6	aquatic vegetation	0.80
00.7	short (<1') terrestrial grass	0.10
00.8	tall (>3') dense grass[3]	0.70
00.9	vegetation > 3 vertical ft above SZF	0.20

Table 15. Substrate code, associated type of substrate, and suitability preference (Beecher and Caldwell 2022).

Code	type of substrate	Spawning					Salmon & Trout Rearing
		salmon	steelhead[4]	resident trout	native chars[5]	whitefish	juvenile & resident adult
1	silt, clay, or organic	0.00	0.00	0.00	0.00	00	0.10
2	sand	0.00	0.00	0.00	0.00	0.00	0.10
3	sm gravel (.1-.5")	0.30	0.50	0.80	1.00	1.00	0.10
4	med gravel (.5-1.5")	1.00	1.00	1.00	1.00	1.00	0.30
5	lrg gravel (1.5-3")	1.00	1.00	0.80	1.00	1.00	0.30
6	sm cobble (3-6")	1.00	1.00	0.50	0.70	1.00	0.50
7	lrg cobble (6-12")	0.50	0.30	0.00	0.70	0.50	0.70
8	boulder (>12")	0.00	0.00	0.00	0.0	0.0	1.00
9	bedrock	0.00	0.00	0.00	0.00	0.00	0.30

4.3.1 Substrate and Cover Mapping

A spatially continuous map of substrate was developed for the study domain by leveraging remote sensing data, hydraulic model results, and field validation. This study utilized a random forest (RF) model to classify substrate type (median grain size) using regression trees. For predictors, we relied on several metrics as described in Table 16, each of which was calculated using the same raster creating a "stack" of predictor variables for each cell that we then used to predict the location's substrate size. For training data, we had substrate measured in the field at 474 points across nine transects.

Modeling was completed in R (R core team 2024) using the Random Forest package (Liaw and Wiener 2002). We used 1,000 trees per model (nTree=1,000) and allowed each iteration to select nine predictors (mtry=9) with all other parameters set to defaults. A square root transformation was applied to the training data to help create more linear relationships, and then the final predictions were back transformed (squared) before final output. The variable importance plot from the Random Forest model (Figure 12) highlighted four predictors that made larger impacts than the others: Velocity, Slope, topographical roughness index (TRI) and Velocity_l. The final model was able to explain about 57% of the overall variance observed in the training data (Figure 13).

Table 16. Parameters used in substrate modeling.

Input Layer	Description
Aspect	Aspect of the 2021 bare earth DEM. Values range from 0 to 360 that express the slope direction, starting from North (0) and continuing clockwise.
Slope	Slope of the 2021 bare earth DEM. Values represent the angle of inclination of the terrain and are expressed in degrees.

TRI	Ruggedness index of the 2021 bare earth DEM. Values represent the quantitative measurement of terrain heterogeneity described by Riley et al. (1999). Each pixel contains the difference in elevation between it and the eight surrounding cells.
Intensity_Green	The peak power ratio of the green laser return to the emitted laser, calculated as a function of surface reflectivity. Represented by a value between 1-256
Intensity_NIR	The peak power ratio of the NIR laser return to the emitted laser, calculated as a function of surface reflectivity. Represented by a value between 1-256
REM_Wide	Elevation value relative to the elevation of the Grande Ronde River thalweg. Values are represented in meters. Radial projection of thalweg elevation using quartic kernels was interpolated and used to detrend the 2021 bare earth DEM.
DistancetoBank	Distance between a cell and the bank of the Grande Ronde River. The bank was represented by the 2021 bathymetric coverage layer. Values are represented in meters.
WettedExtent_Proximity	Distance between a cell and a wetted portion of the Grande Ronde River. The wetted area was represented by the 2021 bathymetric coverage layer. Values are represented in meters.
WSE	Output from the hydraulic model. Water surface elevation at 3266cfs. Values are represented in feet.
WSE_Slope	Slope of the water surface elevation at 3266cfs. Values represent the angle of inclination of the water surface and are expressed in degrees.
Depth	Output from the hydraulic model. Depth at 3266cfs. Values are represented in feet.
Velocity	Output from the hydraulic model. Velocity at 3266cfs. Values are represented in feet per second.
ShearStress	Output from the hydraulic model. Shear Stress at 3266cfs. Values are represented in pounds per square foot.
Froude	Output from the hydraulic model. Froude at 3266cfs. A value less than one indicates subcritical flow and a value greater than one indicates supercritical flow relative to a hydraulic model.
WSE_l	Output from the hydraulic model. Water surface elevation at 2750 cfs. Values are represented in feet.
WSE_Slope_l	Slope of the water surface elevation at 2750cfs. Values represent the angle of inclination of the water surface and are expressed in degrees.
Depth_l	Output from the hydraulic model. Depth at 2750 cfs. Values are represented in feet.
Velocity_l	Output from the hydraulic model. Velocity at 2750 cfs. Values are represented in feet per second.
ShearStress_l	Output from the hydraulic model. Shear Stress at 2750 cfs. Values are represented in pounds per square foot.
Froude_l	Output from the hydraulic model. Froude at 2750 cfs. A value less than one indicates subcritical flow and a value greater than one indicates supercritical flow relative to a hydraulic model.

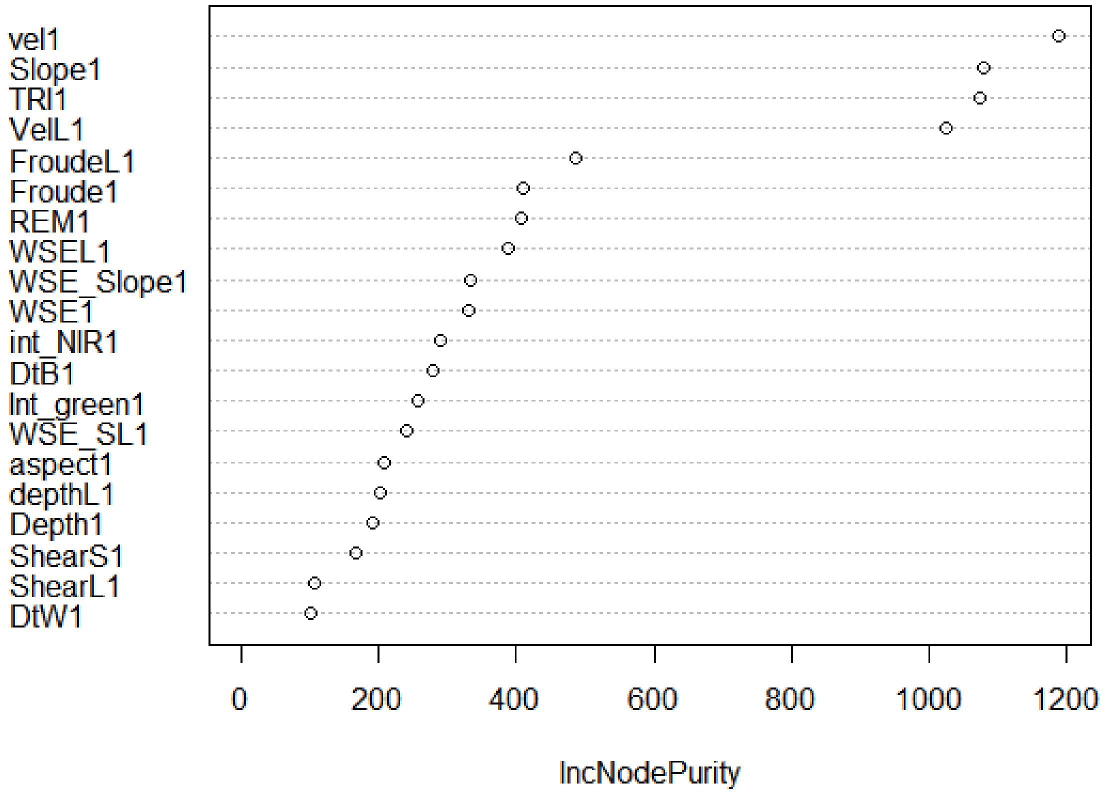


Figure 12. Variable importance plot from Random Forest model used to predict substrate.

The substrate model was validated by comparing results to pebble counts collected within the study area. Pebble count data used for the validation included 148 main stem Grande Ronde measurements recently compiled by W2r (2022), as well as the nine transect substrate data collected for this study. Predicted substrate size was compiled by generating 100 random points within the main channel in the vicinity of the pebble count, followed by averaging the data and computing the D_{16}, D_{50}, and D_{84}. Results were then compared to the pebble count data (Figure 13). In general, the substrate model fell between the D_{50} and D_{84}, which is intuitively appropriate for the intent of this model. Since the objective of the model is to predict dominant substrate size, a prediction between the D_{50} and D_{84} is likely to be a good representation of the dominant substrate by area. These results resemble previously published studies such as Ren et al. 2020.

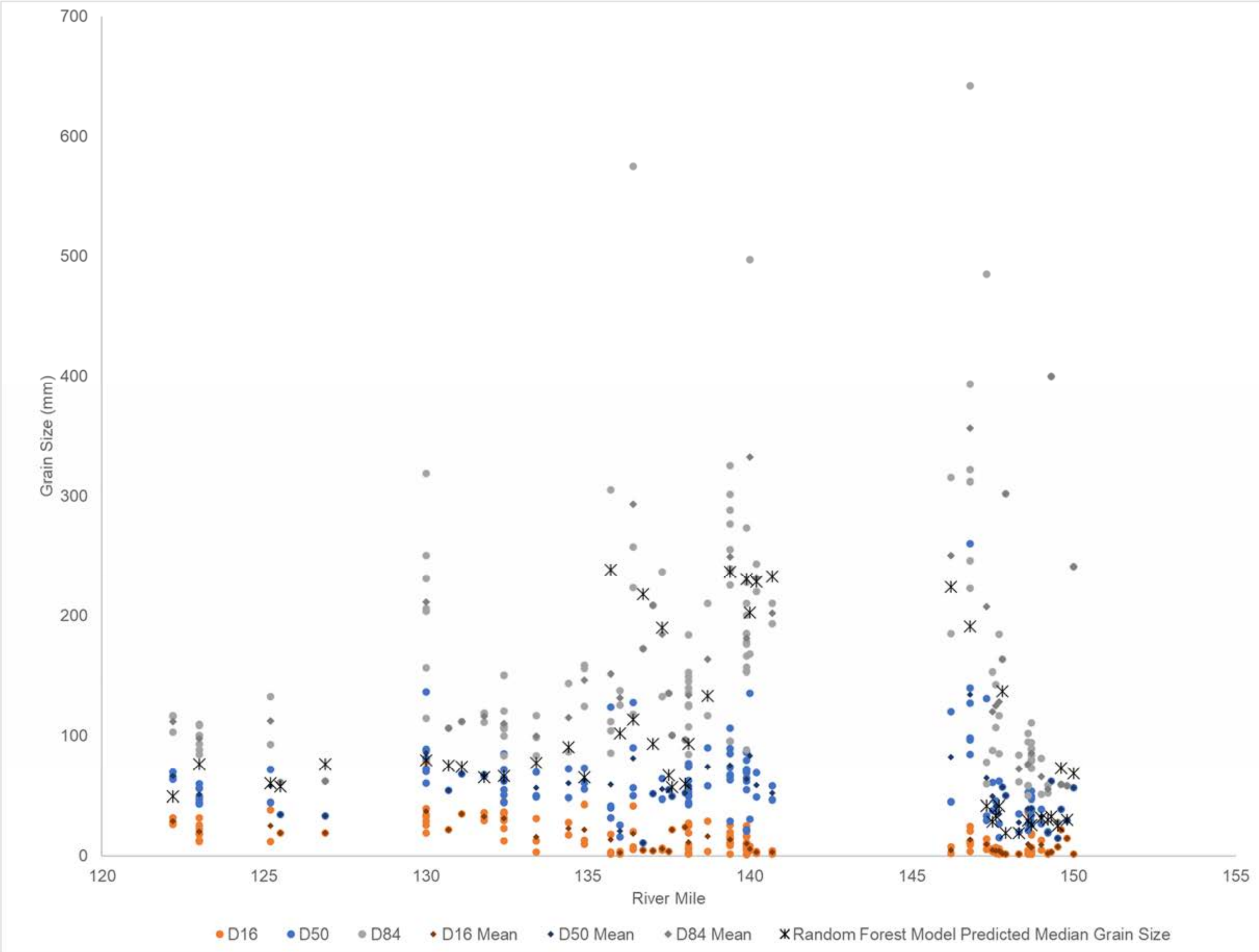


Figure 13. Comparison between pebble count D_{16}, D_{50}, and D_{84} and the predicted median grain size from the random forest model.

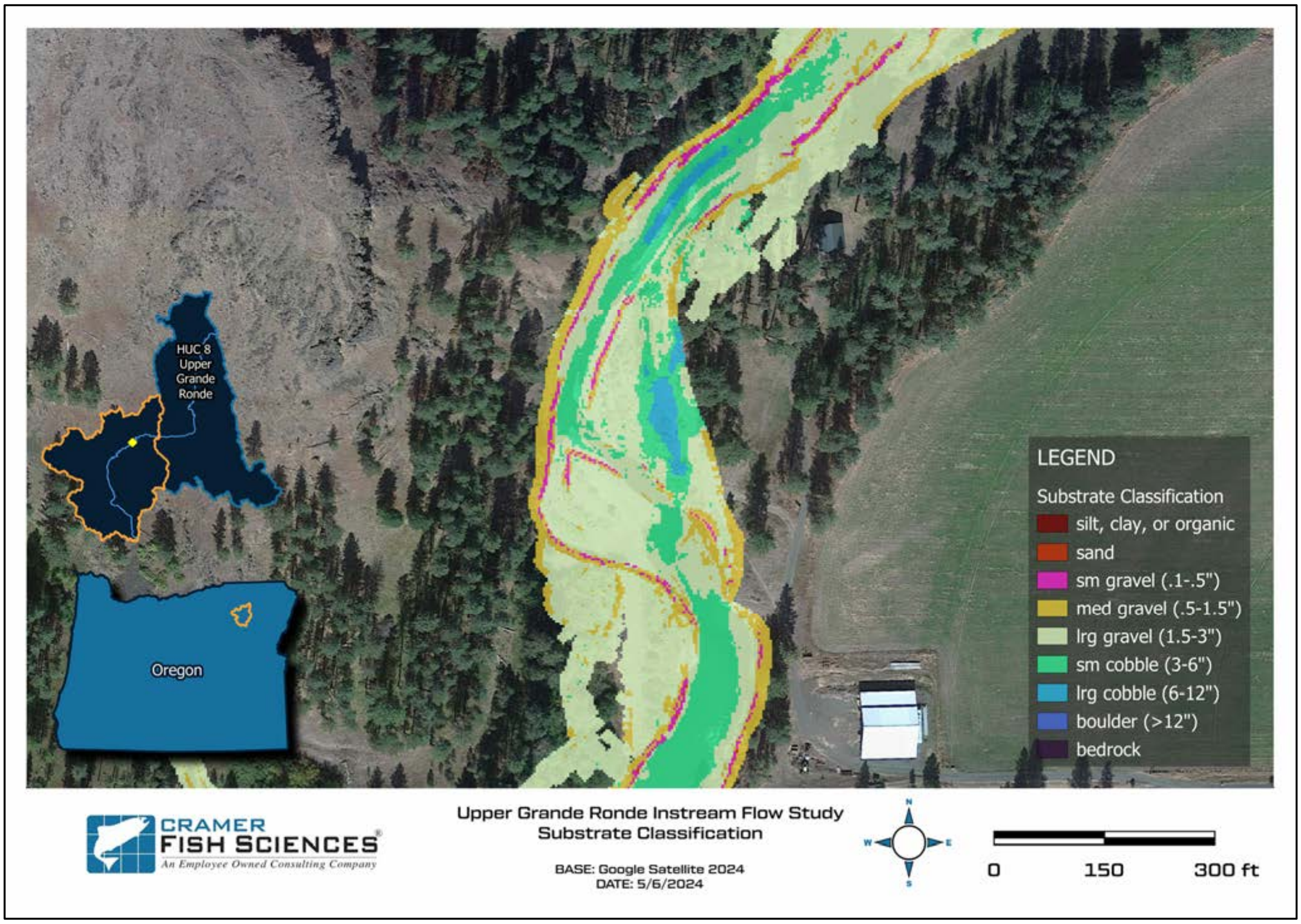


Figure 14. Example of substrate classification results in the Upper Grande Ronde River.

A spatially continuous map of cover was developed for the study domain utilizing remote sensing data products, existing data sources, and field validation. In general, the 2021 LiDAR (NV5 2021) highest hit and bare earth digital elevation model (DEM) were used to create a canopy height map at 1 meter resolution. The canopy height map was then statistically divided into natural breaks (jenks) to determine areas with similar characteristics. These areas were then related to cover classifications based on the CRITFC Riparian Mapping layer (CRITFC 2016) and predominant vegetation (Class IV) classifications. This approach was used to delineate the no cover, overhanging vegetation, short and tall grasses, and vegetation three feet above stage zero flow (SZF). Undercut banks were delineated using the slope derivative of the bare earth DEM, specifying a cutoff of 33 degrees slope angle. Undercut bank areas were then QA/QC'd using visual comparison to high resolution aerial imagery. Rootwads, log jams, and parallel logs were delineated using habitat survey data, which recorded the number of key pieces and non-key pieces in each survey segment. The number of wood pieces was then randomly distributed within the bankfull inundation boundary and buffered to represent the size and diameter of a key or non-key piece, such that number of wood pieces in a reach was equivalent to the surveyed value. Since rootwad, log jams, and parallel log preference values are the same, all types were classified together. Aquatic vegetation was not included in this study because it varies seasonally and annually in the Upper Grande Ronde River, meaning attribution of aquatic vegetation could skew results.

Table 17 Cover code, classification, data source, and methodology.

Code	Type of Cover	Primary Data Source	Methodology
00.0	no cover	2021 LiDAR (NV5 2021)	Includes roads, open gravel bars, unvegetated areas with < 0.25' of canopy height.
00.1	overhanging vegetation[1]	2021 LiDAR (NV5 2021)	Includes vegetation overhanging the bankfull inundation extent and less than 3 feet above SZF
00.2	undercut bank	2021 LiDAR (NV5 2021)	Bare earth DEM slope greater than 33 degrees
00.3	rootwad	Habitat Surveys[4]	Surveyed number of key and non-key pieces randomly spatially distributed within the bankfull inundation boundary
00.4	log jam/ submerged brush	Habitat Surveys[4]	Same method as above
00.5	log(s) parallel to bank	Habitat Surveys[4]	Same method as above
00.6	aquatic vegetation	N/A	Not included in study
00.7	short (<1 foot) terrestrial grass	2021 LiDAR (NV5 2021)	Includes short terrestrial grasses with canopy height between 0.25 and 1 foot
00.8	tall (>3 feet) dense grass[2]	2021 LiDAR (NV5 2021)	Includes areas with canopy height greater than 3 feet and appropriate riparian mapping classification
00.9	vegetation >3 feet above SZF[3]	2021 LiDAR (NV5 2021)	Includes areas with canopy height greater than 3 feet and appropriate riparian mapping classification

[1]This includes low tree branches (<3 vertical feet above water surface elevation at stage of zero flow (SZF)) and bushes overhanging the bankfull water's edge.
[2]This category refers to stout, almost busy type grasses such as reed canary grass up to the bankfull water's edge.
[3]Stage of zero flow (SZF).
[4]Including ODFW, Bureau of Reclamation, CRITFC, and USFS aquatic habitat surveys, provided by the Grande Ronde Model Watershed.

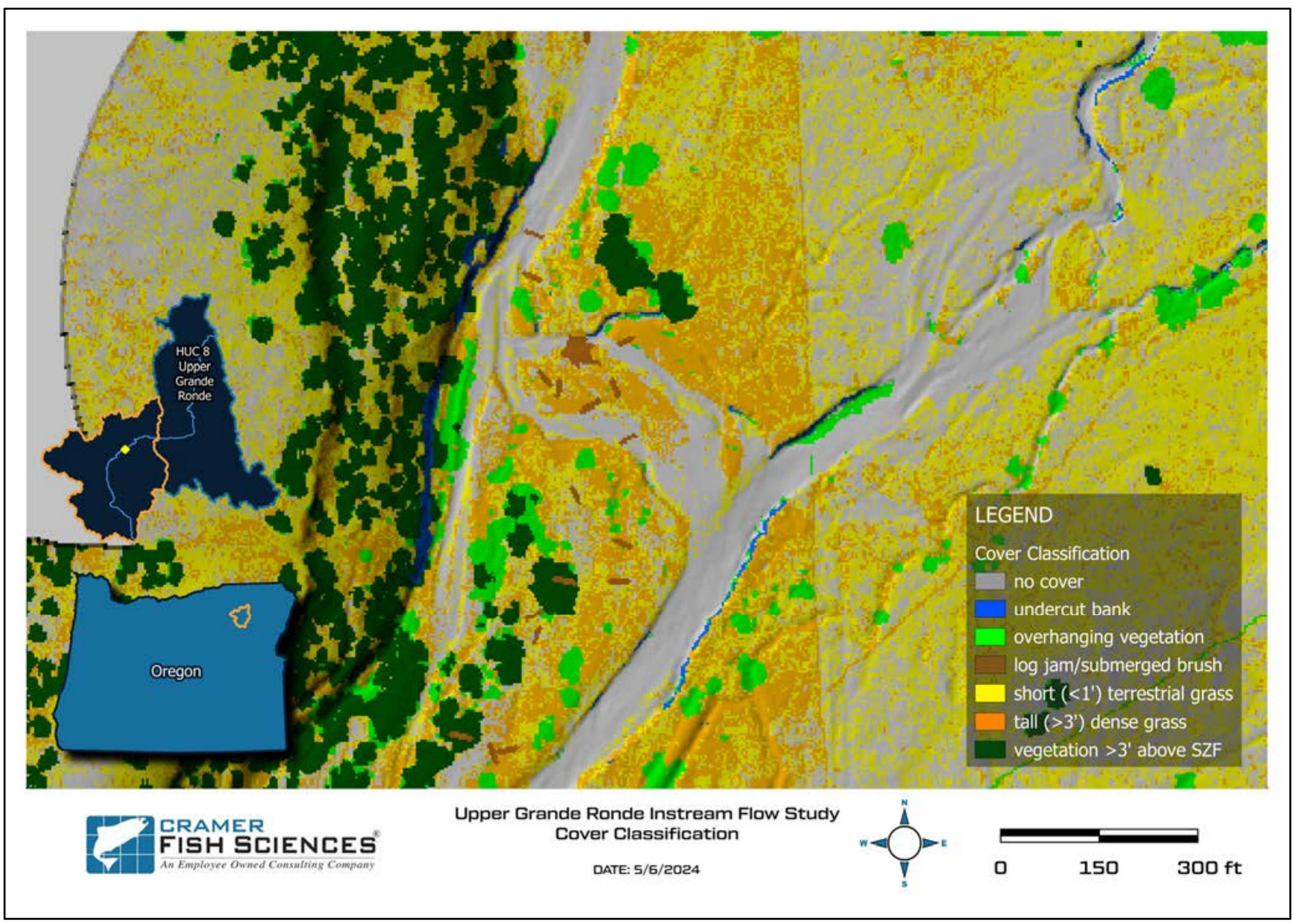


Figure 15. Example of cover classification results in the Upper Grande Ronde River.

4.4 Hydraulic Model

Hydraulic modeling was performed using the 2-D option within the USACE Hydrologic Engineering Center River Analysis System (HEC-RAS) Version 6.4 (USACE 2023) software. The model solves the Saint-Venants Equations at model mesh elements for depth-averaged hydraulic properties, such as depth, velocity, and shear stress. Depth and velocity simulation results are used directly to represent depth and velocity in the habitat suitability analysis. HEC-RAS The following section includes documentation regarding model inputs, development, and calibration.

4.4.1 Topography

Topobathymetric LiDAR (Light Detection and Ranging) was flown between August 17 and September 27, 2020, (NV5 2021), which provided a near-continuous topographic representation of both submerged and unsubmerged terrain at 3 feet resolution. The Void-Interpolated Topobathymetric Bare Earth DEM was used to represent the terrain within the model. LiDAR data was reprojected to the project coordinate reference system: Lambert Conic Conformal, North American Datum 1983 (ft), horizontal datum, and NAVD88 (Geoid18), International feet, vertical datum, as required by OAR 125-600-7550.

4.4.2 Boundary Conditions and Domain

The HEC-RAS 2-D model extends longitudinally from the downstream end of the study area at the OWRD gage near Perry, OR (13318960), to the confluence with the east fork of the Grande Ronde River. The model extends laterally from valley wall to valley wall, spanning beyond the 100-year recurrence interval flood extents. The model also extends upstream from tributary junctions, either to the end of LiDAR availability or to the end of backwater extent.

Model boundary conditions are locations where flows either enter or exit the model domain. The boundary condition at the downstream end of the model is determined by conditions observed at the OWRD gage near Perry, OR, for calibration events and normal depth calculations for model simulations. The boundary condition for all inflow tributaries is flow hydrographs, with values derived from results of the hydrologic analysis (Section 2). For each simulation, the model processed until steady state conditions were achieved throughout the model domain. This was verified by checking the water surface elevation and flow at the downstream end of the model were stable (change of less than 0.001 ft and 0.01 cfs) for a period of no less than two hours.

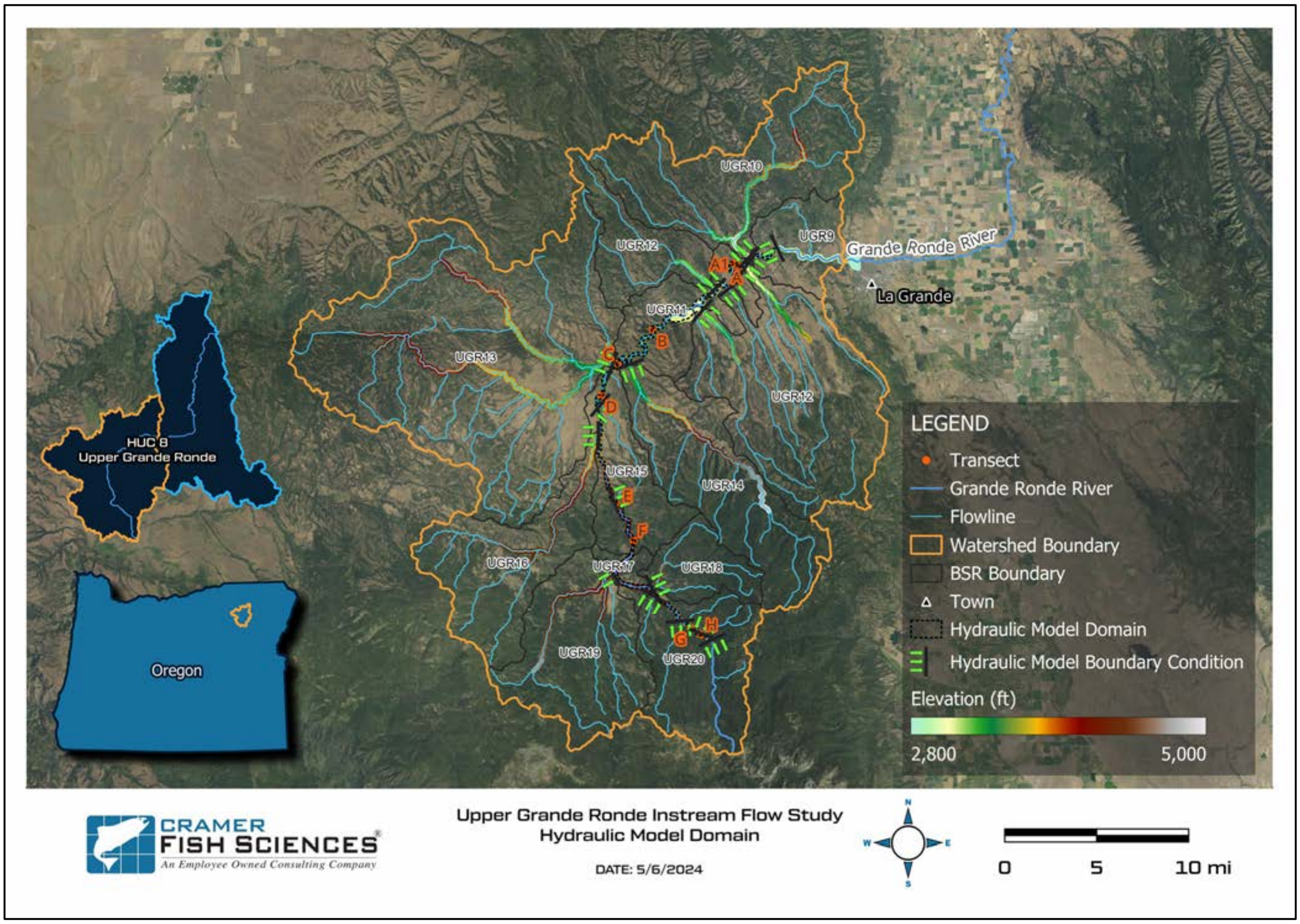


Figure 16. Hydraulic model domain and boundary conditions.

4.4.3 Model Geometry

The HEC-RAS 2-D model is comprised of variable size mesh elements that represent topographic and hydraulic roughness information used in the solution equation. The size of the mesh elements represents the frequency of computational nodes that, when interpolated between, spatially represent simulation results. Smaller mesh cell size allows for increased resolution of changes in hydraulic parameters but requires a shorter time step and results in a longer run time. Therefore, selecting an appropriate mesh cell size is important for the model's accuracy and usability. The model mesh should adequately represent the topographic surface, as well as accurately describe changes in water surface slope and velocity. The appropriate mesh cell size is also determined based on the Courant number, ideally keeping the value below 1.0.

The selected model geometry is comprised of 15-foot mesh cells in the floodplain and overbank area and 6-foot mesh cells in the main channel and side channels. This model geometry allowed for average Courant number below the allowable threshold, reasonable run times, and adequate resolution of terrain features, as well as water surface elevation and velocity characteristics. Because the resolution of the topography is one meter, further decreasing mesh cell size would be met by input data resolution limitations. Main channel cells were oriented longitudinally to the direction of flow, as possible. The resulting model mesh is comprised of 1.14 million cells.

Model geometry also includes hydraulic roughness information. Hydraulic roughness is the representation of the amount of friction experienced by water flowing over a surface and is typically represented by the Manning's roughness coefficient (Manning's n). For the UGR 2-D hydraulic model hydraulic roughness was spatially delineated over the study area based on results from Section 4.3. The substrate and cover map layers were merged so the dominant roughness characteristic was preferred. For example, in areas with an overlapping coverage of sand/silt/organics for substrate and tall vegetation for cover would prefer tall vegetation, as this is the dominant hydraulic roughness constituent.

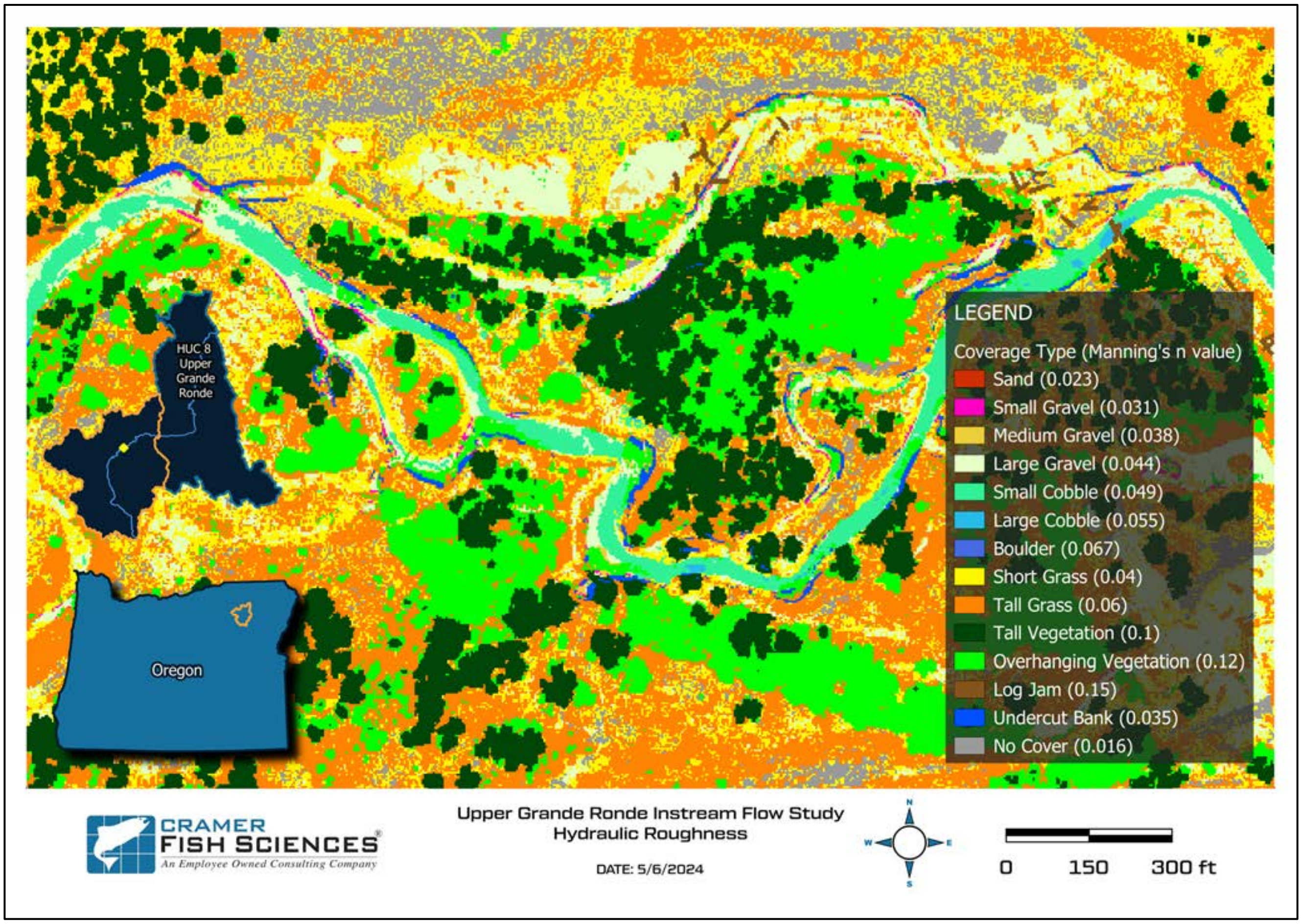


Figure 17. Example of the hydraulic roughness spatial coverage.

A hydraulic roughness (Manning's n) value was then applied to each coverage type. The value is primarily derived from literature values (USACE 2023) but was modified based on results from model calibration (Section 4.3.5). Initial substrate roughness values were determined based on the USFS National Stream and Aquatic Ecology Center Stream Channel Flow Resistance Coefficient Computation Tool (Version 1.1, 2-2018; Yochum 2018), as well as literature equations (Meyer-Peter and Mueller 1948, Limerinos 1970, Hey et al. 1979, Jarrett 1983, Bathurst 1985, Ferguson 2007, and Rickenman and Recking 2011). Values for large woody material were estimated based on previous work by Addy and Wilkinson (2019). The final calibrated Manning's n values for each coverage type are shown in Table 18.

Table 18. Summary of Manning's n hydraulic roughness coefficient for each hydraulic roughness coverage type.

Coverage Type	Manning's n value
No Cover	0.016
Silt, Clay, Organic	0.023
Sand	0.023
Small Gravel	0.031
Medium Gravel	0.038
Large Gravel	0.044
Small Cobble	0.049
Large Cobble	0.055
Boulder	0.067
Undercut Bank	0.035
Overhanging Vegetation	0.120
Rootwad/Log Jam/Parallel Log	0.150
Short Terrestrial Grass	0.040
Tall Terrestrial Grass	0.060

Model control parameters, including solution equation, time step, turbulence model, solution weighting factor (Theta), solver tolerances, and solver iterations, were determined based on best practices for the intended model use of in addition to the model geometry configuration. The Shallow Water Equation for performing 2-D unsteady flow routing was selected to include the momentum component and improve detailed representation of velocity values. The resulting time step required to keep Courant numbers within an acceptable range was two seconds. Additional turbulence modeling was not included because it wasn't beneficial during model calibration and decreased model stability. Theta, solver iterations, and solver tolerances were maintained at default values.

Table 19. Selected model control parameters for the Upper Grande Ronde 2-D hydraulic model.

Parameter	Value
Solution Equation	Shallow Water Equation – Eulerian Method
Time Step	1-2 Seconds
Turbulence Model	None
Theta	1.0
Water Surface Tolerance (ft)	0.01
Volume Tolerance (ft^3)	0.01
Solver Iterations	20

4.4.4 Calibration

Hydraulic model calibration is a critical step to determine confidence in simulated hydraulic properties. The calibration process involves iteratively adjusting model parameters to match observations closely while preserving hydraulic modeling best practices and available science. The calibration process is repeated until model calibration metrics are met, the point of diminishing returns is achieved, and/or simulated accuracy is approximately equal to the resolution and accuracy of the input data. The following section details the calibration objectives.

The first calibration objective is to meet calibration metrics, which were established based on previous benchmarks from Pasternack (2011) and are summarized below:

- Depth and velocity R^2 between 0.4 and 0.8.
- Depth and velocity mean and median percent error less than 30%.
- Slope of linear regression line for depth and velocity greater than 0.9.
- Zero intercept of linear regression line for depth and velocity less than 5% of max value.
- Depth and velocity error histogram equally distributed around zero.

These calibration metrics represent the best available science for hydraulic model calibration specific to instream flow studies and have been used successfully on previous projects (Seattle City Light 2023, Seattle City Light 2023a, and Wright et al. 2016). However, calibration metrics must be achievable given the resolution, accuracy, and precision of the input and observation data. Input and observation data relevant to setting the threshold for model calibration are listed below:

- Accuracy of LiDAR topobathymetric data (NV5 2021): The submerged median difference between LiDAR and check point was -0.08 feet with a 95% confidence interval of 0.32 feet (n = 779). The median error for wetted edge points was -0.003 feet with a confidence interval of 0.27 feet (n = 200). Average 95% confidence interval for relevant points is 0.31 feet.
- Temporal accuracy of LiDAR surface: Observed calibration data was acquired in 2023, but the LiDAR was flown in 2020. Natural topobathymetric change in the Grande Ronde River is expected to occur. The mean error for all surveyed elevation points compared to the 2021 LiDAR was 0.11 feet and 0.09 feet assessed at the 95% confidence interval. However, detected change varied by transect (Table 20).

Table 20. Summary of mean error between LiDAR (2021) and RTK surveyed elevation at each transect.

Transect	Mean Error [ft]
A	0.00
A1	-0.14
B	-0.02
C	0.33
D1	0.23
D2	0.04
E	0.23
F	-0.01
G	0.23
H	0.04

- Accuracy of velocity measurements: Velocity measurements of either collection method represent depth-averaged conditions of velocity, which varies over time due to turbulence. Examining the standard deviation of velocity measurements indicates the degree of variability from the measurements. The average standard deviation of velocity measurements is 0.13 ft/s, with a maximum of 1.36 ft/s. Standard deviation is as reported by instrument used to collect the data.

The above elements represent an upper threshold for model calibration, which is limited by the resolution, accuracy, and precision of input and observation data. In summary, calibration to depth with accuracy beyond a mean error of 0.10 ft and calibration to velocity to greater accuracy than a mean error of 0.13 ft/s is unlikely to be achievable due to resolution, accuracy, and precision of inputs and observed data. These thresholds represent average condition, transects with greater topobathymetric change are likely to have further decreased accuracy thresholds.

4.4.5 Results

The hydraulic model was iteratively calibrated based on performance relative to selected metrics to optimize model results. Model iteration included changes to parameters such as hydraulic roughness, solution equation, time step, model geometry, and others. The performance metrics were tracked to identify the point of diminishing returns. Table 21 and Figure 18 through Figure 21 demonstrate the calibration metrics of the selected model configuration. In general, the calibration to depth observations performed better than velocity, which is consistent with previous studies. Additionally, calibration to higher discharge events typically performed better than lower discharge values, which is due to both inherent model factors and data collection factors. During low flow conditions the proportion of interstitial flow increases, which is not resolved by the model. Additionally, velocity measurements are more likely to be influenced by substrate that is smaller than the resolution of the topobathymetric data. As flow is diverted around individual substrate the complex flow pattern, eddies, and turbulence impact measurement quality. In summary, calibration to depth and velocity observations met calibration criteria in most cases for R^2, percent bias, and histogram distribution. Additionally, calibration objectives were met for depth but not velocity for linear regression slope and y-intercept. Given the input data limitations and intent of the project, this calibration performance was determined to be acceptable.

Table 21. Summary of mean error between LiDAR (2021) and RTK surveyed elevation at each transect.

	Velocity					Depth					
Discharge	**R^2**	**Slope**	**y-Intercept (ft/s)**	**Mean Error (ft/s)**	**Percent Bias (%)**	**R^2**	**Slope**	**y-Intercept (ft)**	**Mean Error (ft)**	**Percent Bias (%)**	**Number of Obs.**
Low	0.31	0.44	1.10	0.18	35.3	0.69	0.86	-0.06	-0.13	-27.6	342
Moderate	0.39	0.57	0.41	0.25	21.9	0.53	0.88	0.04	-0.05	-6.9	345
High	0.40	0.53	0.78	-0.14	-6.5	0.69	1.01	0.13	0.15	11.4	454
Combined	**0.57**	**0.58**	**0.65**	**0.07**	**5.2**	**0.78**	**1.10**	**-0.09**	**0.00**	**0.2**	**1141**

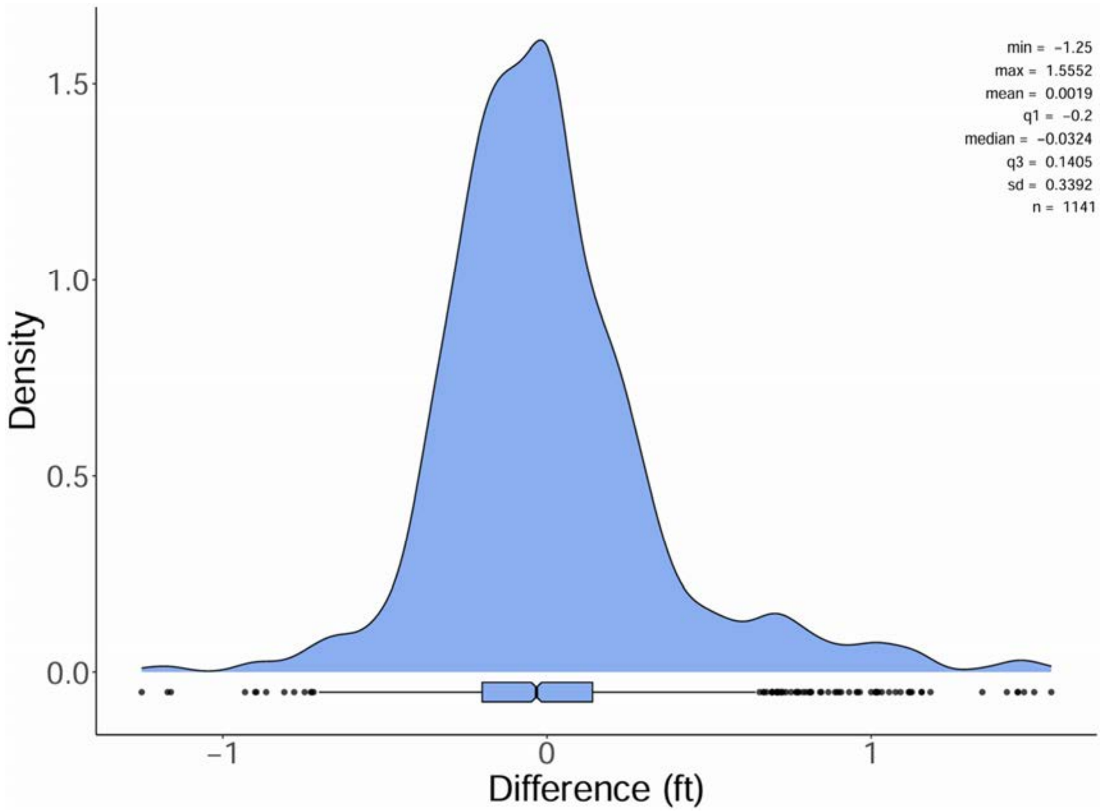


Figure 18. Density plot of depth residual for all three calibration discharges.

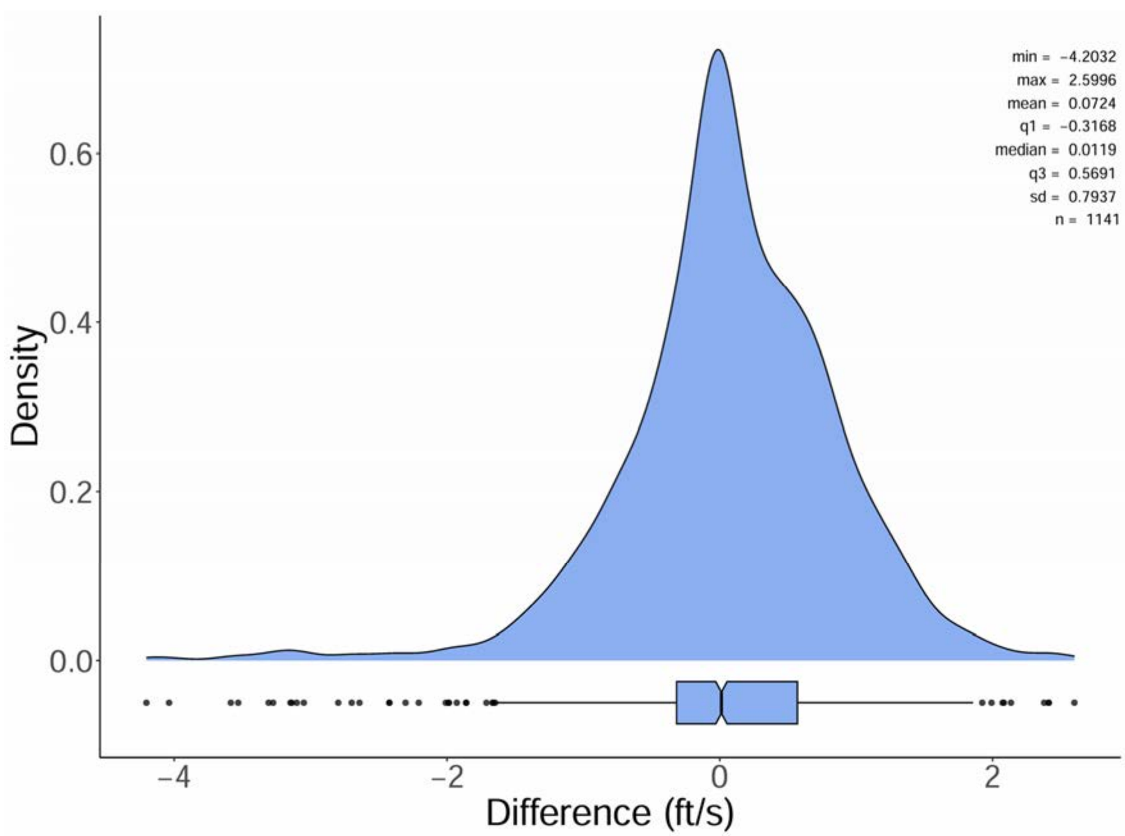


Figure 19. Density plot of velocity residual for all three calibration discharges.

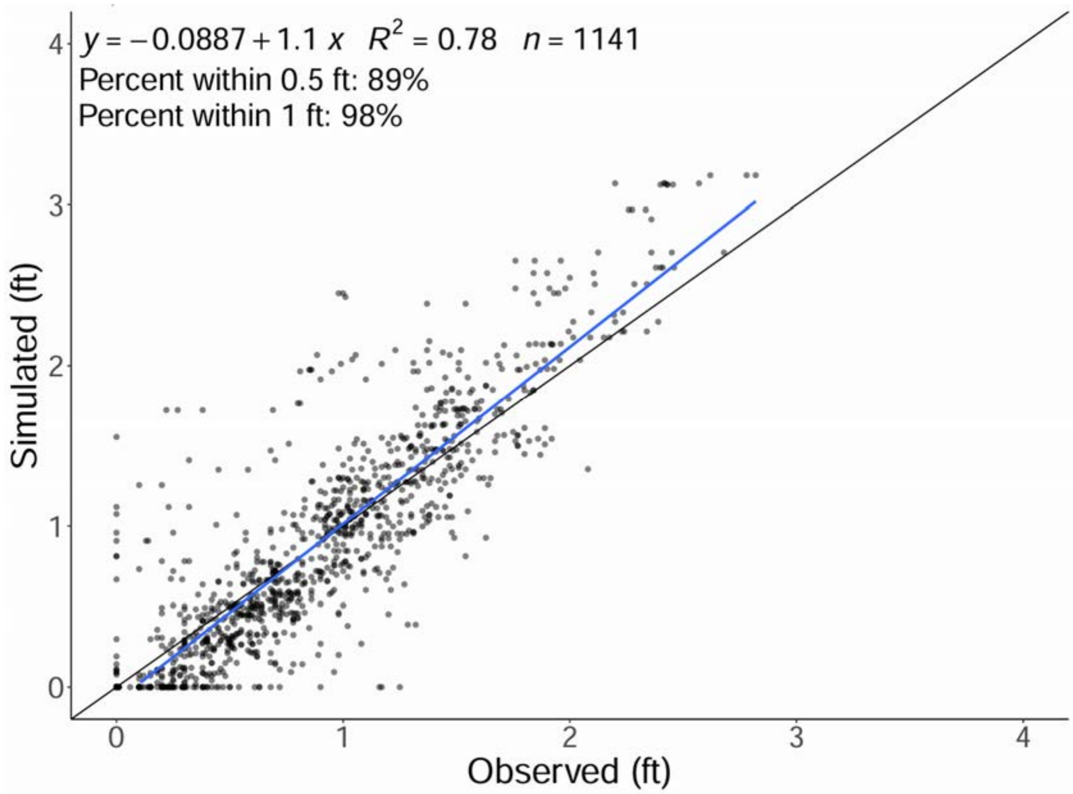


Figure 20. Linear regression plot comparing observed and simulated depth for all three calibration discharges.

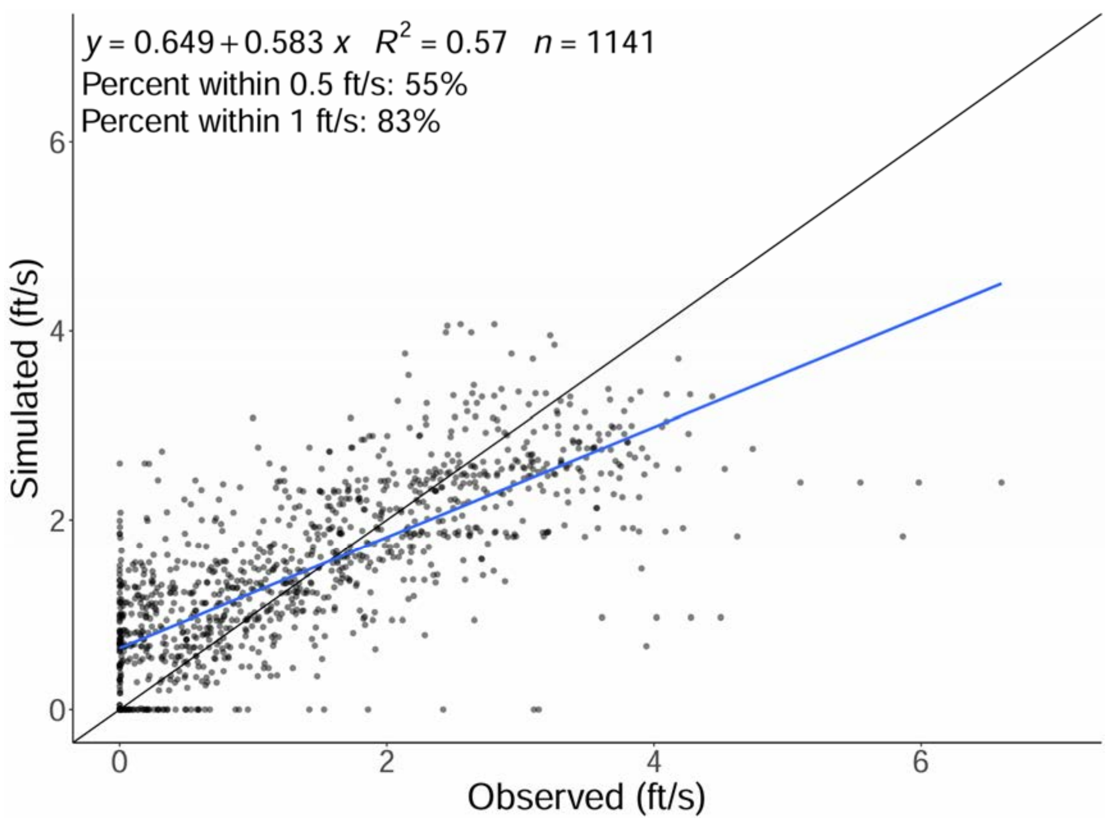


Figure 21. Linear regression plot comparing observed and simulated velocity for all three calibration discharges.

4.4.6 Limitations

Hydraulic modeling performed for the Upper Grande Ronde River follows the best available science, but assumptions and limitations still apply to both hydraulic models generally and the Upper Grande Ronde model specifically. The following includes some primary assumptions and limitations relevant to this project:

- HEC-RAS 2D utilizes and assumes a rigid bed during model simulations (i.e. the bed does not deform under flow conditions). This assumption is not always appropriate for high flow conditions, as sediment transport, erosion, and deposition occur in natural systems.
- HEC-RAS 2D presents hydraulic properties based on a solution of the Shallow Water equations that assumes depth-averaged conditions; therefore, this model carries the limitations and assumptions inherent to a depth-averaged solution.
- LiDAR flown in 2020 was used as the model terrain and to derive model parameters; therefore, the hydraulic model closely resembles conditions at the time of LiDAR acquisition. Rivers are inherently dynamic and change over time, so the intended uses and required resolution of hydraulic model outputs need to consider input resolution and time of acquisition. The hydraulic conditions in this study should be considered a representation of a system in dynamic equilibrium rather than an explicitly accurate representation at each location.
- The Upper Grande Ronde River system's hydrologic analysis relies on the quantity of existing data and best available science to represent conditions at the time of this study. The gage record on the Upper Grande Ronde River was leveraged to the extent possible; however, gage distribution, period of record, and completeness limit the confidence and applicability of hydrologic results, especially considering the degree of nonstationary observed in the gage record.
- The HEC-RAS 2D model input does not include temporally varied parameters such as vegetation condition, ice condition, large wood location, aquatic vegetation, and others. These assumptions are required due to data availability and model utility, however temporally varied factors may impact model results.

4.5 Habitat Suitability Index Analysis

Habitat suitability curves, periodicity, hydraulic model outputs, and substrate and cover mapping information were integrated to provide a detailed analysis of the quality, quantity, timing, and spatial location of suitable habitat under a range of flow conditions for all species and life stages of interest through the habitat suitability index analysis (background described in Section 4.1). The result of the habitat suitability index analysis is to produce flow-habitat relationships for each species and life stage. This habitat suitability index (HSI) analysis provides additional data relative to a typical IFIM assessment, including continuous spatial mapping of suitability indices. The flow-habitat relationship can then be used to inform water management decisions, such as determining instream flow.

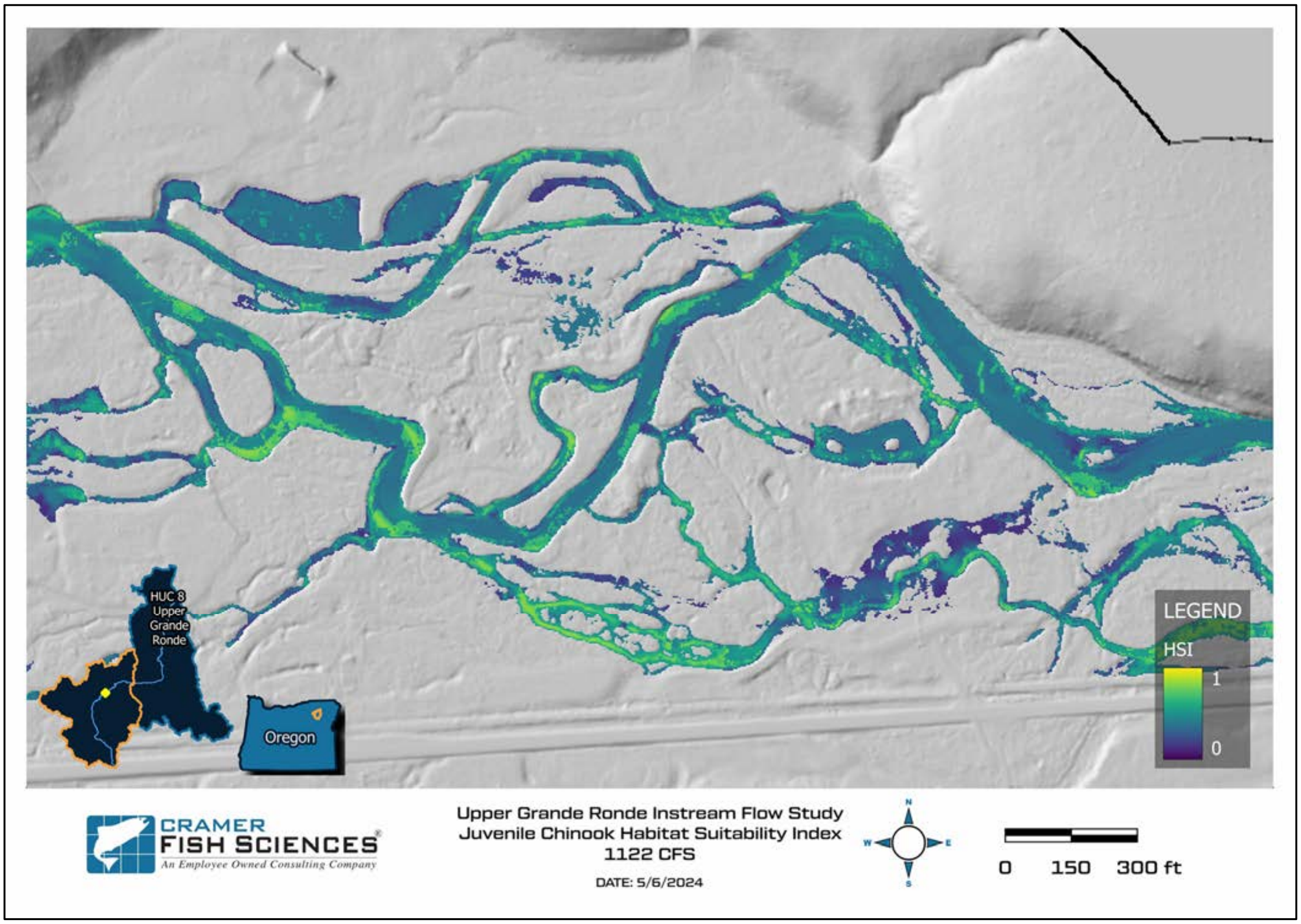


Figure 22. Example of the HSI results for juvenile Chinook at 1122 CFS.

The habitat suitability analysis was performed each flow, species, and life stage, by calculating the suitability for an individual parameter based on the applicable habitat suitability curve for each cell of the habitat suitability model (3.28084 feet x 3.28084 feet). Parameters always included depth and velocity results from the hydraulic model, as well as substrate and/or cover depending on the applicability to the life stage. Additionally, hydraulic habitat suitability (HHSI) was calculated for each flow-species-life stage combination, which only included depth and velocity parameters (Figure 23). Once HSI was calculated for each parameter, a composite HSI was calculated that combined all relevant parameters to that species-life stage combination, using the methodology specified in the *Washington State Instream Flow Study Guidelines* (Beecher and Caldwell 2022). The summation of the composite HSI value over the BSR provides a weighted useable area (WUA), which can be normalized by area to produce nWUA (normalized WUA). All calculations were completed using RStudio (R Core Team, 2024).

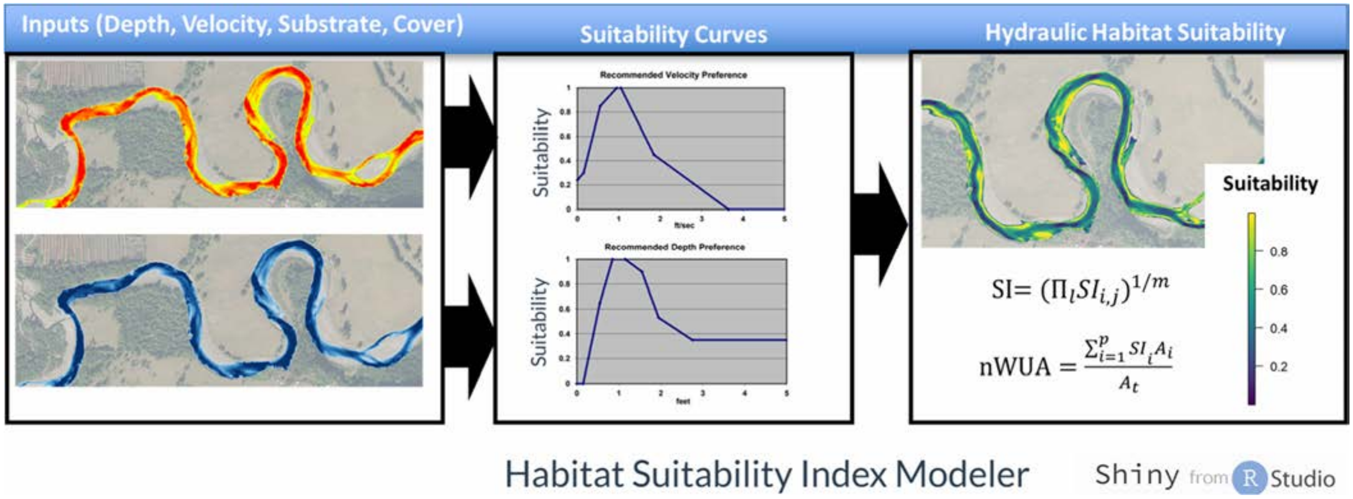


Figure 23. Example schematic depicting the habitat suitability index analysis procedure.

After the HSI was calculated at each flow for each species-life stage combination, the results could be plotted and tabulated relative to flow, which produces a flow-habitat relationship that can be used to relate habitat quality/quantity product to flow and flow duration.

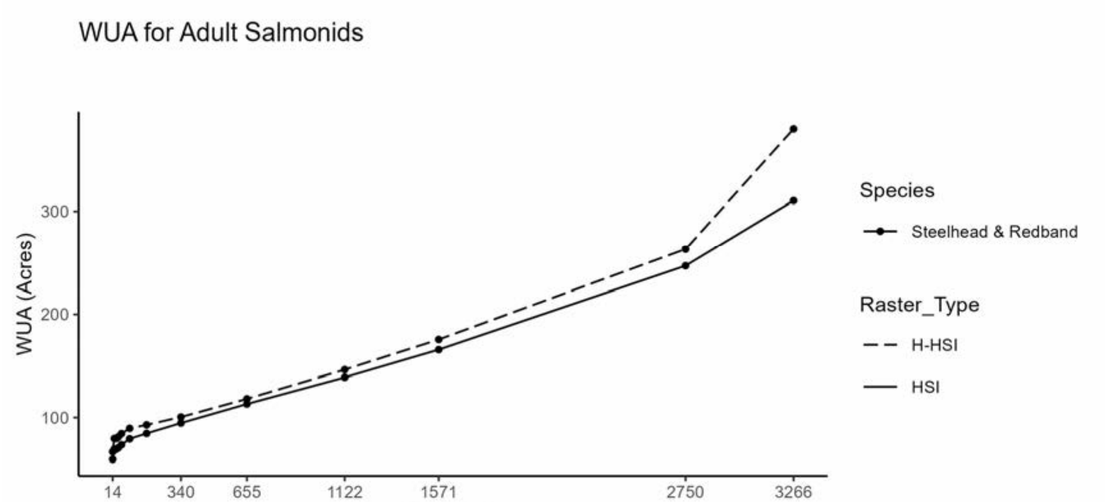
5. RESULTS AND DISCUSSION

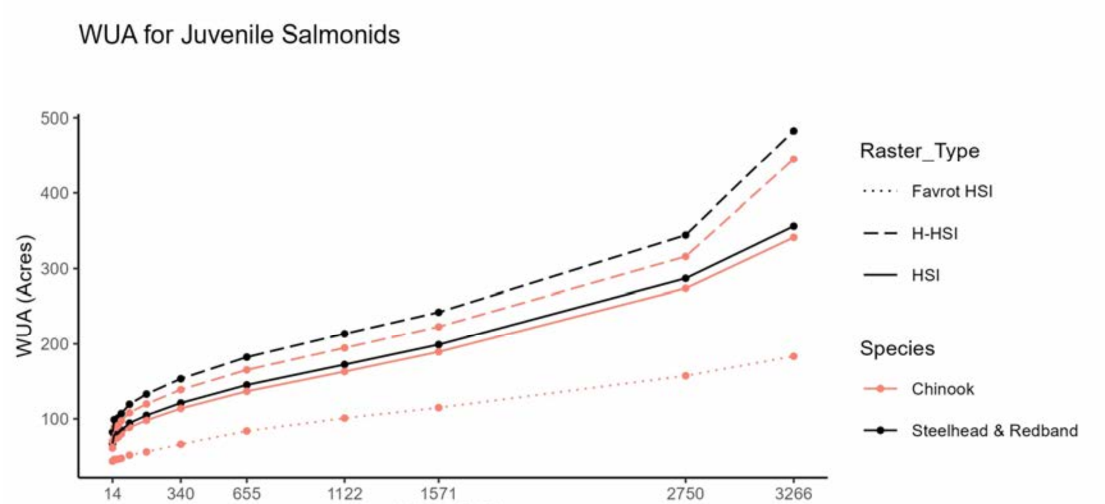
5.1 Instream Flow Targets

Instream (also known as by-pass) flows are both types of minimum flows that are based on the habitat requirements of species life stage requirements. ODFW currently recommends (ODFW 2007, ODFW 2023 using the agency's instream rules (OAR 635-400; last modified in 1989) for determining instream flows dictate that instream water right application amounts must be based on habitat criteria. This is typically done using the Instream Flow Incremental Method, which has been followed for this study. The results of the instream flow habitat suitability analysis include both tabular and graphical outputs that include habitat-flow relationships to help guide water resources managers in adopting target flows (Figure 24 and Table 22).

In general, all species-life stage habitat WUA rises with increasing flow, typically at an exponential rate during lower flows (99%-50%), reaching a linear relationship during moderate flows (50% - 10%), and with a break in rate of change for the high flows (1% and 2-year). This relationship indicates the critical importance of flows below 50% flow duration for all species-life stage combinations. Additionally, for adult and juvenile salmonids, WUA continues to increase with flow, indicating a high relative importance of moderate and high flows. For spawning, the WUA reaches a local maximum around the 30% flow duration. These flows are uncommon during the spawning window for Chinook but are likely critical to steelhead. The curve is also steepest for spawning, which represents the importance of maintaining instream flows for spawning.

Typically, hydraulic habitat suitability (H-HSI) only considers the depth and velocity components of HSI track similarly to the total HSI with slightly lower WUA values. This corroborates that the cover and substrate components of the HSI calculations are relatively appropriate. Additionally, the Favrot et al. (2018) curves follow a similar pattern to the WDFW (2022) curves, providing additional corroboration for the study.





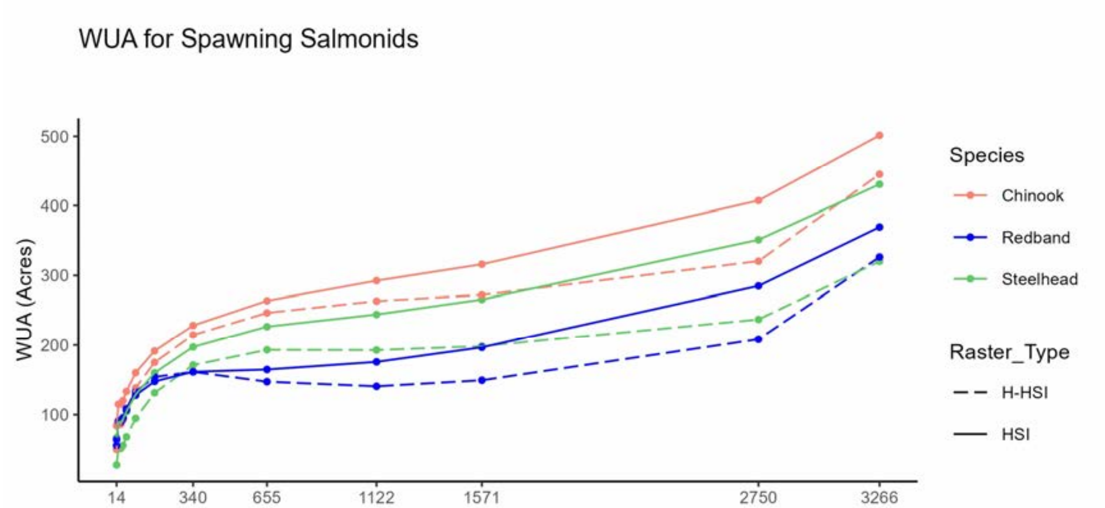


Figure 24. Weighted usable area (WUA) compared to flow for all species-life stage combinations. HSI indicates habitat suitability, H-HSI indicates only hydraulic properties (depth and velocity) habitat suitability.

Table 22. Summary of flow-habitat relationship for all species-life stage combinations for the study area.

Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
3266	2-Year	341.49	501.44	356.41	430.66	310.41	369.37
2750	1%	273.65	407.3	287.04	351.12	247.14	284.96
1571	5%	189.39	316.01	199.00	265.61	165.83	196.67
1122	10%	163.05	292.53	172.42	244.09	138.98	175.72
655	20%	136.69	263.78	145.17	226.52	113.16	164.79
340	30%	113.84	228.20	121.07	197.24	94.66	161.50
176	40%	98.08	191.53	104.62	160.08	84.60	147.68
95	50%	88.64	160.24	94.28	128.79	79.36	127.84
56	60%	79.99	133.27	84.88	104.48	73.57	106.68
41	70%	75.71	120.14	80.68	93.59	70.68	95.68
32	80%	73.96	115.11	79.02	89.62	69.44	91.36
22	90%	67.56	99.63	73.17	78.40	64.50	77.87
14	99%	61.17	84.16	67.33	67.17	59.57	64.39

[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

Because the flow-habitat relationship results in increasing habitat with flow in all cases, the periodicity data for spawning and juvenile Chinook and steelhead was combined with flow duration data from stream gages to produce an annual hydrograph for the WUA by species-life stage combination (Figure 25), with complete data included in Appendix D. This type of analysis allows for examining the overlap between habitat use and availability. For example, Chinook spawning habitat availability does not coincide well with use, as the flow and WUA are low during spawning.

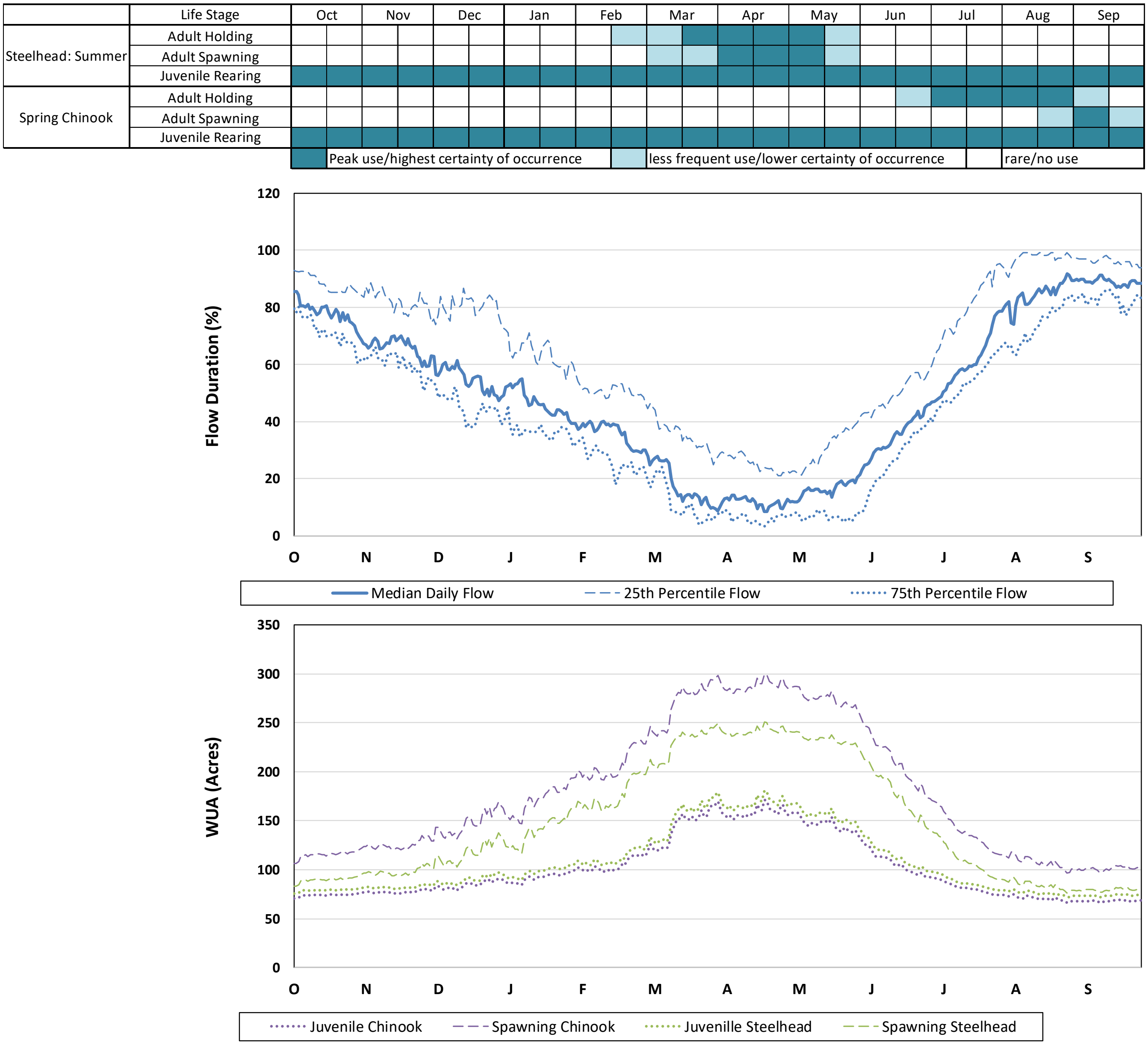


Figure 25. Annual hydrograph with WUA and flow duration for each species-life stage combination assessed at the Grande Ronde River near Perry, OR gage.

5.2 Peak and Flushing Flow Targets

The *Calculating Channel maintenance/elevated Instream Flows when evaluating Water Right Applications for out of stream and storage water rights* report (ODFW 2007) documents the policy basis, guidance, and technical methodology for calculating elevated flows. Allowance for stream discharge to maintain channel form and habitat is alluded to in several places in Oregon statutes and rules. For instance, “Public Use” under ORS 537.332 (5)(b) includes, “Conservation, maintenance and enhancement of aquatic and fish life, wildlife, fish and wildlife habitat and any other ecological values.” (underlined for emphasis) High flows are explicitly allowed in Water Resource Department rules in approving instream water rights even though they are higher than the mean estimated natural flow in OAR 690-077-0015 (4).

The purpose of elevated stream flows is to provide flow conditions conducive to maintaining stream morphology, physical habitat features, and riparian succession. Elevated stream flows may serve multiple purposes including (ODFW 2007):

- Transport and deposition of streambed gravels.
- “Cleaning” gravels by entraining fine sediment to improve spawning habitat and food sources.
- Scouring channels, which provides a source for streambed material and large wood.
- Formation of channel morphologic units such as pools and riffles.
- Transport of riparian vegetation seeds as well as organic material to support succession.
- Transport and deposition of large wood.

Nomenclature for elevated stream flows varies depending on the reference. For this study, a crosswalk was developed between ODFW (2007) and OWRD (2023). Peak flows, also called optimum peak flows (OWRD 2023), elevated flows (ODFW 2007), channel forming flows (Beecher and Caldwell 2022), or habitat-forming flows represent a larger, less frequent flow event that are critical to fluvial geomorphic processes. Flushing flow targets, also referred to as annual peak flushing or channel maintenance (ODFW 2007 and Beecher and Caldwell 2022), represent relatively smaller, more common flows that improve the quality of gravel by transporting fine sediment and organic material. It should be noted that Beecher et al. includes differentiates between flushing flows, channel maintenance flows, and channel forming flows. This study does not include channel forming flows as they are not consistent with the OWRD (2023) requirements.

The methodology for determining both peak and flushing flow targets requires determination of primary channel type, based on sediment characteristics. Table 23 documents average channel type based on sediment characteristics for each BSR, separating each reach into either sand bed, gravel bed, or course bed, which determine the relevant methodology for target flow analysis based on pebble count data. Each BSR will use the gravel bed methodology for elevated target flow analysis; however, UGR 17 contains relatively few pebble counts and therefore has a higher uncertainty.

Table 23. Summary of sediment properties for applicable Biologically Significant Reaches (BSRs).

HUC Reach Name (BSR)	River Mile Start	River Mile End	Average D_{50} (mm)	Channel Type
Coleman Ridge (UGR11)	118.55	130.95	49	Gravel Bed
Warm Spring Creek (UGR15)	130.95	141.00	59	Gravel Bed
Sheep Creek (UGR17)	141.00	145.85	64	Gravel Bed
Meadowbrook Creek (UGR20)	145.85	149.40	49	Gravel Bed

5.2.1 Peak Flow Targets

For estimating the peak flow target, methodology from ODFW (2007), OWRD (2023), and Beecher and Caldwell (2022) were used to extract recommended recurrence interval flows from the flood frequency analysis in Section 2. An estimate for the peak flow target depends on local biological, geological, and hydrological factors that can result in a range of recommended target flows, especially when considering the inter-reach geomorphic variability. Therefore, a best estimate and upper limit were provided for each BSR. The best estimate correlates to the recommended bankfull flow based for interior streams (Castro and Jackson, 2001), which would be considered the effective discharge for most of the reach. The effective discharge represents the flow at which the largest fraction of bed material is transported and is a critical flow for channel morphology and sediment processes that over approximates the channel-forming discharge. In more coarse-grained reaches, the two-year or 10-year recurrence interval flow may be required to initiate sediment transport and contribute to morphological and habitat development.

Table 24. Summary of peak flow targets for applicable Biologically Significant Reaches (BSRs), rounded to the nearest ten cfs.

			Peak Flow Target Method		
HUC Reach Name (BSR)	River Mile Start	River Mile End	Best Estimate 1.5-year Recurrence Interval[1] (cfs)	2-year Recurrence Interval[2] (cfs)	Upper Limit 10-year Recurrence Interval[2] (cfs)
Coleman Ridge (UGR11)	118.55	130.95	2,320	2,870	5,500
Warm Spring Creek (UGR15)	130.95	141.00	980	1,210	2,320
Sheep Creek (UGR17)	141.00	145.85	690	840	1,615
Meadowbrook Creek (UGR20)	145.85	149.40	280	340	660

[1] Castro and Jackson 2001
[2] Beecher and Caldwell 2022, ODWF 2007, OWRD 2023

5.2.2 Flushing Flow Targets

For estimating the flushing flow target, methodology from ODFW (2007), OWRD (2023), and Beecher and Caldwell (2022) were used to determine recommended flows. Recommendations for the flushing flow target include: 80% of bankfull flow (ODFW 2007), initiation of gravel movement (OWRD 2023), and mean annual flow (Beecher and Caldwell 2022). All methods are attempting to approximate this goal using different levels of data availability.

Table 25. Summary of flushing flow targets for applicable Biologically Significant Reaches (BSRs).

			Flushing Flow Target Method			
HUC Reach Name (BSR)	River Mile Start	River Mile End	80% of Bankfull Flow (cfs)[1]	Initiation of Gravel Movement[2] (cfs)	Mean Annual Discharge[3] (cfs)	1.01-year Recurrence Interval[3] (cfs)
Coleman Ridge (UGR11)	118.55	130.95	1,860	976	83	976
Warm Spring Creek (UGR15)	130.95	141.00	780	408	39	408
Sheep Creek (UGR17)	141.00	145.85	550	21	27	21
Meadowbrook Creek (UGR20)	145.85	149.40	220	114	15	114

[1] ODFW 2007
[2] OWRD 2023
[3] Beecher and Caldwell 2022

Due to high variability between potential flushing flows, the preferred methodology was validated through comparing hydraulic model shear stress outputs with sediment incipient motion thresholds to determine the mobile size class. This approach allows a practical relation to be drawn between the physical/biological intention of flushing flows based on sediment size. Model results indicate that the 1.01-year recurrence interval flow (approximately like the 10% flow duration) will mobilize sediment that is smaller than the D_{50} for all reaches. This indicates that flow is appropriate for flushing or cleaning fines and organic material from the substrate. Additionally, the peak/channel-forming flows were checked using the same method. Shear stress results indicate that the 1.5-year recurrence interval flow (approximately like the 1% flow duration) is appropriate to move the D_{50} for most reaches. However, UGR 17 may require a higher flow to mobilize most sediment in steeper and more coarse reaches. It should be noted that this study is not intended as a sediment transport model, and simplifying assumptions have been made that may significantly impact the results of sediment incipient motion predictions, including armoring, hiding, and vertical variability in sediment size. Furthermore, no subsurface particle size distributions data was collected.

Table 26. Summary of average particle size distribution and simulated shear stress for applicable Biologically Significant Reaches (BSRs).

HUC Reach Name (BSR)	Mean D_{16} (mm)	Mean D_{50} (mm)	Mean D_{84} (mm)	1.01-yr Shear Stress (lb/ft^2)	1.5-yr Shear Stress (lb/ft^2)	1.01-yr Mobile Sediment Size (mm) and Class	1.5-yr Mobile Sediment Size (mm) and Class
Coleman Ridge (UGR11)	21	49	94	0.59	0.97	32-64 (Coarse Gravel)	32-64 (Coarse Gravel)
Warm Spring Creek (UGR15)	10	59	166	0.88	1.22	32-64 (Coarse Gravel)	64-128 (Small Cobble)
Sheep Creek (UGR17)	4	64	228	0.41	0.62	16-32 (Medium Gravel)	32-64 (Coarse Gravel)
Meadowbrook Creek (UGR20)	7	49	155	0.76	1.37	32-32 (Coarse Gravel)	64-128 (Small Cobble)

In summary, the following recommendations for peak and flushing flows are below:

- A target peak flow equal to the 1.5-year recurrence interval is recommended for each BSR. The duration of the peak target flow should be approximately 1% duration and occur within the spring freshet months. Sub-reaches particularly within UGR 17 and UGR 20 may require higher flows, up to the 10-year recurrence interval.
- A target flushing flow equal to the 1.01-year recurrence interval is recommended for each BSR. The duration of the peak flushing flow should be approximately 10% duration and occur during the spring freshet months. Sub-reaches particularly within UGR 17 and UGR 20 may require higher flows, up to the 1.5-year recurrence interval.

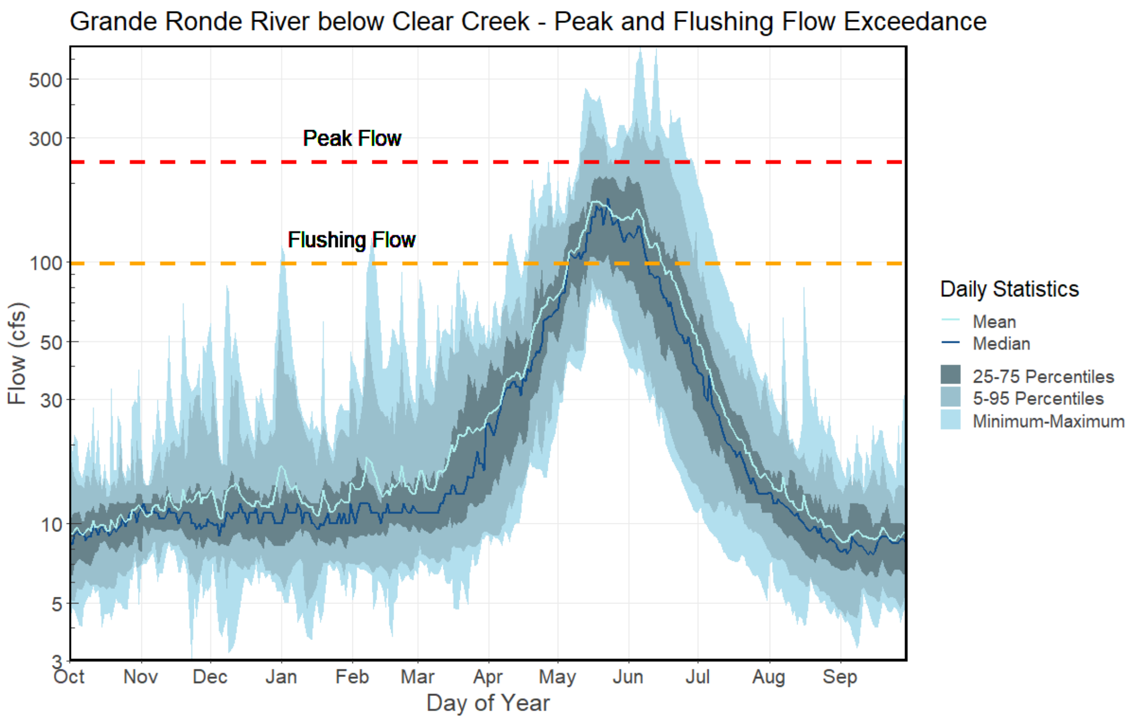


Figure 26. Mean annual hydrograph at the Grande Ronde River below Clear Creek, including target peak and flushing flow targets.

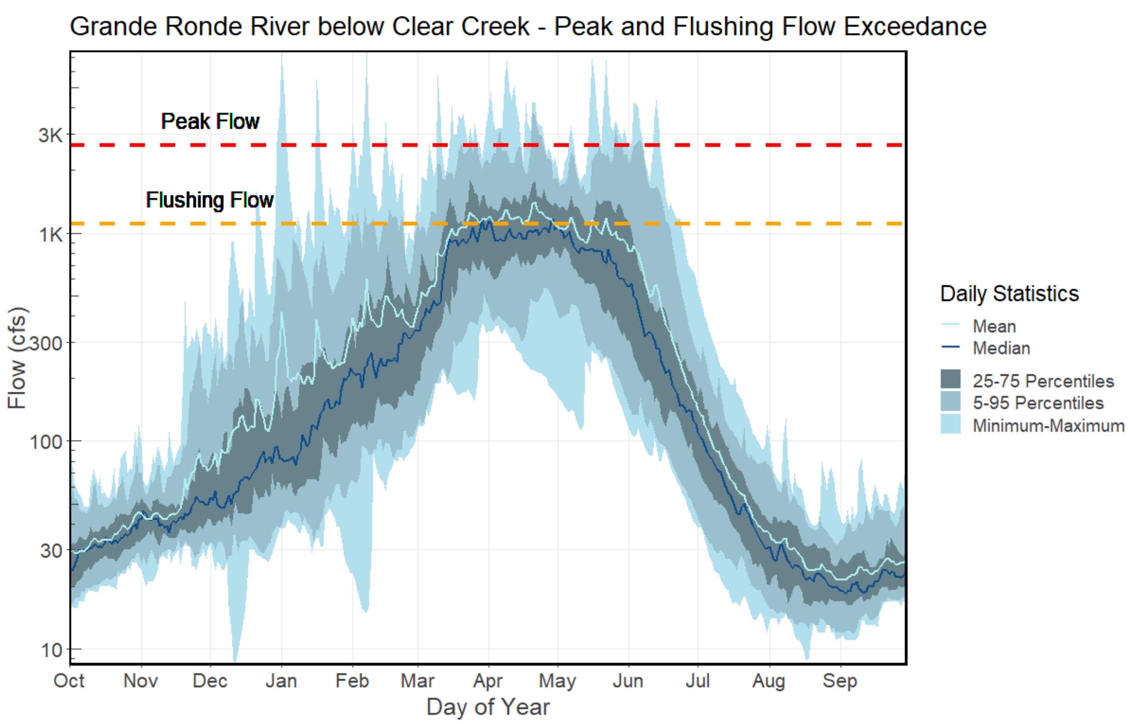


Figure 27 Mean annual hydrograph at the Grande Ronde River at Perry, including target peak and flushing flow targets.

5.3 Limitations and Recommendations for Next Steps

5.3.1 Limitations

In addition to the limitations documented in Section 4 regarding the hydraulic model, there are limitations specific to the instream, peak, and flushing flow targets including:

- LiDAR acquired in 2020 was leveraged to create many of the instream flow datasets, including the substrate and cover layers. Therefore, substrate and cover represent a snapshot in time that corresponds to a potential state of dynamic equilibrium. Substrate and cover vary both seasonally and over longer periods of time, which is not currently represented in the habitat model.
- The LiDAR acquired in 2020 is at one meter by one meter resolution. This may be sufficient to represent spawning habitat used by adults, it likely is less adequate for representing habitat used by juveniles.
- Though the hydraulic model has been calibrated to the target flows, the habitat suitability results have not been evaluated for accuracy. This could be accomplished through bioverification with an Electivity Index, similar to Kammel et al. (2016).
- Physical factors outside of depth, velocity, substrate, and cover can often be limiting for salmonids. Integrating known limiting factors such as temperature, dissolved oxygen, and hyporheic exchange or groundwater/surface water interaction could improve accuracy of habitat suitability.
- Biological factors outside of the typical instream flow parameters may often be the limiting factor for salmonids including competition, predation, metabolism, and food availability. It is important to consider these factors when interpreting HSI results.
- ODFW current guidance for determining instream flow is currently still in development. Technical methodological recommendations are being refined during this study; it is possible that methods will need to be updated. The *ODFW Guidance for Determining Instream Flow Needs* (2022) states:

  > *"In 2015, the Oregon Water Resources Department (WRD) developed Draft Guidelines: A Tool for Conducting Place-Based Integrated Water Resources Planning in Oregon to direct the state's pilot program to advance place-based integrated water resources planning. The guidelines were drafted to ensure that the planning process supported Oregon's Integrated Water Resources Strategy (IWRS; adopted 2012, updated 2017), which serves as a blueprint for meeting the state's instream and out of stream water needs, now and in the future. The IWRS recognized that better understanding instream needs was a Critical Issue and directed the Oregon Department of Fish and Wildlife (ODFW) to determine flows to support instream needs (Action 3A). ODFW began ramping up efforts in 2016 to fulfill the directive, in parallel with the pilot place-based planning process, and our approach to instream flow methodologies has continued to advance as we learn more and refine techniques."*

5.3.2 Recommendations for Next Steps

The results of this study are primarily intended to be used by natural resource managers including water planning, biologists, geomorphologists, ecologists, and engineers to develop instream flow recommendations for water rights applications, water resources planning, and instream flow restoration. This collaborative process balances the needs of the community and the natural flow availability with the needs of aquatic organisms presented in this study to arrive at practical recommendations. The results from this study may also be used to inform habitat restoration actions, biological and ecological studies, and water resources management. Below is a list of potential additional components that could be used to extend the application of this study or refine the results.

Category	Recommended Actions
Improve accuracy/ resolution	• **LiDAR resampling:** Resampling the existing 2020 LiDAR to a high resolution would provide immediate an immediate improvement in the resolution of depth, velocity, substrate, and cover layers. • **Bioverification:** Utilizing electivity index similar to Kammel et al. (2016) to quantify the accuracy of habitat suitability predictions based on fish observations. • **Habitat Suitability Curve Sensitivity:** Utilize additional HSCs to perform sensitivity analyses and best match observed data (for example HSCs in development for the Lostine River). • **Substrate model refinement:** The RF model used to generate the substrate layer includes calibration data primary from within the main channel, collection of additional calibration data in the floodplain could improve accuracy and resolution of predictions in the floodplain. • **Cover:** Integration of seasonally varied cover parameters could improve the estimates of juvenile rearing habitat suitability, including ice as well as vegetation.
Additional habitat parameters	• **Additional life stage resolution:** This study focused on the adult, juvenile, and spawning life stages, however, life stage habitat requirements are known to vary seasonally and diurnally. Additional resolution could examine fry rearing habitat, winter vs. summer rearing, and adult holding for the species without known curves. • **Temperature:** Temperature is known to be a limiting factor for both adult spawning and juvenile rearing in the Grande Ronde River (Justice et al. 2017). Integration of temporally and spatially varied temperature modeling and/or data is likely to improve habitat suitability predictions. • **Hydraulic Conductivity:** Locations with groundwater upwelling and downwelling are significant to spawning adult fish, there are multiple methods to integrate hyporheic exchange to improve habitat suitability predictions. • **Bioenergetics:** Integrating bioenergetic parameters or the development of a bioenergetic model could improve holistic understanding of aquatic organism processes. • **Egg-to-fry survival**: Currently this life stage is underrepresented in the habitat suitability model. Existing results combined with field observations could estimate impacts from fine sediment, redd scour, and other parameters that affect survival.
Additional applications/ analyses	• **Habitat Connectivity:** Although habitat suitability resolution is adequate for some species/life stages, habitat patch size and connectivity are important factors in suitable habitat use. • **Fish Passage:** This model may be leveraged to assess potential passage issues, especially when integrated with a temperature model. • **Climate Change:** This analysis examines flow conditions based on the current gage record, however climate models could be applied to the observed hydrology to predict potential future flow conditions and evaluate impacts. • **Additional species:** The data generated in this study could be used to evaluate habitat suitability of additional aquatic organisms, most notably bull trout, mountain whitefish, freshwater mussels, and Pacific lamprey.

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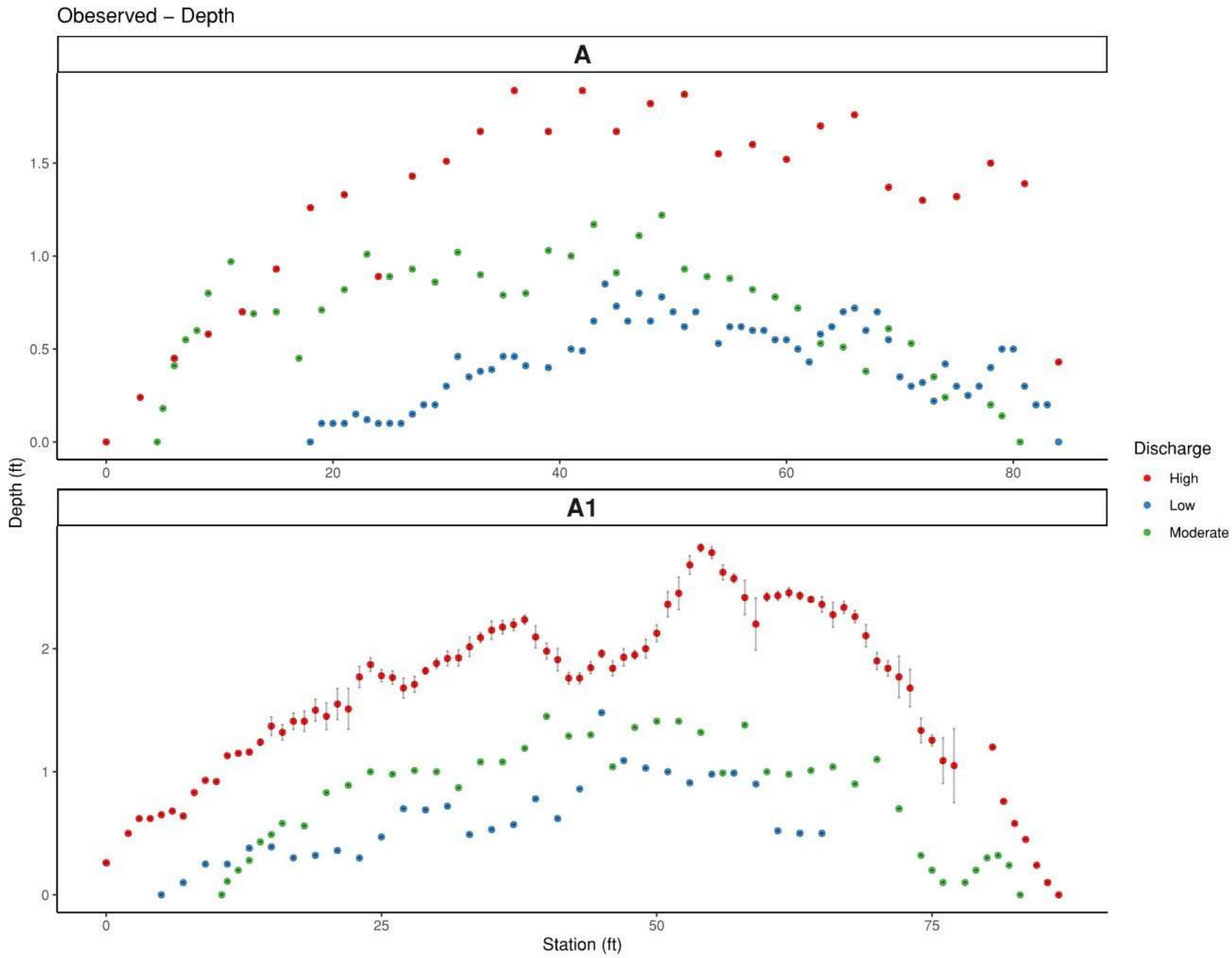
APPENDIX A: TRANSECT SUMMARY


Obeserved – Depth
A
A1
Depth (ft)
Station (ft)
Discharge
High
Low
Moderate
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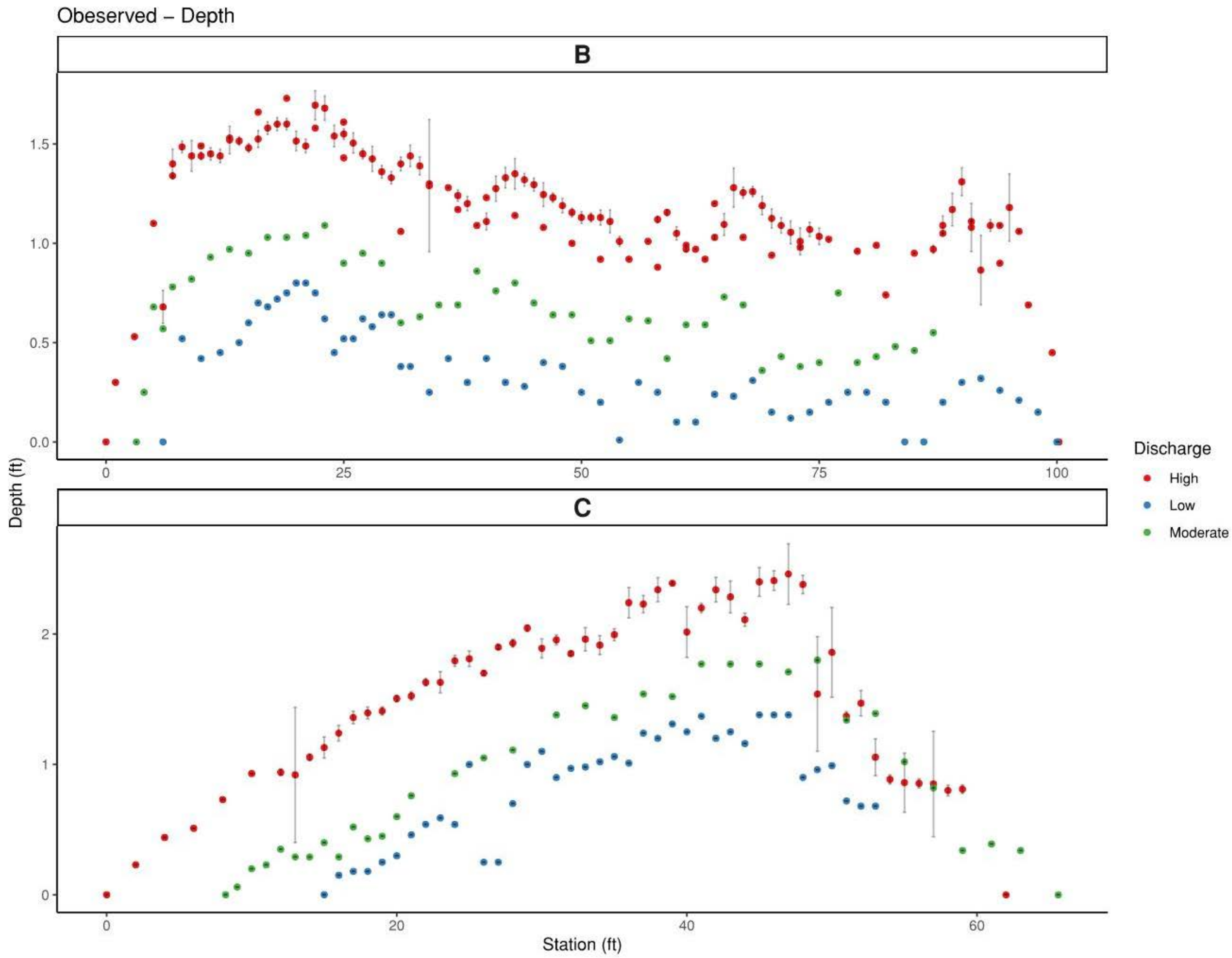
1.0
1.5
0
20
40
60
80
0
1
2
0
25
50
75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B
C
Depth (ft)
Station (ft)
Discharge
High
Low
Moderate
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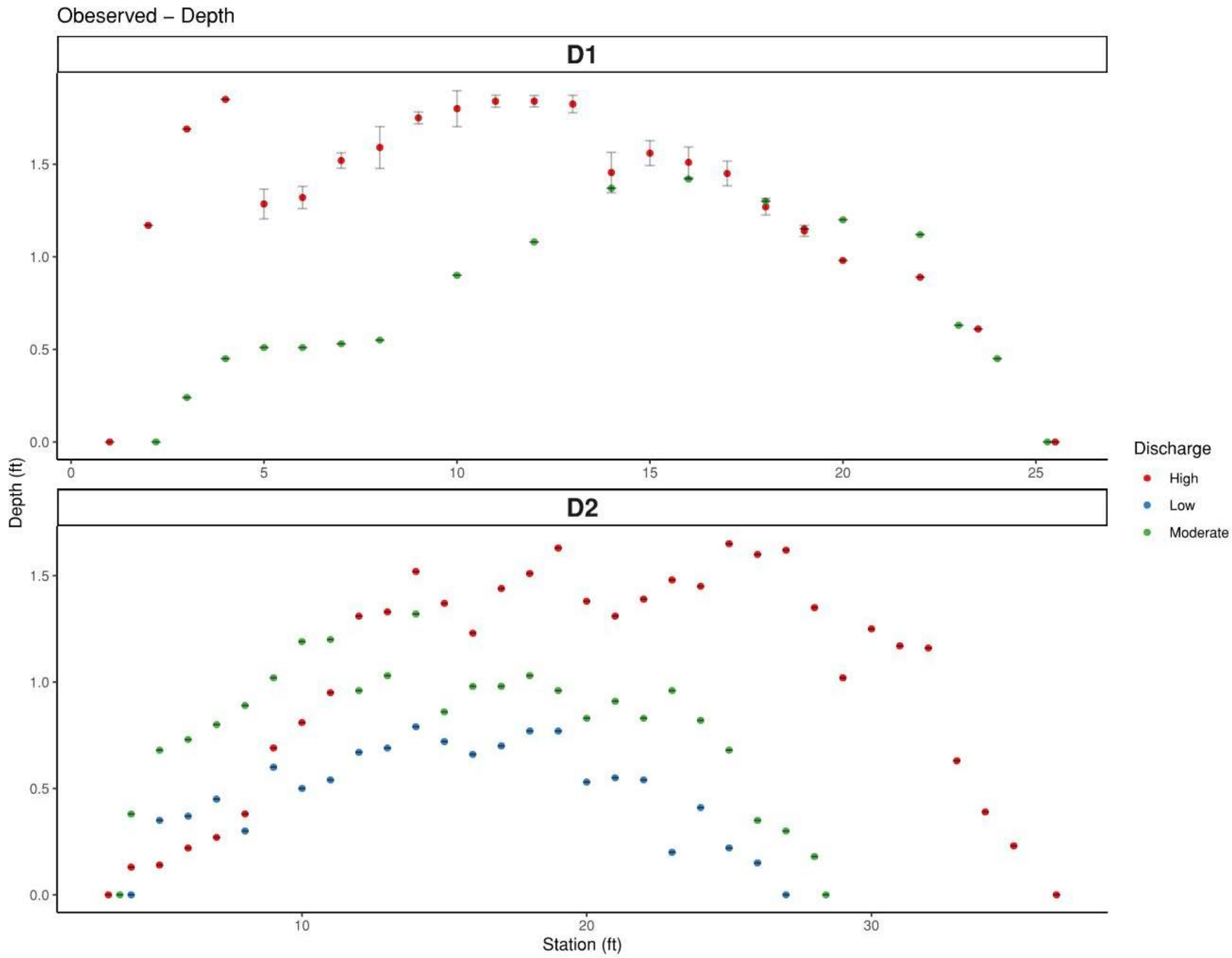
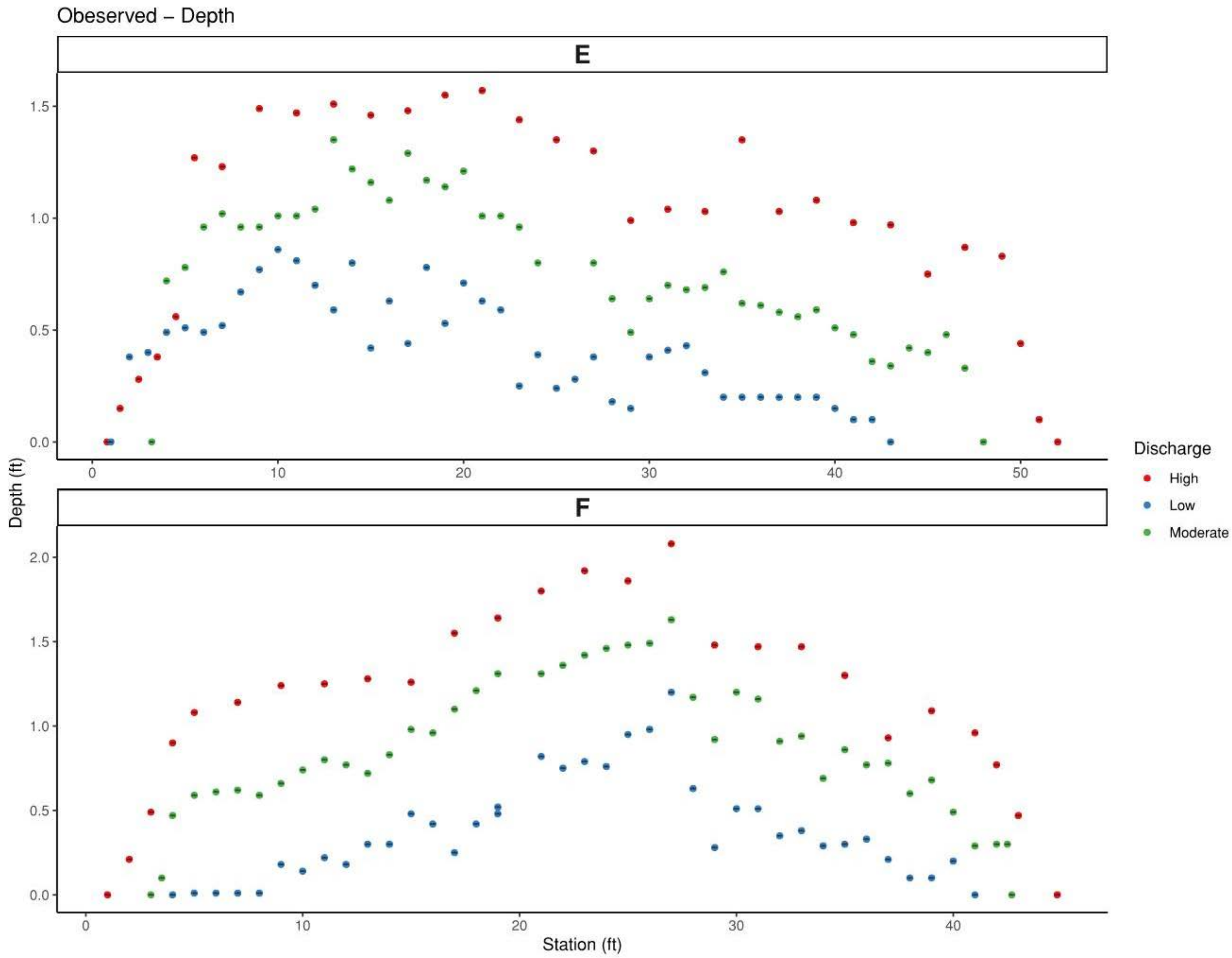
1.0
1.5
0
25
50
75
100
0
1
2
0
20
40
60


Obeserved – Depth
D1
D2
Depth (ft)
Station (ft)
Discharge
High
Low
Moderate
0.0
0.5
1.0
1.5
0
5
10
15
20
25
30


Obeserved – Depth
E
F
Depth (ft)
Station (ft)
Discharge
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Low
Moderate
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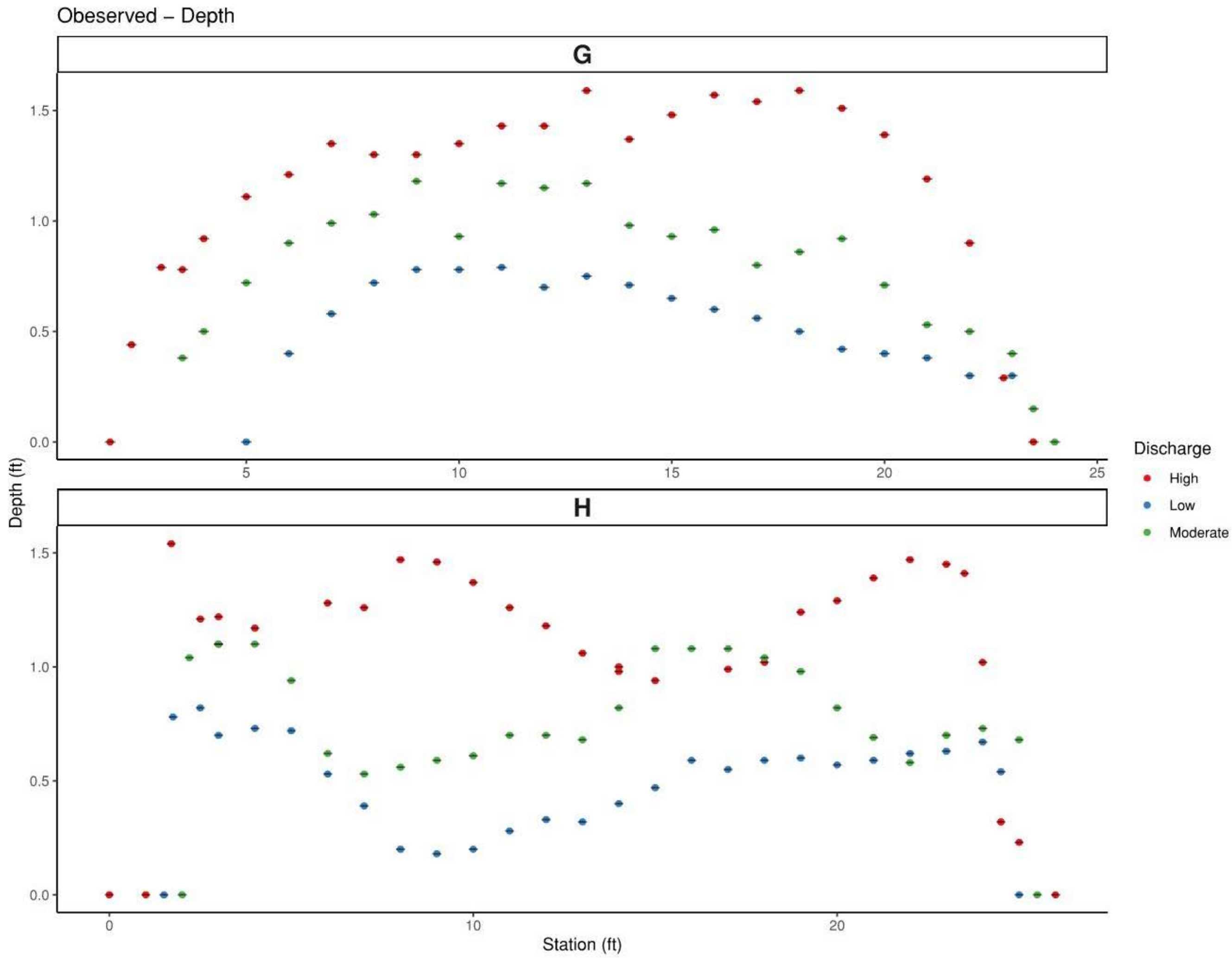
1.0
1.5
2.0
0
10
20
30
40
50


Obeserved – Depth
G
H
Depth (ft)
Station (ft)
Discharge
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Low
Moderate
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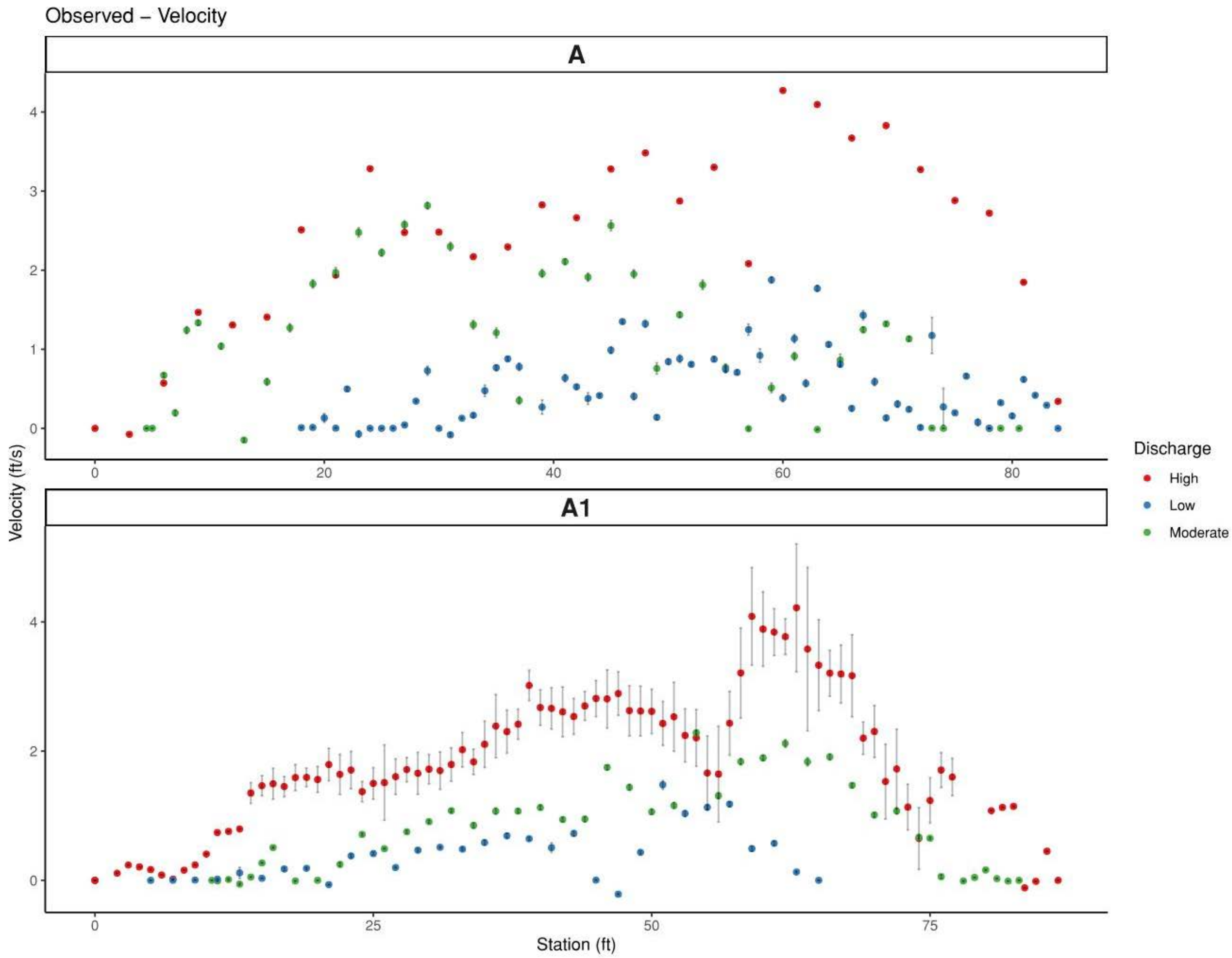
1.0
1.5
5
10
15
20
25
0
10
20


Observed – Velocity
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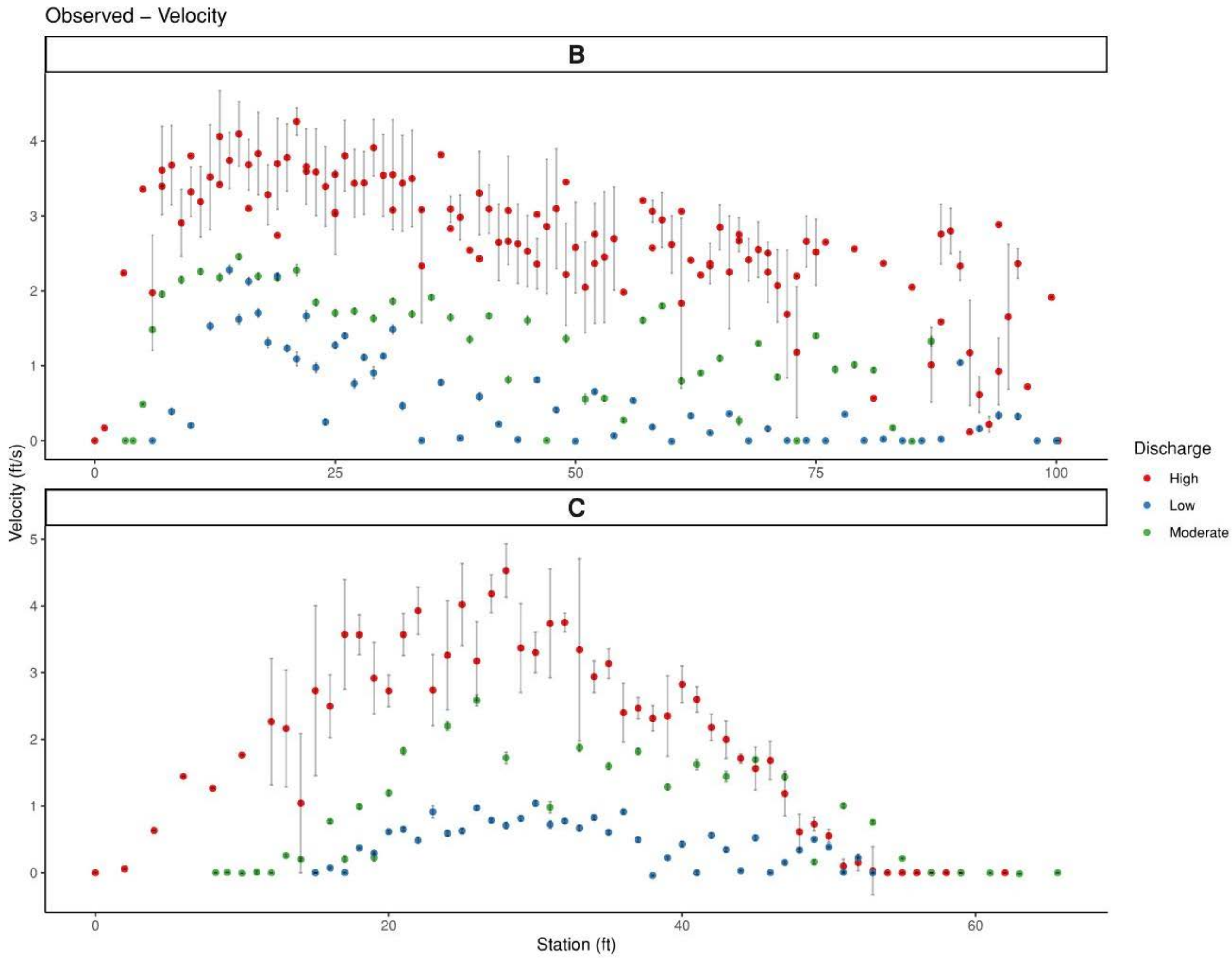
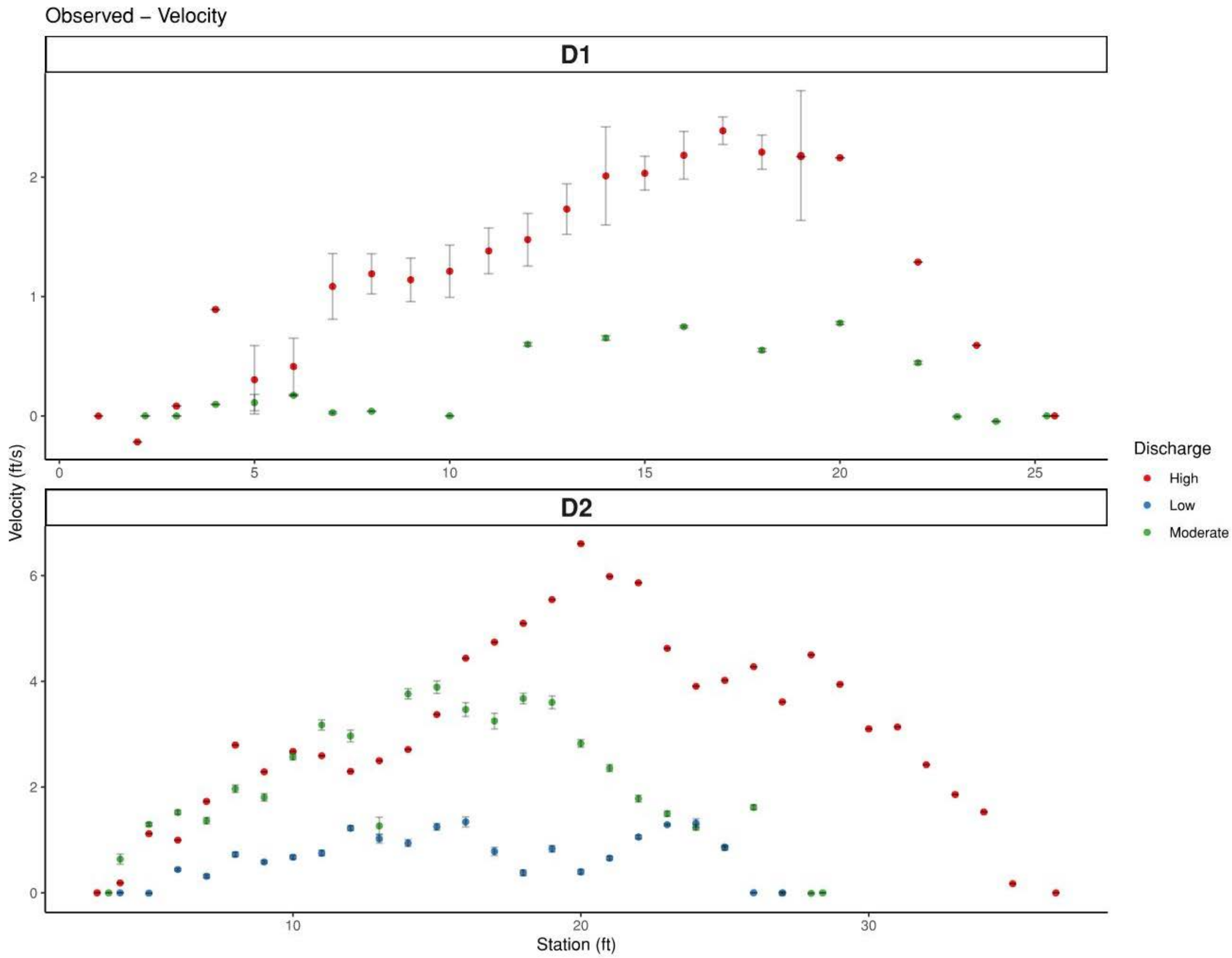
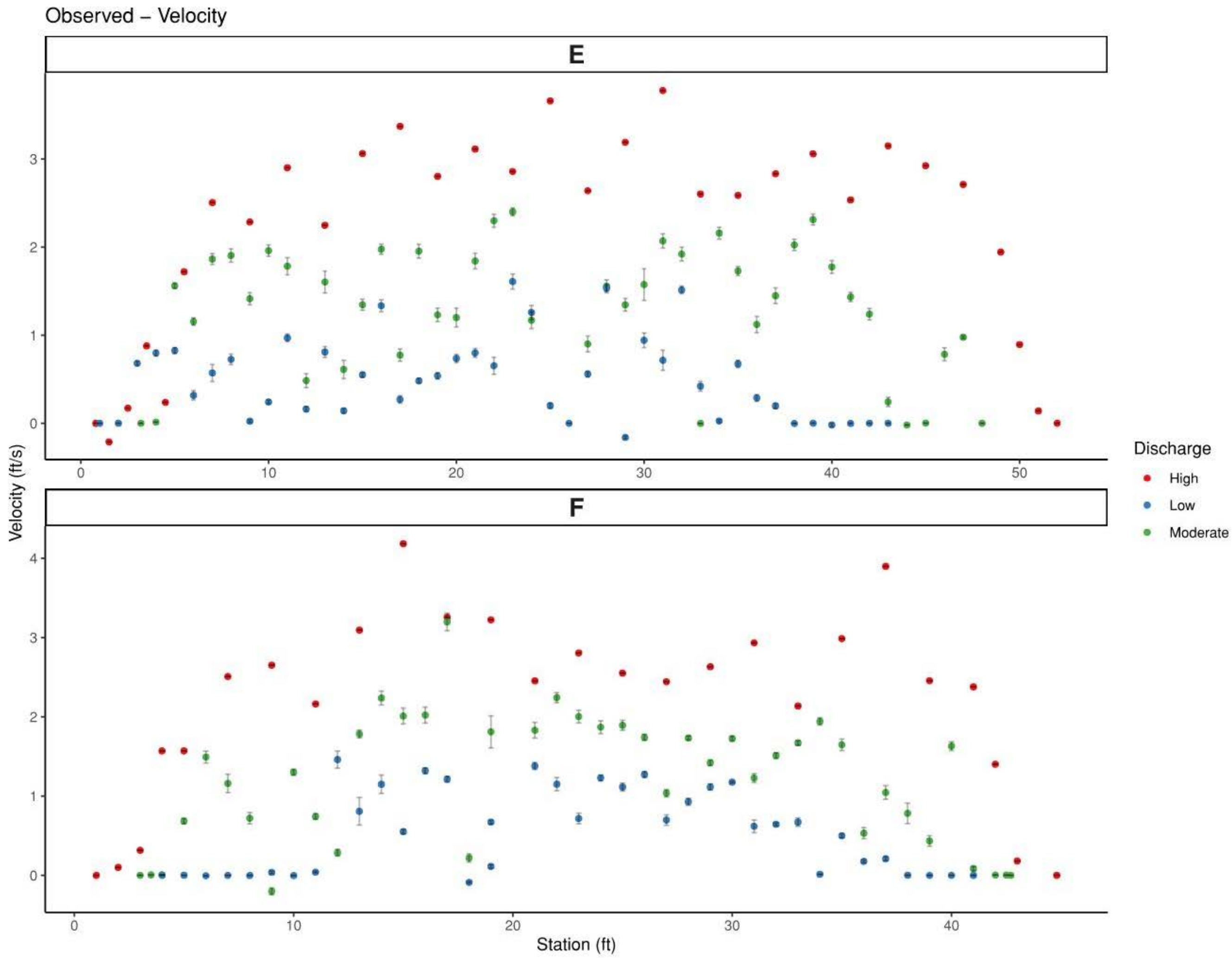
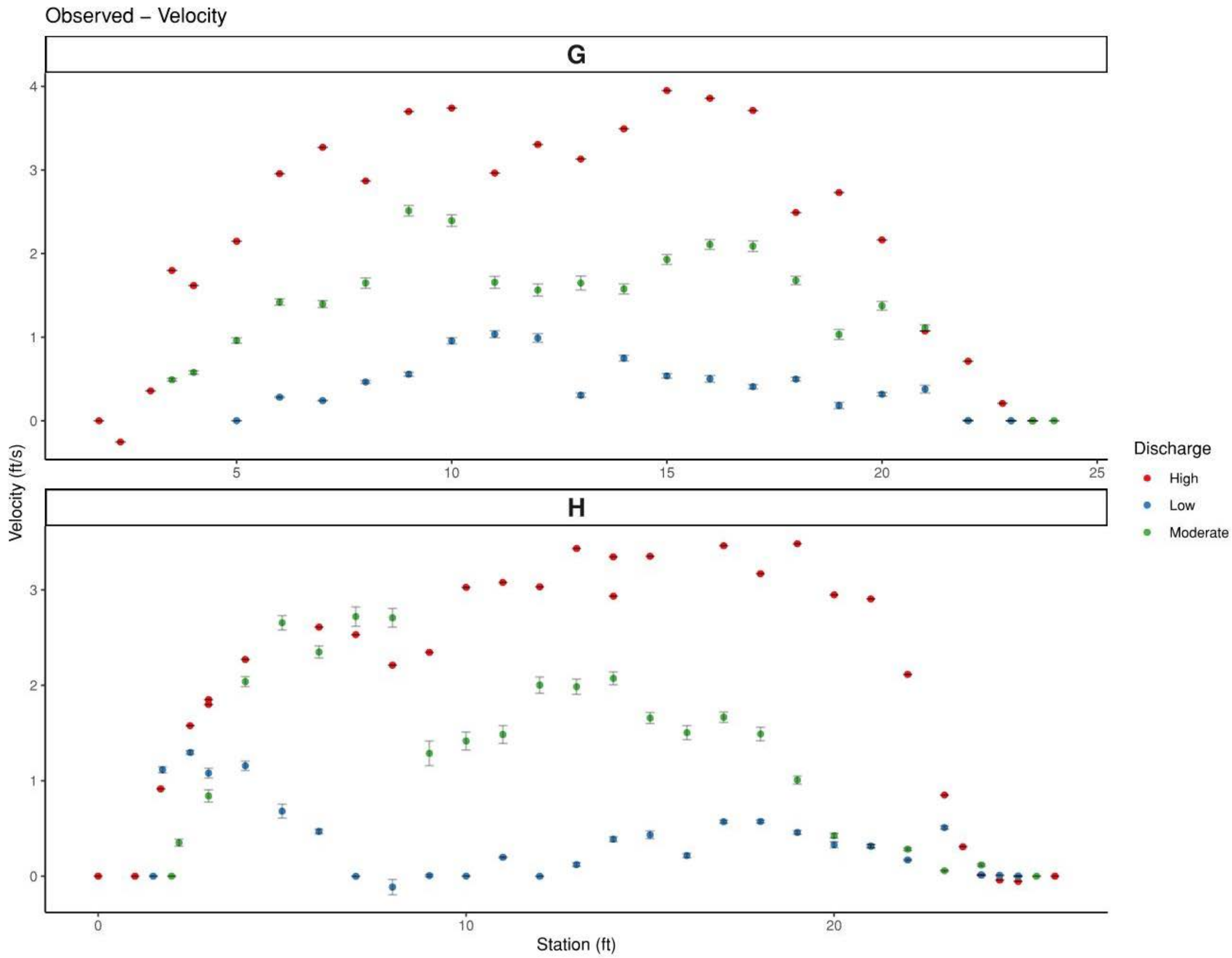
A1
Velocity (ft/s)
Station (ft)
Discharge
High
Low
Moderate


Observed – Velocity
B
C
Velocity (ft/s)
Station (ft)
Discharge
High
Low
Moderate



Observed – Velocity
D1
D2
Velocity (ft/s)
Station (ft)
Discharge
High
Low
Moderate


Observed – Velocity
E
F
Velocity (ft/s)
Station (ft)
Discharge
High
Low
Moderate
0
1
2
3
4
10
20
30
40
50


Observed – Velocity
G
H
Velocity (ft/s)
Station (ft)
Discharge
High
Low
Moderate

APPENDIX B: SPECIES / LIFE STAGE PERIODICITY

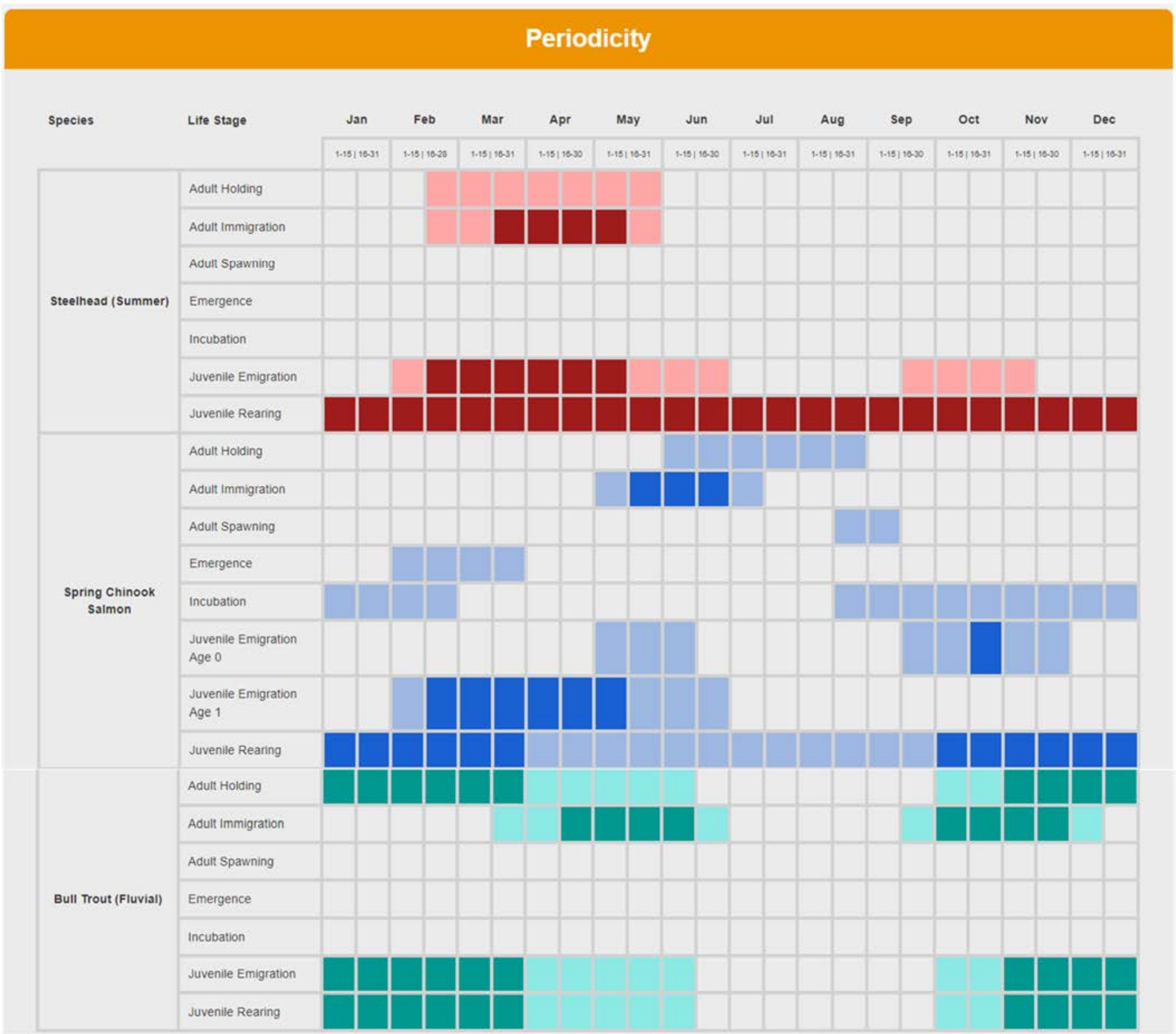


Figure B-1. Reprinted periodicity for UGR-11 from the Grande Ronde Atlas (Atlas Partners 2015).

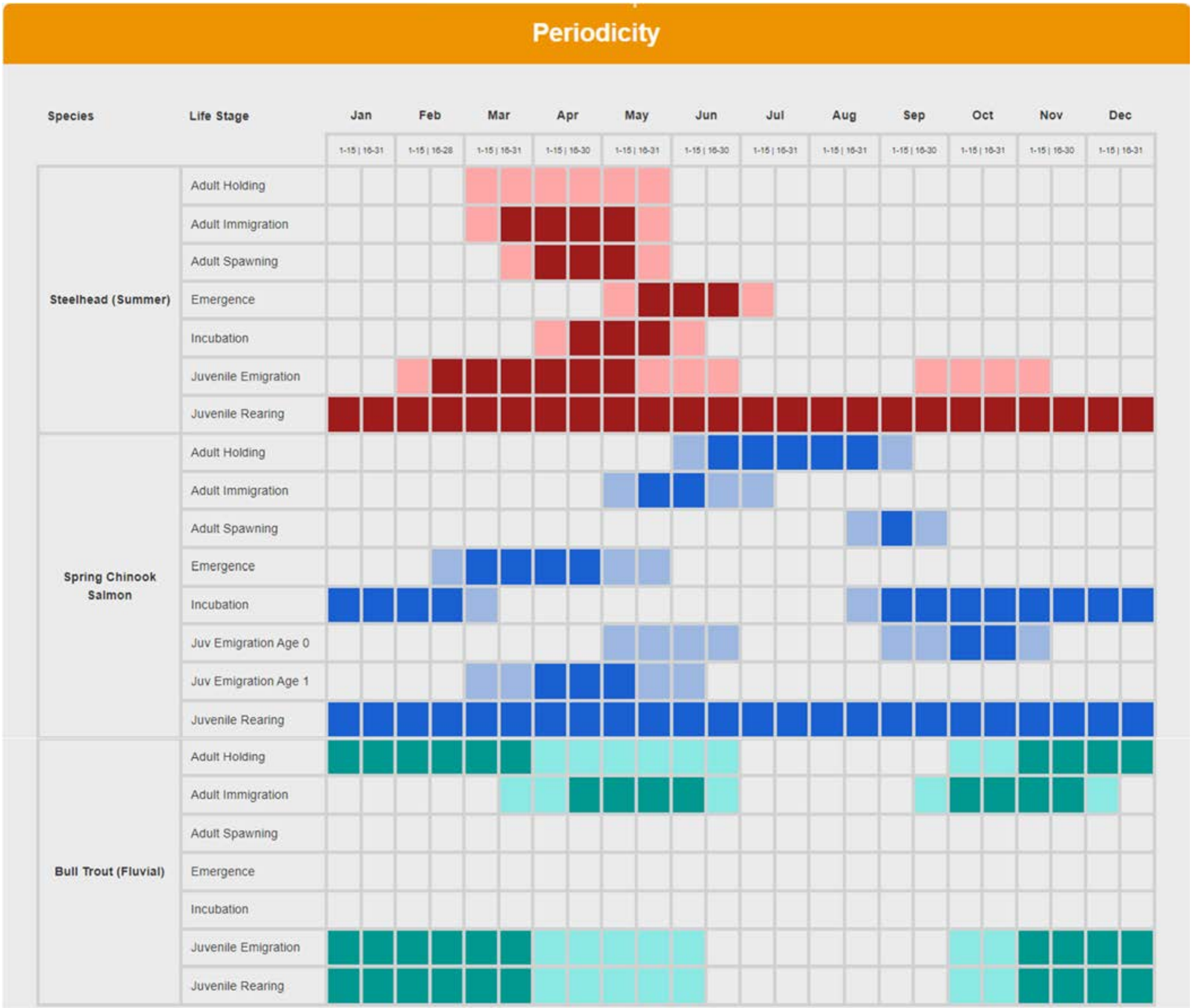


Figure B-2. Reprinted periodicity for UGR-15 from the Grande Ronde Atlas (Atlas Partners 2015).

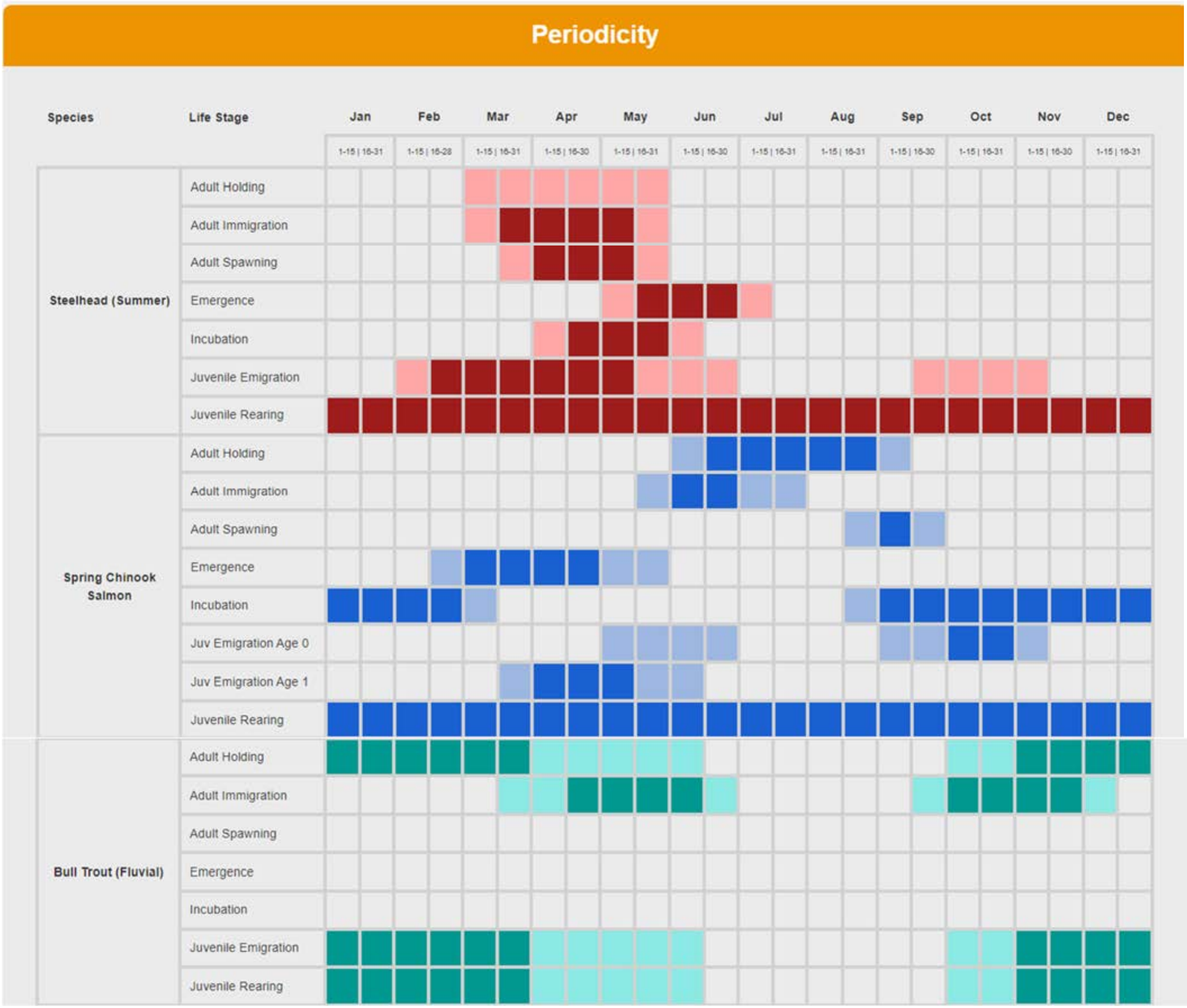


Figure B-2. Reprinted periodicity for UGR-17 from the Grande Ronde Atlas (Atlas Partners 2015).

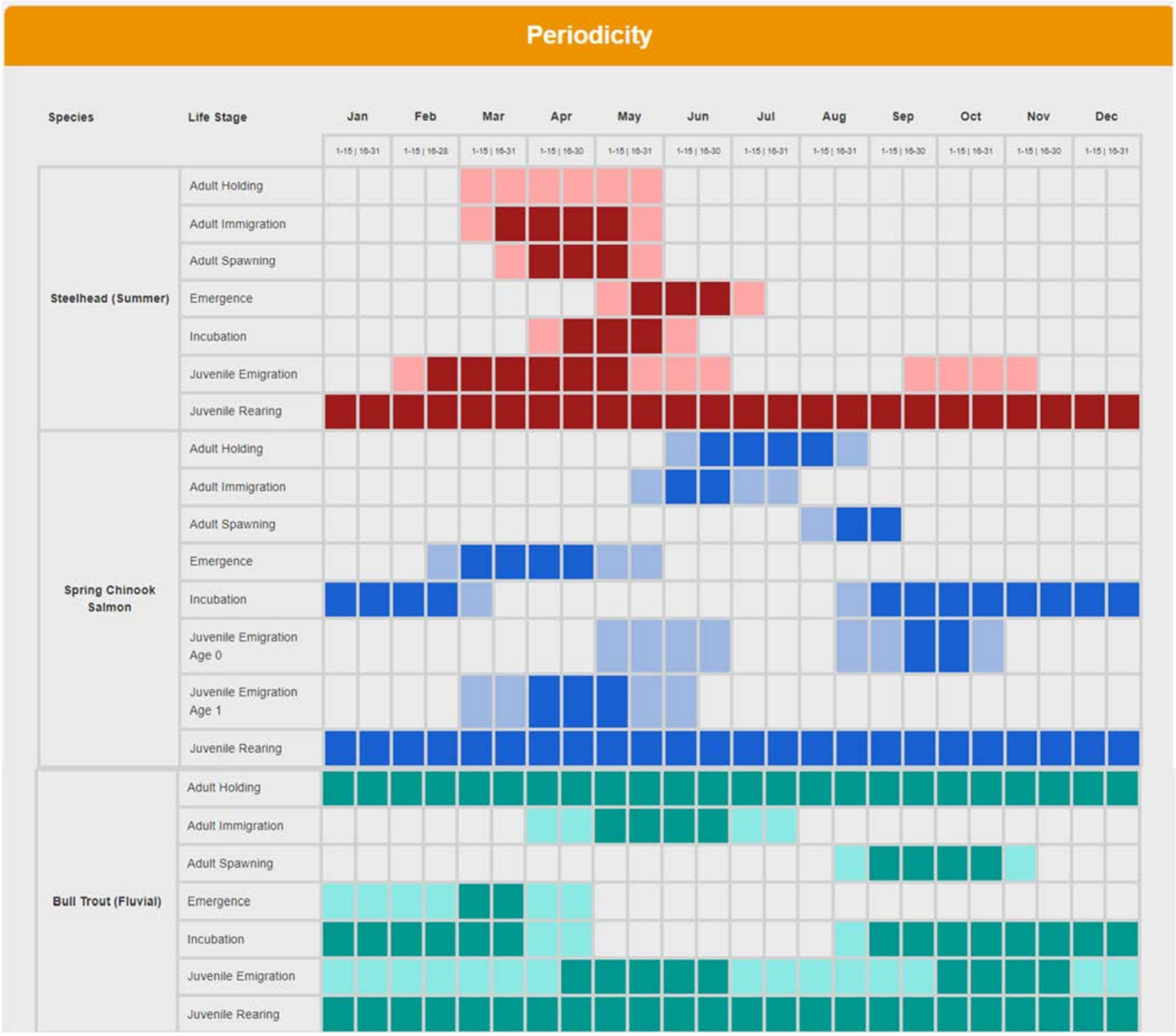


Figure B-3. Reprinted periodicity for UGR-20 from the Grande Ronde Atlas (Atlas Partners 2015).

APPENDIX C: HABITAT SUITABILITY CURVES

Substrate and Cover Suitability - WDFW/Ecology 2022

TABLE 1. Generic Cover/Substrate Codes and Preference Value[1]

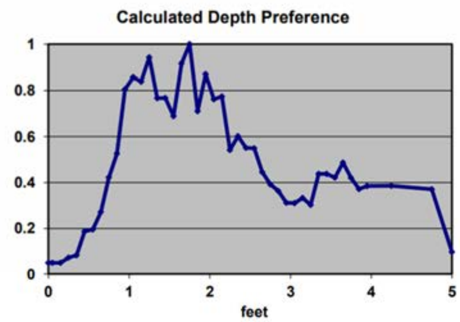
Code	type of cover Note: Cover Codes are not used for spawning						Salmon & Trout Rearing	Whitefish Rearing	
							juvenile & resident adult	juvenile	adult
00.1	undercut bank						1.00	1.00	1.00
00.2	overhanging vegetation near or touching water[2]						1.00	1.00	1.00
00.3	rootwad (including partly undercut)						1.00	1.00	1.00
00.4	log jam/submerged brush pile						1.00	1.00	1.00
00.5	log(s) parallel to bank						0.80	0.80	0.80
00.6	aquatic vegetation						0.80	0.80	0.80
00.7	short (<1’) terrestrial grass						0.10	0.10	0.10
00.8	tall (>3’) dense grass[3]						0.70	0.70	0.10
00.9	vegetation > 3 vertical ft above SZF						0.20	0.20	0.20
Code	type of substrate	Spawning					Salmon & Trout Rearing	Whitefish Rearing	
		salmon	steelhead[4]	resident trout	native chars[5]	whitefish	juvenile & resident adult	juvenile	adult
1	silt, clay, or organic	0.00	0.00	0.00	0.00	00	0.10	0.38	0.15
2	sand	0.00	0.00	0.00	0.00	0.00	0.10	0.38	0.15
3	sm gravel (.1-.5")	0.30	0.50	0.80	1.00	1.00	0.10	0.74	0.76
4	med gravel (.5-1.5")	1.00	1.00	1.00	1.00	1.00	0.30	0.88	0.91
5	lrg gravel (1.5-3")	1.00	1.00	0.80	1.00	1.00	0.30	0.88	0.91
6	sm cobble (3-6")	1.00	1.00	0.50	0.70	1.00	0.50	1.00	1.00
7	lrg cobble (6-12")	0.50	0.30	0.00	0.70	0.50	0.70	1.00	1.00
8	boulder (>12")	0.00	0.00	0.00	0.0	0.0	1.00	1.00	1.00
9	bedrock	0.00	0.00	0.00	0.00	0.00	0.30	0.50	0.30

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

Chinook - Spawning - WDFW/Ecology 2022

FIGURE 2a. Chinook Salmon Stream and River Spawning Depth Preference
For all stocks: Streams and rivers have a MAF <3,000 cfs. Analysis based on 8 studies and 440 redds (American, upper Chehalis, Chelan, Little Naches, Similkameen, Sultan, Yakima, and West Fork Humptulips rivers). **Preference is unchanged from the 2016 edition.**

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.35	0.00
0.95	0.80
1.25	0.94
1.75	1.00
2.75	0.40
99	0.40



HSC notes: The calculated preference from 0.0 to 0.39 ft was based on averages from the binning process, not observations. We decided to use a 0.0 preference from 0.0 to 0.35 ft to reflect a physical minimum depth needed for spawning fish.

For Chinook Salmon Spawning Substrate Preference, use Table 2.

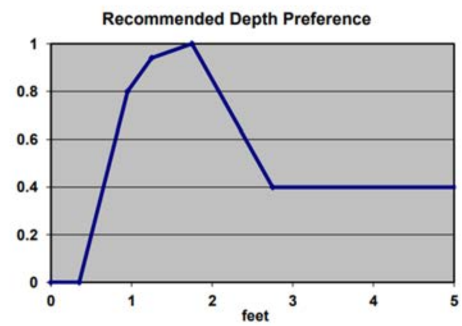
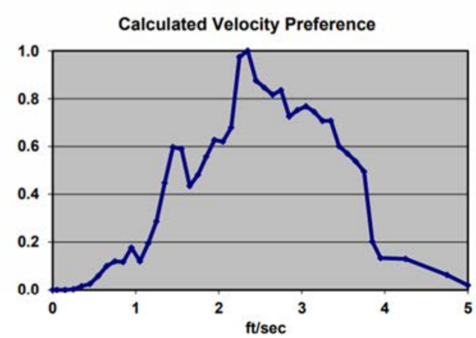


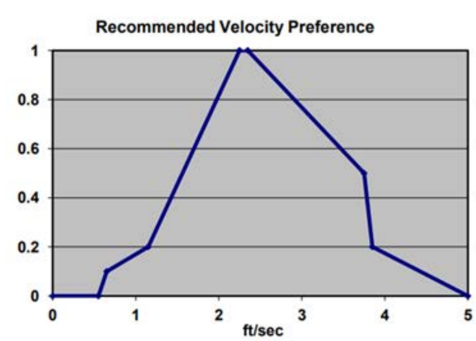
FIGURE 2b. Chinook Salmon Stream and River Spawning Velocity Preference
For all stocks: Streams and rivers have a MAF <3,000 cfs. Analysis based on 8 studies and 440 redds (American, upper Chehalis, Chelan, Little Naches, Similkameen, Sultan, Yakima, and West Fork Humptulips rivers). **Preference is unchanged from the 2016 edition.**

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.00
0.55	0.00
0.65	0.10
1.15	0.20
2.25	1.00
2.35	1.00
3.75	0.50
3.85	0.20
5.0	0.00
99	0.00



HSC notes: The calculated preference from 0.0 to 0.59 ft was based on averages from the binning process, not observations. We decided to use a 0.0 preference from 0.0 to 0.55 ft.

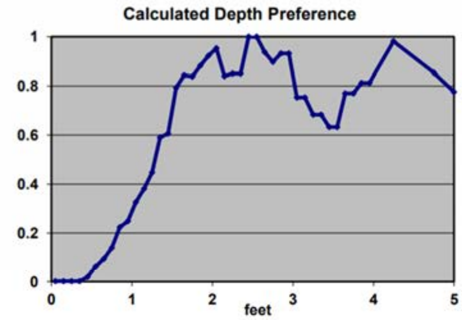
For Chinook Salmon Spawning Substrate Preference, use Table 2.



Chinook - Juvenile - WDFW/Ecology 2022

FIGURE 3a. Chinook Salmon Juvenile Rearing Depth Preference
Analysis based on 9 studies (Dungeness, Chiwawa, Mad & Similkameen, and Tucannon Rivers and Kendall Creek) and 5615 fish. Kendall Creek was a utilization study with 5055 observations. **Preference is unchanged from the 2016 edition.**

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.45	0.00
1.05	0.30
1.65	0.85
2.05	0.95
2.45	1.00
99	1.00



HSC Notes: High preference at depths greater than 5' is only associated with suitable cover or proximity to water's edge. If none of these conditions are present, use a substrate/cover code with a 0.1 preference factor to in the cover/substrate component to adjust the WUA calculation.

For Chinook Salmon Juvenile Rearing Substrate Preference, use Table 3.

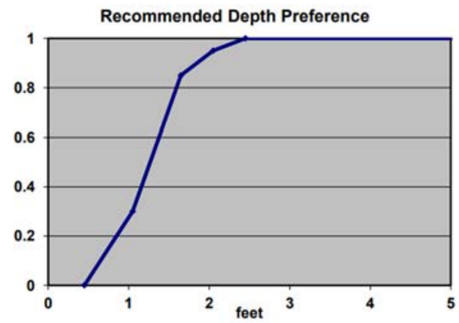
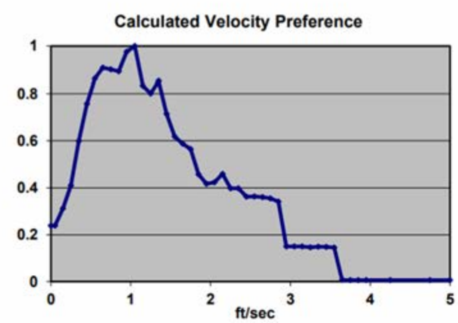


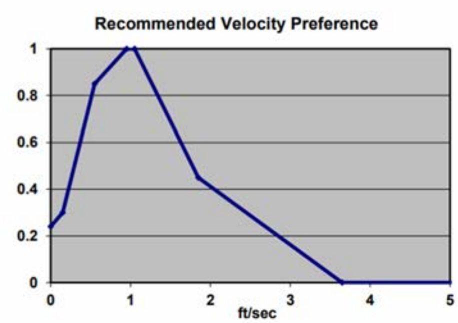
FIGURE 3b. Chinook Salmon Juvenile Rearing Velocity Preference
Analysis based on 9 studies (Dungeness, Chiwawa, Mad & Similkameen, and Tucannon Rivers and Kendall Creek) and 5615 fish. Kendall Creek was a utilization study with 5055 observations.
Preference is unchanged from the 2016 edition.

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.24
0.15	0.30
0.55	0.85
0.95	1.00
1.05	1.00
1.85	0.45
3.65	0.00
99	0.00

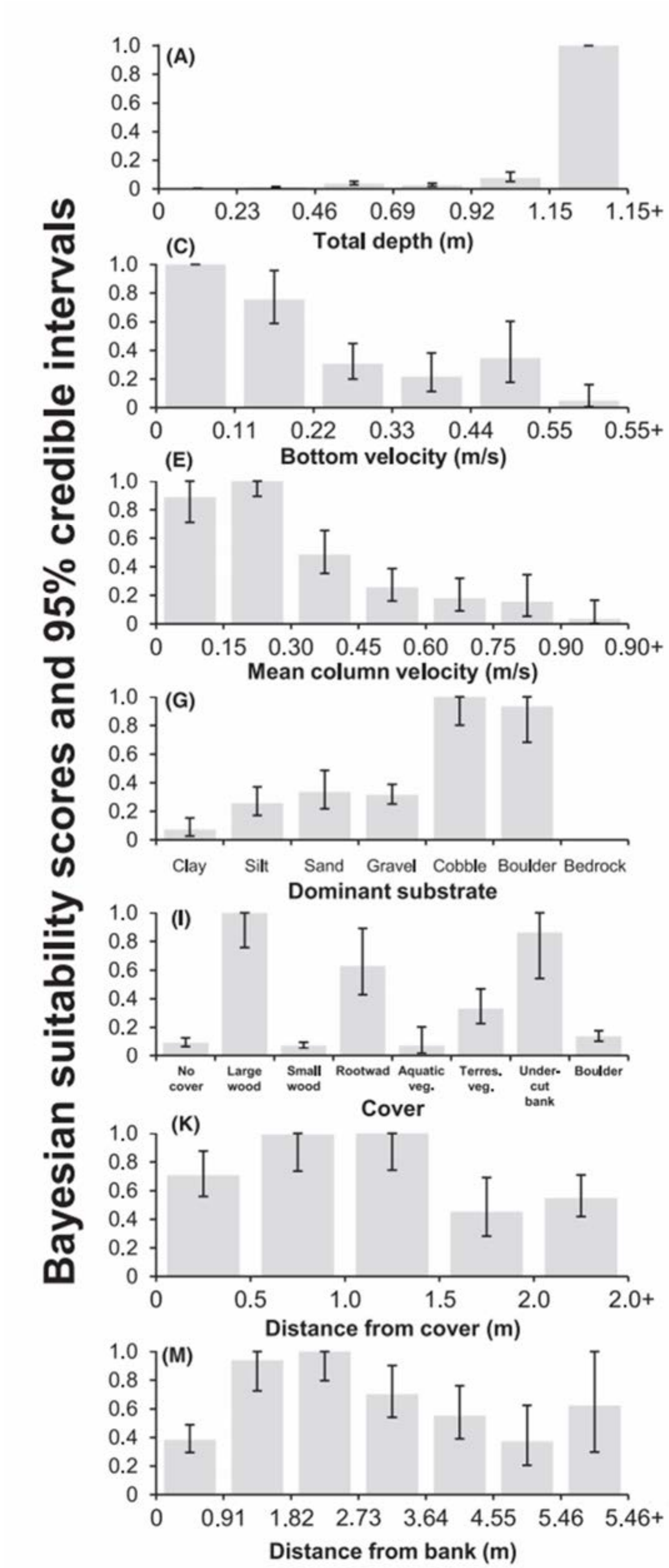


HSC Notes: None

For Chinook Salmon Juvenile Rearing Substrate Preference, use Table 3.



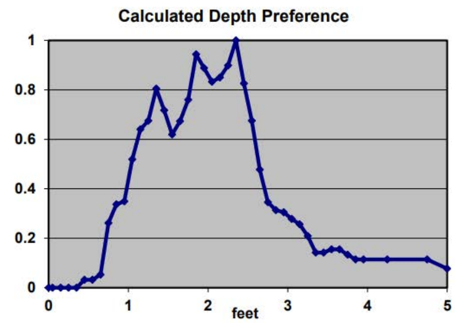
Chinook - Juvenile – Favrot et al. 2018

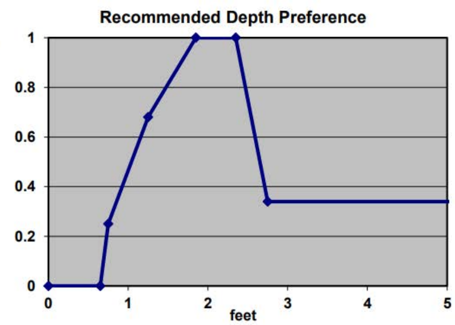


Steelhead (*O. mykiss)* - Spawning - WDFW/Ecology 2022

FIGURE 8a. Steelhead (*O. mykiss*) Spawning Depth Preference
Analysis based on 6 studies, 108 redds (Rock Creek (WRIA 31), Cedar (2) and Sultan rivers and Chelan Fish Channel (2)). **Preference is unchanged from the 2016 edition.**

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.65	0.00
0.75	0.25
1.25	0.68
1.85	1.00
2.35	1.00
2.75	0.34
99	0.34



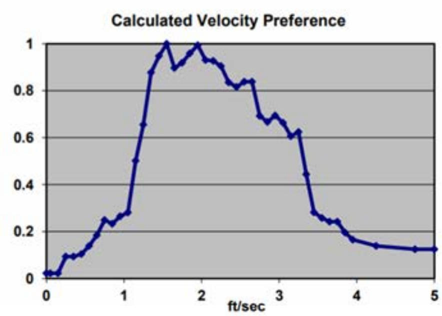


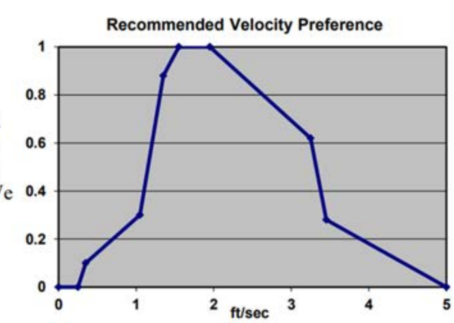
HSC Notes: For depth preference after 2.90 ft, we chose to maintain a 0.34 preference out to 99'.

For Steelhead Spawning Substrate Preference, use Table 4.

FIGURE 8b. Steelhead Spawning Velocity Preference
Analysis based on 6 studies, 108 redds (Rock Creek (WRIA 31), Cedar (2) and Sultan rivers and Chelan Fish Channel (2)). **Preference is unchanged from the 2016 edition.**

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.00
0.25	0.00
0.35	0.10
1.05	0.30
1.35	0.88
1.55	1.00
1.95	1.00
3.25	0.62
3.45	0.28
5.0	0.00
99	0.00





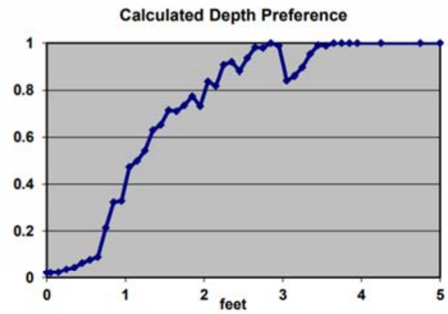
HSC Notes: The highest velocity observation was at 3.55 ft/sec. The calculated preferences from 3.5 to 5.0 ft/sec were based on averages from the binning process, not observations. We chose to continue the slope down from 3.95 ft/sec.

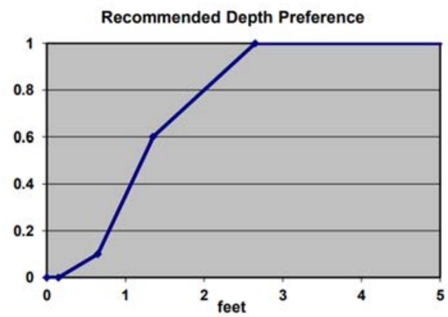
For Steelhead Spawning Substrate Preference, use Table 4.

Steelhead (*O. mykiss)* - Juvenile - WDFW/Ecology 2022

FIGURE 9a. O.mykiss Juvenile Depth Preference
Analysis based on 32 studies and 1954 fish and combines steelhead and resident rainbow juvenile observations (multiple Washington streams of differing sizes and stream types).
This was a new composite curve for the 2016 edition.

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.15	0.00
0.65	0.10
1.35	0.63
2.65	1.00
99	1.00



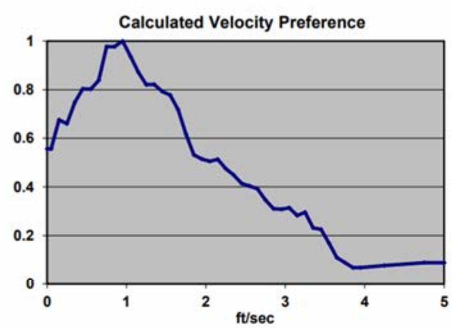


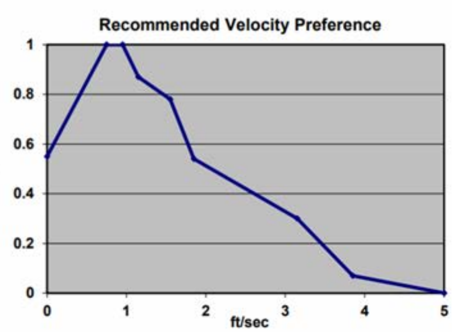
HSC Notes: Smaller streams lack the availability at deeper depths reducing the number of streams used in the composite average preference calculation. This didn't affect the peak in other curves, but it did here. The highest combined composite preference occurred at 2.85 ft involving 25 streams. The highest composite average occurred at 3.85 ft, but only involved 15 streams. We decided to renormalize the calculated preference using the value at 2.85 ft.

For Steelhead and Rainbow Juvenile Substrate Preference, use Table 3.

FIGURE 9b. O.mykiss Juvenile Velocity Preference
Analysis based on 32 studies and 1954 fish and combines steelhead and resident rainbow juvenile observations (multiple Washington streams of differing sizes and stream types).
This was a new composite curve for the 2016 edition.

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.55
0.75	1.00
0.95	1.00
1.15	0.87
1.55	0.78
1.85	0.54
3.15	0.30
3.85	0.07
5.00	0.00
99	0.00





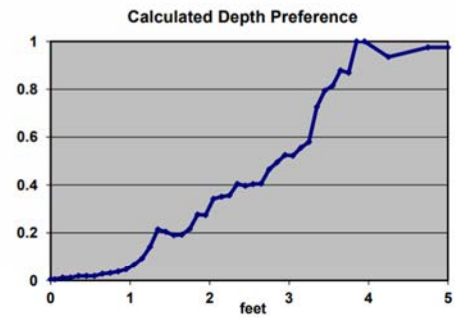
HSC Notes: The highest velocity observation was at 4.05 ft/sec. The calculated preferences from 4.15 to 5.0 ft/sec were based on averages from the binning process, not observations. We chose to slope down to 0.0 at 5.0 ft/sec.

For Steelhead and Rainbow Juvenile Substrate Preference, use Table 3.

Steelhead (*O. mykiss)* - Adult – WDFW/Ecology 2022

FIGURE 11a. Resident Rainbow Trout (*O. mykiss*) Adult Rearing Depth Preference
Analysis based on 15 studies and 638 fish (mostly west side streams but includes Yakima River, upper Yakima, Mill Creek (WRIA 32) and Douglas (2) (WRIA 44) creeks.
This was a new composite curve for the 2016 edition.

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.75	0.03
3.25	0.60
3.45	0.79
3.85	1.00
99	1.00



HSC Notes: None

For Resident Adult Rainbow Trout Rearing Substrate Preference, use Table 3.

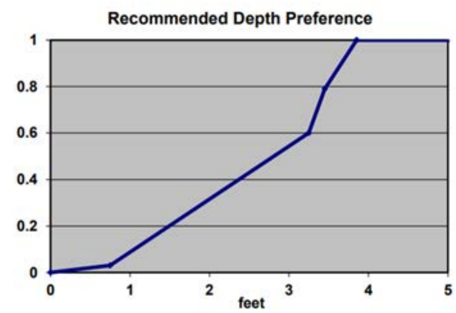
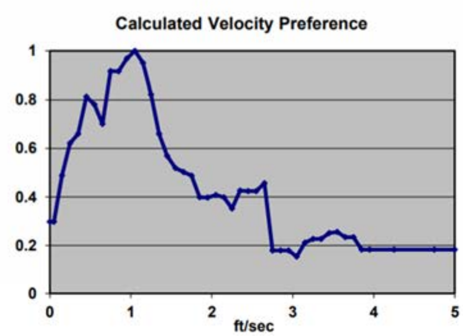


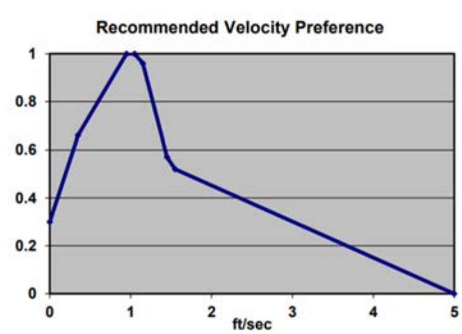
FIGURE 11b. Resident Rainbow Trout Adult Rearing Velocity Preference
Analysis based on 15 studies and 638 fish (Mostly west side streams but includes Yakima River, upper Yakima, Mill Creek (WRIA 32) and Douglas (2) (WRIA 44) creeks.
This was a new composite curve for the 2016 edition.

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.30
0.35	0.66
0.95	1.00
1.05	1.00
1.15	0.96
1.45	0.57
1.55	0.52
5.00	0.00
99	0.00



HSC Notes: None

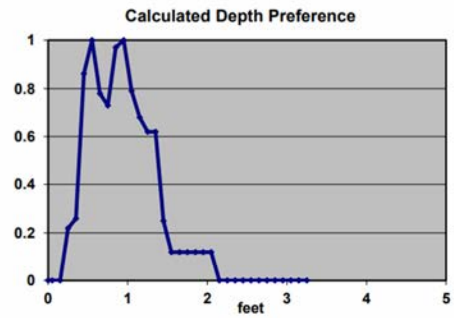
For Resident Adult Rainbow Trout Rearing Substrate Preference, use Table 3.



Resident Rainbow Trout (*O. mykiss)* - Spawning - WDFW/Ecology 2022

FIGURE 10a. Resident Rainbow Trout (*O. mykiss*) Spawning Depth Preference
Analysis based on 2 studies and 27 redds (upper Lake and Muller Creek).
Preference is unchanged from the 2016 edition.

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.15	0.00
0.35	0.30
0.45	0.85
0.55	1.00
0.95	1.00
1.35	0.60
1.45	0.25
99	0.25



HSC Notes: We chose to maintain a 0.25 preference out to 99'.

For Resident Rainbow Trout Spawning Substrate Preference, use Table 5.

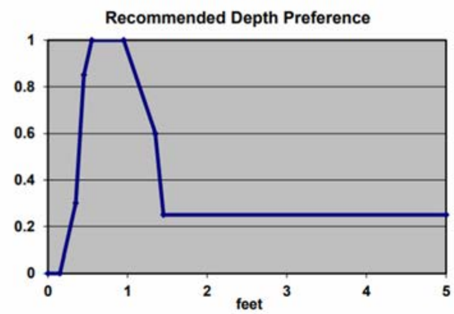
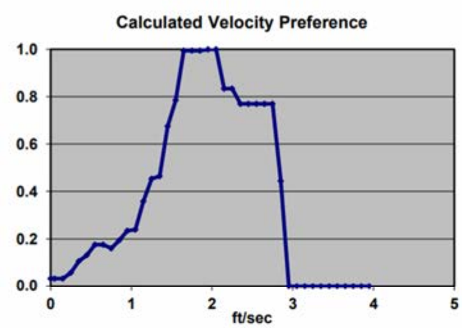


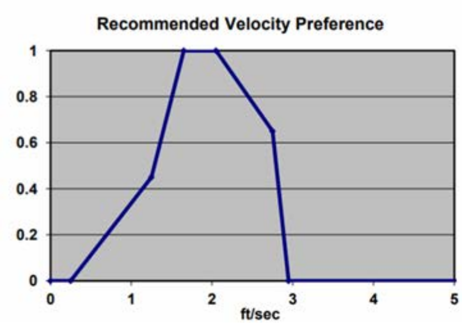
FIGURE 10b. Resident Rainbow Trout Spawning Velocity Preference
Analysis based on 2 studies and 27 redds (upper Lake and Muller Creek).
Preference is unchanged from the 2016 edition.

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.00
0.25	0.00
1.25	0.45
1.65	1.00
2.05	1.00
2.75	0.65
2.95	0.00
99	0.00



HSC Notes: None

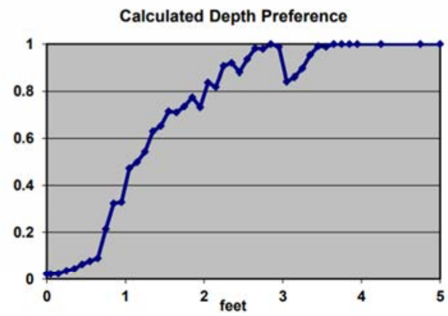
For Resident Rainbow Trout Spawning Substrate Preference, use Table 5.

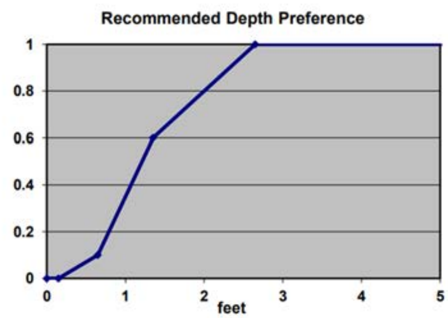


Resident Rainbow Trout (*O. mykiss)* - Juvenile - WDFW/Ecology 2022

FIGURE 9a. O.mykiss Juvenile Depth Preference
Analysis based on 32 studies and 1954 fish and combines steelhead and resident rainbow juvenile observations (multiple Washington streams of differing sizes and stream types).
This was a new composite curve for the 2016 edition.

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.15	0.00
0.65	0.10
1.35	0.63
2.65	1.00
99	1.00



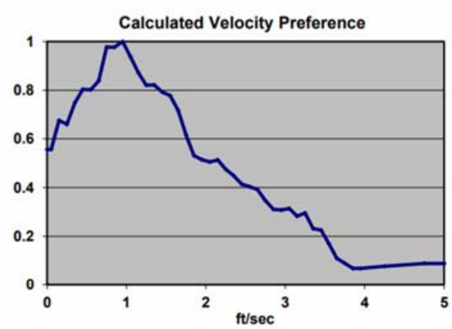


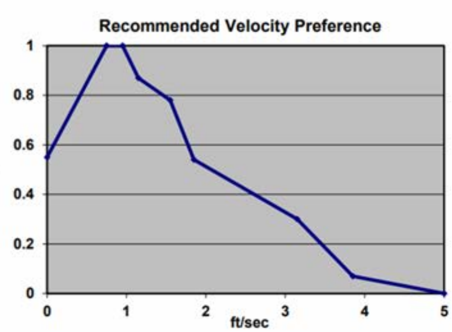
HSC Notes: Smaller streams lack the availability at deeper depths reducing the number of streams used in the composite average preference calculation. This didn't affect the peak in other curves, but it did here. The highest combined composite preference occurred at 2.85 ft involving 25 streams. The highest composite average occurred at 3.85 ft, but only involved 15 streams. We decided to renormalize the calculated preference using the value at 2.85 ft.

For Steelhead and Rainbow Juvenile Substrate Preference, use Table 3.

FIGURE 9b. O.mykiss Juvenile Velocity Preference
Analysis based on 32 studies and 1954 fish and combines steelhead and resident rainbow juvenile observations (multiple Washington streams of differing sizes and stream types).
This was a new composite curve for the 2016 edition.

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.55
0.75	1.00
0.95	1.00
1.15	0.87
1.55	0.78
1.85	0.54
3.15	0.30
3.85	0.07
5.00	0.00
99	0.00





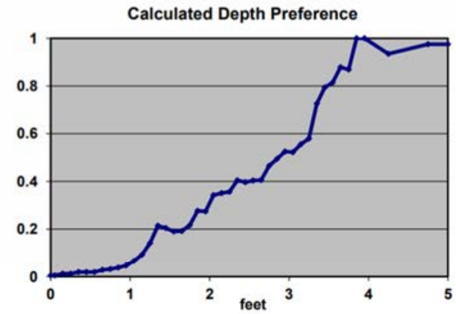
HSC Notes: The highest velocity observation was at 4.05 ft/sec. The calculated preferences from 4.15 to 5.0 ft/sec were based on averages from the binning process, not observations. We chose to slope down to 0.0 at 5.0 ft/sec.

For Steelhead and Rainbow Juvenile Substrate Preference, use Table 3.

Resident Rainbow Trout (*O. mykiss)* - Adult - WDFW/Ecology 2022

FIGURE 11a. Resident Rainbow Trout (*O. mykiss*) Adult Rearing Depth Preference
Analysis based on 15 studies and 638 fish (mostly west side streams but includes Yakima River, upper Yakima, Mill Creek (WRIA 32) and Douglas (2) (WRIA 44) creeks.
This was a new composite curve for the 2016 edition.

Recommended depth preference curve	
Plotted depth (feet)	Depth preference
0.00	0.00
0.75	0.03
3.25	0.60
3.45	0.79
3.85	1.00
99	1.00



HSC Notes: None

For Resident Adult Rainbow Trout Rearing Substrate Preference, use Table 3.

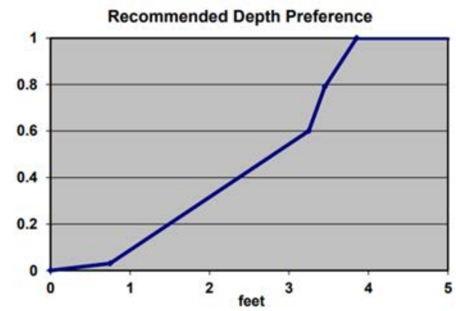
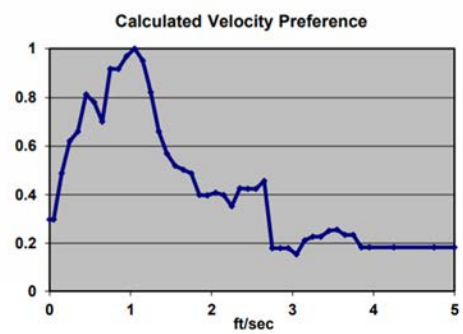


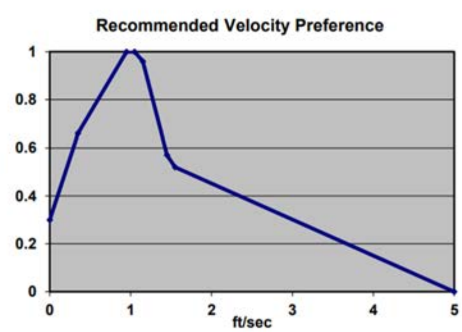
FIGURE 11b. Resident Rainbow Trout Adult Rearing Velocity Preference
Analysis based on 15 studies and 638 fish (Mostly west side streams but includes Yakima River, upper Yakima, Mill Creek (WRIA 32) and Douglas (2) (WRIA 44) creeks.
This was a new composite curve for the 2016 edition.

Recommended velocity preference curve	
Plotted velocity (ft/sec)	Velocity preference
0.00	0.30
0.35	0.66
0.95	1.00
1.05	1.00
1.15	0.96
1.45	0.57
1.55	0.52
5.00	0.00
99	0.00



HSC Notes: None

For Resident Adult Rainbow Trout Rearing Substrate Preference, use Table 3.



APPENDIX D: MODEL CALIBRATION

Discharge	Transect	Variable	Slope	Int	R^2	n	ME	MAE	MSE	RMSE	PBIAS %
All Flows	All Transects	Depth	1.103	-0.089	0.776	1141	0	0.24	0.11	0.34	0.2
	All Transects	Velocity	0.583	0.649	0.569	1141	0.07	0.57	0.63	0.8	5.2
All Flows	A	Depth	0.945	-0.116	0.906	135	-0.15	0.18	0.04	0.21	-22.4
	A1	Depth	1.146	0.114	0.845	160	0.29	0.36	0.23	0.48	24.1
	B	Depth	1.146	-0.094	0.888	217	0.03	0.15	0.04	0.2	3.6
	C	Depth	1.077	-0.044	0.816	129	0.04	0.24	0.12	0.34	3.8
	D1	Depth	0.994	-0.073	0.621	41	-0.08	0.3	0.2	0.45	-7.4
	D2	Depth	0.97	0.168	0.443	85	0.14	0.37	0.28	0.53	18.4
	E	Depth	0.977	-0.147	0.888	118	-0.16	0.18	0.05	0.22	-23.7
	F	Depth	0.771	-0.115	0.866	106	-0.29	0.29	0.12	0.35	-38.3
	G	Depth	1.103	-0.08	0.745	67	0.01	0.21	0.08	0.28	0.7
	H	Depth	0.743	0.257	0.475	83	0.06	0.23	0.12	0.34	7.6
	A	Velocity	0.741	0.623	0.745	135	0.34	0.48	0.4	0.63	30.3
	A1	Velocity	0.434	0.729	0.464	160	0.02	0.62	0.61	0.78	1.6
	B	Velocity	0.654	0.535	0.765	217	-0.1	0.47	0.39	0.62	-5.3
	C	Velocity	0.645	0.373	0.783	129	-0.05	0.43	0.36	0.6	-4.4
	D1	Velocity	0.578	0.395	0.649	41	0.04	0.37	0.23	0.48	4.6
	D2	Velocity	0.253	1.077	0.165	85	-0.45	1.16	2.58	1.61	-22.1
	E	Velocity	0.769	0.575	0.668	118	0.29	0.51	0.45	0.67	23.4
	F	Velocity	1.033	0.519	0.714	106	0.56	0.65	0.76	0.87	46.7
	G	Velocity	0.541	0.67	0.62	67	0.03	0.58	0.56	0.75	1.8
	H	Velocity	0.494	0.67	0.649	83	0.05	0.57	0.51	0.72	3.8
High		Depth	1.01	0.132	0.692	454	0.15	0.29	0.17	0.41	11.4
Low	All Transects	Depth	0.855	-0.063	0.693	342	-0.13	0.18	0.05	0.22	-27.6
Moderate		Depth	0.878	0.04	0.532	345	-0.05	0.23	0.11	0.33	-6.9
High		Velocity	0.438	1.106	0.4	454	-0.14	0.73	0.98	0.99	-6.5
Low	All Transects	Velocity	0.567	0.407	0.308	342	0.18	0.37	0.24	0.49	35.3
Moderate		Velocity	0.532	0.78	0.388	345	0.25	0.57	0.57	0.76	21.9
Low	A	Depth	0.525	0.008	0.646	64	-0.19	0.2	0.06	0.24	-45.7
	A1	Depth	1.199	-0.048	0.711	31	0.07	0.22	0.07	0.27	12
	B	Depth	0.932	-0.107	0.766	57	-0.13	0.14	0.03	0.17	-36.3
	C	Depth	0.732	0.089	0.778	39	-0.13	0.19	0.05	0.23	-16.2
	D2	Depth	0.861	-0.002	0.74	24	-0.07	0.11	0.02	0.14	-14.3
	E	Depth	0.754	-0.096	0.774	43	-0.2	0.2	0.05	0.23	-47.9
	F	Depth	0.606	-0.034	0.745	38	-0.18	0.19	0.06	0.24	-48.5
	G	Depth	0.677	0.042	0.587	19	-0.13	0.14	0.04	0.19	-24.6
	H	Depth	0.292	0.216	0.123	27	-0.12	0.18	0.07	0.27	-25.9
	A	Velocity	0.587	0.569	0.334	64	0.36	0.45	0.31	0.56	68.9
	A1	Velocity	-0.185	0.649	0.026	31	0.18	0.52	0.47	0.69	45
	B	Velocity	0.68	0.214	0.581	57	0.02	0.32	0.18	0.43	3.2
	C	Velocity	0.171	0.399	0.08	39	0.02	0.26	0.1	0.32	5.3
	D2	Velocity	0.831	0.367	0.475	24	0.25	0.33	0.21	0.46	35.3
	E	Velocity	0.435	0.525	0.176	43	0.24	0.44	0.32	0.57	49
	F	Velocity	0.857	0.275	0.544	38	0.2	0.32	0.21	0.46	35.7
	G	Velocity	0.711	0.323	0.465	19	0.19	0.26	0.1	0.32	44
	H	Velocity	0.021	0.533	0.002	27	0.17	0.37	0.22	0.47	45.9
Moderate	A	Depth	0.8	0.015	0.797	42	-0.12	0.16	0.03	0.19	-17.8
	A1	Depth	1.038	0.307	0.444	44	0.34	0.43	0.38	0.62	43.5
	B	Depth	0.39	0.413	0.176	45	0.01	0.16	0.06	0.24	1.3
	C	Depth	1.009	-0.12	0.932	35	-0.11	0.16	0.04	0.2	-13.3
	D1	Depth	0.912	-0.127	0.846	17	-0.19	0.2	0.07	0.26	-26.5
	D2	Depth	1.119	0.014	0.84	27	0.11	0.17	0.04	0.2	13.7
	E	Depth	0.856	-0.073	0.836	44	-0.18	0.19	0.05	0.22	-24
	F	Depth	0.779	-0.153	0.875	42	-0.34	0.34	0.14	0.37	-40.3
	G	Depth	0.891	-0.027	0.521	23	-0.11	0.2	0.09	0.3	-14.4
	H	Depth	0.456	0.45	0.241	26	0.04	0.17	0.08	0.28	5.7
	A	Velocity	0.516	1.005	0.475	42	0.47	0.57	0.62	0.79	42.4
	A1	Velocity	0.252	0.65	0.17	44	0.06	0.51	0.41	0.64	7.6

	B	Velocity	0.207	1.122	0.207	45	0.13	0.49	0.44	0.66	10.5
	C	Velocity	0.668	0.261	0.637	35	0	0.32	0.23	0.48	-0.6
	D1	Velocity	0.368	0.438	0.115	17	0.28	0.34	0.21	0.45	115.3
	D2	Velocity	0.428	0.925	0.454	27	-0.19	0.78	0.87	0.93	-9.6
	E	Velocity	0.421	1.272	0.285	44	0.52	0.63	0.66	0.81	40
	F	Velocity	0.866	0.914	0.531	42	0.76	0.8	1.03	1.01	64.2
	G	Velocity	0.738	0.274	0.527	23	-0.06	0.5	0.32	0.57	-4.6
	H	Velocity	0.299	0.91	0.324	26	0.04	0.58	0.56	0.75	2.9
High	A	Depth	0.911	-0.006	0.916	29	-0.12	0.16	0.04	0.19	-9.3
	A1	Depth	1.166	0.075	0.9	85	0.35	0.37	0.21	0.45	21.2
	B	Depth	1.001	0.115	0.816	115	0.12	0.14	0.03	0.19	9.8
	C	Depth	0.896	0.431	0.716	55	0.27	0.31	0.22	0.46	18
	D1	Depth	0.86	0.152	0.401	24	-0.03	0.38	0.29	0.54	-2.5
	D2	Depth	0.633	0.68	0.193	34	0.31	0.7	0.63	0.79	31.3
	E	Depth	0.964	-0.04	0.887	31	-0.07	0.13	0.03	0.19	-7.7
	F	Depth	0.848	-0.186	0.815	26	-0.36	0.38	0.19	0.43	-31.5
	G	Depth	0.881	0.343	0.775	25	0.21	0.27	0.1	0.31	18.9
	H	Depth	0.274	0.998	0.342	30	0.24	0.33	0.19	0.44	22.9
	A	Velocity	0.749	0.71	0.79	29	0.11	0.43	0.29	0.54	4.7
	A1	Velocity	0.377	1.005	0.514	85	-0.11	0.65	0.63	0.79	-6.1
	B	Velocity	0.437	1.258	0.572	115	-0.24	0.54	0.45	0.67	-9
	C	Velocity	0.551	0.717	0.735	55	-0.17	0.62	0.62	0.79	-8.8
	D1	Velocity	0.559	0.399	0.607	24	-0.15	0.42	0.29	0.54	-12.1
	D2	Velocity	0.063	1.768	0.007	34	-1.11	2.07	5.65	2.38	-36.2
	E	Velocity	0.894	0.218	0.816	31	-0.01	0.42	0.28	0.53	-0.4
	F	Velocity	0.848	1.086	0.628	26	0.76	0.93	1.18	1.09	35.3
	G	Velocity	0.402	1.203	0.656	25	-0.14	0.79	0.84	0.92	-6.1
	H	Velocity	0.401	1.101	0.755	30	-0.09	0.69	0.67	0.82	-4.3

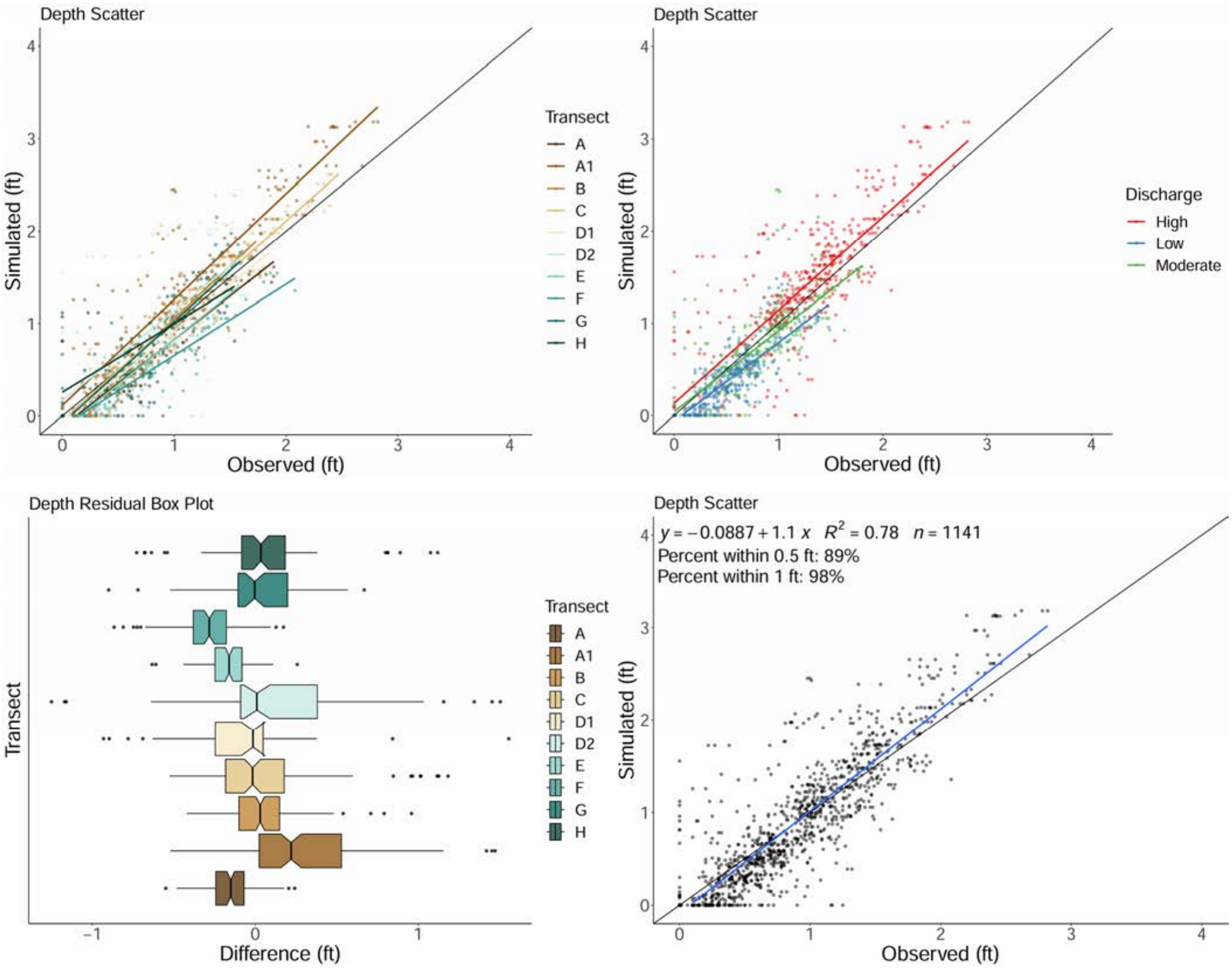


Figure D-1. Linear regression of simulated compared to observed depth at each transect (top left), combined by flow (top right), depth residual error at each transect (bottom left), and for all comparison data combined (bottom right).

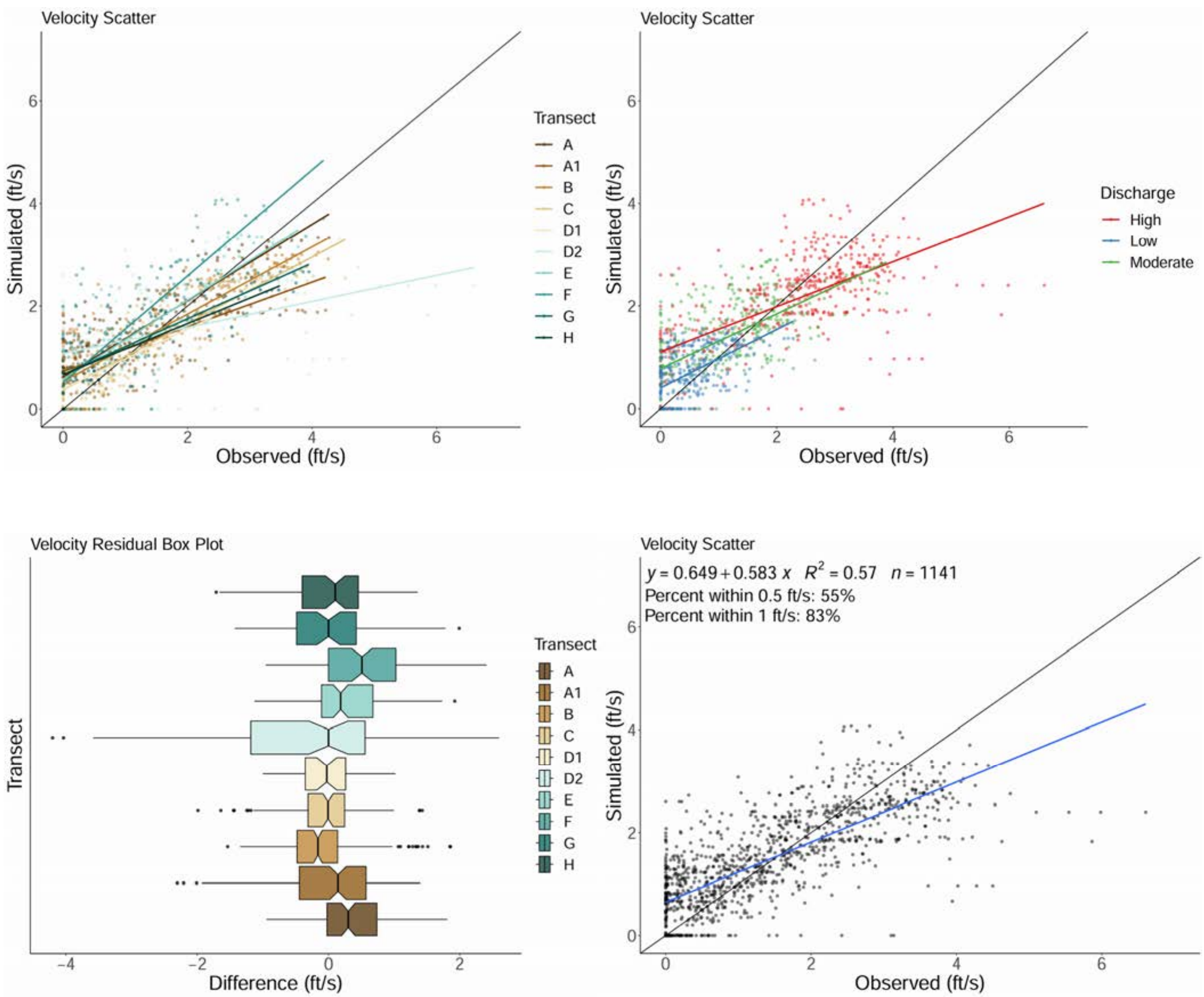


Figure D-2. Linear regression of simulated compared to observed velocity at each transect (top left), combined by flow (top right), velocity residual error at each transect (bottom left), and for all comparison data combined (bottom right).

APPENDIX E: FLOW-HABITAT RELATIONSHIP CURVES

Weighted Usable Area by Flow and Flow Duration by BSR

Study Area

Study Area: HSI WUA

Flow (cfs)	Flow Duration	Weighted Usable Area (Acres)					
		Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
3266	2-Year	341.49	501.44	356.41	430.66	310.41	369.37
2750	1	273.65	407.3	287.04	351.12	247.14	284.96
1571	5	189.39	316.01	199	265.61	165.83	196.67
1122	10	163.05	292.53	172.42	244.09	138.98	175.72
655	20	136.69	263.78	145.17	226.52	113.16	164.79
340	30	113.84	228.2	121.07	197.24	94.66	161.5
176	40	98.08	191.53	104.62	160.08	84.6	147.68
95	50	88.64	160.24	94.28	128.79	79.36	127.84
56	60	79.99	133.27	84.88	104.48	73.57	106.68
41	70	75.71	120.14	80.68	93.59	70.68	95.68
32	80	73.96	115.11	79.02	89.62	69.44	91.36
22	90	67.57	99.64	73.18	78.4	64.51	77.88
14	99	61.17	84.16	67.33	67.17	59.57	64.39

[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

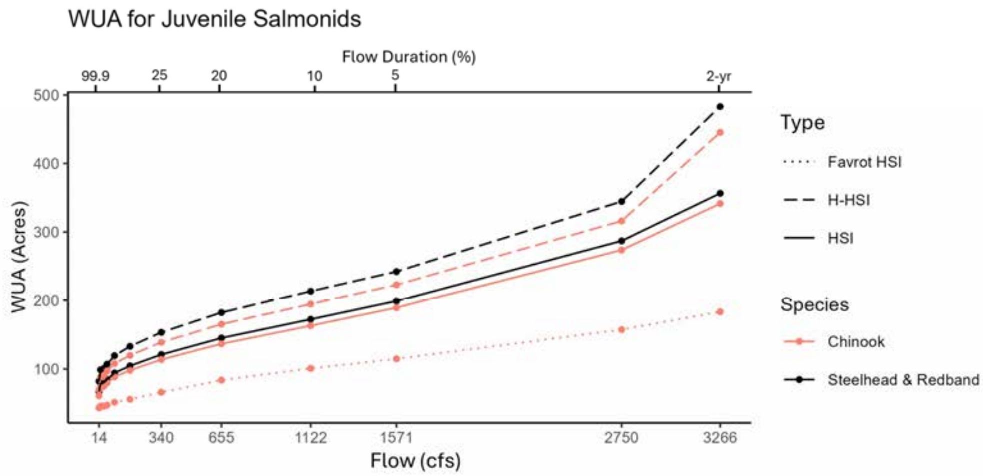
Study Area: Favrot WUA

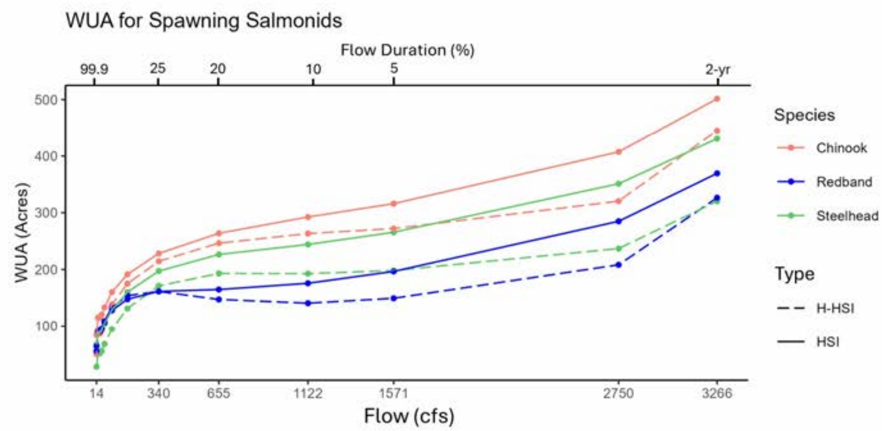
Flow (cfs)	Flow Duration	Weighted Usable Area (Acres) Chinook Juvenile
3266	2-Year	183.32
2750	1	157.37
1571	5	114.81
1122	10	100.93
655	20	83.83
340	30	66.19
176	40	55.99
95	50	51.68
56	60	47.46
41	70	46.39
32	80	46.03
22	90	44.85
14	99	43.66

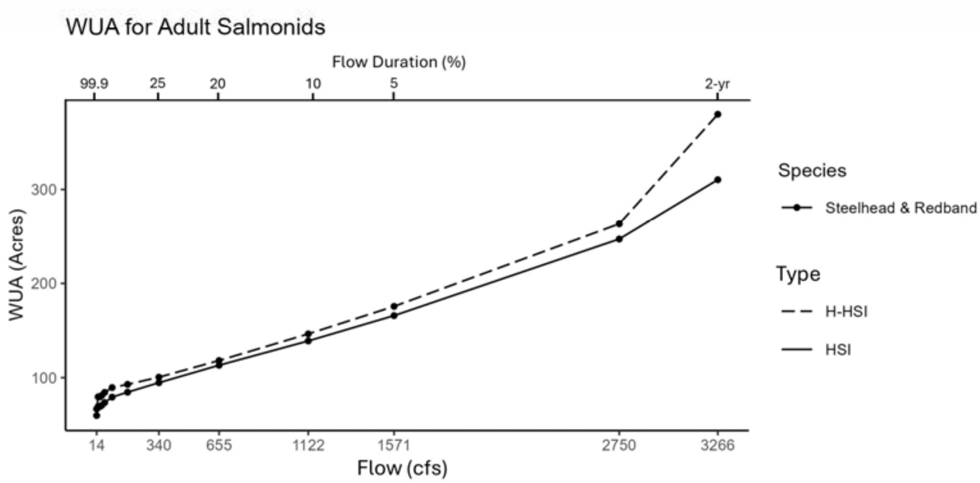
Study Area: H-HSI

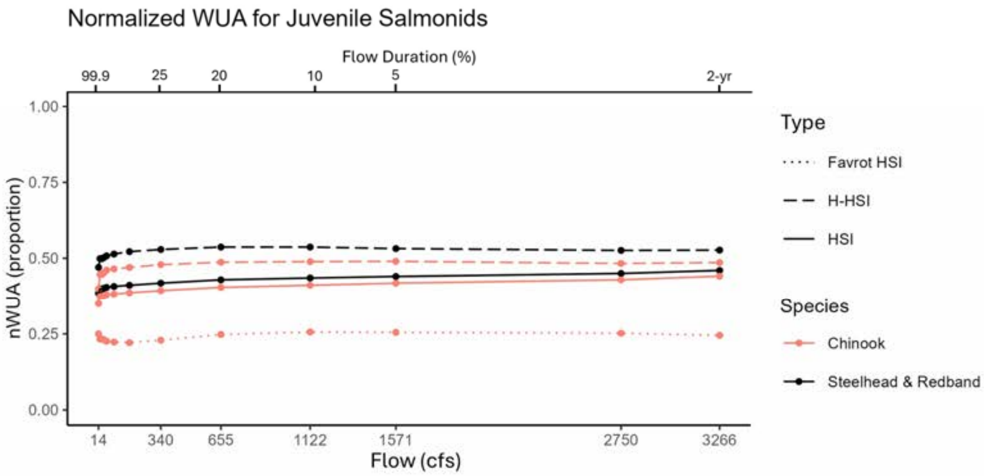
		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
3266	2-Year	445.18	445.03	483.06	320.24	380.01	326.4
2750	1	316.08	320.45	344.53	236.96	263.3	208.32
1571	5	222.81	272.12	242.21	198.3	175.64	149.33
1122	10	194.63	263.34	213.48	192.75	146.43	140.67
655	20	165.28	246.41	182.3	193.07	118.19	147.28
340	30	138.88	214.49	153.39	171.14	100.51	161.37
176	40	119.85	175.11	132.98	131.36	92.87	154.08
95	50	108.06	138.4	119.38	94.79	89.5	132.69
56	60	97.21	107.81	107.03	68.25	84.37	108.67
41	70	91.21	92.25	101.19	56.05	81.14	95.13
32	80	88.71	86.3	98.86	51.66	79.67	89.74
22	90	79.35	68.24	90.61	39.87	73.24	72.76
14	99	69.99	50.17	82.35	28.08	66.8	55.78

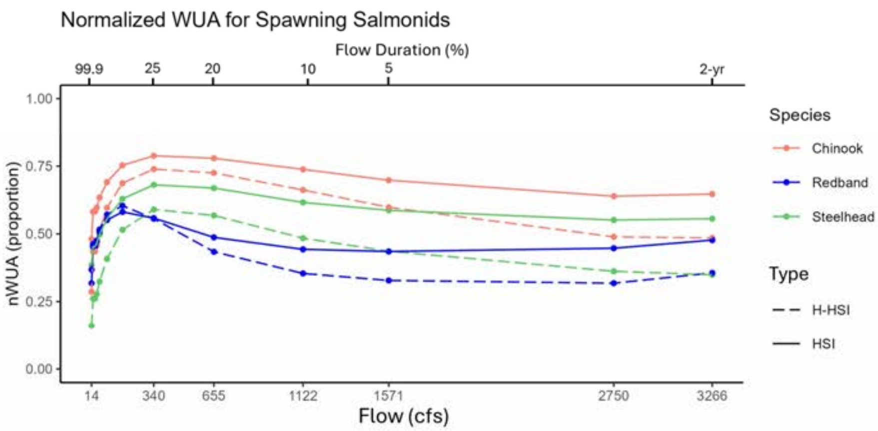
[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

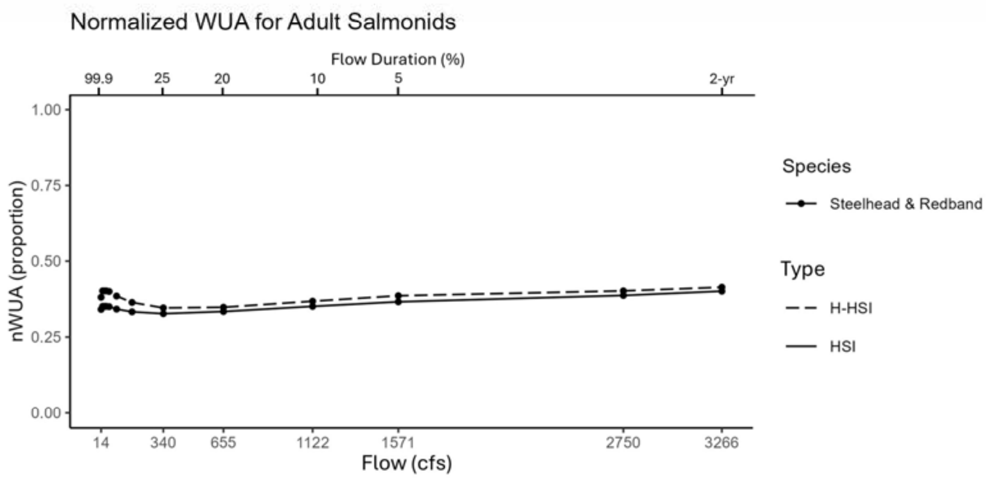

WUA for Juvenile Salmonids
Flow Duration (%)
99.9
25
20
10
5
2-yr
WUA (Acres)
500
400
300
200
100
14
340
655
1122
1571
2750
3266
Flow (cfs)
Type
Favrot HSI
H-HSI
HSI
Species
Chinook
Steelhead & Redband


WUA for Spawning Salmonids
Flow Duration (%)
99.9
25
20
10
5
2-yr
WUA (Acres)
500
400
300
200
100
14
340
655
1122
1571
2750
3266
Flow (cfs)
Species
Chinook
Redband
Steelhead
Type
H-HSI
HSI


WUA for Adult Salmonids
Flow Duration (%)
99.9
25
20
10
5
2-yr
WUA (Acres)
300
200
100
14
340
655
1122
1571
2750
3266
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI


Normalized WUA for Juvenile Salmonids
Flow Duration (%)
99.9
25
20
10
5
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
14
340
655
1122
1571
2750
3266
Flow (cfs)
Type
Favrot HSI
H-HSI
HSI
Species
Chinook
Steelhead & Redband


Normalized WUA for Spawning Salmonids
Flow Duration (%)
99.9
25
20
10
5
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
14
340
655
1122
1571
2750
3266
Flow (cfs)
Species
Chinook
Redband
Steelhead
Type
H-HSI
HSI


Normalized WUA for Adult Salmonids
Flow Duration (%)
99.9
25
20
10
5
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
14
340
655
1122
1571
2750
3266
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI

BSR 11

BSR 11: HSI WUA

		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
2874	2-Year	201.24	295.15	210.61	255.64	185.89	218.79
2420	1	174.07	256.34	182.75	222.27	161.19	186.55
1382	5	116.09	189.83	122.25	159.89	104.64	122.37
987	10	98.59	173.83	104.41	146.08	85.31	105.31
576	20	80.65	155.14	85.3	137.17	65.86	94.77
299	30	65.97	135.72	69.64	121.58	52.81	91.85
154	40	54.87	113.79	58.36	97.76	45.6	84.04
83	50	48.04	93.22	51.09	76.52	41.84	72.29
49	60	42.16	75.51	44.85	60.55	38.07	59.69
36	70	39.19	67.01	42.03	53.57	36.12	53.1
28	80	38.01	63.84	40.95	51.1	35.31	50.54
19	90	34.15	54.98	37.54	44.81	32.4	43.14
12	99	30.29	46.12	34.12	38.52	29.48	35.74

[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

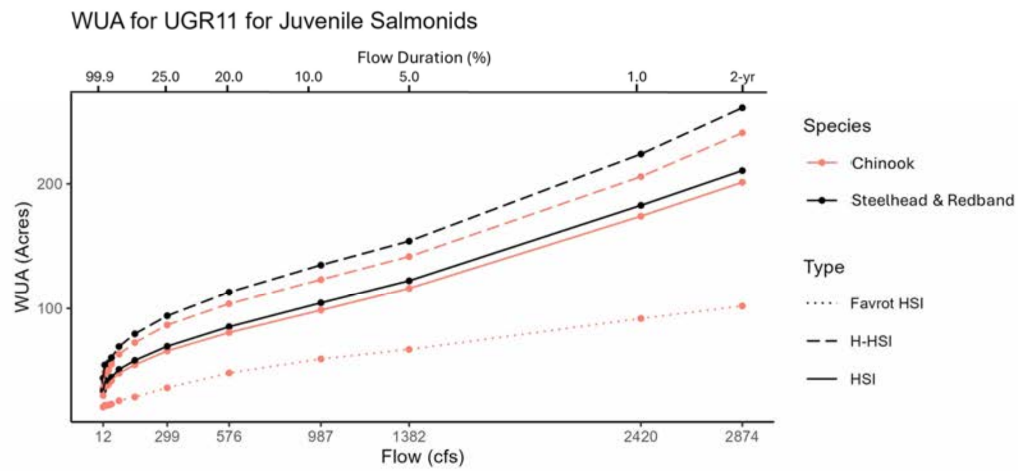
BSR 11: Favrot HSI

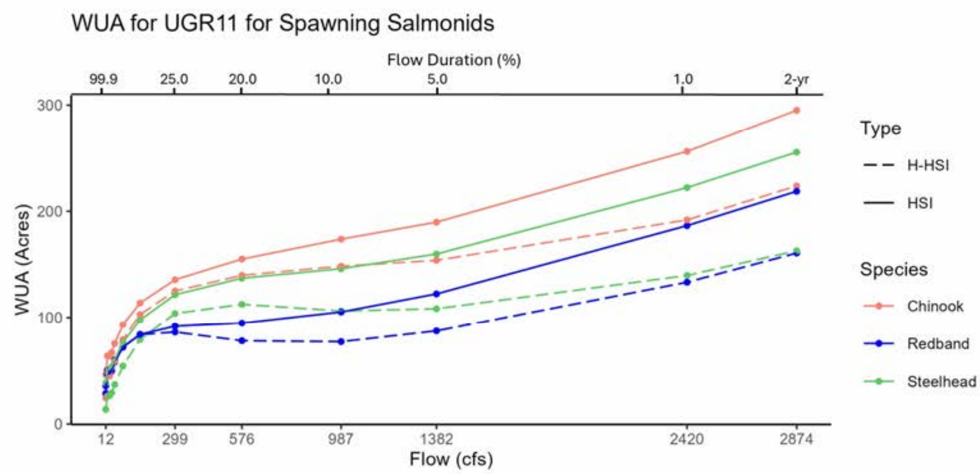
Flow (cfs)	Flow Duration	Weighted Usable Area (Acres) Chinook Juvenile
2874	2-Year	101.91
2420	1	91.9
1382	5	67.11
987	10	59.54
576	20	48.26
299	30	36.43
154	40	29.14
83	50	26.13
49	60	23.4
36	70	22.71
28	80	22.47
19	90	21.82
12	99	21.16

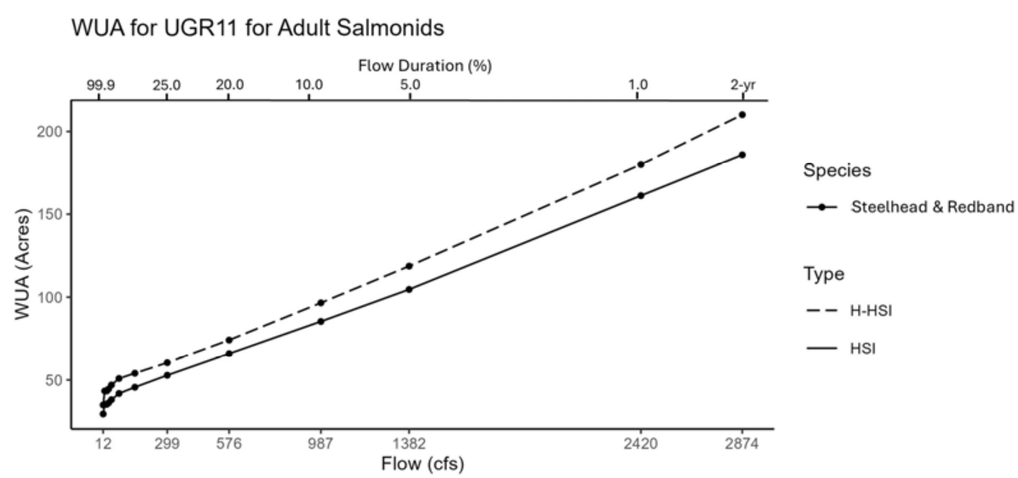
BSR 11: H-HSI WUA

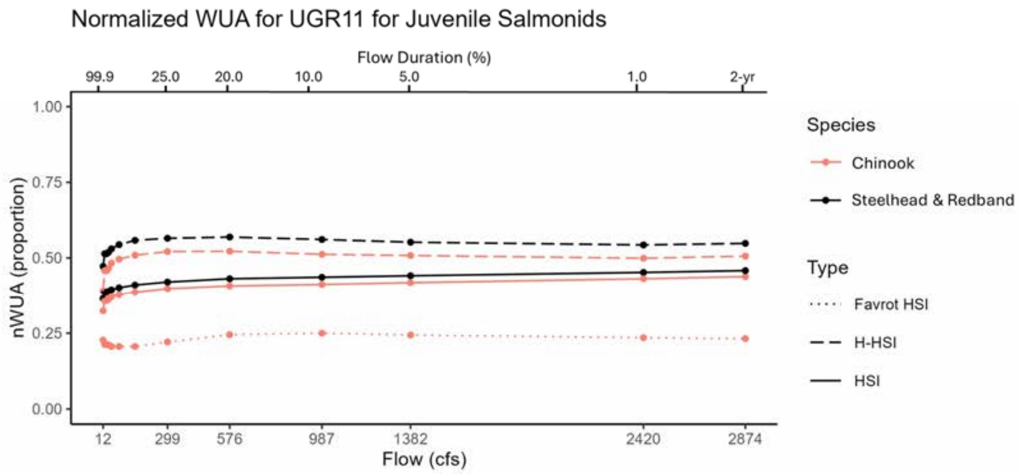
		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
2874	2-Year	240.8	223.83	260.95	162.92	210.17	160.78
2420	1	205.77	191.94	223.88	139.75	180.01	133.38
1382	5	141.68	153.95	154.07	108.38	118.68	87.43
987	10	123.16	148.44	134.87	106.25	96.54	77.28
576	20	103.71	139.84	113.03	112.58	74.07	78.13
299	30	86.71	125.07	94.08	103.91	60.38	86.34
154	40	72.6	102.95	79.6	79.2	54.03	83.86
83	50	63.28	79.01	69.4	54.42	50.87	71.97
49	60	55.11	58.83	60.51	36.95	46.93	58.14
36	70	50.59	48.77	56.3	29.2	44.44	50.22
28	80	48.75	45.02	54.67	26.51	43.35	47.09
19	90	42.64	34.76	49.44	20.11	39.13	37.93
12	99	36.52	24.49	44.21	13.7	34.9	28.76

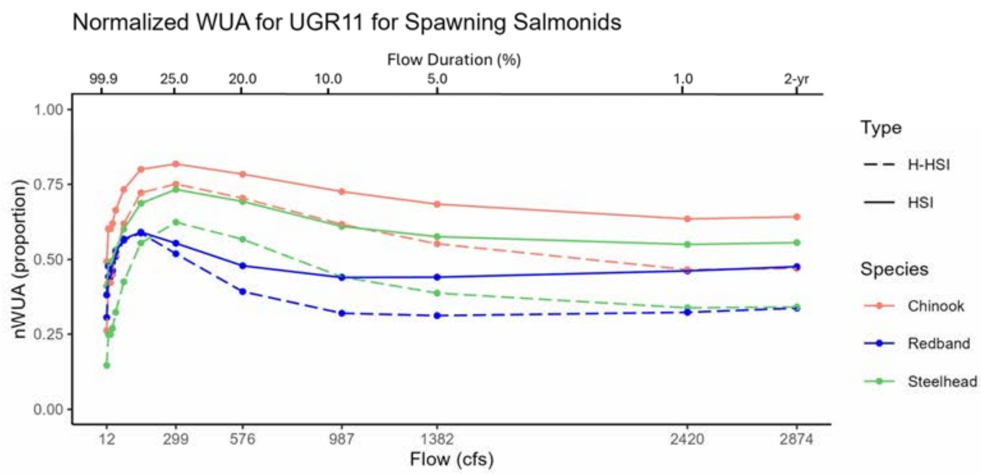
[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

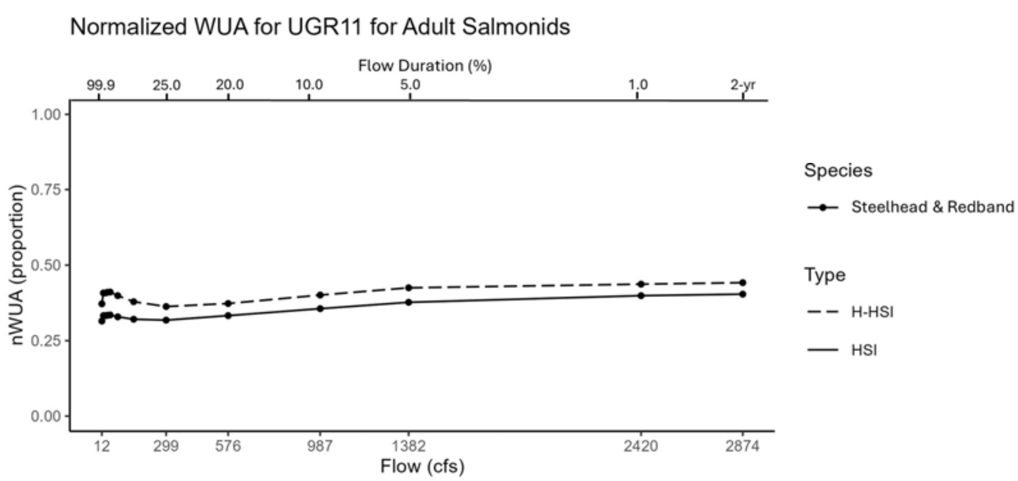

WUA for UGR11 for Juvenile Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
100
200
12
299
576
987
1382
2420
2874
Flow (cfs)
Species
Chinook
Steelhead & Redband
Type
Favrot HSI
H-HSI
HSI


WUA for UGR11 for Spawning Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
0
100
200
300
12
299
576
987
1382
2420
2874
Flow (cfs)
Type
H-HSI
HSI
Species
Chinook
Redband
Steelhead


WUA for UGR11 for Adult Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
50
100
150
200
12
299
576
987
1382
2420
2874
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI


Normalized WUA for UGR11 for Juvenile Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
12
299
576
987
1382
2420
2874
Flow (cfs)
Species
Chinook
Steelhead & Redband
Type
Favrot HSI
H-HSI
HSI


Normalized WUA for UGR11 for Spawning Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
12
299
576
987
1382
2420
2874
Flow (cfs)
Type
H-HSI
HSI
Species
Chinook
Redband
Steelhead


Normalized WUA for UGR11 for Adult Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
12
299
576
987
1382
2420
2874
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI

BSR 15

BSR 15: HSI

		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
1211	2-Year	68.76	94.13	70.79	80.65	59.94	61.84
515	1	50.65	75.64	52.46	64.36	42.08	44.44
385	5	42.7	71.76	44.34	59.53	35.01	39.17
316	10	38.4	69.25	40.23	56.35	31.64	37.71
233	20	33.73	64.92	35.97	52.2	28.44	38.39
124	30	28.3	54.97	30.54	44.06	24.94	39.88
67	40	25.36	45.43	27.21	35.88	23.11	36.66
38	50	23.64	38.14	25.15	29.29	22.06	31.13
23	60	21.82	32.05	23.06	23.96	20.65	25.43
18	70	20.98	29.08	22.14	21.45	20.02	22.48
14	80	20.64	27.96	21.78	20.54	19.75	21.37
9	90	19.16	24.11	20.32	17.55	18.55	17.67
6	99	17.68	20.25	18.85	14.55	17.35	13.97

[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

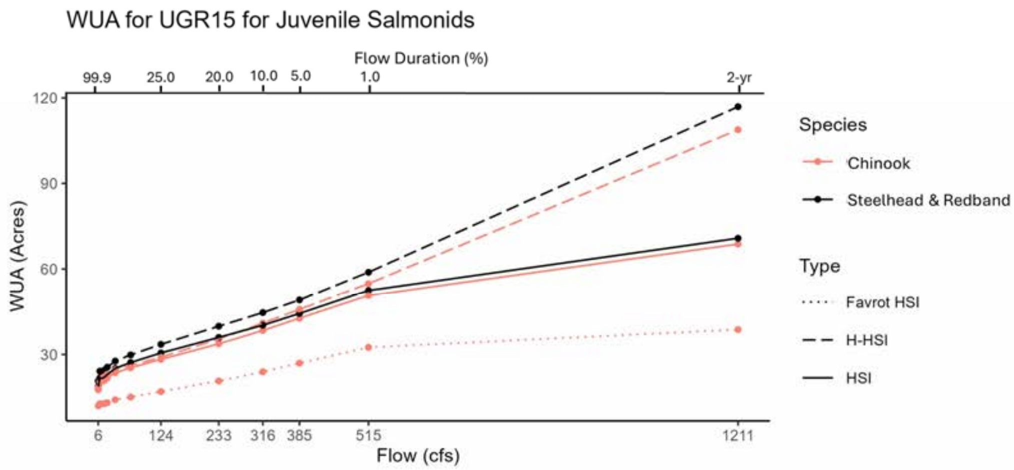
BSR 15: Favrot HSI

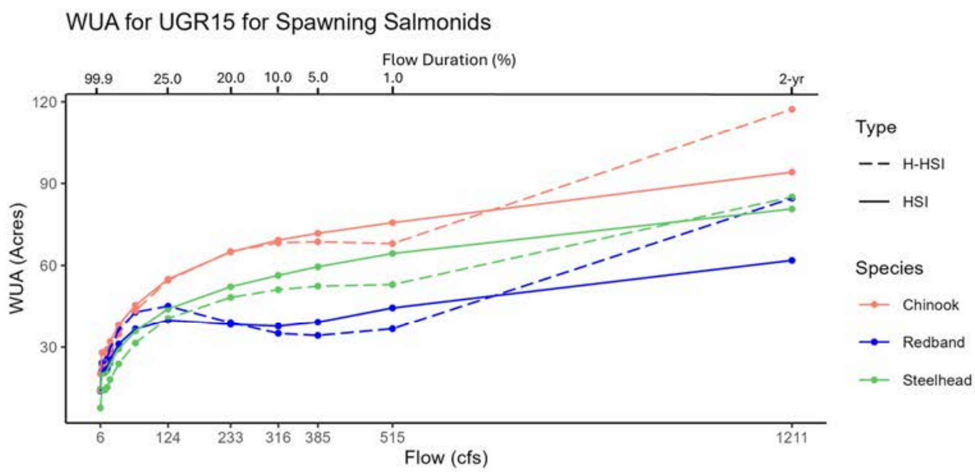
Flow (cfs)	Flow Duration	Weighted Usable Area (Acres) Chinook Juvenile
1211	2-Year	38.72
515	1	32.49
385	5	27
316	10	23.96
233	20	20.75
124	30	17.05
67	40	15.15
38	50	14.23
23	60	13.19
18	70	12.9
14	80	12.8
9	90	12.44
6	99	12.07

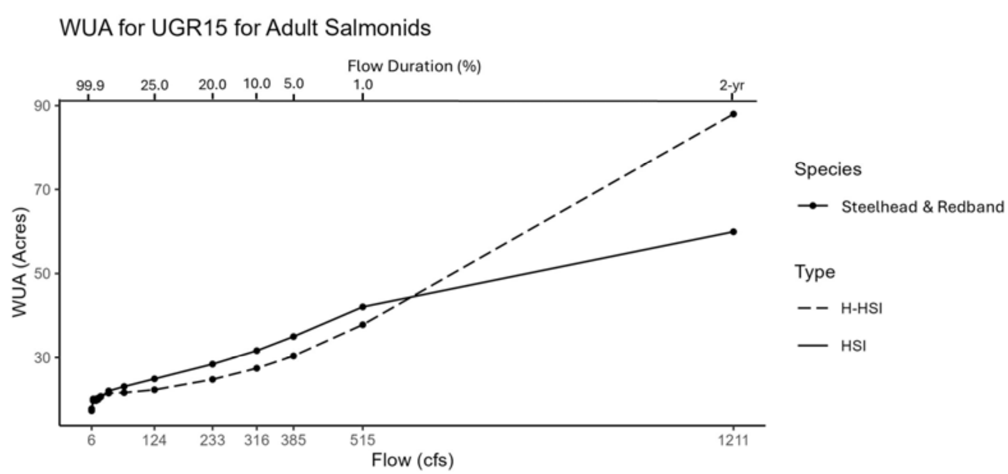
BSR 15: H-HSI

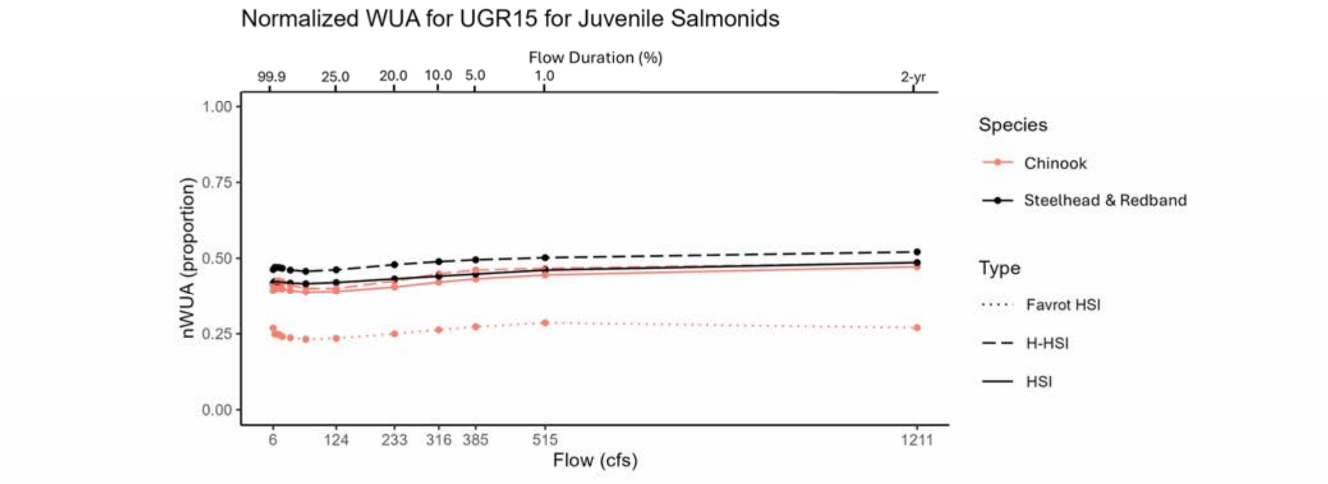
		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
1211	2-Year	108.77	117.28	116.83	85.05	88	84.58
515	1	54.86	68	58.88	53	37.84	36.72
385	5	45.76	68.66	49.08	52.43	30.38	34.27
316	10	40.99	68.28	44.67	51.13	27.46	35.04
233	20	35.39	65.1	39.88	48.3	24.81	39.01
124	30	29.06	54.57	33.55	40.59	22.34	45.11
67	40	26.15	43.37	29.86	31.47	21.65	42.88
38	50	24.71	34.71	27.72	23.85	21.54	36.31
23	60	23.12	27.95	25.59	18.15	20.77	29.43
18	70	22.28	24.47	24.59	15.34	20.35	25.65
14	80	21.92	23.17	24.2	14.32	20.15	24.21
9	90	20.19	18.70	22.51	11.05	18.98	19.38
6	99	18.46	14.23	20.81	7.78	17.81	14.54

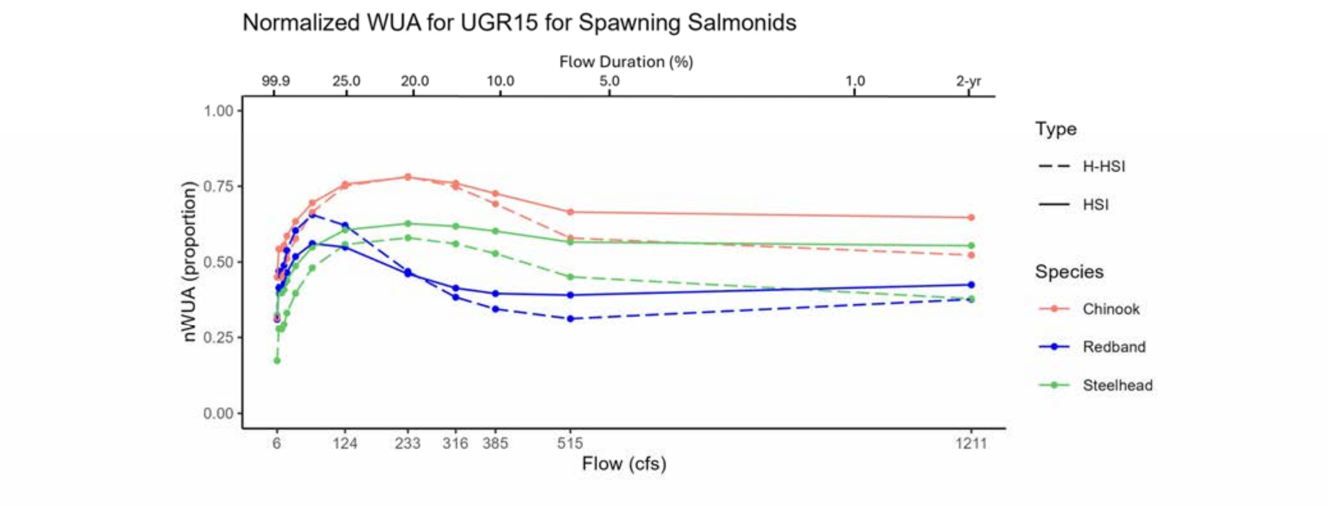
[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

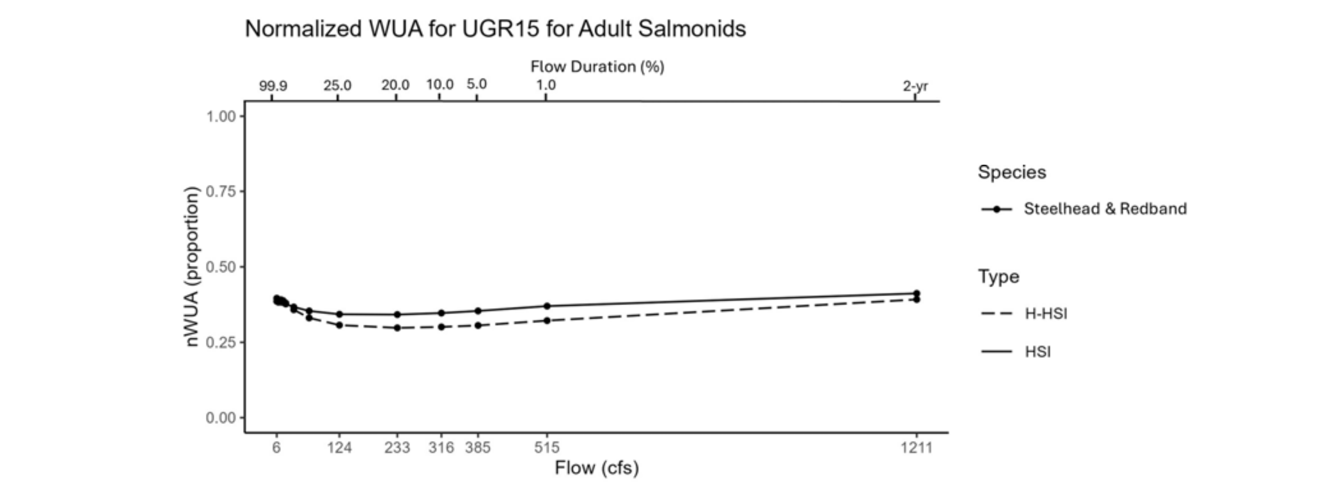

WUA for UGR15 for Juvenile Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
120
90
60
30
6
124
233
316
385
515
1211
Flow (cfs)
Species
Chinook
Steelhead & Redband
Type
Favrot HSI
H-HSI
HSI


WUA for UGR15 for Spawning Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
120
90
60
30
6
124
233
316
385
515
1211
Flow (cfs)
Type
H-HSI
HSI
Species
Chinook
Redband
Steelhead


WUA for UGR15 for Adult Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
90
70
50
30
6
124
233
316
385
515
1211
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI


Normalized WUA for UGR15 for Juvenile Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
6
124
233
316
385
515
1211
Flow (cfs)
Species
Chinook
Steelhead & Redband
Type
Favrot HSI
H-HSI
HSI


Normalized WUA for UGR15 for Spawning Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
6
124
233
316
385
515
1211
Flow (cfs)
Type
H-HSI
HSI
Species
Chinook
Redband
Steelhead


Normalized WUA for UGR15 for Adult Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
6
124
233
316
385
515
1211
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI

BSR 17

BSR 17: HSI

		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
842	2-Year	50.48	82.9	53.09	69.27	45.42	65.93
406	1	28.95	48.14	30.95	40.99	25.47	32.72
274	5	16.85	34.45	18.04	29.13	13.81	20.84
209	10	14.33	31.26	15.45	26.64	11.71	20.21
141	20	12.46	27.55	13.51	23.53	10.43	20.85
74	30	11.03	23.07	11.9	19.29	9.59	19.38
42	40	10.25	19.52	10.94	15.78	9.16	16.71
26	50	9.75	17.35	10.35	13.74	8.87	14.82
18	60	9.22	15.54	9.8	12.18	8.5	13.14
14	70	8.96	14.63	9.55	11.44	8.32	12.29
12	80	8.84	14.23	9.43	11.12	8.23	11.92
9	90	8.26	12.65	8.9	9.95	7.79	10.49
6	99	7.68	11.06	8.37	8.77	7.35	9.05

[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

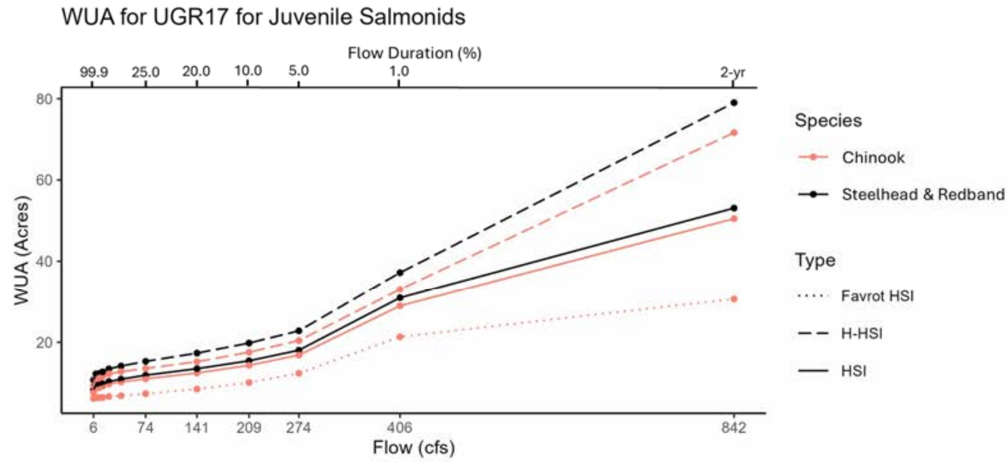
BSR 17 Favrot HSI:

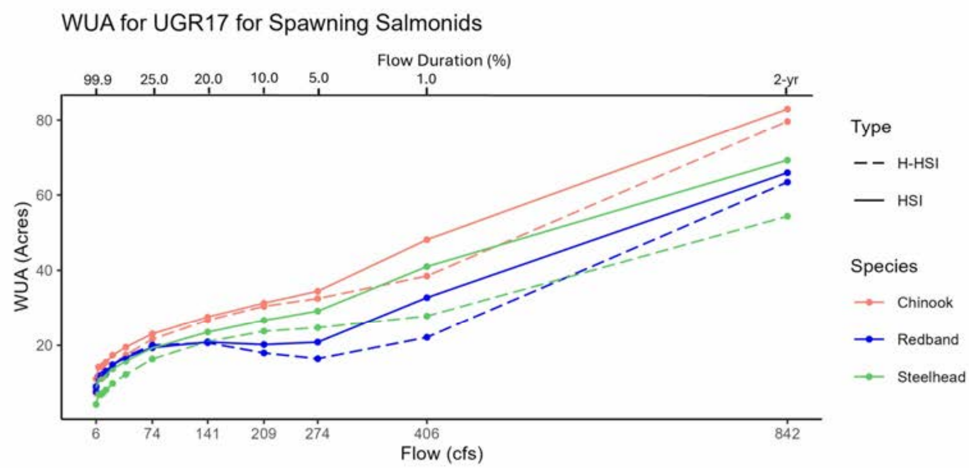
Flow (cfs)	Flow Duration	Weighted Usable Area (Acres) Chinook Juvenile
842	2-Year	30.64
406	1	21.35
274	5	12.38
209	10	10.11
141	20	8.5
74	30	7.37
42	40	6.88
26	50	6.68
18	60	6.46
14	70	6.41
12	80	6.4
9	90	6.31
6	99	6.21

BSR 17: H-HSI

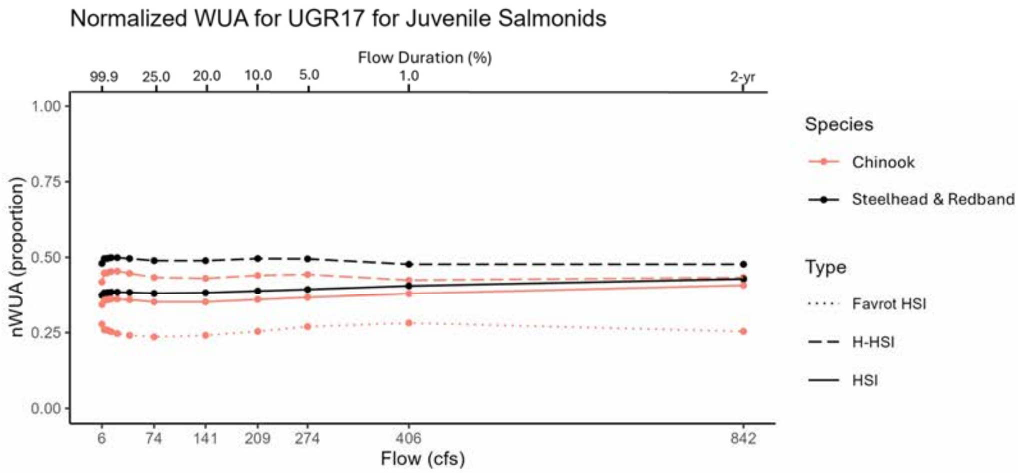
		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
842	2-Year	71.66	79.63	79.03	54.36	61.44	63.42
406	1	33.03	38.48	37.18	27.79	26.11	22.13
274	5	20.4	32.49	22.8	24.71	14.33	16.44
209	10	17.55	30.42	19.8	23.77	12.31	17.95
141	20	15.22	26.69	17.33	21	11.17	20.67
74	30	13.57	21.63	15.31	16.35	10.68	20.04
42	40	12.79	17.45	14.17	12.26	10.62	17.08
26	50	12.25	14.88	13.46	9.89	10.49	14.85
18	60	11.58	12.78	12.74	8.16	10.14	12.84
14	70	11.22	11.66	12.39	7.3	9.94	11.77
12	80	11.05	11.17	12.23	6.94	9.84	11.29
9	90	10.2	9.27	11.48	5.64	9.27	9.5
6	99	9.35	7.36	10.73	4.33	8.7	7.7

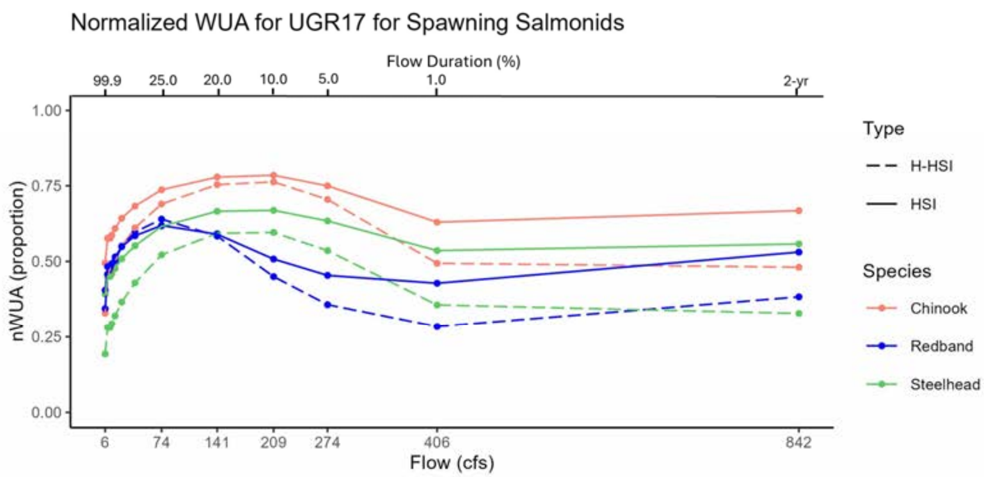
[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

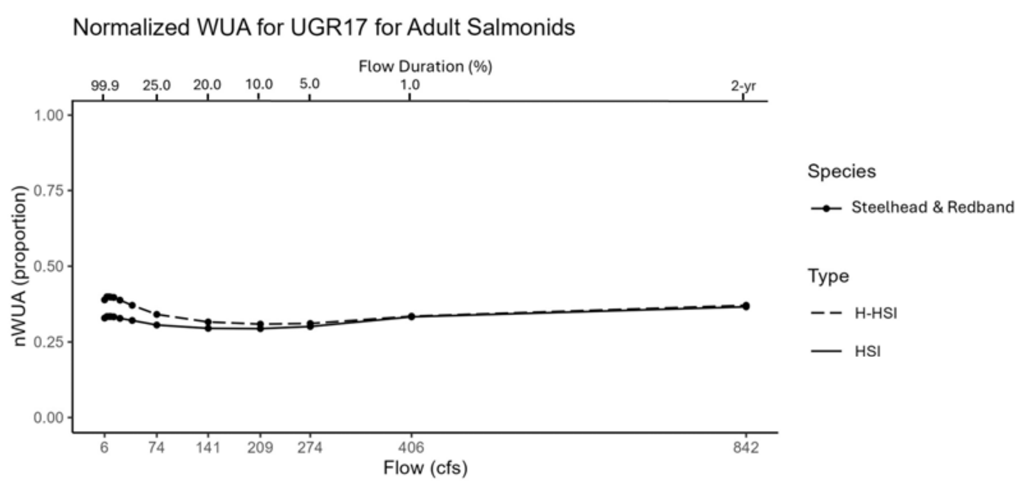

WUA for UGR17 for Juvenile Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
80
60
40
20
6
74
141
209
274
406
842
Flow (cfs)
Species
Chinook
Steelhead & Redband
Type
Favrot HSI
H-HSI
HSI


WUA for UGR17 for Spawning Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
80
60
40
20
6
74
141
209
274
406
842
Flow (cfs)
Type
H-HSI
HSI
Species
Chinook
Redband
Steelhead


WUA for UGR17 for Adult Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
WUA (Acres)
60
40
20
6
74
141
209
274
406
842
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI


Normalized WUA for UGR17 for Juvenile Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
6
74
141
209
274
406
842
Flow (cfs)
Species
Chinook
Steelhead & Redband
Type
Favrot HSI
H-HSI
HSI


Normalized WUA for UGR17 for Spawning Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
6
74
141
209
274
406
842
Flow (cfs)
Type
H-HSI
HSI
Species
Chinook
Redband
Steelhead


Normalized WUA for UGR17 for Adult Salmonids
Flow Duration (%)
99.9
25.0
20.0
10.0
5.0
1.0
2-yr
nWUA (proportion)
1.00
0.75
0.50
0.25
0.00
6
74
141
209
274
406
842
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI

BSR 20

BSR 20: HSI WUA

		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
344	2-Year	26.75	38.8	27.99	32.71	23.61	30.03
300	1	23.05	33.47	24.24	28.41	20.3	25.03
165	5	15.04	24.34	15.95	20.39	13	16.93
104	10	12.38	20.96	13.24	17.23	10.84	15.22
50	20	10.14	16.84	10.93	13.53	9.22	13.78
26	30	8.85	13.39	9.49	10.5	8.25	11.62
17	40	8.16	11.32	8.71	8.7	7.71	9.86
15	50	7.85	10.53	8.36	8.03	7.45	9.12
12	60	7.42	9.65	7.88	7.3	7.07	8.24
11	70	7.27	9.25	7.73	6.98	6.95	7.86
10	80	7.19	9.03	7.64	6.81	6.88	7.65
8	90	6.77	8.07	7.23	6.07	6.53	6.73
5	99	6.35	7.11	6.81	5.32	6.18	5.81

[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

BSR 20: Favrot HSI WUA

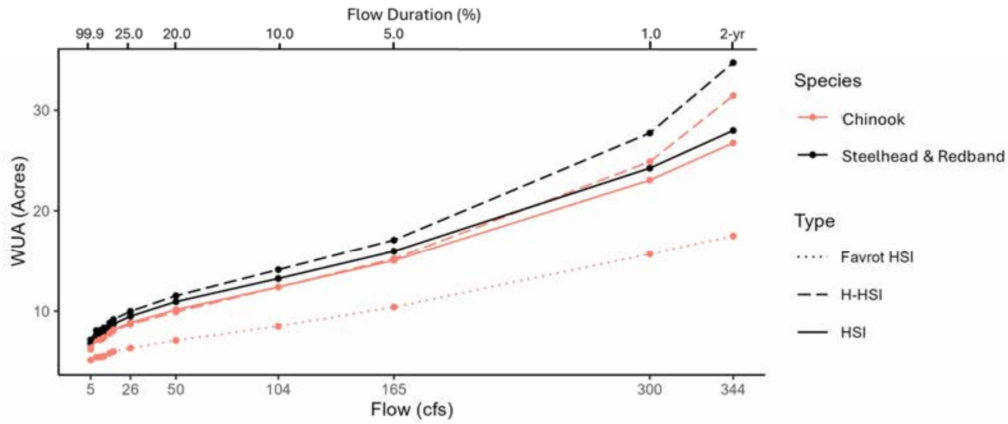
Flow (cfs)	Flow Duration	Weighted Usable Area (Acres) Chinook Juvenile
344	2-Year	17.48
300	1	15.68
165	5	10.4
104	10	8.49
50	20	7.09
26	30	6.34
17	40	5.98
15	50	5.81
12	60	5.52
11	70	5.46
10	80	5.43
8	90	5.29
5	99	5.14

BSR 20: H-HSI WUA

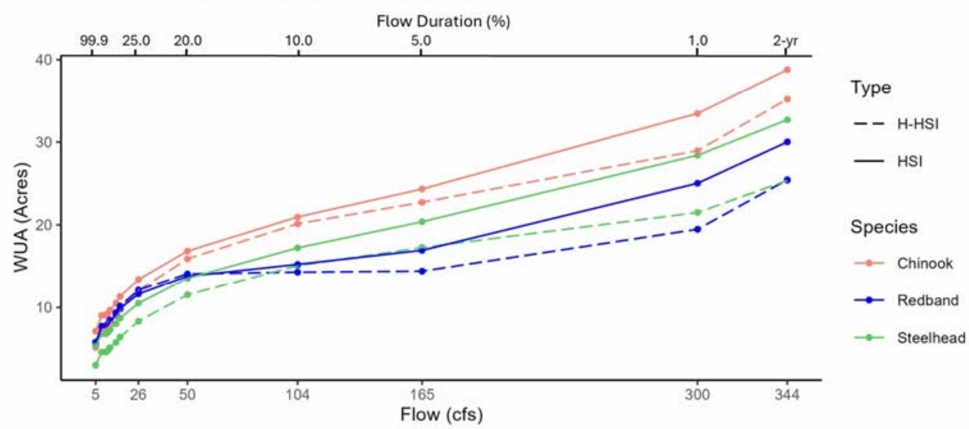
		Weighted Usable Area (Acres)					
Flow (cfs)	Flow Duration	Chinook		Steelhead			Redband
		Juvenile	Spawning	Juvenile[1]	Spawning	Adult[1]	Spawning
344	2-Year	31.45	35.21	34.73	25.37	25.25	25.46
300	1	24.88	28.97	27.74	21.5	19.51	19.48
165	5	15.21	22.74	17.07	17.27	11.15	14.41
104	10	12.38	20.14	14.12	15.07	9.32	14.29
50	20	9.91	15.89	11.52	11.53	8.08	14.07
26	30	8.68	12.05	9.98	8.33	7.49	12.1
17	40	8.05	9.74	9.16	6.42	7.17	10.15
15	50	7.78	8.92	8.81	5.78	6.99	9.37
12	60	7.39	8.07	8.33	5.14	6.7	8.46
11	70	7.24	7.61	8.17	4.79	6.6	7.99
10	80	7.15	7.36	8.07	4.6	6.54	7.73
8	90	6.68	6.25	7.605	3.805	6.21	6.595
5	99	6.21	5.14	7.14	3.01	5.88	5.46

[1] HSCs for juvenile steelhead and redband are the same, HSCs for adult rearing for steelhead and redband are the same.

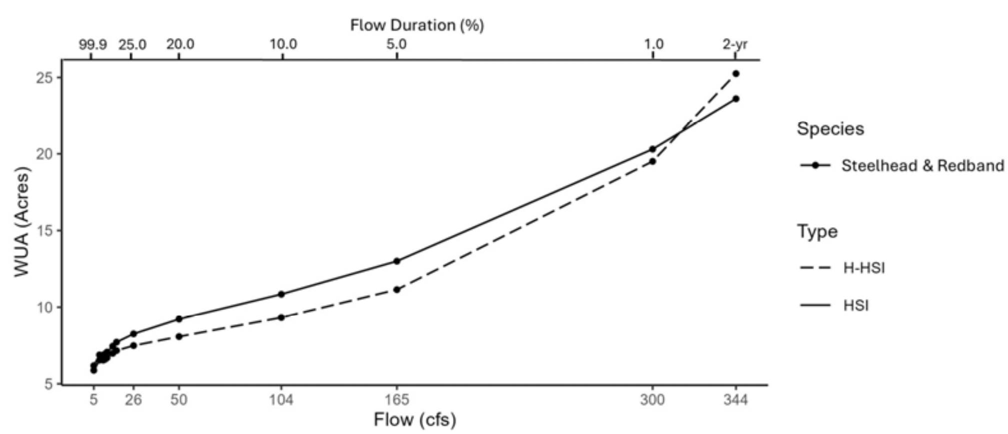
WUA for UGR20 for Juvenile Salmonids

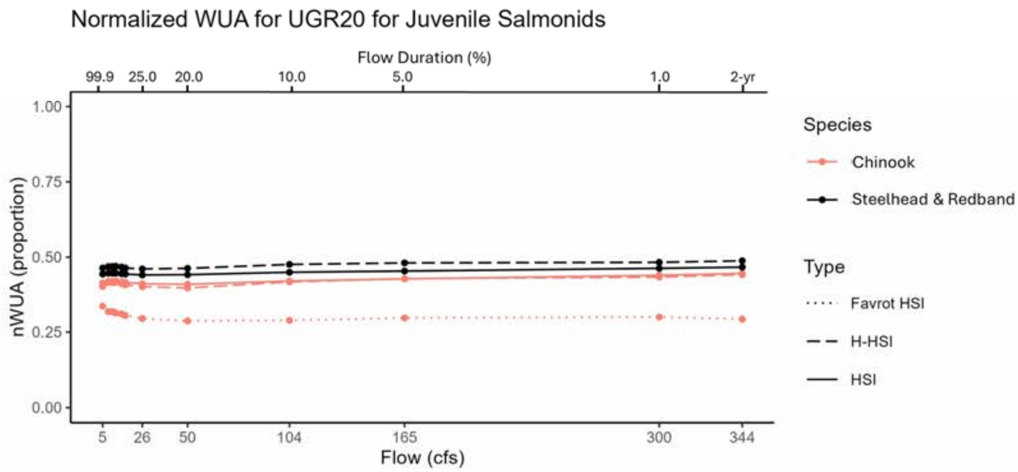


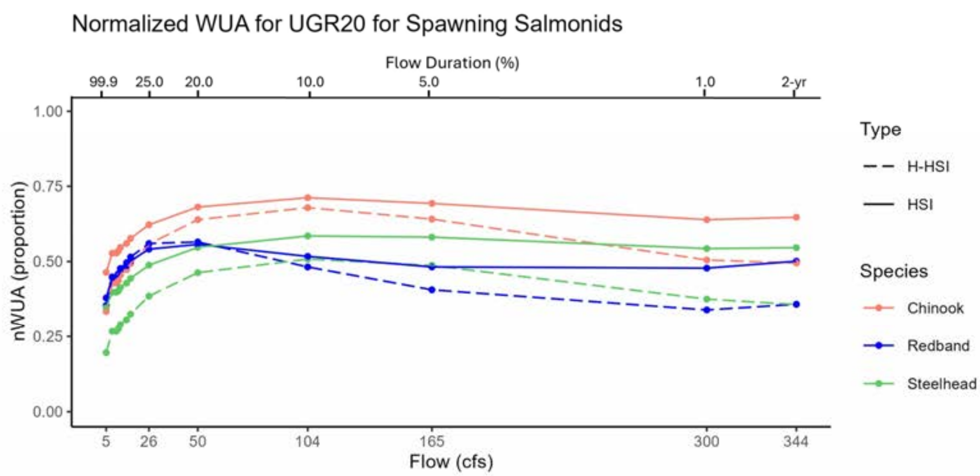
WUA for UGR20 for Spawning Salmonids

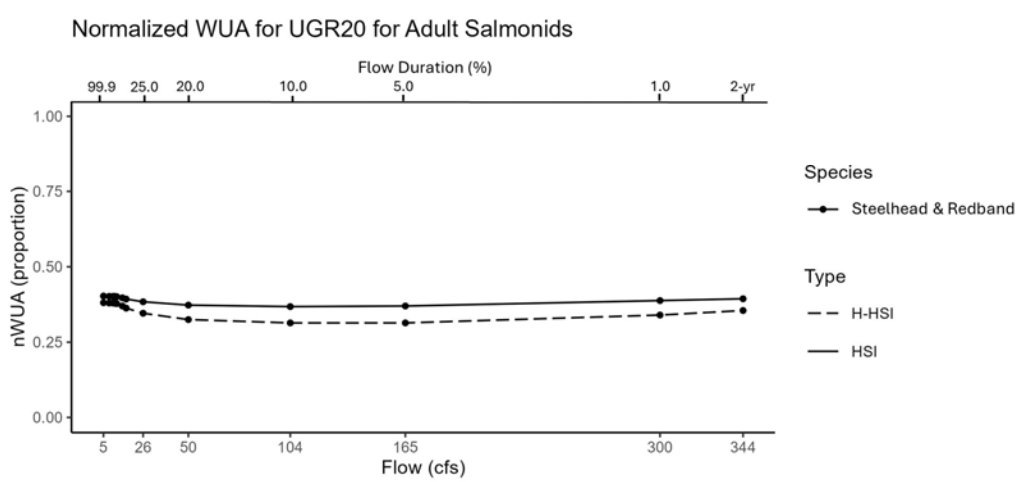


WUA for UGR20 for Adult Salmonids




Normalized WUA for UGR20 for Juvenile Salmonids
Flow Duration (%)
99.9 25.0 20.0 10.0 5.0 1.0 2-yr
nWUA (proportion)
1.00 0.75 0.50 0.25 0.00
5 26 50 104 165 300 344
Flow (cfs)
Species
Chinook
Steelhead & Redband
Type
Favrot HSI
H-HSI
HSI


Normalized WUA for UGR20 for Spawning Salmonids
Flow Duration (%)
99.9 25.0 20.0 10.0 5.0 1.0 2-yr
nWUA (proportion)
1.00 0.75 0.50 0.25 0.00
5 26 50 104 165 300 344
Flow (cfs)
Type
H-HSI
HSI
Species
Chinook
Redband
Steelhead


Normalized WUA for UGR20 for Adult Salmonids
Flow Duration (%)
99.9 25.0 20.0 10.0 5.0 1.0 2-yr
nWUA (proportion)
1.00 0.75 0.50 0.25 0.00
5 26 50 104 165 300 344
Flow (cfs)
Species
Steelhead & Redband
Type
H-HSI
HSI