

# REPORT



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## Chinook Salmon Spawning Habitat Availability in the Lower Columbia River

**Submitted to:**

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Cover Photo: Google Earth image of Norn's Creek mouth and fan on the Columbia River near Castlegar, BC.

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## Executive Summary

The completion of Grand Coulee Dam in the early 1940s stopped the natural migration of anadromous fish into the upper Columbia River. First Nations groups have been on the forefront of investigating the feasibility of reintroducing of anadromous fish into the Columbia River upstream of this dam. A key part of this work is to assess the availability of habitat for the early life stages of salmon species that may once again utilize upstream reaches of the Columbia River and its tributaries. The Canadian Columbia River Inter-tribal Fisheries Commission (CCRFC) contracted Golder Associates Ltd. (Golder) to conduct preliminary assessments on the amount of potential spawning habitat available for Chinook Salmon (*Oncorhynchus tshawytscha*), Steelhead and Rainbow Trout (*Oncorhynchus mykiss*) in the Transboundary Reach of the Columbia River.

In this report we build on the previous work done for this project in 2016 (Golder 2016), addressing some of the recommendations that were made for further research. We summarize the most recent 15 years of hydrographic information available from the Kootenay and Columbia rivers for the time period when Chinook Salmon are most likely to spawn, if they were transplanted into the area. The hydrographic data were summarized, and all combinations of the Kootenay and Columbia rivers discharges, using the median, low and high flows, were estimated. These data were used to model Chinook Salmon spawning habitat at two different reaches of the lower Kootenay and Columbia rivers that are hypothesized to have potential for supporting Chinook Salmon spawning.

A River2D model, previously used to model Mountain Whitefish (*Prosopium williamsoni*) spawning in the area, was used to simulate depth, velocities and available substrate at a variety of flows, based on the recent hydrographs. Habitat Suitability Criteria (HSC) developed in the Washington State for the Columbia-Snake rivers and other Large Rivers (Beecher et al. 2016) were used in conjunction with the hydraulic model, to project Weighted Usable Area (WUA) for Chinook Salmon and Steelhead spawning in the two reaches that has been previously modelled. The depth and velocity Habitat Suitability Index (HSI) curves for Rainbow Trout developed in Thorley and Baxter (2011) were also used for analysis. Substrate data for inclusion in this program were provided by BC Hydro (Preston 2014). Using literature defined values for required area of useable habitat per redd developed for the Hanford Reach of the Columbia River and observed actual use of available habitat, estimates on the range of redds that the suitable spawning habitat within the study area could potentially support were provided.

The modelling predicted Chinook Salmon spawning areas ranging from 3,000 m<sup>2</sup> to 119,000 m<sup>2</sup> in the Columbia River with the median flow at 22,000 m<sup>2</sup> with the Large River HSC, and 112,000 m<sup>2</sup> using the Columbia-Snake HSC. The Kootenay River Reach model predicted a range of 2,000 m<sup>2</sup> to 75,000 m<sup>2</sup> with the median estimate of 4,000 m<sup>2</sup> and 62,000 m<sup>2</sup> using the Large Rivers and Columbia-Snake HSC, respectively. The combined areas estimate at the median values were 26,000 m<sup>2</sup> and 178,000 m<sup>2</sup> using the Large Rivers and Columbia-Snake HSC, respectively. The median values for the Columbia reach represented 5% (Large Rivers HSC) to 26% (Columbia-Snake HSC) of the wetted area available and for the Kootenay River Reach; 1% (Large Rivers HSC) to 18% (Columbia-Snake HSC) of the wetted area was available for Chinook Salmon spawning. Using values for average required area of useable habitat per Chinook Salmon redd developed for the Hanford Reach of the Columbia River, and observed actual use of available habitat of 15%, it was estimated that 93 to 565 redds or spawning pairs (depending upon the HSC used) could be supported by this habitat for the combined reaches investigated.



The WUA and number of redds estimated in the current study year that incorporated available substrate data were substantially lower than the estimates provided in the previous study year (Golder 2016). This is largely due to the relatively high amounts of habitat within the River 2D model boundaries that did not have substrate data associated with it, and subsequently had to be removed from the analysis. Consequently, the current WUA and number of redd estimates are believed to be downwardly biased, and the actual available Chinook spawning habitat is predicted to be somewhere in between the estimates generated in both study years.

The loss of Chinook Salmon runs into the study area that resulted from the completion of Grand Coulee Dam eliminated an important food and nutrient source for White Sturgeon (Hildebrand and Parsley 2013). Potential impacts of this loss on over-wintering fitness, spawning frequency and fecundity for White Sturgeon have been identified (Hildebrand and Birch 1996). The re-introduction of Chinook Salmon and other anadromous fish into the study area will result in a shift in the fish community towards pre-development conditions. This in turn will provide White Sturgeon in the Keenleyside Reach of the Columbia River with important food and nutrient sources that will likely result in improved fitness and spawning success.

Recommendations for future work include:

- 1) Expand investigations into the entire reach of the Columbia and Kootenay rivers between Lake Roosevelt and the barrier at Brilliant and Hugh L. Keenleyside dams, including significant tributaries. A geomorphological approach should be used to determine additional study sites for detailed habitat modelling. For example, one site on the Transboundary Reach that may have significant amounts of suitable spawning habitat for Chinook Salmon is the Genelle area, based on the channel morphology and large amounts of gravel substrates present.
- 2) Extend substrate mapping to include areas within existing River2D models that have no data. Also examine the extent of available substrate data within additional study sites, if selected. The current substrate mapping may also need to be extended to increase coverage in these areas as well, to facilitate comparison of existing Rainbow Trout use with modelled projections.
- 3) Examine potential opportunities to conduct physical works (i.e., substrate enhancement) within all study areas if one or both of the above recommendations are met.



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Lower Columbia and Kootenay River Annual Hydrographs

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River 2D Hydraulic Model Outputs

### APPENDIX C

Lower Columbia and Kootenay River WUA Estimates



## 1.0 INTRODUCTION

The completion of Grand Coulee Dam in the early 1940s stopped the natural migration of anadromous fish into the upper Columbia River. First Nations groups have been on the forefront of investigating the feasibility of reintroducing anadromous fish into the Columbia River upstream of this dam. A key part of this work is to assess the availability of habitat for the early life stages of salmon species that may once again utilize upstream reaches of the Columbia River and its tributaries. The Canadian Columbia River Inter-tribal Fisheries Commission (CCRIFC) contracted Golder Associates Ltd. (Golder) to conduct preliminary assessments on the amount of potential spawning habitat available for Chinook Salmon (*Oncorhynchus tshawytscha*), Steelhead and Rainbow Trout (*Oncorhynchus mykiss*) in the Transboundary Reach of the Columbia River.

### 1.1 Study Objectives

This report builds on the findings, data and recommendations reported in the previous study on Chinook Salmon spawning Habitat Suitability Criteria (HSC) and spawning habitat availability in the Transboundary Reach of the Columbia River (Golder 2016). The specific study objectives of this program are as follows:

- 1) Develop, by literature review, spawning HSC for depth and velocity of Steelhead and Rainbow Trout in large rivers (the Columbia River if possible).
- 2) Incorporate available substrate data (provided by BC Hydro) to improve suitability models for species of interest.
- 3) Apply the HSC to the outputs of the River 2D model for the area covered by the BC Hydro CLBMON-47 lower Columbia River Whitefish Spawning Topography Program.
- 4) Provide estimates of available spawning habitat (m<sup>2</sup> and proportion of total wetted area within modelled boundaries) over a broad range of flows during the potential spawning period.
- 5) If possible, compare spatially modelled spawning areas for Rainbow Trout to documented redd distribution as a means to validate the accuracy of the modelling result.
- 6) Use spawner estimates to examine possible scenarios for the amount of spawner biomass that Chinook Salmon would provide the food web, with a focus on the benefits to White Sturgeon (*Acipenser transmontanus*) recovery.
- 7) Provide a brief report outlining methods and results of the analysis.
- 8) Provide (in attachments to this document) detailed figures that outline the amount of suitable habitat over the range of flows examined.



## **1.2 Report Scope**

A literature review was also conducted to provide preferred spawning habitat criteria (depth, velocity and substrate preferences) of Steelhead and Rainbow Trout to provide a range of both depths and velocities in which spawning activity rates are the highest. BC Hydro has conducted substrate mapping in most of the lower Columbia River (Preston 2014), and has provided the results from that program for inclusion into this program's suitability modelling.

The depth, velocity and substrate ranges were then compared to data from outputs of the CLBMON-47 Lower Columbia River Whitefish Spawning Ground Topography Program River 2D Hydraulic Models that BC Hydro has provided for this program (Golder 2014). All data analyzed and presented are limited to the sections of the overall study area that are contained within these models. Data from 99 runs of each of the RIVER 2D hydraulic models (a total of 198) were used to estimate available spawning habitat for another species (Mountain Whitefish over a wide range of flow levels, Golder 2014). Multiple runs from the full data set were selected and used to complete a similar analysis for the species of interest in the same area.

## **2.0 METHODS**

### **2.1 Study Area**

The study area for this program encompasses the area of the CLBMON-47 River 2D Hydraulic Models. These hydraulic models cover the section of the lower Columbia River from Norn's Fan to the upstream end of Tin Cup Rapids, and the lower Kootenay River from the Highway 3 Bridge to the confluence with the Columbia River. The lower Kootenay River model also includes a 1 km section of the Columbia River (500 m of river both upstream and downstream of the confluence).

### **2.2 Selection of Potential Spawning Period**

#### **2.2.1 Chinook Salmon**

To estimate the potential spawning period for Chinook Salmon in the study area, a literature review examining the range of water temperatures during the spawning period of populations in other systems was conducted (Bjornn and Reiser 1991; Carter 2005; Healey 1991; McCullough et al. 2001). The results of the review were then compared to water temperatures recorded at the Norn's Fan Water Gauging Station on the lower Columbia River, and from temperature thermistors deployed in the lower Kootenay River (Golder 2016). The potential spawning period was estimated between 1 September and 1 December so that the historical local water temperatures were consistent with temperatures recorded for the spawning period of populations in other systems.

#### **2.2.2 Steelhead and Rainbow Trout**

To estimate the potential spawning period for Steelhead and Rainbow Trout in the study area, a literature review on studies examining the spawning of local Rainbow Trout population was conducted (Thorley and Baxter 2011; Irvine et al. 2014; Baxter et al. 2016). The potential spawning period for Rainbow Trout was estimated between 1 March and 1 July; this period was also used for Steelhead spawning.



## 2.3 River 2D Hydraulic Model Output Selections

### 2.3.1 Chinook Salmon Spawning Period

The two study area reaches that were modelled using River 2D are located at the confluence of the Kootenay and Columbia rivers. Both sites are hydraulically influenced by the discharge of both rivers as a result of backwater effects. Consequently, combinations of flows from the two rivers are needed for the model to predict depths and velocities throughout the study areas (Golder 2014). The September-November hydrographs from 2001-2015 for both the Columbia and Kootenay rivers (see Appendix A) were examined and used to calculate the 7Q10 value, the annual 7-day minimum and maximum flows with a 10-year recurrence interval (i.e., flows that are only likely to be exceeded once every 10 years). For this, the rolling 7-day average discharges were calculated within each year and each river. Then, the minimum and maximum values of the rolling 7-day averages were calculated for every year, resulting in 15 data points of minimum and maximum yearly discharges for the two rivers. These were used to perform frequency analysis; the flow data were ordered from smallest to largest, ranked, and fitted to a log Pearson type III distribution, a distribution commonly used in the analysis of flood recurrence periods. A cut-off discharge value was then calculated, where a cut-off value of 1/10 represented one exceedance for every 10 years (for the maximum flow), and a cut-off of 9/10 represented 9 exceedances every 10 years (for the minimum flow [i.e., identifying a flow so low that a lower discharge value would only be likely to occur once per 10 years]). In addition to the 7Q10 values, the median discharge value during September-November of 2001-2015 was calculated for both Columbia and Kootenay rivers using daily flow values.

Once the 7Q10 and median values were calculated, all possible combinations of minimum 7Q10, median flow, and maximum 7Q10 flows at Columbia and Kootenay rivers were created (Table 1). These combinations were matched with model runs from the CLBMON-47 River 2D Hydraulic Models, so that the modeled discharges were as close as possible to the constructed combinations of 7Q10 and median values (Table 1). Note that for the Columbia River, there was no difference between the three models representing lowest Kootenay River discharge (calculated 7Q10 of 223.3 m<sup>3</sup>/s, modeled discharge 375 m<sup>3</sup>/s) and the median Kootenay River discharge (calculated 464.8 m<sup>3</sup>/s, modeled 375 m<sup>3</sup>/s). The output of the Columbia River models was therefore reduced to six scenarios, whereas the Kootenay River output included all nine possible scenarios.

**Table 1: Flow scenarios and chosen River2D model runs for Chinook Salmon spawning period, detailed by river.**

Calculated discharge values		River2D Hydraulic Model Run		
Columbia River Q	Kootenay River Q	River	Columbia River Q Modeled	Kootenay River Q Modeled
449.4	223.3	Columbia River	412.5	375
1091.2	223.3		1062.5	375
2047.6	223.3		2037.5	375
449.4	464.8		412.5	375
1091.2	464.8		1062.5	375
2047.6	464.8		2037.5	375
449.4	946.6		412.5	875
1091.2	946.6		1062.5	875
2047.6	946.6		2037.5	875
449.4	223.3		575	250
1091.2	223.3	Kootenay River	1225	250
2047.6	223.3		2200	250
449.4	464.8		575	500
1091.2	464.8		1225	500
2047.6	464.8		2200	500
449.4	946.6		575	1000
1091.2	946.6		1225	1000
2047.6	946.6		2200	1000

### 2.3.2 Steelhead and Rainbow Trout Spawning Period

The methodology utilized for selecting River 2D hydraulic model outputs for the potential Chinook spawning period (Section 2.3.1) was also used in selecting outputs for the potential Rainbow Trout and Steelhead spawning period. The March-July hydrographs from 2001-2015 for both the Columbia and Kootenay rivers (see Appendix A) were examined and used to calculate the 7Q10 value, the annual 7-day minimum and maximum flows with a 10-year recurrence interval (i.e., flows that are only likely to be exceeded once every 10 years).

Once the 7Q10 and median values were calculated, all possible combinations of minimum 7Q10, median flow, and maximum 7Q10 flows at Columbia and Kootenay rivers were created (Table 2). These combinations were matched with model runs from the CLBMON-47 River 2D Hydraulic Models so that the modeled discharges were as close as possible to the constructed combinations of 7Q10 and median values (Table 2). Note that for the highest calculated Kootenay River Q (calculated 7Q10 of 2934 m<sup>3</sup>/s), the closest existing modeled discharge was 1625 m<sup>3</sup>/s (Table 2). Therefore outputs with this value were selected as the best fit, but due to the differences in calculated versus modelled discharge, estimates provided on the available spawning habitat for these species may be downwardly biased.

**Table 2: Flow scenarios and chosen River2D model runs for Steelhead and Rainbow Trout Spawning Period, detailed by river.**

Calculated discharge values		River2D Hydraulic Model Run		
Columbia River Q	Kootenay River Q	River	Columbia River Q Modeled	Kootenay River Q Modeled
397.2	271.6	Columbia River Model	412.5	375
758.7	271.6		737.5	375
1771.0	271.6		1712.5	375
397.2	844.0		412.5	875
758.7	844.0		737.5	875
1771.0	844.0		1712.5	875
397.2	2933.8		412.5	1625
758.7	2933.8		737.5	1625
1771.0	2933.8		1712.5	1625
397.2	271.6		250	250
758.7	271.6	Kootenay River Model	575	250
1771.0	271.6		1875	250
397.2	844.0		412.5	875
758.7	844.0		737.5	875
1771.0	844.0		1712.5	875
397.2	2933.8		412.5	1625
758.7	2933.8		737.5	1625
1771.0	2933.8		1712.5	1625

## 2.4 Substrate Mapping

Substrate data for inclusion in this program were provided by BC Hydro (Preston 2014). A GIS layer/overlay of the corresponding substrate data within the boundaries of the River 2D models was created and incorporated into the habitat suitability modelling for the species of interest.

## 2.5 Data Analysis

For each model node, the outputs of the different flow scenarios from the River2D model included the depth and water velocity predicted under the modeled flow, as well as each node's area ( $m^2$ ). These data were used to produce maps of depths and velocities at both sites under the individual flow scenarios. The overlay of substrate data on River2D nodes was used to estimate the area of each substrate type within each River2D node.



Chinook Salmon Habitat Suitability Index (HSI) curves, developed as a function of depth and water velocity (Beecher et al. 2016), were used to calculate the weighted usable area (WUA) available to Chinook Salmon for spawning. Two separate HSI curves were available for each of depth and velocity – one developed for large rivers, with mean annual flow  $\geq$  3,000 cfs (85 m<sup>3</sup>/s) and the other developed for the very large Columbia-Snake rivers, with mean annual flow  $\geq$  100,000 cfs (2,832 m<sup>3</sup>/s; Table 2).

**Table 3: Chinook Salmon spawning preference in relation to depth and velocity, detailed by type of river (large rivers and Columbia-Snake; see Beecher et al. [2016] for details).**

Parameter	Value	Preference	
		Large Rivers	Columbia - Snake
Depth (ft)	0.00	0.0	0.0
	0.55	0.0	---
	1.05	0.75	---
	1.55	1.0	0.0
	5.05	1.0	0.4
	8.15	---	1.0
	10	0.0	---
	30	0.0	1.0
	35	0.0	0.0
	99	0.0	0.0
Velocity (ft/sec)	0.00	0.0	0.0
	0.35	---	0.0
	0.55	0.0	---
	0.75	0.79	---
	1.55	1.0	---
	1.65	---	0.50
	2.45	---	1.0
	3.55	0.0	1.0
	4.95	0.0	0.2
	6.55	0.0	0.1
	7.0	0.0	0.0
	99	0.0	0.0

The curves for Chinook and Steelhead were transformed into metric units (m for depth and m/s for velocity) and interpolated to a resolution of 0.01, with a linear interpolation between every two specified preference values. The depth and velocity HSI curves for Rainbow Trout developed in (Thorley and Baxter 2011) were used for analysis. The HSI curves were used to predict HSI values at 0.01 m or m/s steps for depth and velocity, respectively. The depth HSI curve followed the equation:  $HSI = e^{-7.66+14.14 \times Depth - 6.54 \times Depth^2}$ , and the velocity HSI curve followed the equation:  $HSI = e^{-4.37+13.94 \times Velocity - 11.12 \times Velocity^2}$ .



The three HSI curves (for depth, velocity, and substrate type; Tables 2-5) were used to calculate separate HSI values for the study area. For each model node, four types of HSI values were calculated:

- 1) HSI based on depth only
- 2) HSI based on velocity only
- 3) HSI based on substrate only
- 4) HSI based on combined depth, velocity, and substrate, calculated by multiplying the former three HSI values

These four HSI estimates were calculated separately for each species, and using both the larger river HSI curves and the Columbia-Snake HSI curves for Chinook, resulting in 16 distinct HSI values for each node within each model run.

Once the HSI values of each model node were calculated, the WUA value of the node was estimated by multiplying the node's area by each of the sixteen HSI values associated with the node. Note that if more than one substrate type was mapped to a single River2D node, then the area estimated for each substrate was used to estimate the WUA, rather than the total node area. To estimate the distribution of the depths and velocities available within each flow scenario, the percent of available spawning habitat within each depth or velocity value (to 0.01 m or 0.01 m/s) and substrate type was estimated by dividing the total WUA value within each depth, velocity, or substrate bin by the total available wetted area within each flow scenario. The total WUA value available within each flow scenario under the combined (depth, velocity, and substrate) HSI curves was calculated by summing the WUA values of all model nodes.

All analyses were performed in R v.3.3.2 (R Core Team 2016); plotting was performed using the packages ggplot2 (Wickham 2009) and ggmap (Kahle and Wickham 2013).



**Table 4: Steelhead Salmon spawning preference in relation to depth and velocity; see Beecher et al. (2016) for details.**

Parameter	Value	Preference
Depth (ft)	0	0
	0.65	0
	0.75	0.25
	1.25	0.68
	1.85	1
	2.35	1
	2.75	0.34
	99	0.34
	0	0
	0.25	0
Velocity (ft/sec)	0.35	0.1
	1.05	0.3
	1.35	0.88
	1.55	1
	1.95	1
	3.25	0.62
	3.45	0.28
	5	0
	99	0
	0	0
	0.65	0
	0.75	0.25

**Table 5: Salmonid spawning preference in relation to substrate; see Beecher et al. (2016) for details.**

Substrate	Preference		
	Chinook	Steelhead	Rainbow Trout
Fines	0	0	0
Gravel	1	1	0.9
Medium cobbles	0.75	0.65	0.25
Large cobbles	0.5	0.3	0
Boulder / rip-rap	0	0	0



## 3.0 RESULTS

### 3.1 River 2D Hydraulic Model Output Selection

Frequency analysis of the minimum 7Q10 flows during the potential Chinook spawning period in the Columbia River during 2001-2015 estimated that the minimum flow, expected to only be lower once in 10 years (i.e., flow exceedance in 9 out of 10 years) was 449.4 m<sup>3</sup>/s (Figure 1). Frequency analysis of the maximum 7Q10 flows in the Columbia River during 2001-2015 estimated that the maximum flow, expected to only be higher once in 10 years (i.e., flow exceedance in 1 out of 10 years) was 2,047.6 m<sup>3</sup>/s (Figure 2).

For the potential Steelhead and Rainbow Trout spawning period in the Columbia River during 2001-2015, the estimated minimum flow, expected to only be lower once in 10 years (i.e., flow exceedance in 9 out of 10 years) was 397.2 m<sup>3</sup>/s (Figure 3). Frequency analysis of the maximum 7Q10 flows in the Columbia River during 2001-2015 estimated that the maximum flow, expected to only be higher once in 10 years (i.e., flow exceedance in 1 out of 10 years) was 1,771.0 m<sup>3</sup>/s (Figure 4).

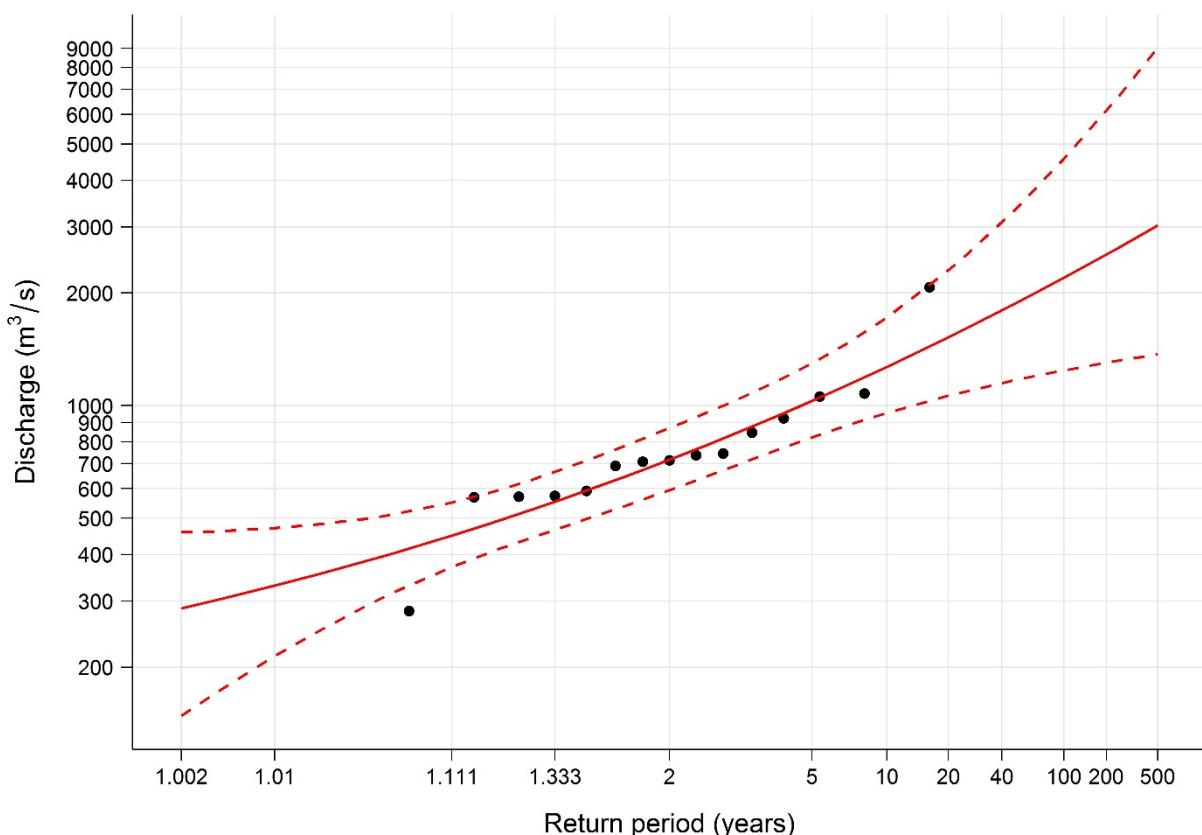


Figure 1: Frequency analysis of Columbia River 7Q10 minimum flows based on minimum 7-day rolling averages of discharge during Chinook spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the 95% confidence interval.

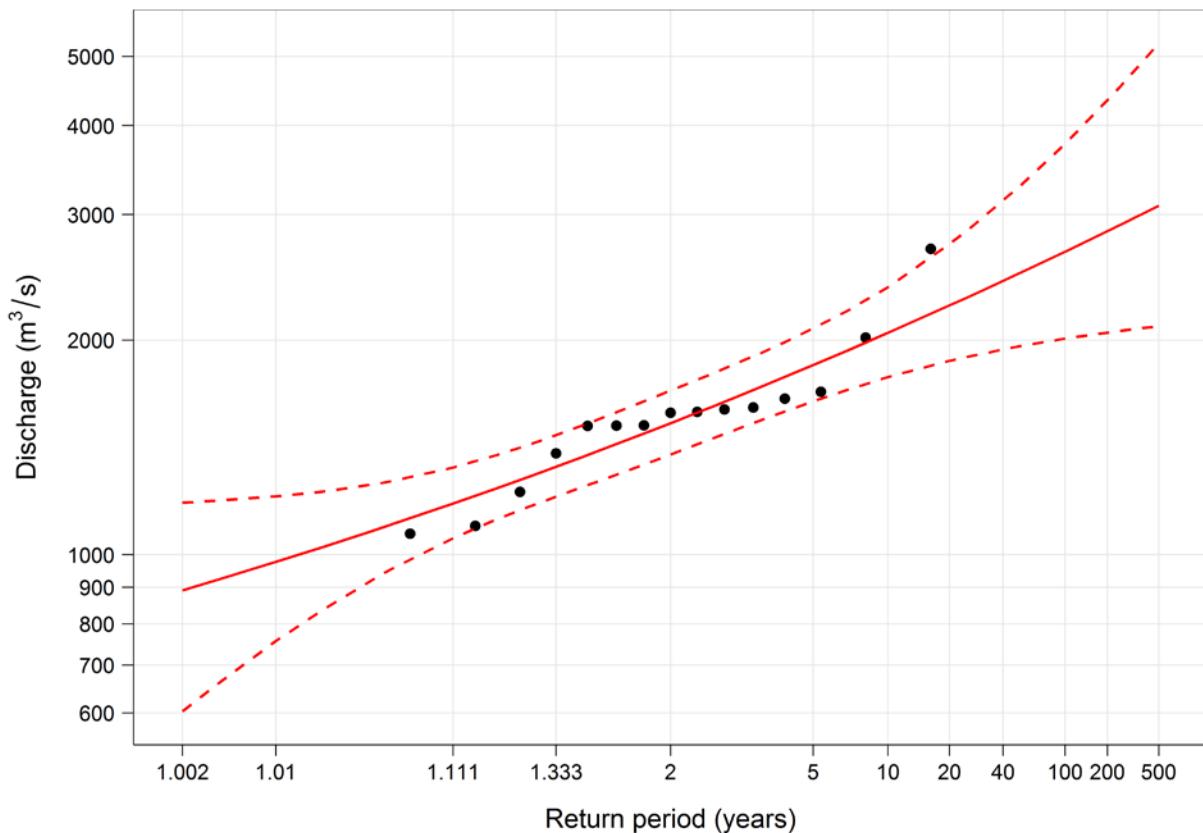


Figure 2: Frequency analysis of Columbia River 7Q10 maximum flows based on maximum 7-day rolling averages of discharge during Chinook spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the 95% confidence interval.

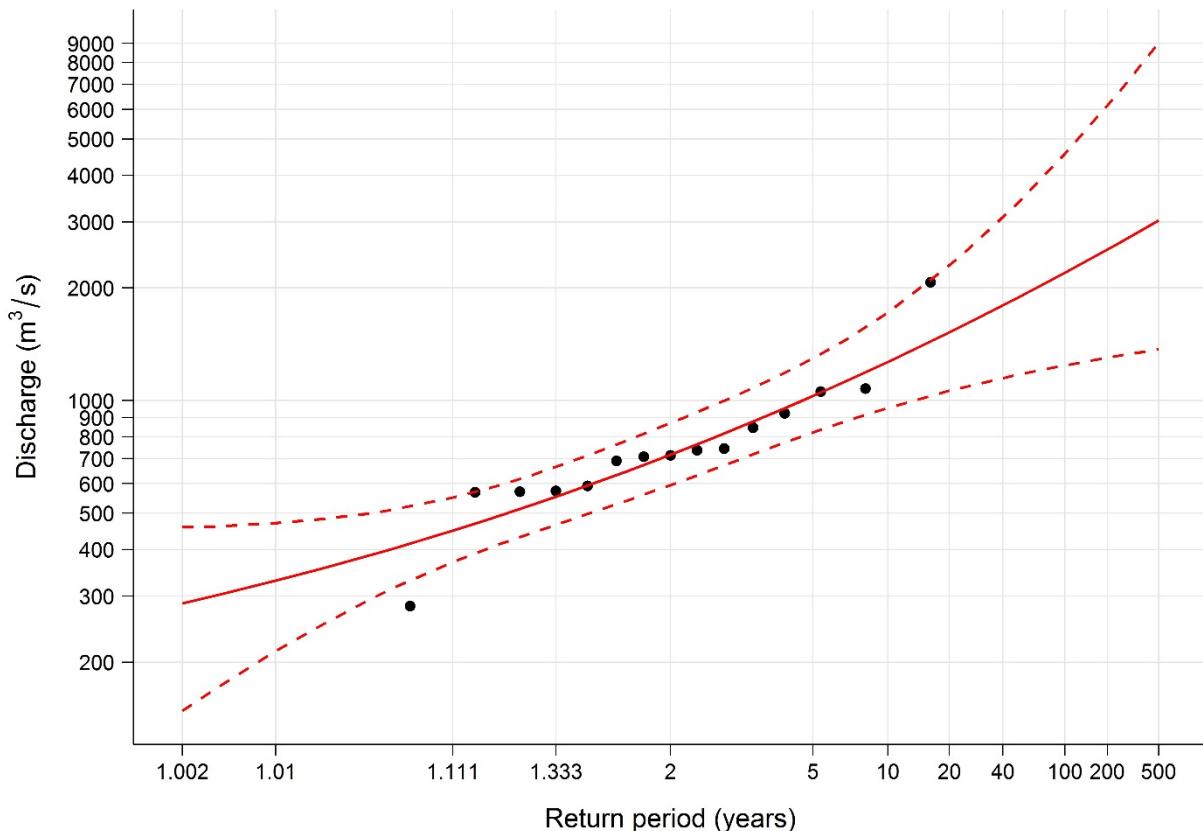


Figure 3: Frequency analysis of Columbia River 7Q10 minimum flows based on minimum 7-day rolling averages of discharge during the Steelhead and Rainbow Trout spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the 95% confidence interval.

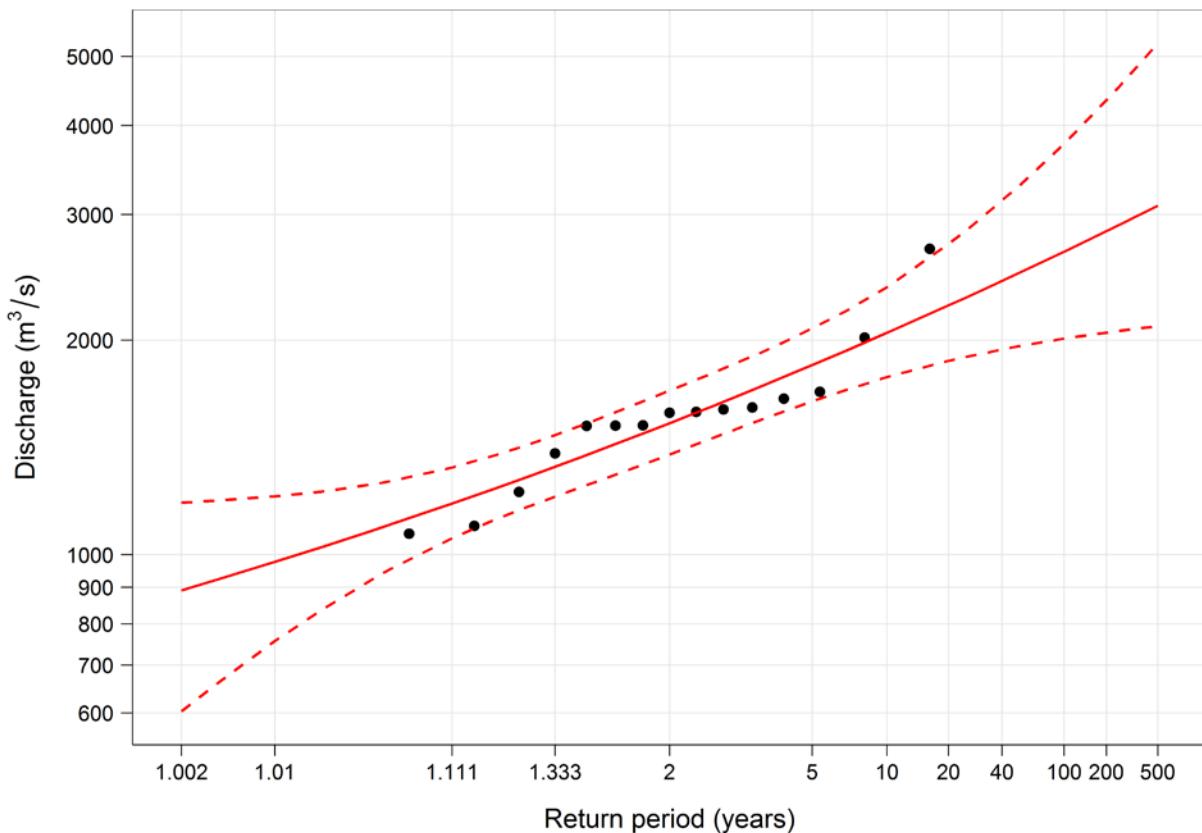


Figure 4: Frequency analysis of Columbia River 7Q10 maximum flows based on maximum 7-day rolling averages of discharge during the Steelhead and Rainbow Trout spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the 95% confidence interval.

Frequency analysis of the minimum 7Q10 flows during the potential Chinook spawning period in the Kootenay River during 2001-2015 estimated that the minimum flow, expected to only be lower once in 10 years (i.e., flow exceedance in 9 out of 10 years) was 223.3  $m^3/s$  (Figure 5). Frequency analysis of the maximum 7Q10 flows in the Kootenay River during 2001-2015 estimated that the maximum flow, expected to only be higher once in 10 years (i.e., flow exceedance in 1 out of 10 years) was 946.6  $m^3/s$  (Figure 6).

For the potential Steelhead and Rainbow Trout spawning period in the Kootenay River during 2001-2015, the estimated minimum flow, expected to only be lower once in 10 years (i.e., flow exceedance in 9 out of 10 years) was 271.6  $m^3/s$  (Figure 7). Frequency analysis of the maximum 7Q10 flows in the Kootenay River during 2001-2015 estimated that the maximum flow, expected to only be higher once in 10 years (i.e., flow exceedance in 1 out of 10 years) was 2933.8  $m^3/s$  (Figure 8).

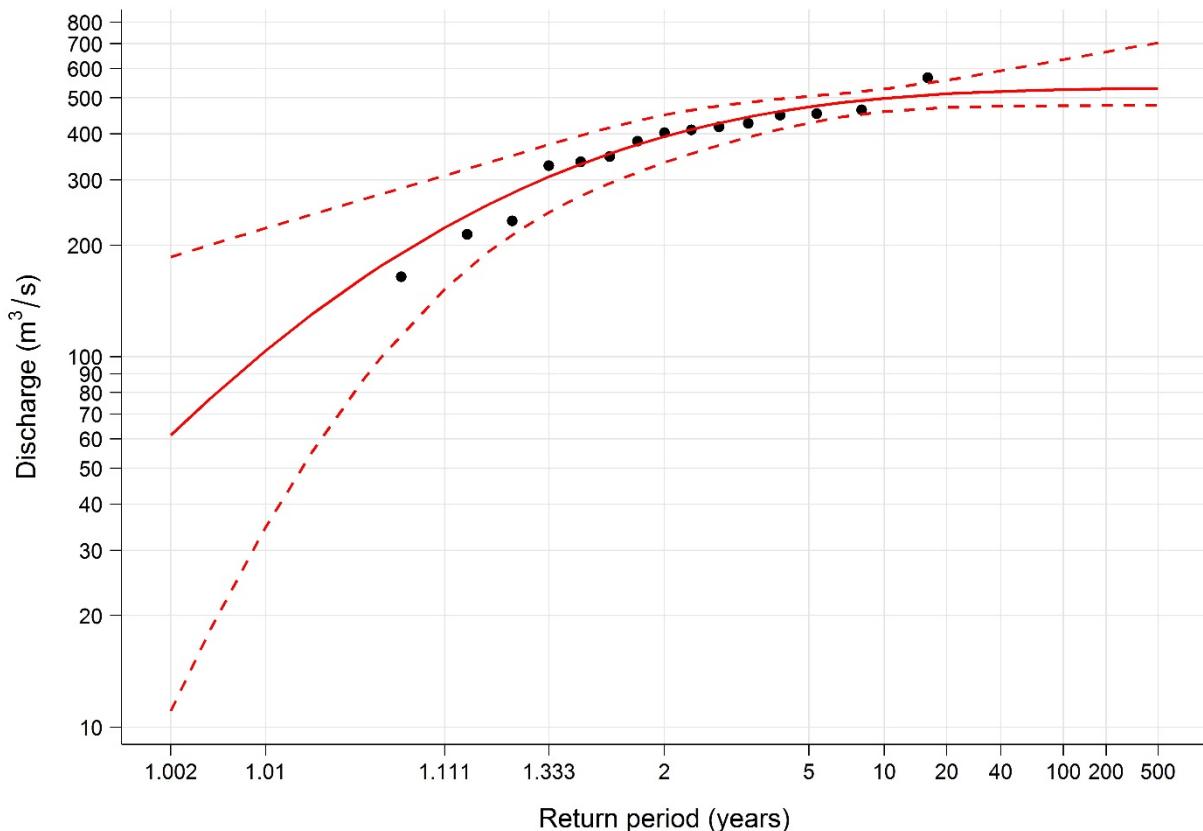


Figure 5: Frequency analysis of Kootenay River 7Q10 minimum flows based on minimum 7-day rolling averages of discharge during Chinook spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the 95% confidence interval.

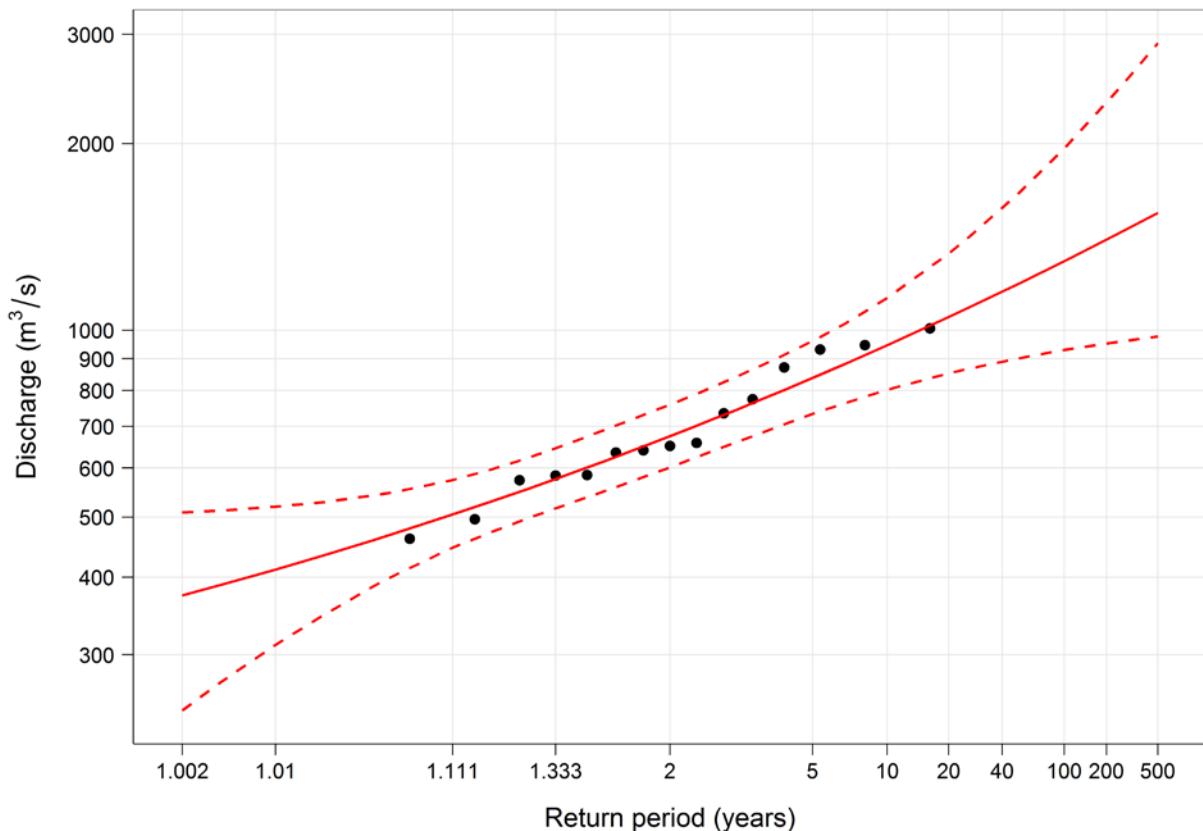


Figure 6: Frequency analysis of Kootenay River 7Q10 maximum flows based on maximum 7-day rolling averages of discharge during Chinook spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the fitted distribution curve; dashed red lines represent the 95% confidence interval

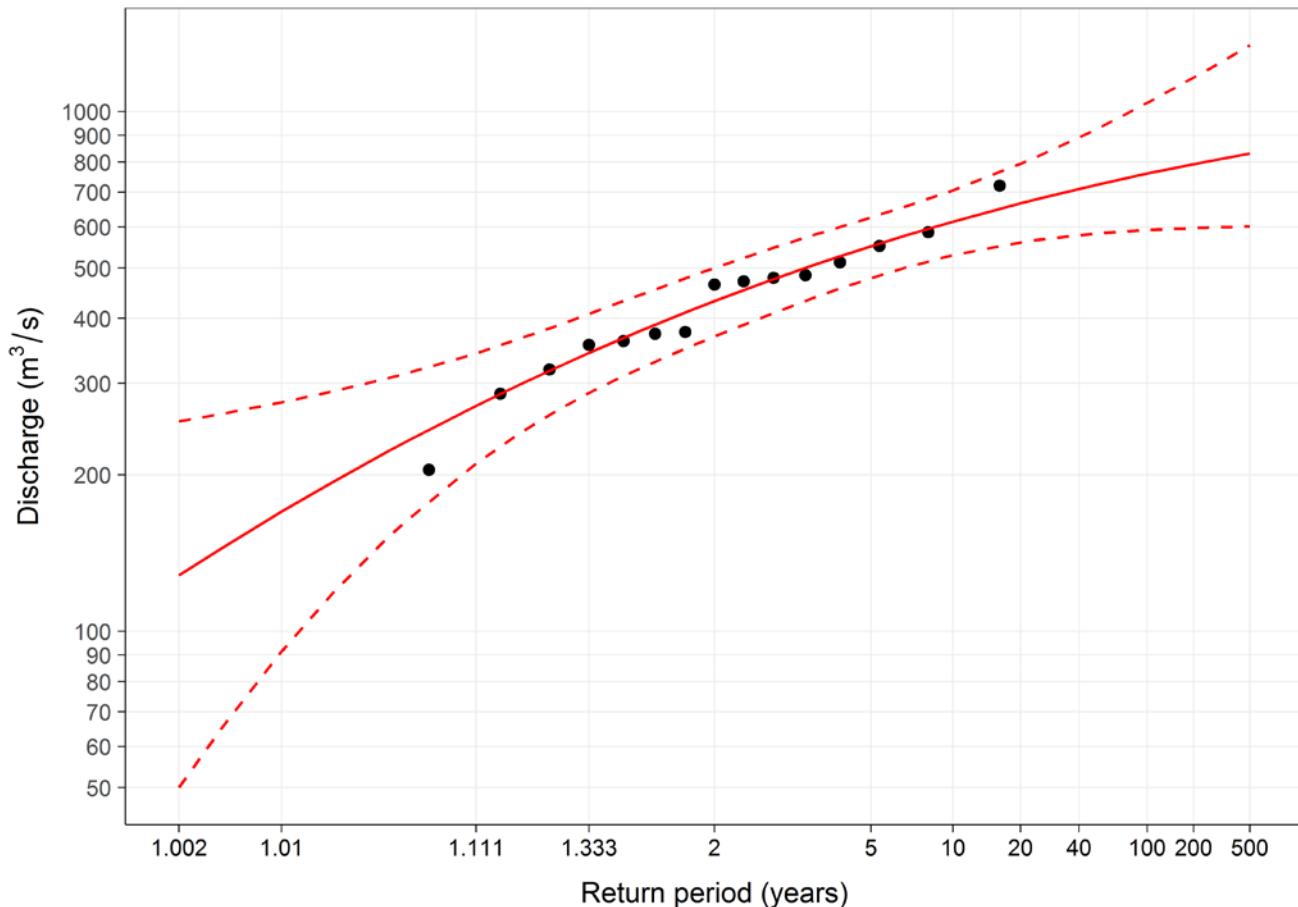


Figure 7: Frequency analysis of Kootenay River 7Q10 minimum flows based on minimum 7-day rolling averages of discharge during the Steelhead and Rainbow Trout spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the 95% confidence interval.

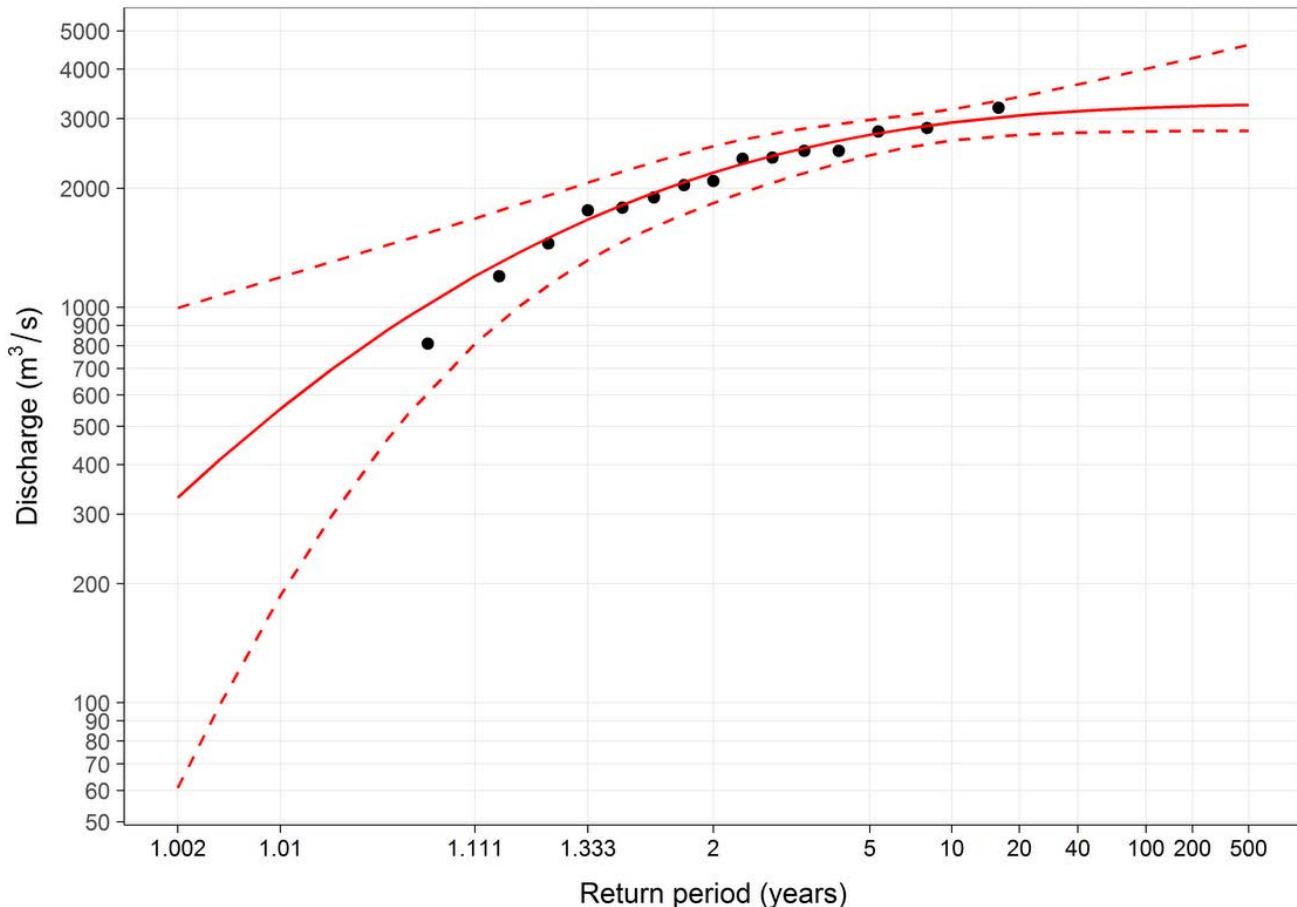


Figure 8: Frequency analysis of Kootenay River 7Q10 maximum flows based on maximum 7-day rolling averages of discharge during the Steelhead and Rainbow Trout spawning period from 2001-2015 (black dots); solid red line represents the fitted distribution curve; dashed red lines represent the 95% confidence interval.

### 3.2 Substrate Mapping

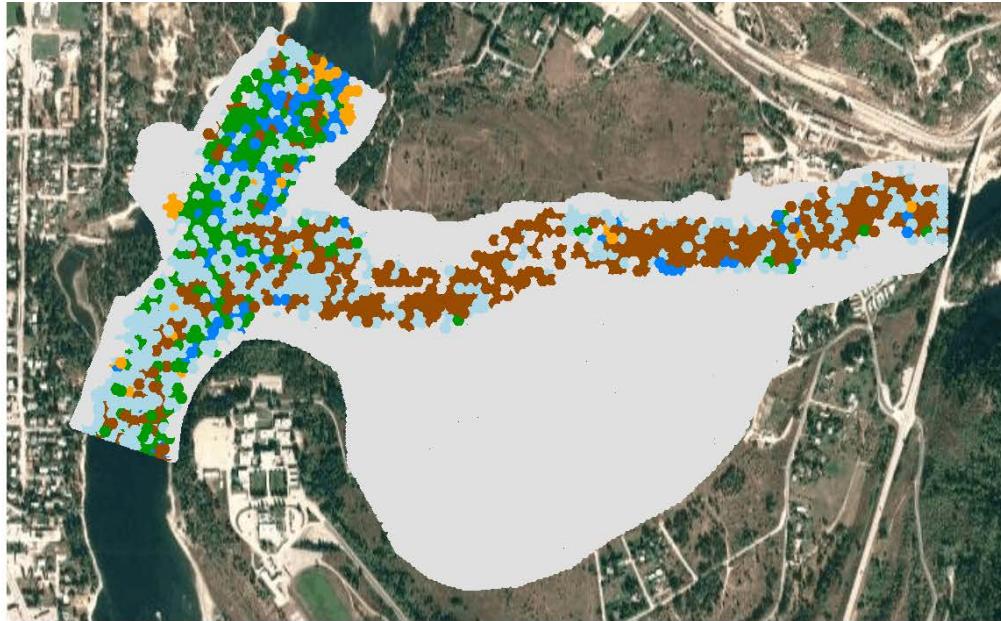
The extent of the substrate mapping within the boundaries of the River 2D hydraulic models for the lower Columbia and lower Kootenay River is presented in Figure 9 and Figure 10, respectively. A total of 55% and 67% of River2D-modeled area did not have associated substrate data for the lower Columbia and lower Kootenay River models, respectively. These areas without substrate data were removed from the data analysis of this program.



CPR Island  
substrate type

Unknown	Gravel	Large cobbles
Blue	Green	Brown
Fines	Medium cobbles	Boulder / rip-rap

Figure 9: Extent of substrate mapping within the River 2D Hydraulic model on the lower Columbia River, near Castlegar, BC.



Kootenay substrate type     ● Unknown     ● Gravel     ● Large cobbles  
    ● Fines     ● Medium cobbles     ● Boulder / rip-rap

Figure 10: Extent of substrate mapping within the River 2D Hydraulic model on the lower Kootenay River, near Castlegar, BC.

### 3.3 Lower Columbia River 2D Hydraulic Model

For the cumulative distribution of WUA available to spawning by the three salmonid species at the modeled section of the Columbia River based on depth-only HSI, Kootenay discharge had little, if any, effect for Chinook (Figure 11). For Rainbow Trout and Steelhead, Kootenay discharge had a positive relationship with WUA at the lowest Columbia discharge ( $412.5 \text{ m}^3/\text{s}$ ) but not at the other examined discharges.

For Chinook, estimated total WUA based on large rivers HSI curves generally reached its maximum value at depths of approximately 2-3 m, whereas total WUA based on the Columbia-Snake HSI curves reached its maximum values only at 9-10 m. Under the Columbia-Snake HSI depth curves, a substantially higher proportion of the total wetted area was available for spawning (71-84% of total wetted area depending on discharge scenario) in comparison to the total WUA under the large rivers curves (3-29% of total wetted area, depending on scenario; Figure 11).

For Rainbow Trout, estimated total WUA generally reached its maximum value (0.7-12%) at depths of approximately 1-2 m (Figure 11). Estimated total WUA decreased with an increase in Columbia discharge. Of the examine scenarios, the highest total WUA for the species was 11%, under the lowest Columbia discharge. For Steelhead, estimated total WUA generally reached its maximum value (34-37%) at depths of approximately 9-12 m (Figure 11). Estimated total WUA decreased slightly with an increase in Columbia discharge.

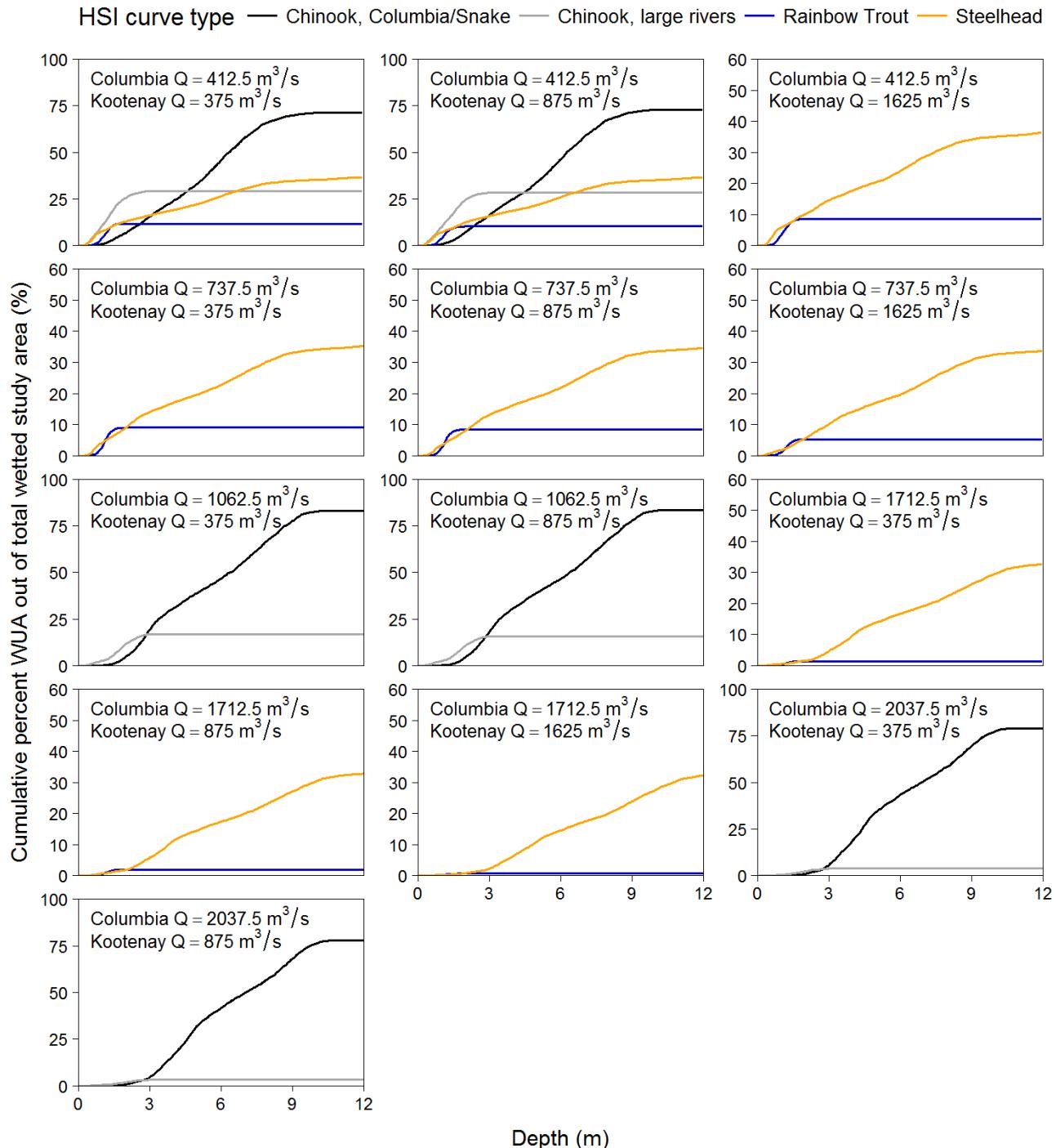


Figure 11: Cumulative distribution of weighted usable area (WUA) out of total wetted area for each model run for the Columbia River, estimated using depth-based HSI values; data plotted by model flow level (panels) and colour-coded by species and type of HSI curve.



For the cumulative distribution of WUA available to Chinook Salmon spawning at the modeled section of the Columbia River based on velocity-only HSI, Kootenay River discharge only influenced the availability of very fast (> 2.5 m/s) habitat (Figure 12). This had little effect on the distribution of WUA, since these habitats had a suitability index of 0. The differences between WUA values based on the two types of HSI curves were substantially smaller than observed for depth-based HSI curves. In addition, as opposed to depth-based WUA estimates, the Large River curves of velocity-based WUA estimates resulted in a higher availability of suitable spawning habitat (42-60% of total wetted area depending on discharge scenario) than the Columbia-Snake HSI curve (41-43% of total wetted area). This result is a direct outcome of a narrower HSI curve – while large river HSI values were 1.0 for velocities of 1.55 to 3.55 ft/sec (0.47 m/s and 1.08 m/s, respectively), the Columbia-Snake HSI values were 1.0 only for velocities between 2.45 and 3.55 ft/sec (0.75 m/s and 1.08 m/s, respectively), thereby reducing the resulting WUA estimate. Estimated cumulative WUA curves from the Large Rivers HSI curves reached their maximum values at approximately 1-1.5 m/s, whereas the Columbia-Snake cumulative WUA curves reached their maximum values at approximately 1.5-2.0 m/s (Figure 12).

For Rainbow Trout, estimated total WUA generally reached its maximum value (26-39%) at velocities of approximately 1 m/s (Figure 12). Estimated total WUA decreased slightly with an increase in Columbia discharge, but increased with an increase in Kootenay discharge. Of the examined scenarios, the highest total WUA for the species was 39%, under the lowest Columbia discharge (412.5 m<sup>3</sup>/s) and the higher Kootenay discharge (1,625 m<sup>3</sup>/s).

For Steelhead, estimated total WUA generally reached its maximum value at velocities of approximately 1-1.5 m/s (Figure 12). Estimated total WUA decreased with an increase in Columbia discharge to 1,713 m<sup>3</sup>/s (but not 738 m<sup>3</sup>/s) and slightly increased with Kootenay discharge. The highest estimated WUA was 47%, under the lowest Columbia discharge (413 m<sup>3</sup>/s) and the higher Kootenay discharge (1625 m<sup>3</sup>/s).

The cumulative distribution of WUA available to Chinook Salmon spawning at the modeled section of the Columbia River based on substrate-only HSI was influenced little by changes in flows, since only dewatering of nodes would influence the substrate-based HSI (Figure 13). Across all flow scenarios, Rainbow Trout had the lowest cumulative percent WUA of the three examine species, followed by Steelhead and Chinook Salmon.

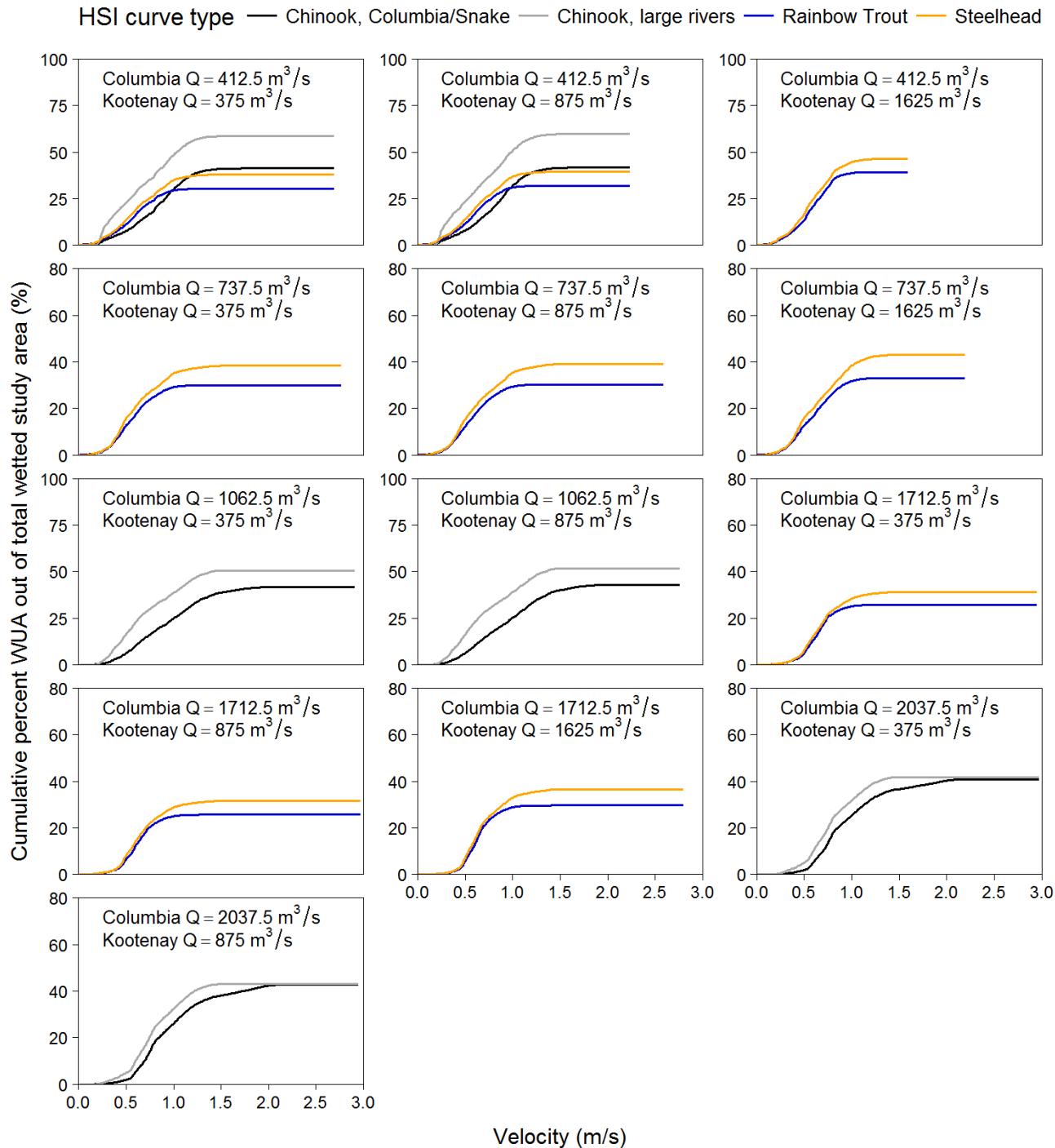
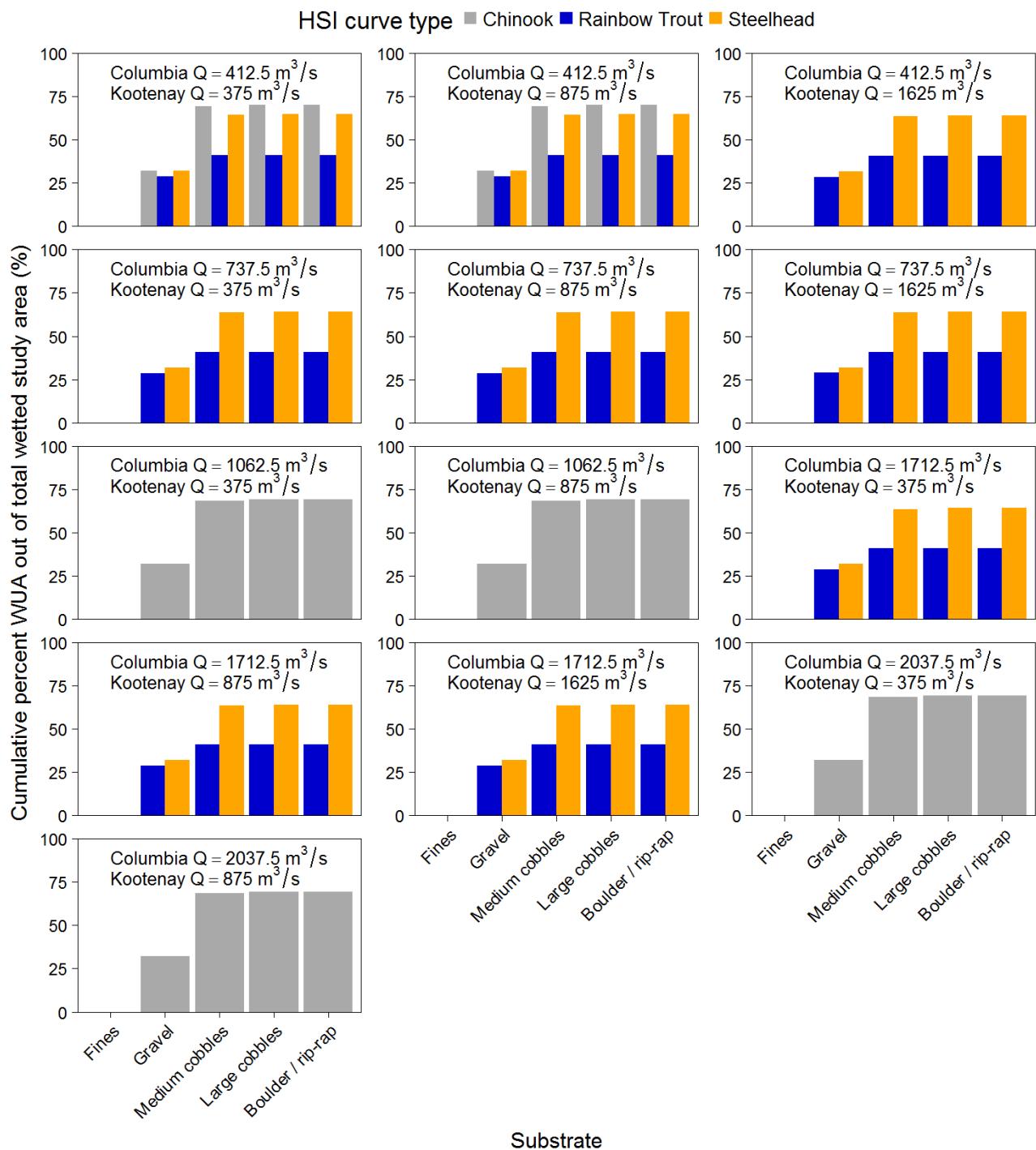


Figure 12: Cumulative distribution of weighted usable area (WUA) out of total wetted area for each model run for the Columbia River, estimated using velocity-based HSI values; data plotted by model flow level (panels) and colour-coded by species and type of HSI curve.



**Figure 13:** Cumulative distribution of weighted usable area (WUA) out of total wetted area for each model run for the Columbia River, estimated using substrate-based HSI values; data plotted by model flow level (panels) and colour-coded by species and type of HSI curve.



For Chinook, total available WUA values based on the combined (depth, velocity and substrate) large river HSI values for the Columbia River ranged from 3,158 m<sup>2</sup> under high flows for the Columbia River and the Kootenay River to 29,923 m<sup>2</sup> under low flows at both Columbia and Kootenay rivers (Table 6). The percentage of WUA out of total wetted area ranged between 0.7% and 7.6%. Under the Columbia-Snake combined HSI curve, total available WUA values ranged from 88.185 m<sup>2</sup> under high flows from both rivers to 112,731 m<sup>2</sup> under low flows from both rivers. The percentage of WUA out of total wetted area was higher than under the Large River HSI curve, ranging from 19.4% to 29.7%.

For Rainbow Trout, total WUA estimates ranged between 167 m<sup>2</sup> (0.04% WUA) under high discharge values from both rivers to 4,179 m<sup>2</sup> (1.06%) under low discharge (Table 6). For Steelhead, total WUA estimates ranged from 26,333 m<sup>2</sup> (6.1%) under high Columbia and low Kootenay flows to 36,368 m<sup>2</sup> (9.2%) under low discharges from both rivers (Table 6).

Maps of Columbia River habitat depth, velocity, substrate, and HSI values for the three species are provided in Appendix B, Figures B1 to B7. The WUA for depths, velocities, and substrate, separate and combined are summarized in tabular format in Appendix C by incremental depths (0.5 m bin size) and velocities (0.15 m/s bin size).

**Table 6: Total WUA estimate under each modeled flow scenario using the combined (depth, velocity, and substrate) HSI curve, detailed by river and type of HSI curve.**

Species	River	Modeled Discharge (m <sup>3</sup> /s)		Large Rivers - Chinook		Columbia-Snake - Chinook		Other – Steelhead/Rainbow	
		Columbia	Kootenay	WUA (m <sup>2</sup> )	% WUA	WUA (m <sup>2</sup> )	% WUA	WUA (m <sup>2</sup> )	% WUA
Chinook	Columbia	412.5	375	29,923	7.57	112,731	28.52	---	---
		1062.5	375	23,922	5.58	107,262	25.02	---	---
		2037.5	375	3,993	0.92	84,050	19.36	---	---
		412.5	875	29,493	7.36	119,209	29.73	---	---
		1062.5	875	21,934	5.11	112,423	26.18	---	---
		2037.5	875	3,158	0.73	88,185	20.30	---	---
	Kootenay	2200	250	3,531	0.99	28,138	7.88	---	---
		575	500	10,518	3.09	75,286	22.09	---	---
		1225	500	3,907	1.11	62,188	17.66	---	---
		2200	500	2,967	0.83	43,301	12.08	---	---
		575	1000	6,516	1.86	69,763	19.91	---	---
		1225	1000	3,845	1.08	60,197	16.89	---	---
Rainbow Trout	Columbia	2200	1000	1,876	0.52	48,448	13.47	---	---
		575	250	14,391	4.31	68,919	20.66	---	---
		1225	250	6,172	1.77	54,069	15.55	---	---
		412.5	375	---	---	---	---	4,179	1.06
		737.5	375	---	---	---	---	4,478	1.07



Species	River	Modeled Discharge (m³/s)		Large Rivers - Chinook		Columbia-Snake - Chinook		Other – Steelhead/Rainbow	
		Columbia	Kootenay	WUA (m²)	% WUA	WUA (m²)	% WUA	WUA (m²)	% WUA
		1712.5	875	---	---	---	---	507	0.12
Steelhead	Kootenay	412.5	1625	---	---	---	---	3,477	0.83
		737.5	1625	---	---	---	---	1,777	0.42
		1712.5	1625	---	---	---	---	167	0.04
		250	250	---	---	---	---	1,162	0.36
		575	250	---	---	---	---	1,472	0.44
		1875	250	---	---	---	---	190	0.05
		412.5	875	---	---	---	---	538	0.16
		737.5	875	---	---	---	---	414	0.12
		1712.5	875	---	---	---	---	156	0.04
		412.5	1625	---	---	---	---	248	0.07
		737.5	1625	---	---	---	---	178	0.05
		1712.5	1625	---	---	---	---	159	0.04
Steelhead	Columbia	412.5	375	---	---	---	---	36,368	9.20
		737.5	375	---	---	---	---	34,312	8.20
		1712.5	375	---	---	---	---	26,333	6.07
		412.5	875	---	---	---	---	37,886	9.45
		737.5	875	---	---	---	---	35,082	8.34
		1712.5	875	---	---	---	---	26,563	6.14
		412.5	1625	---	---	---	---	46,182	11.06
		737.5	1625	---	---	---	---	40,169	9.39
		1712.5	1625	---	---	---	---	31,868	7.34
		250	250	---	---	---	---	23,966	7.41
Steelhead	Kootenay	575	250	---	---	---	---	20,167	6.05
		1875	250	---	---	---	---	13,384	3.77
		412.5	875	---	---	---	---	20,293	5.85
		737.5	875	---	---	---	---	16,531	4.71
		1712.5	875	---	---	---	---	14,453	4.04
		412.5	1625	---	---	---	---	20,028	5.62
		737.5	1625	---	---	---	---	20,403	5.71
		1712.5	1625	---	---	---	---	13,017	3.62



### **3.4 Lower Kootenay River 2D Hydraulic Model**

For the cumulative distribution of WUA available to Chinook Salmon spawning at the modeled section of the Kootenay River based on depth-only HSI, WUA values generally decreased with an increase in the discharge of both Columbia and Kootenay rivers (Figure 14). Similar to the Columbia River, estimated WUA values based on large rivers HSI curves generally reached their maximum value at depths of approximately 2-3 m, whereas WUA values based on the Columbia-Snake HSI curves reached their maximum values only at 9-10 m. Under the Columbia-Snake HSI depth curves, a substantially higher proportion of the total wetted area was available for spawning (approximately 71-85% of total wetted area depending on discharge scenario) in comparison to the total WUA under the large rivers curves (approximately 2-29% of total wetted area).

For Rainbow Trout, estimated total WUA generally reached its maximum value (0.4-11%) at depths of approximately 1-2 m (Figure 14). Total WUA estimates decreased with an increase in both Columbia and Kootenay discharge (except for increase in Columbia discharge from 250 m<sup>3</sup>/s to 575 m<sup>3</sup>/s, where WUA increased slightly). Of the examined scenarios, the highest total WUA for the species was 11%, under the lowest Kootenay and second lowest Columbia discharges. For Steelhead, estimated total WUA generally reached its maximum value (34-36%) at depths of approximately 9-12 m. Estimated total WUA decreased with an increase in either Columbia or Kootenay discharge; the effect was especially strong at shallow depths ( $\leq 3$  m: Figure 14).

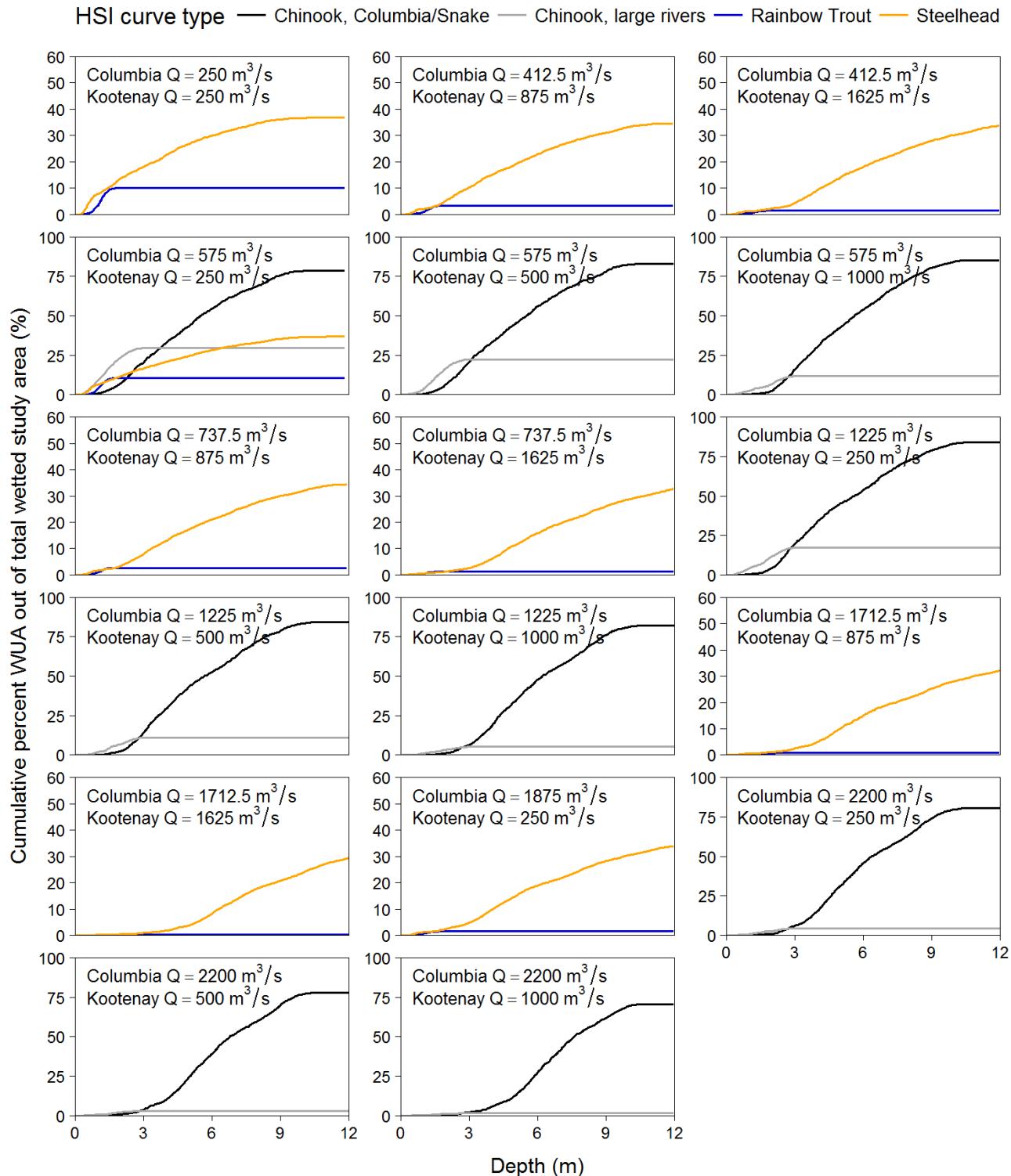


Figure 14: Cumulative distribution of weighted usable area (WUA) out of total wetted area for each model run for the Kootenay River, estimated using depth-based HSI values; data plotted by model flow level (panels) and colour-coded by species and type of HSI curve.



For the cumulative distribution of WUA available to Chinook Salmon spawning at the modeled section of the Kootenay River based on velocity-only HSI, an increase in either Columbia or Kootenay discharge generally resulted in substantial decreases in available WUA (Figure 15). However, at the highest Columbia discharge, an increase in Kootenay discharge resulted in increased WUA values. The differences between WUA values based on the two types of HSI curves were smaller than observed for depth-based HSI curves, except for the scenario with low Kootenay flow (250 m<sup>3</sup>/s) and high Columbia flow (2,200 m<sup>3</sup>/s), where the difference between the two HIS curves was largest. Similar to the Columbia River results, for velocity-based WUA estimates, the large river HSI curves resulted in a higher availability of suitable spawning habitat (40-57% of total wetted area depending on discharge scenario) than the Columbia-Snake HSI curve (22-47% of total wetted area). The Kootenay results suggested a strong influence of discharge from either river on the available spawning habitat. Under the low Kootenay flow (250 m<sup>3</sup>/s) and the Columbia-Snake HSI habitat, available WUA decreased from 48% at low Columbia flow to 23% under high Columbia flow. Similarly, at low Columbia flow (575 m<sup>3</sup>/s), available WUA decreased from 48% under low Kootenay discharge to 35% under high Kootenay discharge. Estimated cumulative WUA curves from the large rivers HSI curves reached their maximum values at velocities of approximately 1-1.5 m/s, whereas the Columbia-Snake cumulative WUA curves reached their maximum values at velocities of approximately 1.5-2.0 m/s.

For Rainbow Trout, estimated total WUA generally reached its maximum value (11-36%) at velocities of approximately 1 m/s (Figure 15). Estimated total WUA decreased with an increase in either Columbia or Kootenay discharge, except for at the highest examined Columbia discharge. Of the examined scenarios, the highest total WUA for the species was 36%, under the lowest Columbia and Kootenay discharges (250 m<sup>3</sup>/s and 250 m<sup>3</sup>/s, respectively). For Steelhead, estimated total WUA generally reached its maximum value at velocities of approximately 1-1.5 m/s (Figure 15). Estimated total WUA generally decreased with an increase in either Columbia or Kootenay discharge, except for at the highest examined Columbia discharge. The highest estimated WUA for the species was 43%, under the lowest Columbia and Kootenay discharges (250 m<sup>3</sup>/s and 250 m<sup>3</sup>/s, respectively).

The cumulative distribution of WUA available to Chinook Salmon spawning at the modeled section of the Kootenay River based on substrate-only HSI was influenced little by changes in flows, since only dewatering of nodes would influence the substrate-based HSI (Figure 16). Similar to the Columbia results, across all flow scenarios, Rainbow Trout had the lowest cumulative percent WUA of the three examine species, followed by Steelhead and Chinook Salmon.

Total available WUA values based on the combined (depth, velocity, and substrate) large-river HSI values for Chinook Salmon in the Kootenay River ranged from 1,876 m<sup>2</sup> (0.5%) under high flows at both Columbia and Kootenay to 14,391 m<sup>2</sup> (4.3%) under low flows for both rivers (Table 6). Under the Columbia-Snake combined HIS curve for Chinook Salmon, available WUA values ranged from 28,138 m<sup>2</sup> (7.9%) under high flows from the Columbia and low flows from the Kootenay, to 68,919 m<sup>2</sup> (20.7%) under low flows from both rivers (Table 6).

For Rainbow Trout, WUA estimates ranged between 156 m<sup>2</sup> (0.04% WUA) under high Columbia discharge and intermediate Kootenay discharge to 4,478 m<sup>2</sup> (1.1%) under intermediate Columbia discharge and low Kootenay discharge (Table 6). For Steelhead, WUA ranged from 13,017 m<sup>2</sup> (3.6%) under high Columbia and Kootenay discharge to 46,182 m<sup>2</sup> (11.1%) under low Columbia discharge and high Kootenay discharge (Table 6).

Maps of lower Kootenay River habitat depth, velocity, substrate, and HSI for the three species are provided in Appendix B, Figures B8 to B13. The WUA for depths, velocities, and substrate, separate and combined are summarized in tabular format in Appendix C by incremental depths (0.5 m bin size) and velocities (0.15 m/s bin size).

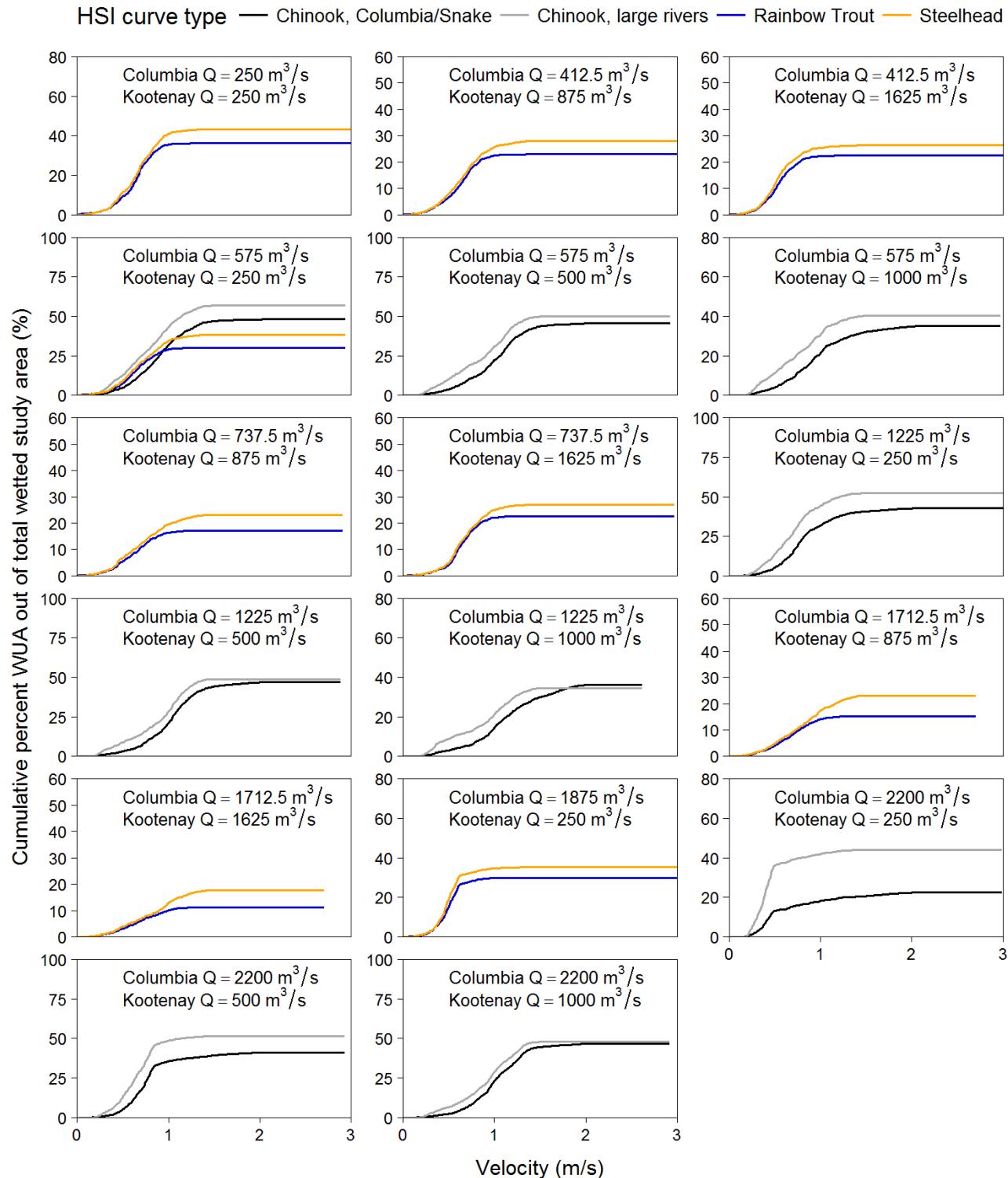


Figure 15: Cumulative distribution of weighted usable area (WUA) out of total wetted area for each model run for the Kootenay River, estimated using velocity-based HSI values; data plotted by model flow level (panels) and colour-coded by species and type of HSI curve.

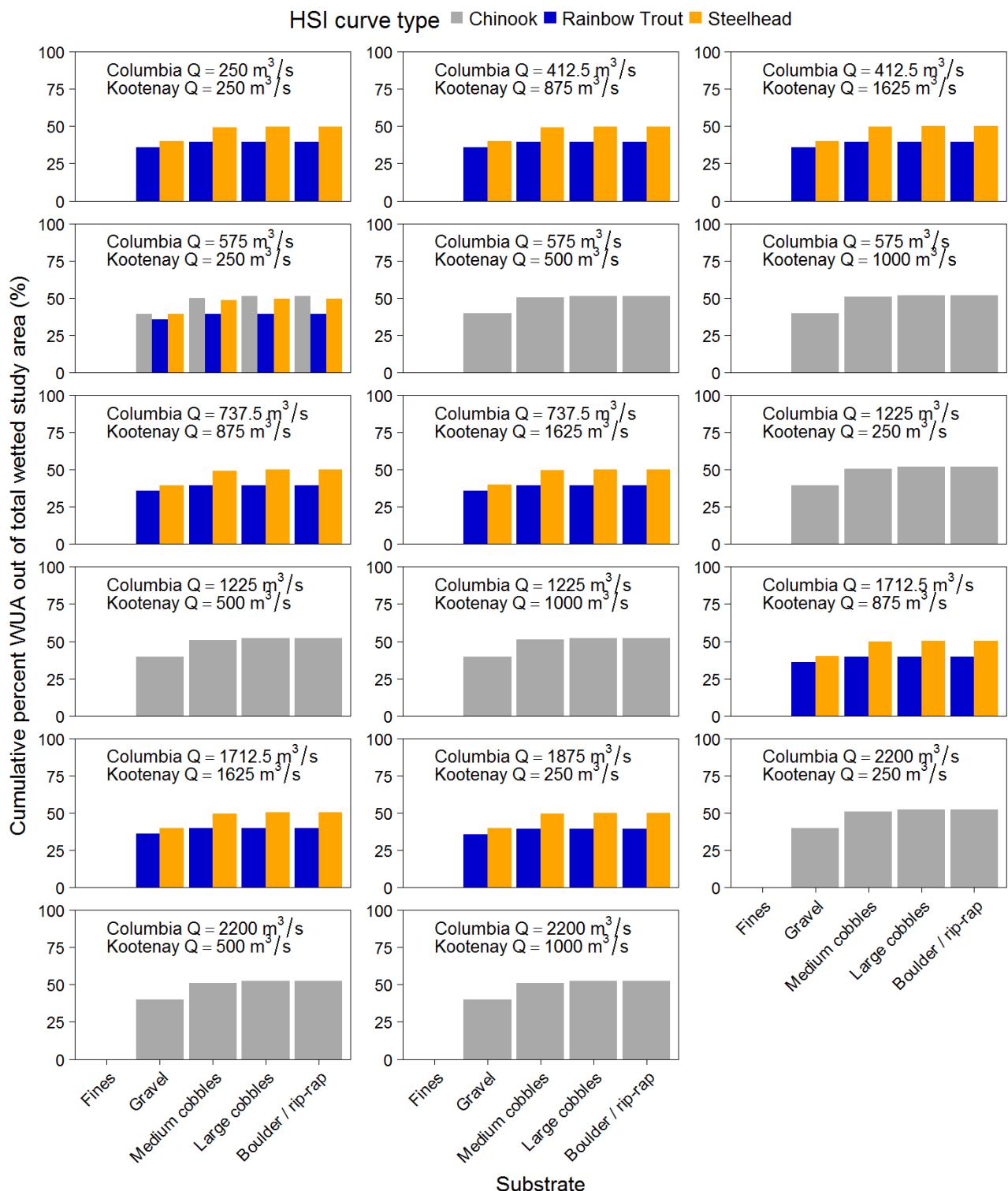


Figure 16: Cumulative distribution of weighted usable area (WUA) out of total wetted area for each model run for the Kootenay River, estimated using substrate-based HSI values; data plotted by model flow level (panels) and colour-coded by species and type of HSI curve.



## 4.0 DISCUSSION

The first objective was to develop spawning habitat suitability criteria for depth and velocity of Steelhead and Rainbow Trout, as well as incorporate available substrate data to improve suitability models for these species and Chinook Salmon in large rivers (the Columbia River, if possible). To maintain consistency and comparability with the results of the previous document (Golder 2016), velocity and depth HSC curves for Steelhead, and preferred spawning substrate values for all three species of interest were selected from Beecher et al. 2016 for meeting this objective. For Rainbow Trout, HSC curves for velocity and depth were selected from Thorley and Baxter 2011, which reports on the local populations in the lower Columbia and lower Kootenay River.

### 4.1 Chinook Salmon Spawning Habitat Availability

The potential spawning period of Chinook Salmon within the program study area was determined by literature review for the previous report (Golder 2016). Based on the range of spawning timing identified by Healy (1991) and discussions with CCRIFC on maximum temperatures associated with spawning, the time period from September 1 to December 1 was selected as the maximum possible spawn timing window of stocks that would be introduced into the study area (Warnock et al. 2016). Only spawning habitat available during this time period was assessed, since other issues that could potentially impact incubation success, such as egg stranding, bed scouring, temperatures, etc. were beyond the scope of this study. The HSCs were applied to the outputs of the River 2D model for the area covered by the BC Hydro CLBMON-47 Lower Columbia River Whitefish Spawning Topography Program (Golder 2014). The projected available habitat was limited to the geographical area that has been the target of this program.

This report included mapped distributions (Appendix B) and modelled estimates of available Chinook Salmon spawning habitat ( $m^2$  and proportion of total area within modelled boundaries) over a broad range of flows during the potential spawning period. The results indicate approximate median discharge WUA of approximately 3,900  $m^2$  (Large River HSC) to 62,000  $m^2$  (Columbia-Snake HSC) in the Kootenay River Study Area and approximately 24,000  $m^2$  (Large River HSC) to 107,000  $m^2$  (Columbia-Snake HSC) in the Columbia River Study Area. Moreover, the model suggests that at the median flow, the available spawning habitat based on combined depth and velocity HSC results in WUA composing 5.6% to 25.0% of the wetted area of the Columbia River Study Area and 1.1% to 17.7% of the Kootenay River Study Area (using Large River and Columbia-Snake HSC, respectively).

A literature review of spawning habitat requirements of Fall Chinook Salmon was conducted in the previous year of this program (Golder 2016). Similar to the previous report, we applied the estimate of redd size ( $45 m^2$ ) that includes additional observed spatial separation and percent occupancy from Geist et al. (2006) to determine the number of redds that the two study areas could potentially support (Table 7). These projections, using approximate median flows, range from 31 to 1,130 redds that may be supported by the habitat within these areas, depending upon assumptions. Similar to the previous year, river discharge had relatively less effect on the number of supported redds, compared to the chosen suitability curve. The proportion of habitat available that is utilized also has a large effect, using the ranges suggested by Geist et al. (2006). Using a 15% midpoint of the range (bold values in table) summary as a “best estimate”, the number of redds supported would range from 93 to 565 for both areas combined at the median flow, dependent upon the selected HSC curve. These estimates have high uncertainty based on previously discussed limitations of the model used in this study.



**Table 7: Number of redds supported based on estimated WUA of Chinook Spawning Habitat with alternative assumptions. Values in bold and italics represent the median flow scenario.**

**Note:** WUA estimates and number of redds from 2016 (estimated using only depth and velocity) are included in brackets.

Assumptions			WUA	# of Redds				
Reach	HSC	Discharge (cms)		% Utilization--45 m <sup>2</sup> per redd				
		Columbia	Kootenay	m <sup>2</sup>	5	10	15	
Columbia	Large Rivers	412.5	375	29,923 (52,930)	33 (59)	66 (118)	100 (176)	199 (353)
		1062.5	375	23,922 (71,875)	<b>27 (80)</b>	<b>53 (160)</b>	<b>80 (240)</b>	<b>159 (479)</b>
		2037.5	375	3,993 (97,155)	4 (108)	9 (216)	13 (324)	27 (648)
		412.5	875	29,493 (54,838)	33 (61)	66 (122)	98 (183)	197 (366)
		1062.5	875	21,934 (71,127)	24 (79)	49 (158)	73 (237)	146 (474)
		2037.5	875	3,158 (89,747)	4 (100)	7 (199)	11 (299)	21 (598)
	Columbia/Snake	412.5	375	112,731 (138,801)	125 (154)	251 (308)	376 (463)	752 (925)
		1062.5	375	107,262 (166,288)	<b>119 (185)</b>	<b>238 (370)</b>	<b>358 (554)</b>	<b>715 (1,109)</b>
		2037.5	375	84,050 (246,097)	93 (273)	187 (547)	280 (820)	560 (1,641)
		412.5	875	119,209 (148,236)	132 (165)	265 (329)	397 (494)	795 (988)
Kootenay	Large Rivers	1062.5	875	112,423 (176,575)	125 (196)	250 (392)	375 (589)	749 (1,177)
		2037.5	875	88,185 (260,275)	98 (289)	196 (578)	294 (868)	588 (1,735)
		2200	250	3,531 (21,085)	4 (23)	8 (47)	12 (70)	24 (141)
		575	500	10,518 (41,125)	12 (46)	23 (91)	35 (137)	70 (274)
		1225	500	3,907 (32,930)	<b>4 (37)</b>	<b>9 (73)</b>	<b>13 (110)</b>	<b>26 (220)</b>
		2200	500	2,967 (41,257)	3 (46)	7 (92)	10 (138)	20 (275)
		575	1000	6,516 (41,457)	7 (46)	14 (92)	22 (138)	43 (276)
		1225	1000	3,845 (53,714)	4 (60)	9 (119)	13 (179)	26 (358)
	Columbia/Snake	2200	1000	1,876 (34,593)	2 (38)	4 (77)	6 (115)	13 (231)
		575	250	14,391 (54,586)	16 (61)	32 (121)	48 (182)	96 (364)
		1225	250	6,172 (50,244)	7 (56)	14 (112)	21 (167)	41 (335)
		2200	250	28,138 (88,560)	31 (98)	63 (197)	94 (295)	188 (590)
Combined	Large Rivers (Columbia/Kootenay median values combined)	575	500	75,286 (147,635)	84 (164)	167 (328)	251 (492)	502 (984)
		1225	500	62,188 (176,795)	<b>69 (196)</b>	<b>138 (393)</b>	<b>207 (589)</b>	<b>415 (1,179)</b>
	Columbia/Snake (Columbia/Kootenay median values combined)	2200	500	43,301 (176,588)	48 (196)	96 (392)	144 (589)	289 (1,177)
		575	1000	69,763 (126,723)	78 (141)	155 (282)	233 (422)	465 (845)
		1225	1000	60,197 (147,337)	67 (164)	134 (327)	201 (491)	401 (982)
	2200 (Columbia/Kootenay median values combined)			48,448 (224,225)	54 (249)	108 (498)	161 (747)	323 (1,495)
	575 (Columbia/Kootenay median values combined)			68,919 (144,572)	77 (161)	153 (321)	230 (482)	459 (964)
	1225 (Columbia/Kootenay median values combined)			54,069 (151,575)	60 (168)	120 (337)	180 (505)	360 (1,011)
	Large Rivers (Columbia/Kootenay median values combined)			31 (117)	62 (233)	<b>93 (349)</b>	185 (699)	
	Columbia/Snake (Columbia/Kootenay median values combined)			188 (381)	376 (762)	<b>565 (1,144)</b>	1,130 (2,287)	



The WUA and number of redds estimates in the current study year that incorporated available substrate data were substantially lower than the estimates provided in the previous study year (Table 7; Golder 2016). This is largely due to the relatively high amounts of habitat within the River 2D model boundaries that did not have substrate data associated with it, and subsequently had to be removed from the analysis. Consequently, the current WUA and number of redd estimates are believed to be downwardly biased, and the actual available Chinook spawning habitat is somewhere in between the estimates from both study years.

These estimates from both study years were based on the median river flows that were estimated from the past 15 years of hydrology data used in this study. In general, during the putative spawning period of Chinook Salmon, river flows have not resulted in highly variable WUA, suggesting significant habitat will be available during the low and high flow years. Although these estimates may be substantially lower than the previous year's results, there still appears to be significant amounts of spawning habitat available for Chinook Salmon in the reaches examined.

Although it is not the intent of this study to estimate total spawning capacity of the reach of the Columbia basin accessible above Lake Roosevelt, the distribution of Rainbow Trout spawners suggests significant numbers of Chinook spawners are likely to occur outside of the study areas, and in areas where substrate data was not available (Irvine et al. 2014). Expansion of investigations into other habitats is needed to provide a realistic estimate of spawning habitat potential in the greater area of the Transboundary Reach of the Columbia River.

## 4.2 Steelhead and Rainbow Trout Spawning Habitat Availability

For Steelhead, the results indicate approximate median discharge WUA of approximately 16,500 m<sup>2</sup> in the Kootenay River Study Area and approximately 35,000 m<sup>2</sup> in the Columbia River Study Area. The model also suggests that at the median flow, the available spawning habitat based on combined depth and velocity HSC results in WUA composing 4.7% of the wetted area of the Kootenay River Study Area and 8.3% of the Columbia River Study Area.

For Rainbow Trout, the results indicate approximate median discharge WUA of approximately 400 m<sup>2</sup> in the Kootenay River Study Area and approximately 3,800 m<sup>2</sup> in the Columbia River Study Area. Moreover, the model suggests that at the median flow, the available spawning habitat based on combined depth and velocity HSC results in WUA composing <1% of the wetted area in both study areas.

Similar to the current estimates for Chinook Salmon spawning habitat availability, the WUA estimates for Steelhead and Rainbow Trout spawning are believed to be downwardly biased. Furthermore, the contrast between Rainbow Trout and Steelhead WUA estimates likely do not accurately represent actual spawning habitat availability in the study area, considering the large size of Rainbow Trout in the Keenleyside Reach of the lower Columbia River. As a proposed method to validate the accuracy of the current modelling results (Objective 5; Section 1.1), comparisons of spatially modelled spawning areas for Rainbow Trout to the documented distribution of redds (Irvine et al. 2014; Thorley and Baxter 2011) could not be made. This is due to the relatively high uncertainty related to the WUA estimates as a result of the limited coverage of the substrate mapping, and the exclusion of large areas from the current analysis where the highest amounts of Rainbow Trout spawning have been documented in the past (i.e., Norn's Creek Fan in the Columbia River Study Area: Irvine et al. 2014, Thorley and Baxter 2011).



### 4.3 Benefits to White Sturgeon Recovery

The loss of anadromous fish (i.e., Chinook Salmon) runs into the Keenleyside Reach of the lower Columbia River that resulted from the construction of Grand Coulee Dam eliminated an important food source for White Sturgeon (Hildebrand and Parsley 2013; Fisheries and Oceans Canada 2014). Historical nutrient inputs into the Canadian portion of the Columbia River system have also been reduced in part with the elimination of these runs. Prior to the construction of Grand Coulee Dam, anadromous fish runs were likely a significant source of marine derived nitrogen, phosphorus, and trace elements, in addition to being a direct food source for White Sturgeon (Hildebrand and Parsley 2013). Potential impacts of this loss on White Sturgeon over-wintering fitness, spawning frequency and fecundity have been identified (Hildebrand and Birch 1996). Ptolemy and Vennesland (2004) reported that in the Canadian portion of the Columbia River, prey reduction through the loss of anadromous salmon runs has altered the prey availability of native fishes and invertebrates, affecting all life-history stages of White Sturgeon.

White Sturgeon presence has been associated with Rainbow Trout spawning activity in the Transboundary Reach (Irvine et al. 2013). This is a strong indication that White Sturgeon may be using spawning salmonids and salmonid eggs as a food source. The re-introduction of Chinook Salmon into the study area will result in a shift in the fish community towards pre-development conditions. With the estimated number of redds (2 to 795 redds; Table 7) that may be supported by the potential Chinook spawning habitat, 4 to 1,590 spawners are predicted to utilize the study area at the median flow scenario. Using the midpoint estimate for the number of redds that may be supported (93 to 565 redds using 15% utilization within the combined suitable spawning habitat; Table 7), 186 to 1,130 spawners could spawn within the study area of this program. As there are several other sites in the Transboundary Reach that potentially have suitable Chinook spawning habitat, and these results are downwardly biased given the limited coverage of substrate data, it is believed that the total number of spawners utilizing the Transboundary Reach will be substantially higher.

It is also possible that escapement to the Transboundary Reach could far exceed the spawner abundance needed to reach functional redd capacity, as redd counts tend to stabilize as escapement increases (Groves et al. 2013). Alternatively, escapement could be lower than that predicted based on spawning habitat availability if there are survival bottlenecks at other life cycle stages prior to, or after spawning (Warnock et al. 2016). Thus, the relationship between habitat area and spawner abundance as estimated in this study should not be considered an indicator of the escapement capacity. Even using estimates generated in this study, the potential influx of Chinook Salmon may provide substantial amounts of biomass and nutrients for the food web, which in turn will provide White Sturgeon in the Transboundary Reach with important food and nutrient sources that will have positive benefits to their overall fitness and spawning success.

### 4.4 Opportunities for Physical Works

Based on the limited coverage of the substrate mapping within the River 2D hydraulic models, and the potential for many other areas in the lower Columbia and lower Kootenay River to have suitable spawning areas for Chinook Salmon, opportunities to conduct physical works to improve spawning habitat have not been discussed. Opportunities may be identified if the coverage of the substrate mapping is to extend within the current study area, or if detailed habitat modelling is conducted at additional sites.



## 5.0 SUMMARY

Possible scenarios were examined to assign substrate values to areas outside of the current substrate mapping. One such scenario was to assume that non substrate mapped areas have the same proportion of substrate as the mapped areas, which would allow expansion of the WUA and allow comparison with known Rainbow Trout distribution. In comparison to the deep, high velocity thalweg that the substrate mapping focused on, the excluded areas mainly contain shallower habitats with lower velocity, and therefore would likely have a higher proportion of smaller substrates (i.e., gravels and fines). Therefore, efforts to assign substrates to the excluded areas were not conducted at this time. Consequently, the current WUA and number of redd estimates are believed to be downwardly biased, and the actual available Chinook spawning habitat is predicted to be somewhere in between the estimates generated in both study years (Golder 2016).

This study is considered very preliminary and is designed to provide a quick snapshot of potential spawning habitat for Chinook Salmon if passage into this reach of the Columbia River occurs in the future. In their spatial hierarchy from watershed to reach to site, Geist et al. (2006) advised obtaining more specific information to align habitat predictions with actual use. In the case of the reaches examined in this study, there are no historical data, other than current use by other salmonids, that can be used to determine why some areas of suitable habitat are being used and others are not. Consequently, these predictions will likely always rely on analogies with other habitats currently being used by spawning Chinook Salmon to determine likely capacities and will have greater uncertainty than studies conducted where Chinook Salmon spawning is occurring. However, much more refinement can be obtained to determine available spawning habitat within the entire 60+ km reach of the Columbia River that extends from Lake Roosevelt to HLK and Brilliant dams. Geomorphological investigations to determine likely spawning habitat could provide the basis for detailed hydraulic modelling and substrate mapping of other subsections of this entire reach of the Columbia River. Much more refinement of the 2D models presented in this study can be accomplished by expanding current substrate mapping, as well as examining upwelling and interstitial flow.

Although this habitat is likely highly suited for successful spawning of large salmonids, based on spring use of the area for large Rainbow Trout spawning (Irvine et al. 2014), there are other areas within the Columbia River upstream of Lake Roosevelt and below HLK that may be equally or more suitable for Chinook spawning. Consequently, the model output that indicates percentage of the area of the total wetted area at the discharges indicated, may be of equal or more value in determining the quality of habitat available in the Columbia River above Lake Roosevelt. There are also extensive reaches of the Columbia River drainage upstream from the study area that have historical pre-dam records of Chinook Salmon spawning, but have significant barriers from upper Columbia River Basin dams that would need to be addressed to provide access.



## **6.0 RECOMMENDATIONS**

The following recommendations are presented to strengthen the analysis and dataset:

- 1) Expand investigations into the entire reach of the Columbia and Kootenay rivers between Lake Roosevelt and the barrier at Brilliant and Hugh L. Keenleyside dams, including significant tributaries. A geomorphological approach should be used to determine additional study sites for detailed habitat modelling. For example, one site on the lower Columbia River that may have significant amounts of suitable spawning habitat for Chinook Salmon is the Genelle area, based on the channel morphology and large amounts of gravel substrates present.
- 2) Extend substrate mapping to include areas within existing River2D models that have no data. Also examine the extent of available substrate data within additional study sites, if selected. The current substrate mapping may also need to be extended to increase coverage in these areas as well, to facilitate comparison of existing Rainbow Trout use with modelled projections.
- 3) Examine potential opportunities to conduct physical works (i.e., substrate enhancement) within all study areas if one or both of the above recommendations are met.



## **7.0 CLOSURE**

We trust that this report meets your current requirements. If you have any further questions, please do not hesitate to contact the undersigned.

**GOLDER ASSOCIATES LTD.**

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Project Manager, Fisheries Biologist

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Shawn Redden, BSc, RPBio  
Associate, Senior Fisheries Biologist

BH/SU/DS/SR/cmc

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## 8.0 LITERATURE CITED

- Beecher, Hal, Brad Caldwell, and Jim Pacheco. 2016. Instream Flow Study Guidelines. Technical and Habitat Suitability Issues Including Fish Preference Curves. UPDATED, March 9, 2016. Water Resources, Department of Ecology, PO Box 47600, Olympia, WA 98504-7600. 2016 Update. No 04-11-007.
- Bjorner, T. c. and D.W. Reiser. 1991. Habitat Requirements of Salmonids in Streams, Chapter 4: In: Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19:83-139.
- Carter, Katherine. 2005. The Effects of Temperature on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage. Implications for Klamath Basin TMDLs. California Regional Water Quality Control Board, North Coast Region. 26 pp. Downloaded on 25 March, 2016 from <http://projects.northcoastresourcepartnership.org/docs.php?oid=1000008665&ogid=1000002244>
- Fisheries and Oceans Canada. 2014. Recovery strategy for White Sturgeon (*Acipenser transmontanus*) in Canada [Final]. In *Species at Risk Act Recovery Strategy Series*. Ottawa: Fisheries and Oceans Canada. 252 pp.
- Geist, David R., Evan V. Arntzen, Yi-Ju Chien, Timothy P. Hanrahan, Christopher J. Murray, William A. Perkins, Marshall C. Richmond, Yulong Xie. 2006. Spawning Habitat Studies of Hanford Reach Fall Chinook Salmon (*Oncorhynchus tshawytscha*). Final Report Prepared by Pacific Northwest National Laboratory, Richland, Washington. Prepared for U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon. Project No. 1994-069-00. Contract No. 00000652. September. Document ID #P110555.
- Golder Associates Ltd. 2014. Lower Columbia River whitefish spawning ground topography survey: Year 3 data report. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 10-1492-0142F: 68 p. + 3 app.
- Golder Associates Ltd. 2016. Chinook Salmon Spawning Habitat Availability in the Lower Columbia River. Report prepared for the Canadian Columbia River Inter-tribal Fisheries Commission, Cranbrook, BC. Golder Report No. 1538622F: 24 p. + 3 app.
- Groves, P. A., Chandler, J. A., Alcorn, B., Richter, T. J., Connor, W. P., Garcia, A. P., & Bradbury, S. M. (2013). Evaluating salmon spawning habitat capacity using redd survey data. *North American Journal of Fisheries Management*, 33(4), 707-716.
- Healey, M. C. 1991. Life History of Chinook Salmon (*Oncorhynchus tshawytscha*). In: Pacific Salmon Life Histories. Edited by C. Groot and L. Margolis. Department of Fisheries and Oceans, Biological Sciences Branch, Pacific Biological Station, Nanaimo, British Columbia, Canada. Published by UBC Press. 1991, reprinted 1998. pp 313-393.
- Hildebrand, L., and G. Birch. 1996. Canadian Columbia River White Sturgeon stock stabilization discussion document. Report to BC Ministry of Environment, Lands and Parks.
- Hildebrand, L. R. and M. Parsley. 2013. Upper Columbia White Sturgeon Recovery Plan – 2012 Revision. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 129p. + 1 app. Available at: [www.uppercolumbiasturgeon.org](http://www.uppercolumbiasturgeon.org)



Irvine, R.L., J.T.A. Baxter and J.L. Thorley (2013). WLR Monitoring Study No. CLBMON-46 (Year 6) Lower Columbia River Rainbow Trout Spawning Assessment. *Columbia River Water Use Plan*. BC Hydro, Castlegar. A Mountain Water Research and Poisson Consulting Ltd Final Report.

Irvine, R.L., J.T.A. Baxter and J.L. Thorley. 2014. WLR Monitoring Study No. CLBMON-46 (Year 7) Lower Columbia River Rainbow Trout Spawning Assessment. *Columbia River Water Use Plan*. BC Hydro, Castlegar. A Mountain Water Research and Poisson Consulting Ltd. Final Report.

J.T.A. Baxter, J.L. Thorley and Robyn L. Irvine (2016). WLR Monitoring Study No. CLBMON-46 (Year 8) Lower Columbia River Rainbow Trout Spawning Assessment. *Columbia River Water Use Plan*. BC Hydro, Castlegar. A Mountain Water Research and Poisson Consulting Ltd. Final Report.

Kahle, D. and H. Wickham. 2013. ggmap: A package for spatial visualization with Google Maps and OpenStreetMap. R package version 2.3. <http://CRAN.R-project.org/package=ggmap>.

McCullough, Dale, Shelley Spawlding, Debra Sturdevant, and Mark Hicks. 2001. Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids, Issue Paper 5. EPA-910-D-01-005 Environmental Protection Agency. Prepared as Part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project.114 pp.

Preston, Jon. 2014. Acoustic Riverbed Classification of the lower Columbia River. Report prepared for BC Hydro, Castlegar, BC. 21 pp. + 4 app.

Ptolemy, J., and R. Vennesland. 2004. COSEWIC assessment and update status report of the white sturgeon *Acipenser transmontanus*. Report written for COSEWIC Secretariat, Ottawa, ON.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>.

Thorley, J.L. and J.T.A. Baxter (2011). WLR Monitoring Study No. CLBMON-46 (Year 4) Lower Columbia River Rainbow Trout Spawning Assessment. *Columbia River Water Use Plan*. BC Hydro, Castlegar. Mountain Water Research and Poisson Consulting Ltd.

Warnock, W.G., Stroud, D.H.P, and J.E. Merz. 2016. Donor stock selection of Chinook Salmon for reintroduction to the Transboundary Reach of the Columbia River. Report prepared for the Canadian Columbia River Inter-Tribal Fisheries Commission. 153 pp.

Wickham, H. 2009. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.



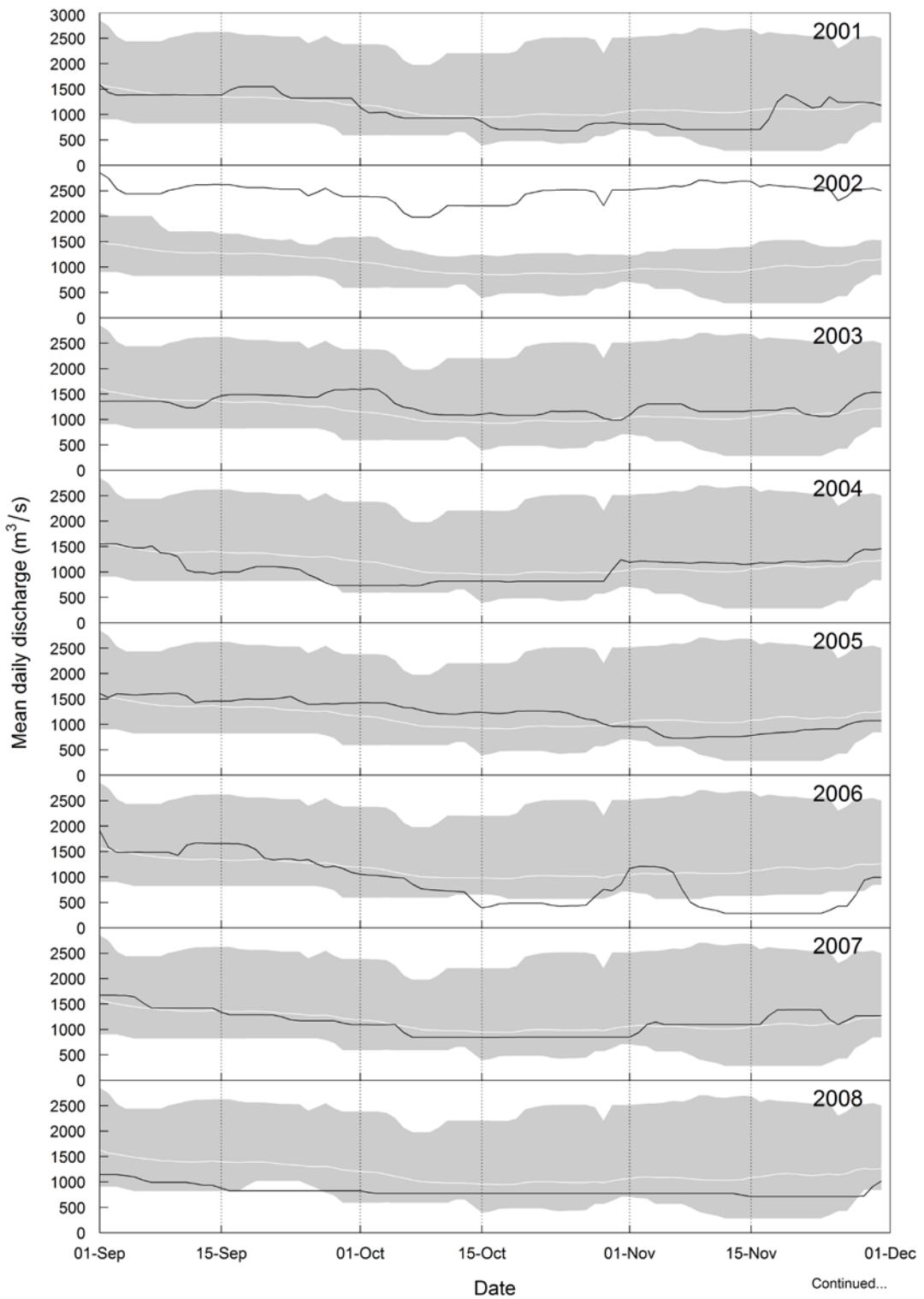
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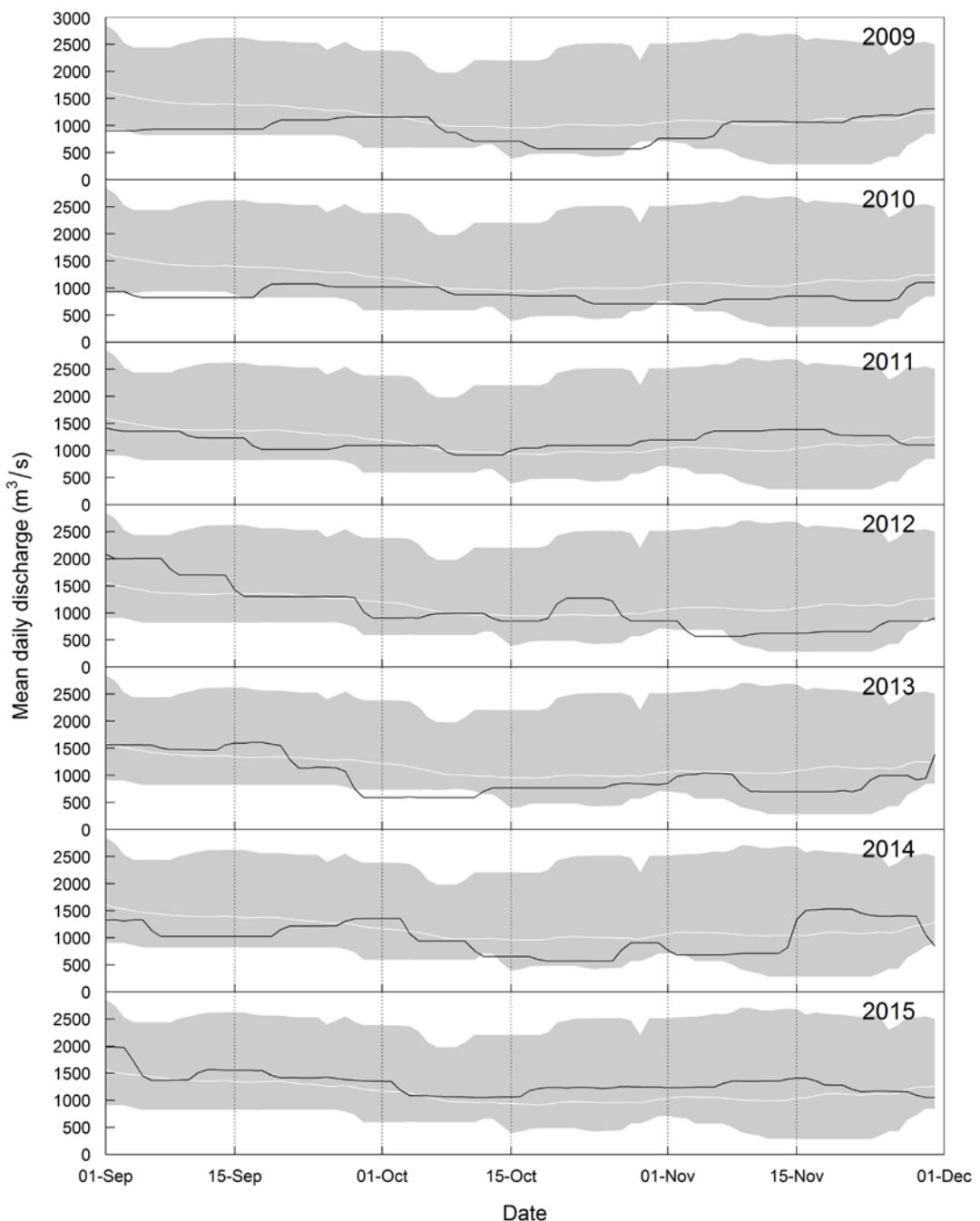
# APPENDIX A

## Lower Columbia and Kootenay River Annual Hydrographs

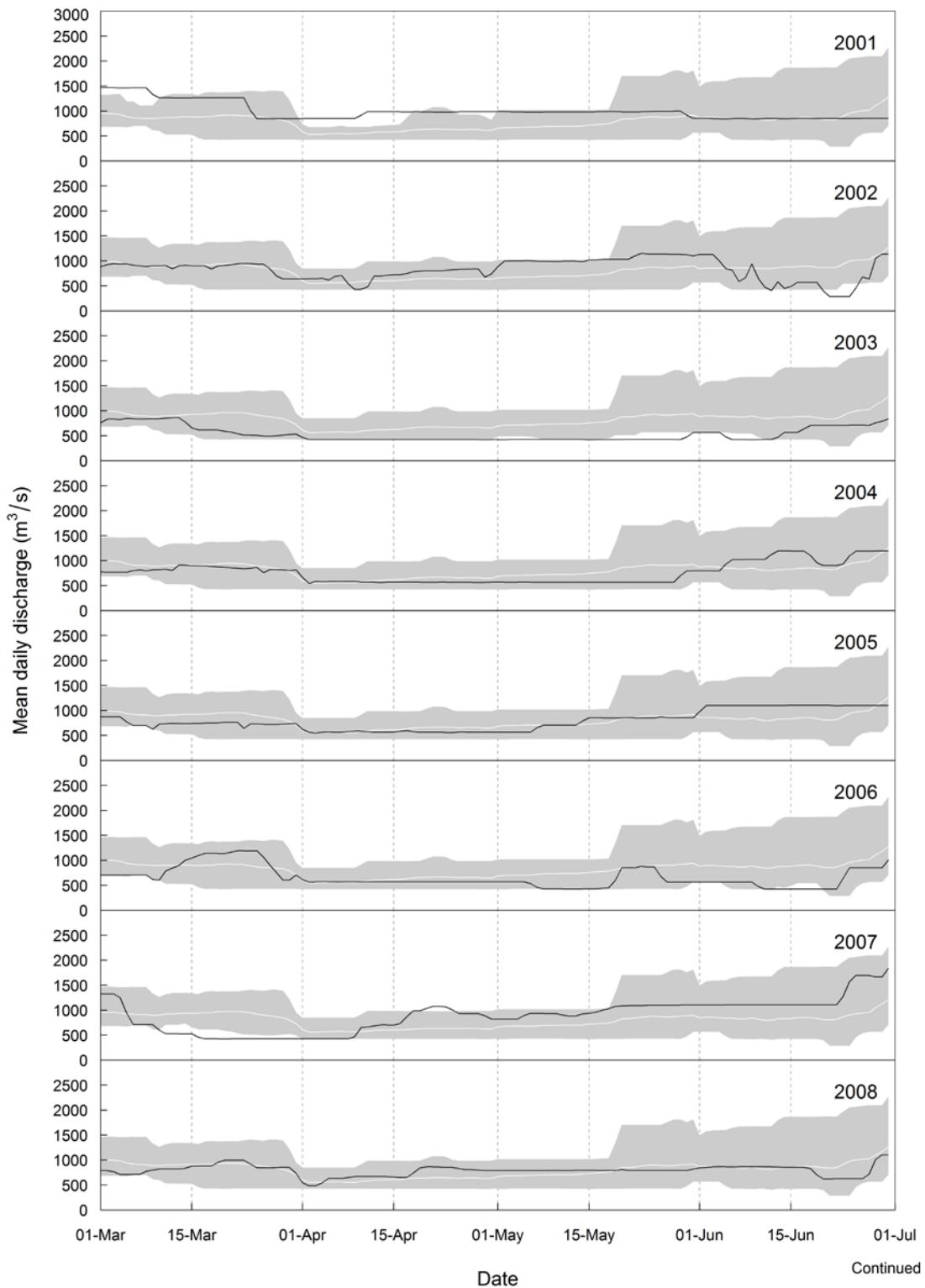


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*Figure A1. Mean daily discharge ( $m^3/s$ ) for the Columbia River at Hugh L. Keenleyside Dam during Chinook spawning period, 2001-2015. The shaded area represents minimum and maximum mean daily discharge values recorded during other study years (between 2001 and 2015). The white line represents average mean daily discharge values over the same time period.*

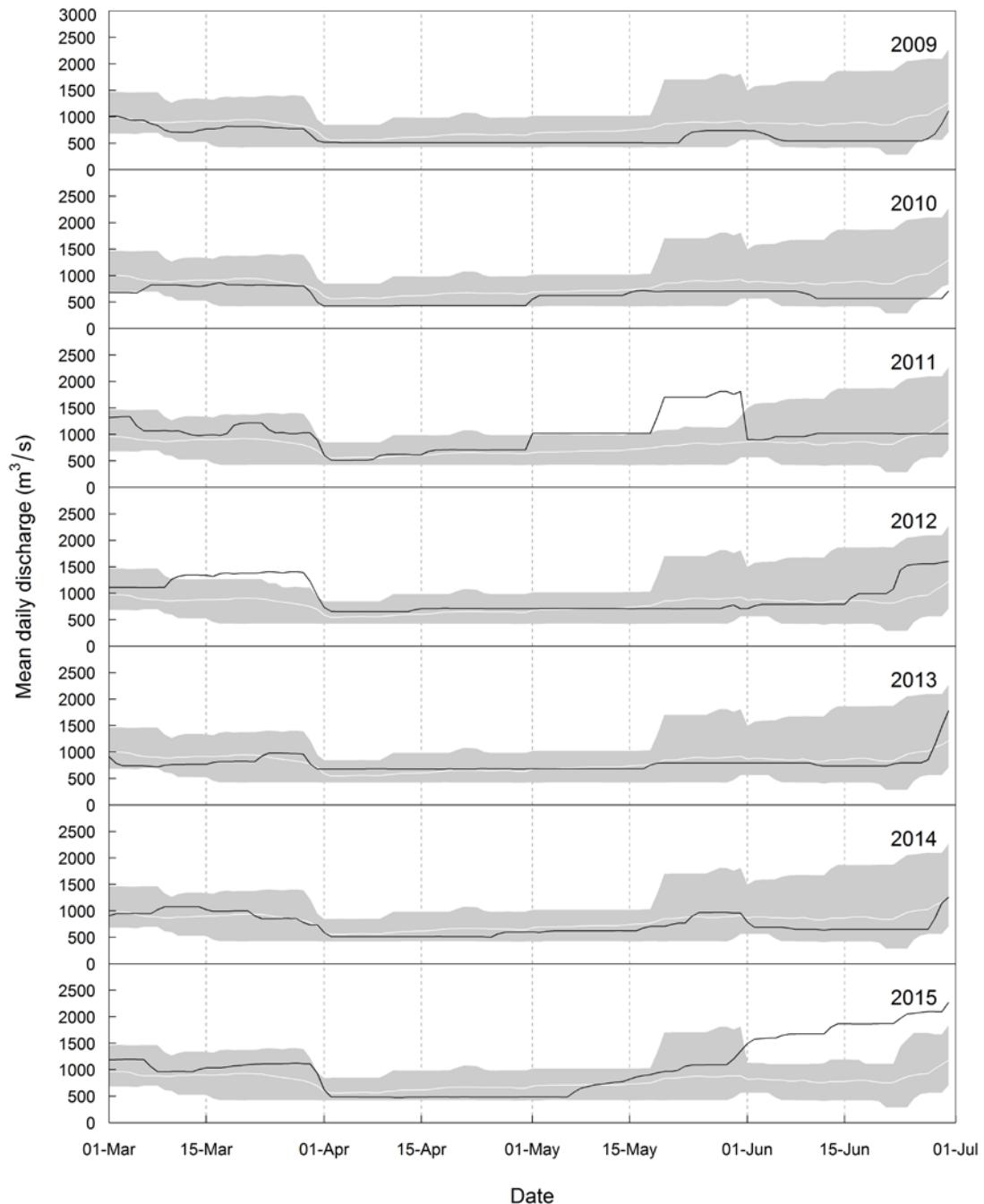


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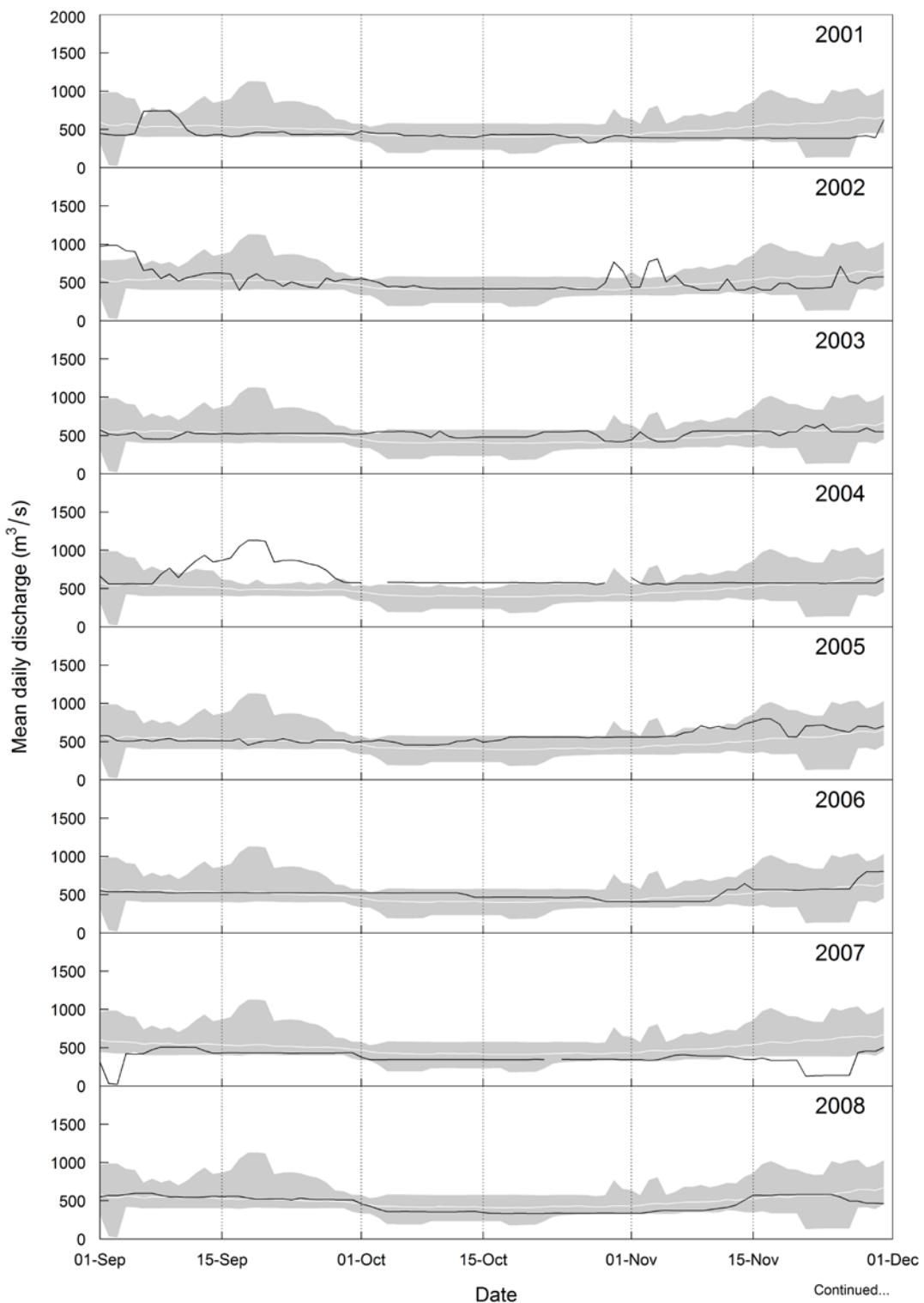


*Figure A2. Mean daily discharge ( $m^3/s$ ) for the Columbia River at Hugh L. Keenleyside Dam during Rainbow Trout spawning period, 2001-2015. The shaded area represents minimum and maximum mean daily discharge values recorded during other study years (between 2001 and 2015). The white line represents average mean daily discharge values over the same time period*

Continued

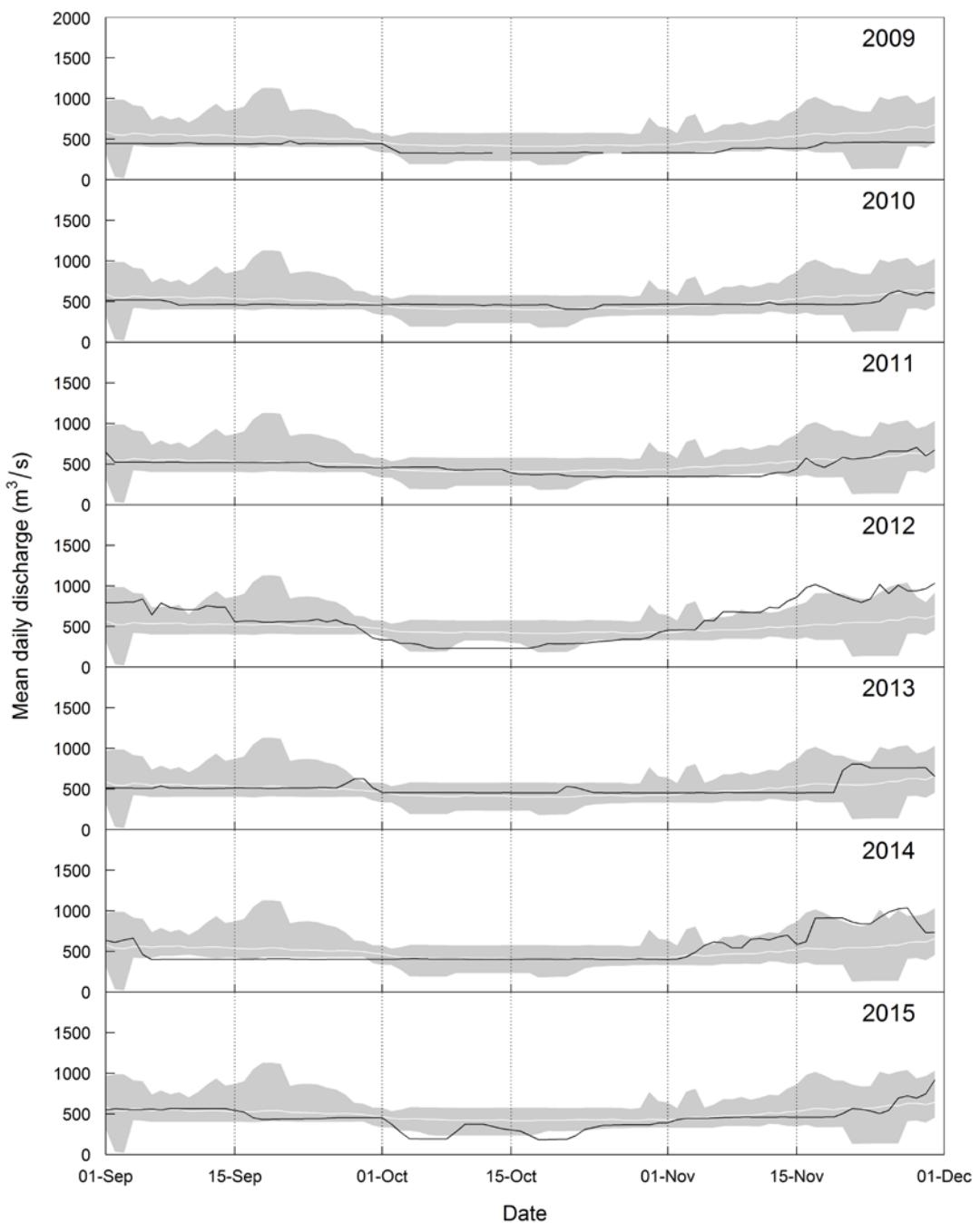


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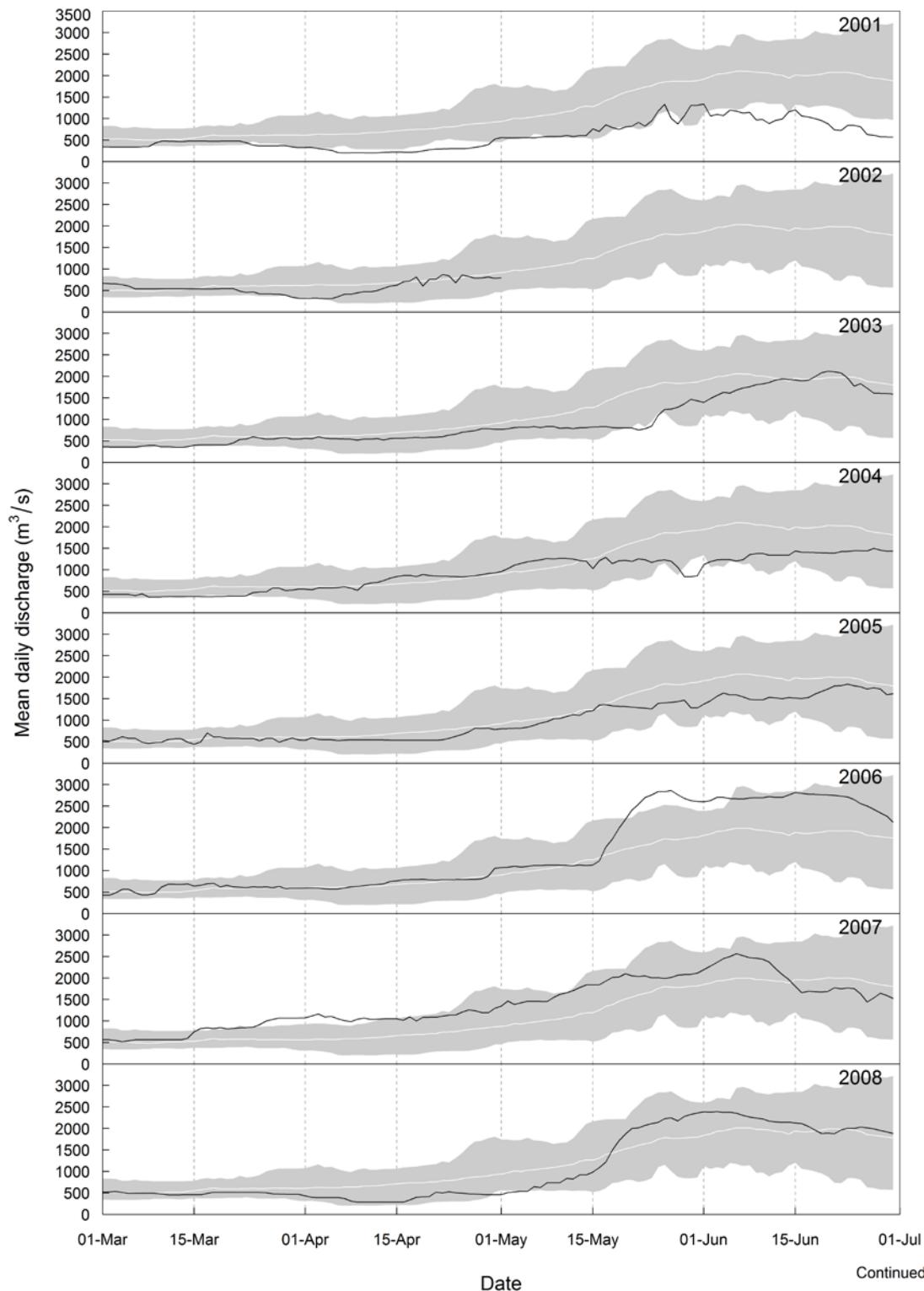


*Figure A3. Mean daily discharge ( $\text{m}^3/\text{s}$ ) for the Kootenay River at Brilliant Dam during Chinook spawning period, 2001-2015. The shaded area represents minimum and maximum mean daily discharge values recorded during other study years (between 2001 and 2015). The white line represents average mean daily discharge values over the same time period.*

Continued...

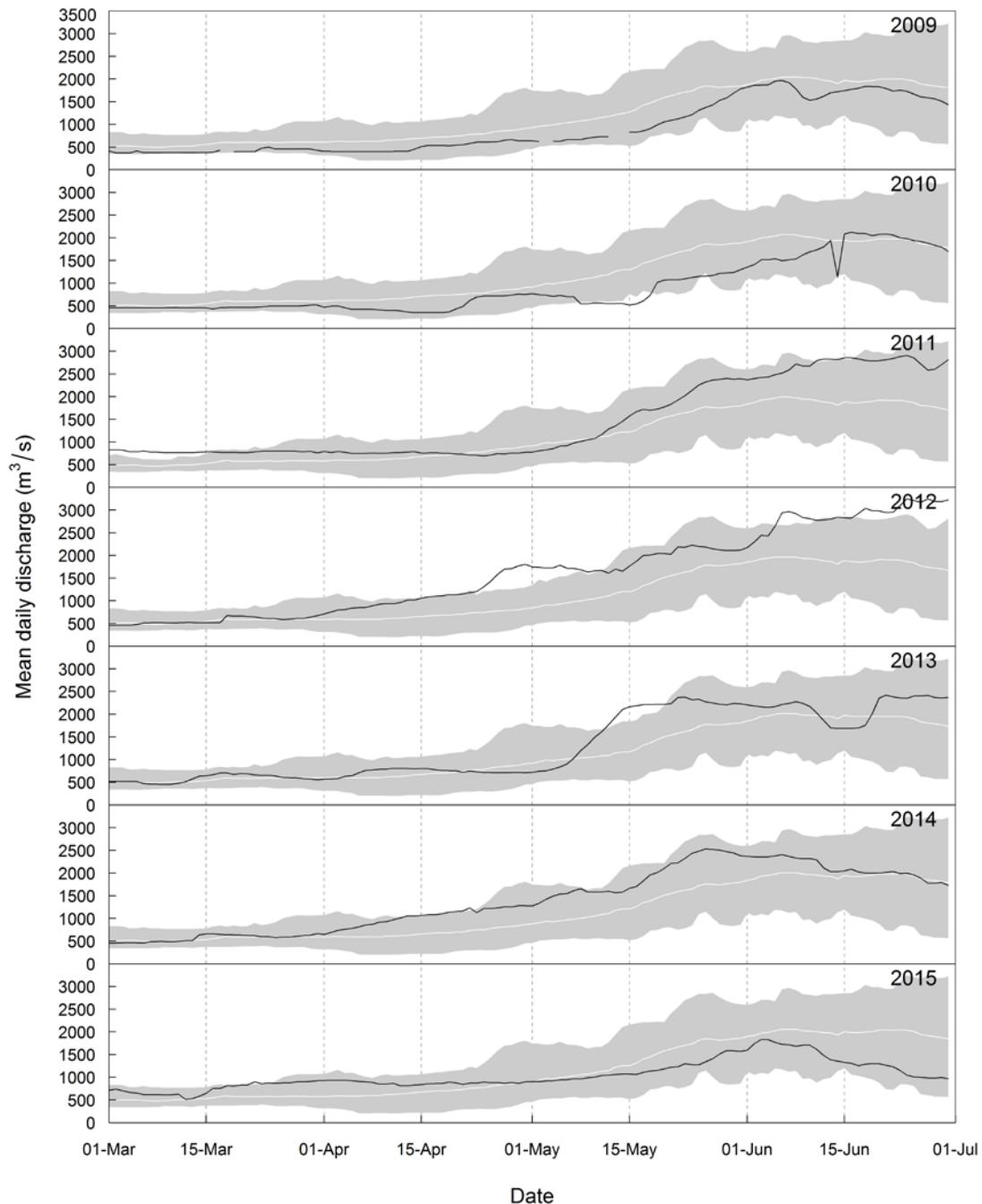


*Figure A3. Concluded.*



*Figure A4. Mean daily discharge ( $m^3/s$ ) for the Kootenay River at Brilliant Dam during Rainbow Trout spawning period, 2001-2015. The shaded area represents minimum and maximum mean daily discharge values recorded during other study years (between 2001 and 2015). The white line represents average mean daily discharge values over the same time period*

Continued



*Figure A4. Concluded*



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# **APPENDIX B**

## **River 2D Hydraulic Model Outputs**

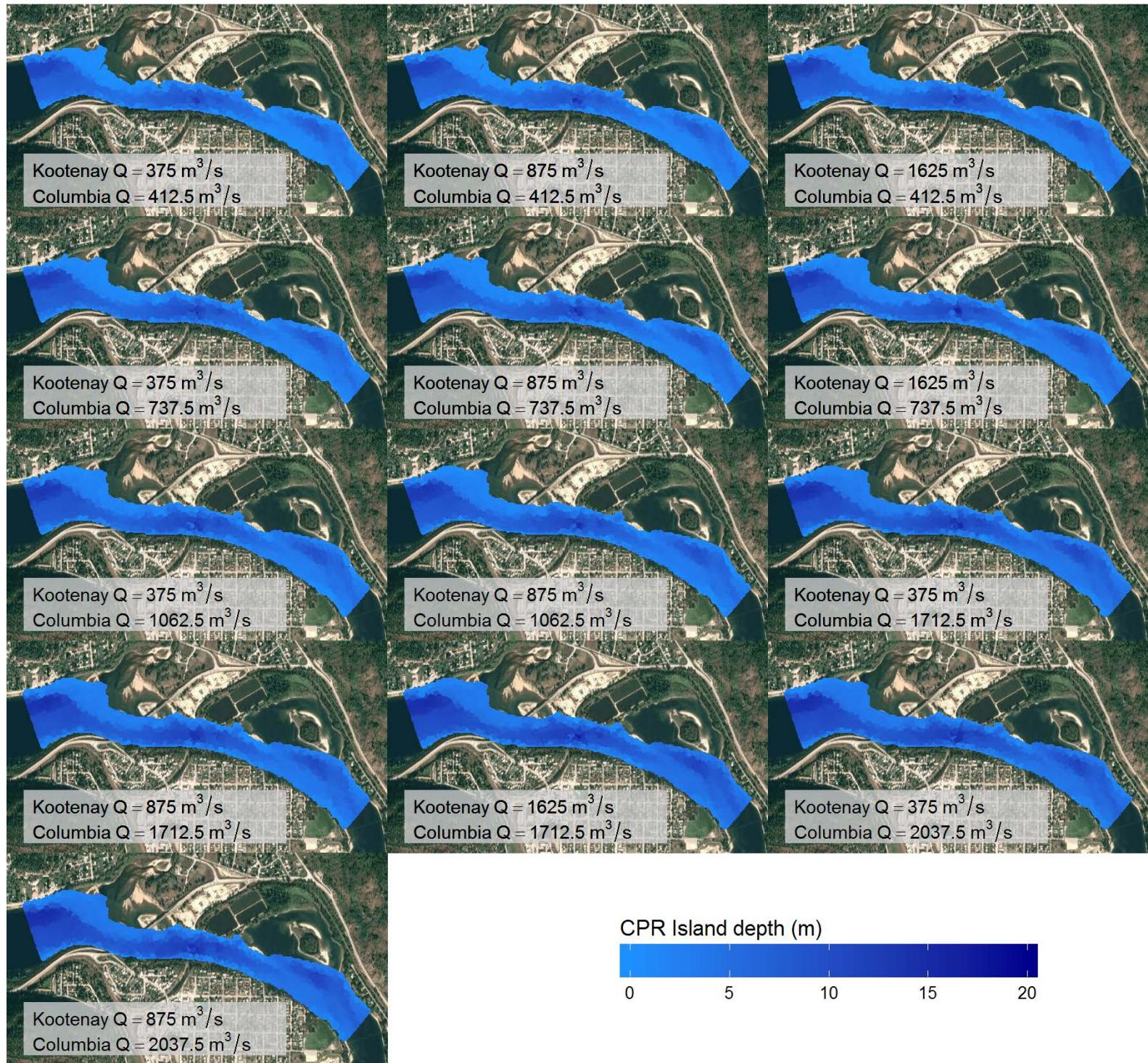


Figure B1. Map of depth (m) at Columbia River, plotted by River2D model run (panels).

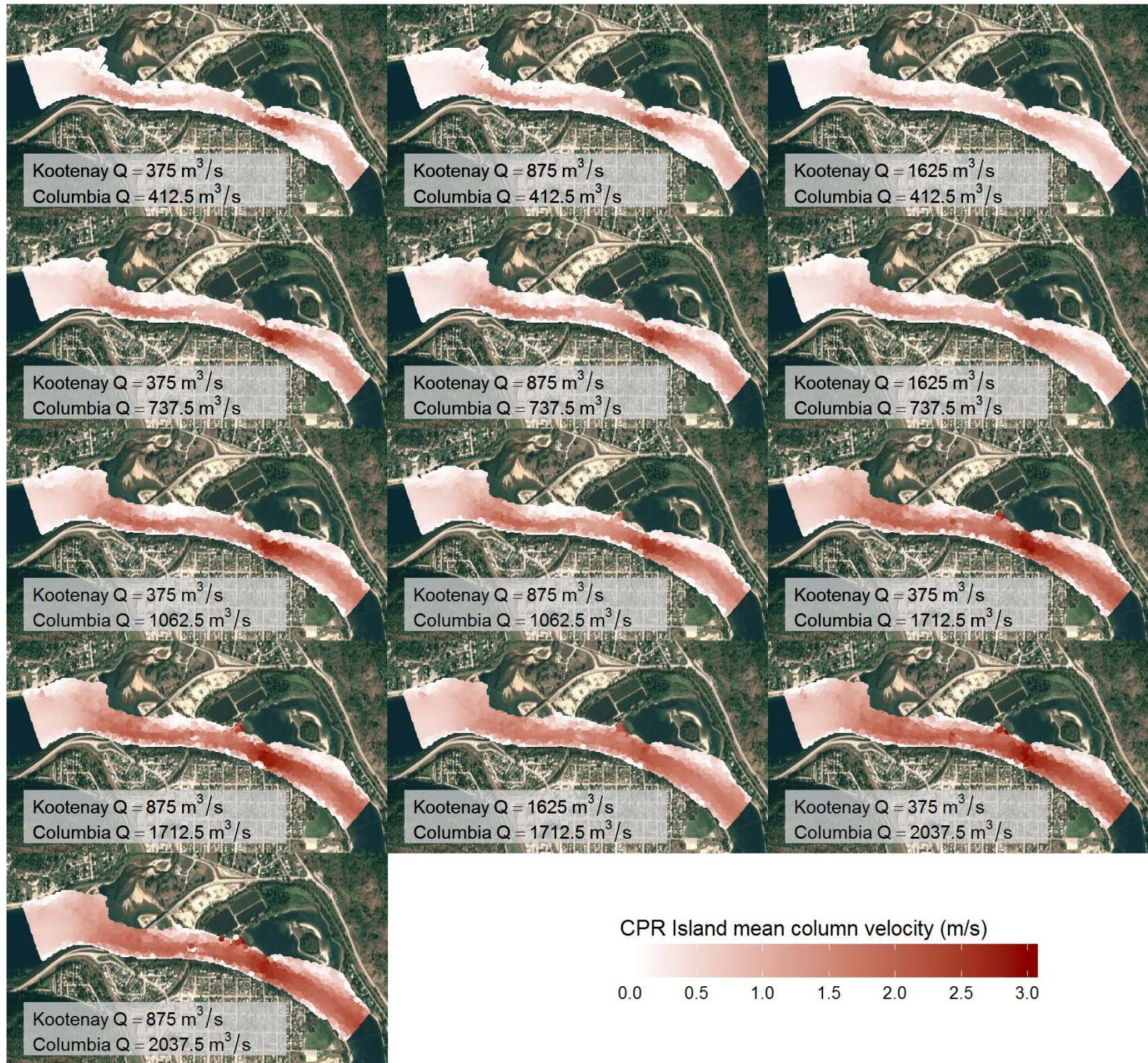


Figure B2. Map of velocity (m/s) at Columbia River, plotted by River2D model run (panels).

CPR Island Combined HSI   ●  $\leq 0.2$    ●  $0.2 < \text{HSI} \leq 0.4$    ●  $0.4 < \text{HSI} \leq 0.6$    ●  $0.6 < \text{HSI} \leq 0.8$    ●  $> 0.8$

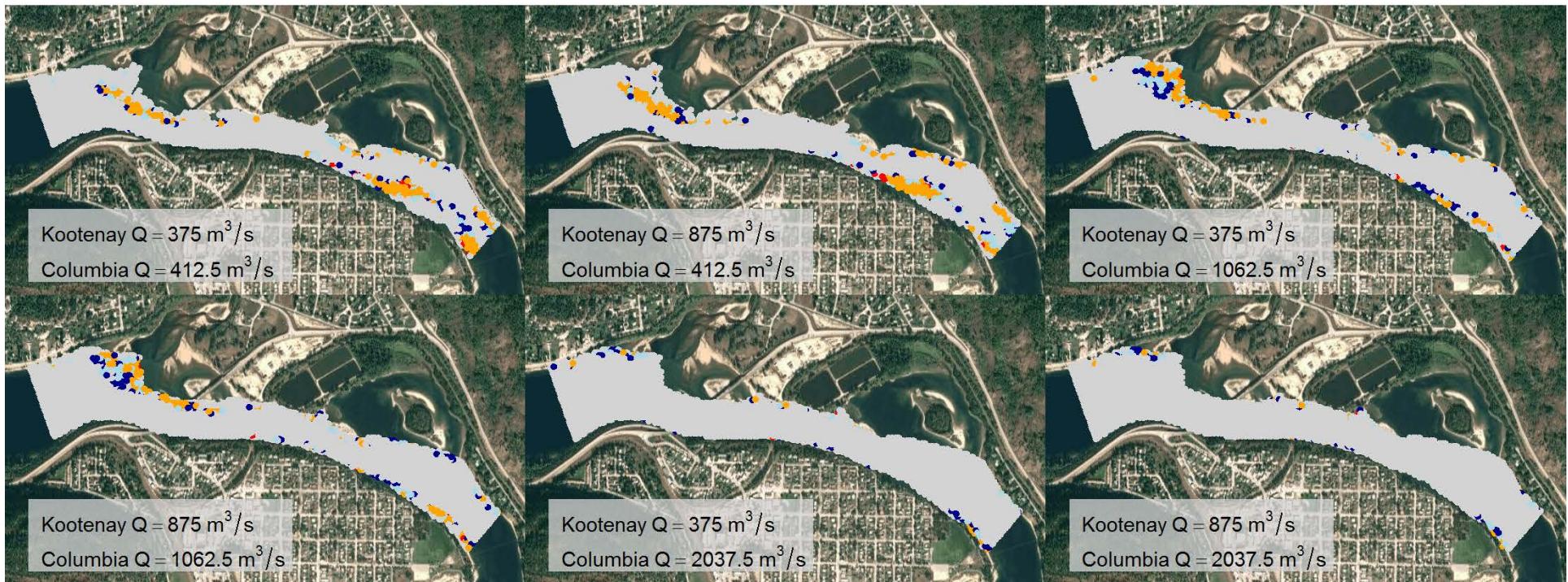


Figure B3. Combined HSI (based on depth, velocity, and substrate) for Chinook Salmon at Columbia River, plotted by River2D model run (panels). HSI calculations were based on the large river HSI curve (for rivers with mean annual discharge  $\geq 85.0 \text{ m}^3/\text{s}$ ).

CPR Island Combined HSI   ●  $\leq 0.2$    ●  $0.2 < \text{HSI} \leq 0.4$    ●  $0.4 < \text{HSI} \leq 0.6$    ●  $0.6 < \text{HSI} \leq 0.8$    ●  $> 0.8$

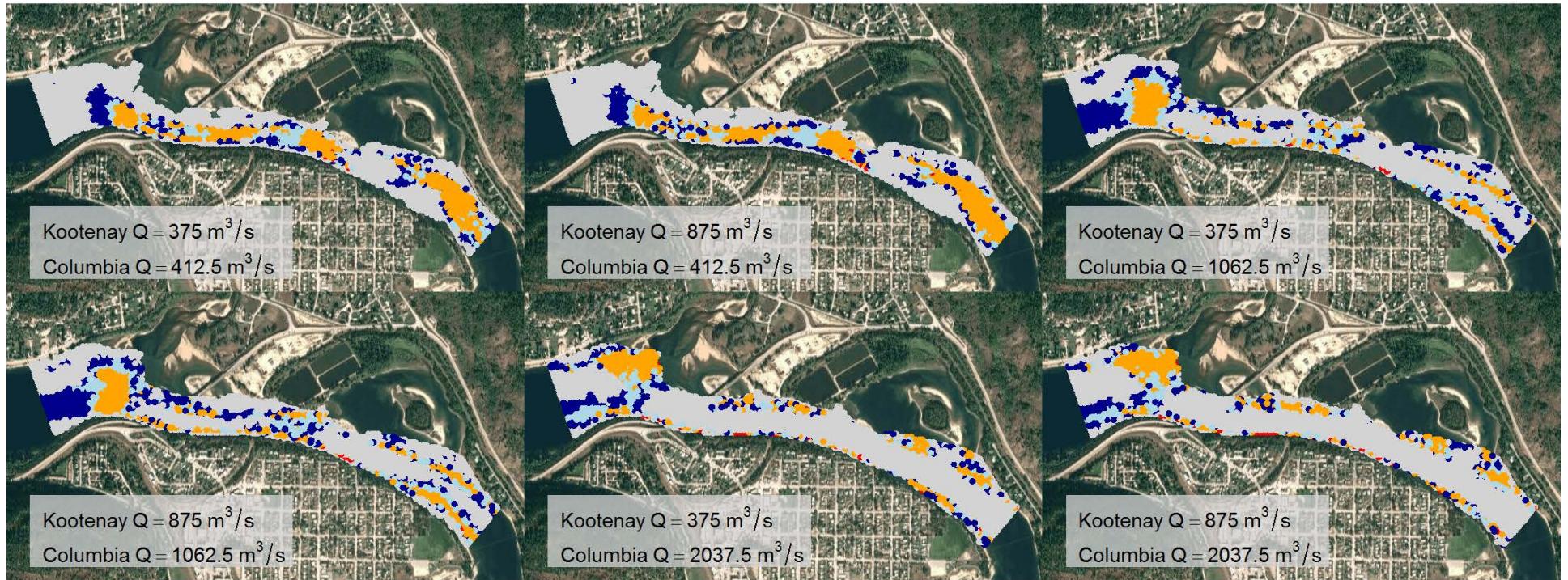


Figure B4. Combined HSI (based on depth, velocity, and substrate) for Chinook Salmon at Columbia River, plotted by River2D model run (panels). HSI calculations were based on the Columbia-Snake HSI curve (for rivers with mean annual discharge  $\geq 2,831.7 \text{ m}^3/\text{s}$ ).

CPR Island Combined HSI   ●  $\leq 0.2$    ●  $0.2 < \text{HSI} \leq 0.4$    ●  $0.4 < \text{HSI} \leq 0.6$    ●  $0.6 < \text{HSI} \leq 0.8$    ●  $>0.8$



Figure B5. Combined HSI (based on depth, velocity, and substrate) for Rainbow Trout at Columbia River, plotted by River2D model run (panels).

CPR Island Combined HSI   ●  $\leq 0.2$    ●  $0.2 < \text{HSI} \leq 0.4$    ●  $0.4 < \text{HSI} \leq 0.6$    ●  $0.6 < \text{HSI} \leq 0.8$    ●  $>0.8$



Figure B6. Combined HSI (based on depth, velocity, and substrate) for Steelhead at Columbia River, plotted by River2D model run (panels).



Figure B7. Map of depth (m) at Kootenay River, plotted by River2D model run (panels).

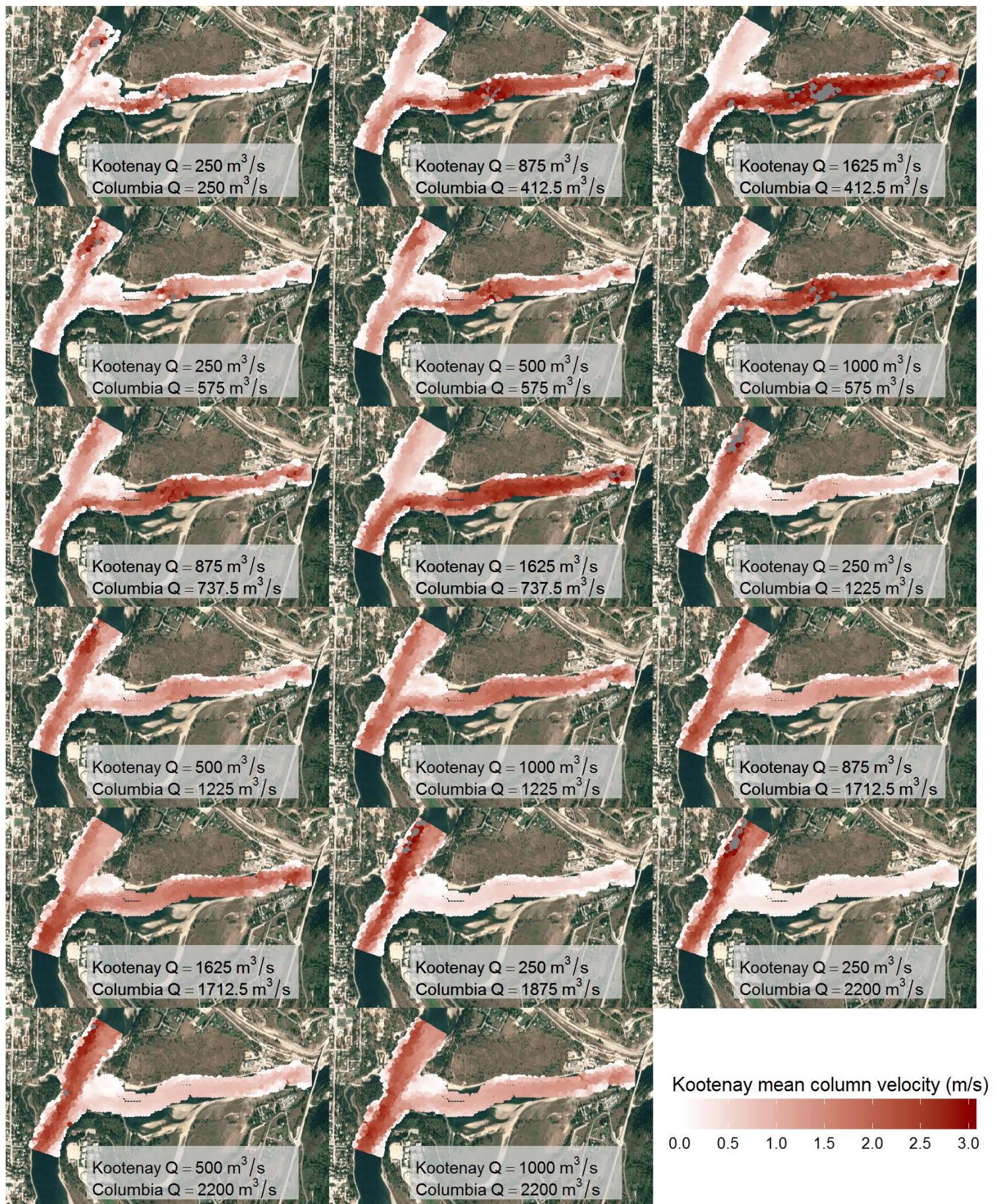


Figure B8. Map of velocity (m/s) at Kootenay River, plotted by River2D model run (panels).

Kootenay Combined HSI

●  $\leq 0.2$  ●  $0.2 < \text{HSI} \leq 0.4$  ●  $0.4 < \text{HSI} \leq 0.6$  ●  $0.6 < \text{HSI} \leq 0.8$  ●  $>0.8$



Figure B9. Combined HSI (based on depth, velocity, and substrate) for Chinook Salmon at Kootenay River, plotted by River2D model run (panels). HSI calculations were based on the large river HSI curve (for rivers with mean annual discharge  $\geq 85.0 \text{ m}^3/\text{s}$ ).

### Kootenay Combined HSI

●  $\leq 0.2$  ●  $0.2 < \text{HSI} \leq 0.4$  ●  $0.4 < \text{HSI} \leq 0.6$  ●  $0.6 < \text{HSI} \leq 0.8$  ●  $> 0.8$

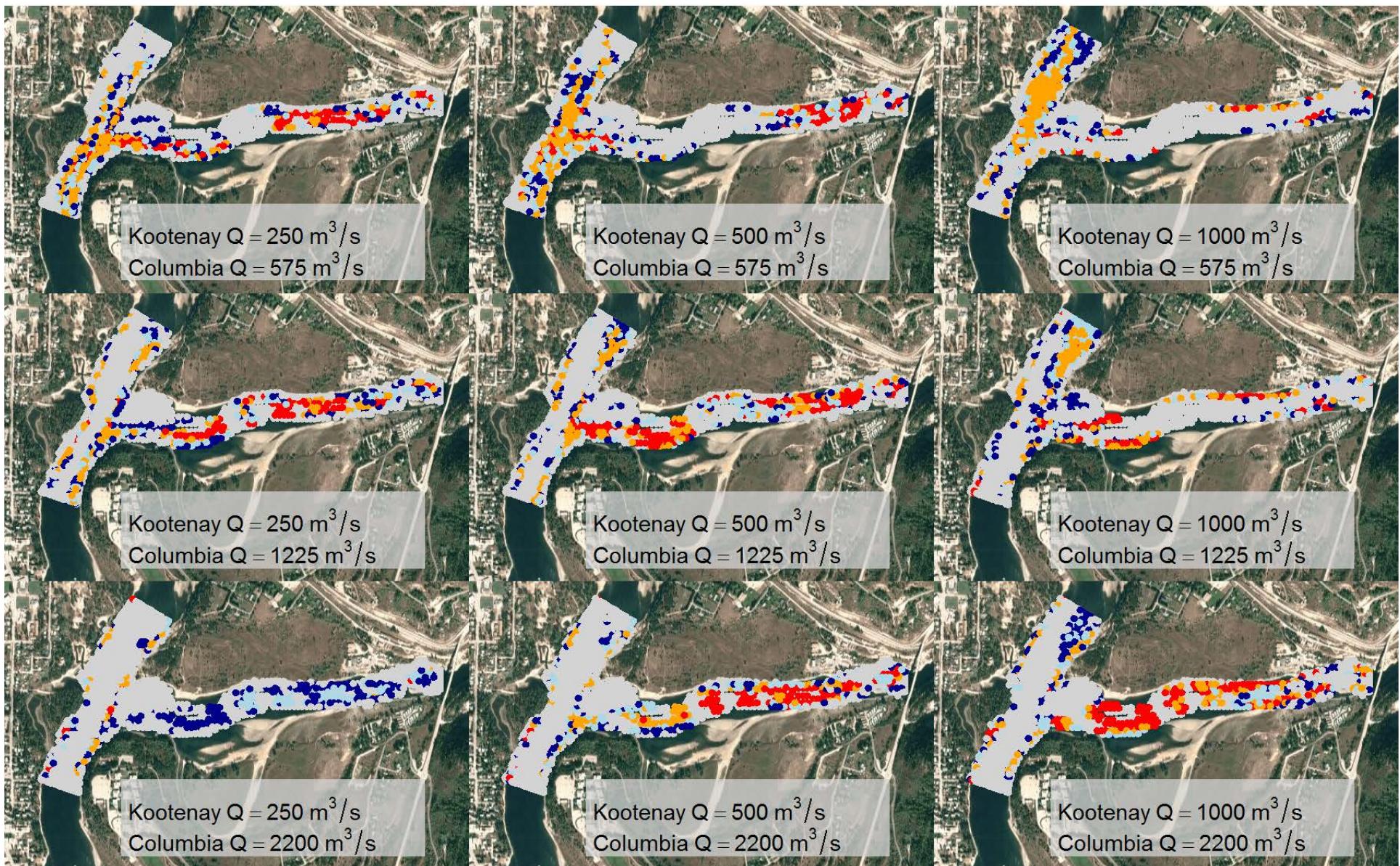


Figure B10. Combined HSI (based on depth, velocity, and substrate) for Chinook Salmon at Kootenay River, plotted by River2D model run (panels). HSI calculations were based on the Columbia-Snake HSI curve (for rivers with mean annual discharge  $\geq 2,831.7 \text{ m}^3/\text{s}$ )

Kootenay Combined HSI

- $\leq 0.2$
- $0.2 < \text{HSI} \leq 0.4$
- $0.4 < \text{HSI} \leq 0.6$
- $0.6 < \text{HSI} \leq 0.8$
- $> 0.8$



Figure B11. Combined HSI (based on depth, velocity, and substrate) for Rainbow Trout at Kootenay River, plotted by River2D model run (panels).

Kootenay Combined HSI

- $\leq 0.2$
- $0.2 < \text{HSI} \leq 0.4$
- $0.4 < \text{HSI} \leq 0.6$
- $0.6 < \text{HSI} \leq 0.8$
- $> 0.8$

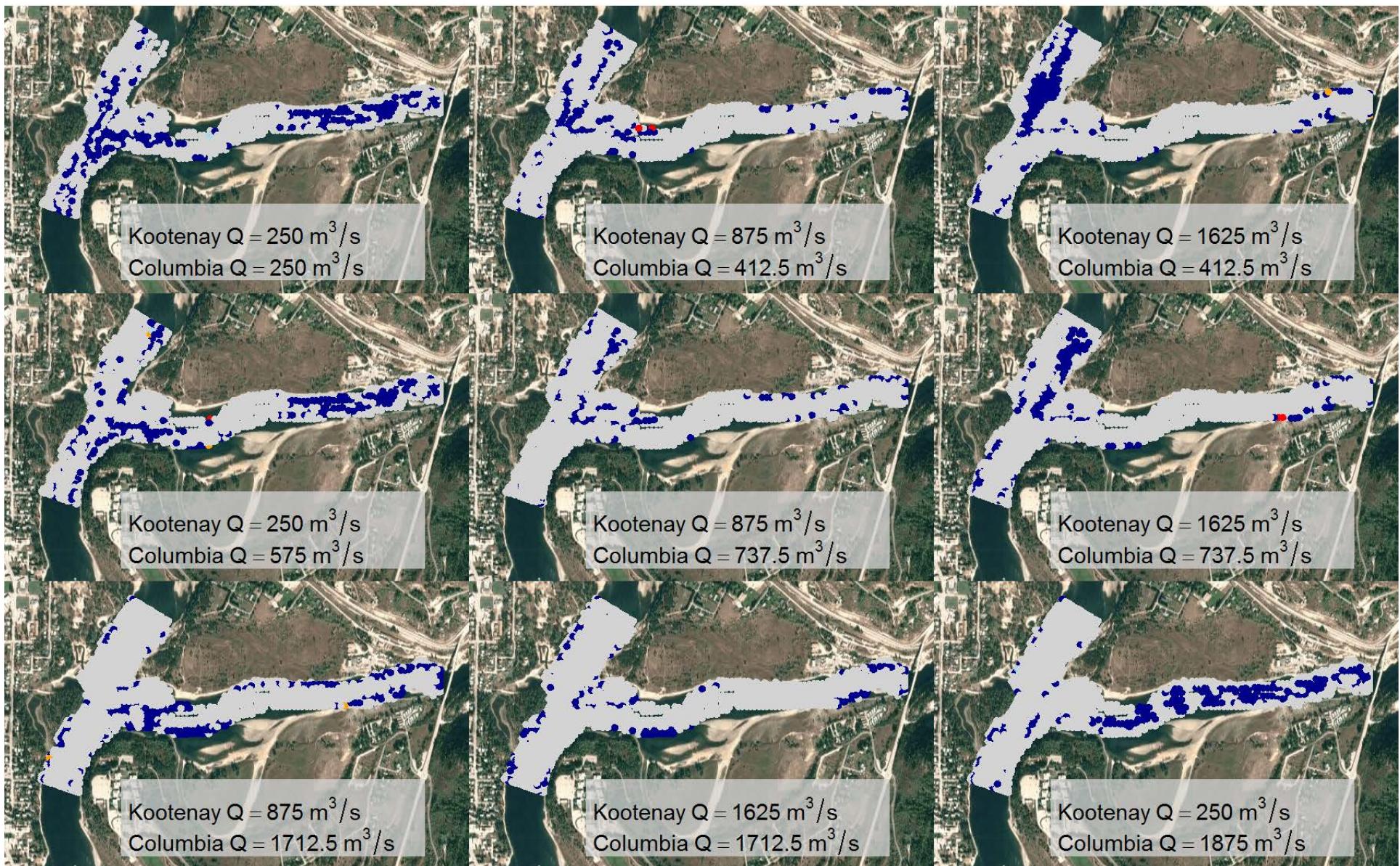


Figure B12. Combined HSI (based on depth, velocity, and substrate) for Steelhead at Kootenay River, plotted by River2D model run (panels).



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GOLDER ASSOCIATES LTD.

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# APPENDIX C

## Lower Columbia and Kootenay River WUA Estimates









River	Discharge (m³/s)			Weighted Usable Area (m²)				River	Discharge (m³/s)			Weighted Usable Area (m²)			
	Columbia	Kootenay	Depth Bin (m)	Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout	Steelhead		Columbia	Kootenay	Depth Bin (m)	Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout	Steelhead
Columbia	2037.5	875	8	0	20,414	---	---	Kootenay	1875	250	12	---	---	0	851
Columbia	2037.5	875	8.5	0	25,026	---	---	Kootenay	1875	250	12.5	---	---	0	768
Columbia	2037.5	875	9	0	22,048	---	---	Kootenay	1875	250	13	---	---	0	201
Columbia	2037.5	875	9.5	0	13,201	---	---	Kootenay	1875	250	13.5	---	---	0	321
Columbia	2037.5	875	10	0	6,802	---	---	Kootenay	1875	250	14	---	---	0	92
Columbia	2037.5	875	10.5	0	392	---	---	Kootenay	2200	250	0	719	0	---	---
Columbia	2037.5	875	11	0	0	---	---	Kootenay	2200	250	0.5	1,360	147	---	---
Columbia	2037.5	875	11.5	0	0	---	---	Kootenay	2200	250	1	4,625	1,328	---	---
Columbia	2037.5	875	12	0	0	---	---	Kootenay	2200	250	1.5	2,758	1,553	---	---
Columbia	2037.5	875	12.5	0	0	---	---	Kootenay	2200	250	2	4,176	7,046	---	---
Columbia	2037.5	875	13	0	0	---	---	Kootenay	2200	250	2.5	2,297	10,602	---	---
Columbia	2037.5	875	13.5	0	0	---	---	Kootenay	2200	250	3	47	12,556	---	---
Columbia	2037.5	875	14	0	0	---	---	Kootenay	2200	250	3.5	0	20,661	---	---
Columbia	2037.5	875	14.5	0	0	---	---	Kootenay	2200	250	4	0	29,129	---	---
Columbia	2037.5	875	15	0	0	---	---	Kootenay	2200	250	4.5	0	28,500	---	---
Columbia	2037.5	875	15.5	0	0	---	---	Kootenay	2200	250	5	0	24,569	---	---
Columbia	2037.5	875	16	0	0	---	---	Kootenay	2200	250	5.5	0	26,360	---	---
Columbia	2037.5	875	16.5	0	0	---	---	Kootenay	2200	250	6	0	18,895	---	---
Columbia	2037.5	875	17	0	0	---	---	Kootenay	2200	250	6.5	0	15,296	---	---
Columbia	2037.5	875	17.5	0	0	---	---	Kootenay	2200	250	7	0	14,212	---	---
Kootenay	2200	250	7.5	0	15,796	---	---	Kootenay	2200	250	8	0	18,613	---	---
Kootenay	2200	250	8.5	0	18,554	---	---	Kootenay	2200	250	9	0	13,744	---	---
Kootenay	2200	250	9.5	0	7,513	---	---	Kootenay	2200	250	10	0	3,163	---	---
Kootenay	2200	250	10.5	0	225	---	---	Kootenay	2200	250	11	0	0	---	---
Kootenay	2200	250	11.5	0	0	---	---	Kootenay	2200	250	12	0	0	---	---
Kootenay	2200	250	12.5	0	0	---	---	Kootenay	2200	250	13	0	0	---	---
Kootenay	2200	250	13.5	0	0	---	---	Kootenay	2200	250	14	0	0	---	---
Kootenay	2200	250	14.5	0	0	---	---	Kootenay	2200	500	0	540	0	---	---
Kootenay	2200	500	0.5	1,641	171	---	---	Kootenay	2200	500	1	1,493	436	---	---
Kootenay	2200	500	1.5	3,823	2,182	---	---	Kootenay	2200	500	2	1,923	2,762	---	---
Kootenay	2200	500	2.5	1,493	8,090	---	---	Kootenay	2200	500	3	19	11,562	---	---
Kootenay	2200	500	3.5	0	11,865	---	---	Kootenay	2200	500	4	0	20,643	---	---
Kootenay	2200	500	4.5	0	30,197	---	---	Kootenay	2200	500	5	0	27,459	---	---
Kootenay	2200	500	5.5	0	24,596	---	---	Kootenay	2200	500	6	0	26,330	---	---
Kootenay	2200	500	6.5	0	18,917	---	---	Kootenay	2200	500	7	0	15,563	---	---
Kootenay	2200	500	7.5	0	13,938	---	---	Kootenay	2200	500	8	0	15,235	---	---
Kootenay	2200	500	8.5	0	19,953	---	---	Kootenay	2200	500	9	0	16,825	---	---
Kootenay	2200	500	9.5	0	8,700	---	---	Kootenay	2200	500	10	0	3,617	---	---
Kootenay	2200	500	10.5	0	143	---	---	Kootenay	2200	500	11	0	0	---	---
Kootenay	2200	500	11	0	0	---	---	Kootenay	2200	500	12	0	0	---	---
Kootenay	2200	500	12.5	0	0	---	---	Kootenay	2200	500	13.5	0	0	---	---
Kootenay	2200	500	14	0	0	---	---	Kootenay	2200	1000	0	157	0	---	---
Kootenay	2200	1000	0.5	1,168	132	---	---	Kootenay	2200	1000	1	883	277	---	---
Kootenay	2200	1000	1.5	1,586	889	---	---	Kootenay	2200	1000	2	997	1,741	---	---
Kootenay	2200	1000	2.5	1,039	4,477	---	---	Kootenay	2200	1000	3	4	3,600	---	---
Kootenay	2200	1000	3.5	0	8,803	---	---	Kootenay	2200	1000	4	0	11,549	---	---
Kootenay	2200	1000	4.5	0	13,449	---	---	Kootenay	2200	1000	5	0	23,266	---	---
Kootenay	2200	1000	5.5	0	29,506	---	---	Kootenay	2200	1000	6	0	24,196	---	---
Kootenay	2200	1000	6.5	0	27,150	---	---	Kootenay	2200	1000	7	0	25,736	---	---
Kootenay	2200	1000	7.5	0	18,723	---	---	Kootenay	2200	1000	8	0	12,106	---	---
Kootenay	2200	1000	8.5	0	15,826	---	---	Kootenay	2200	1000	9	0	15,907	---	---
Kootenay	2200	1000	9.5	0	12,268	---	---	Kootenay	2200	1000	10	0	4,430	---	---
Kootenay	2200	1000	10.5	0	348	---	---	Kootenay	2200	1000	11	0	0	---	---
Kootenay	2200	1000	11.5	0	0	---	---	Kootenay	2200	1000	12	0	0	---	---
Kootenay	2200	1000	12.5	0	0	---	---	Kootenay	2200	1000	13	0	0	---	---
Kootenay	2200	1000	13.5	0	0	---	---	Kootenay	2200	1000	14	0	0	---	---
Kootenay	2200	1000	14.5	0	0	---	---	Kootenay	2200	1000	15	0	0	---	---
Kootenay	2200	1000	15.5	0	0	---	---	Kootenay	2200	1000	16	0	0	---	---









River	Discharge (m³/s)		Weighted Usable Area (m²)				River	Discharge (m³/s)		Velocity Bin (m)	Weighted Usable Area (m²)			
	Columbia	Kootenay	Velocity Bin (m)	Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout	Steelhead	Columbia	Kootenay		Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout	Steelhead
Kootenay	2200	250	2.4	0	0	---	Kootenay	2200	250	2.55	0	0	---	---
Kootenay	2200	250	2.7	0	0	---	Kootenay	2200	250	2.85	0	0	---	---
Kootenay	2200	250	3	0	0	---	Kootenay	2200	250	3.15	0	0	---	---
Kootenay	2200	250	3.3	0	0	---	Kootenay	2200	250	3.45	0	0	---	---
Kootenay	2200	500	0	0	147	---	Kootenay	2200	500	0.15	9,891	2,798	---	---
Kootenay	2200	500	0.3	20,951	7,895	---	Kootenay	2200	500	0.45	40,472	22,083	---	---
Kootenay	2200	500	0.6	51,146	42,741	---	Kootenay	2200	500	0.75	44,545	44,545	---	---
Kootenay	2200	500	0.9	8,819	8,819	---	Kootenay	2200	500	1.05	4,531	4,612	---	---
Kootenay	2200	500	1.2	2,692	3,133	---	Kootenay	2200	500	1.35	1,926	3,626	---	---
Kootenay	2200	500	1.5	17	2,824	---	Kootenay	2200	500	1.65	0	1,875	---	---
Kootenay	2200	500	1.8	0	1,472	---	Kootenay	2200	500	1.95	0	1,134	---	---
Kootenay	2200	500	2.1	0	98	---	Kootenay	2200	500	2.25	0	0	---	---
Kootenay	2200	500	2.4	0	0	---	Kootenay	2200	500	2.55	0	0	---	---
Kootenay	2200	500	2.7	0	0	---	Kootenay	2200	500	2.85	0	0	---	---
Kootenay	2200	500	3	0	0	---	Kootenay	2200	500	3.15	0	0	---	---
Kootenay	2200	1000	0	0	117	---	Kootenay	2200	1000	0.15	8,563	2,372	---	---
Kootenay	2200	1000	0.3	11,885	4,380	---	Kootenay	2200	1000	0.45	10,670	6,100	---	---
Kootenay	2200	1000	0.6	18,127	15,330	---	Kootenay	2200	1000	0.75	24,153	24,153	---	---
Kootenay	2200	1000	0.9	39,327	39,327	---	Kootenay	2200	1000	1.05	26,264	26,859	---	---
Kootenay	2200	1000	1.2	26,340	30,670	---	Kootenay	2200	1000	1.35	6,561	10,603	---	---
Kootenay	2200	1000	1.5	19	2,930	---	Kootenay	2200	1000	1.65	0	2,091	---	---
Kootenay	2200	1000	1.8	0	2,158	---	Kootenay	2200	1000	1.95	0	1,378	---	---
Kootenay	2200	1000	2.1	0	52	---	Kootenay	2200	1000	2.25	0	0	---	---
Kootenay	2200	1000	2.4	0	0	---	Kootenay	2200	1000	2.55	0	0	---	---
Kootenay	2200	1000	2.7	0	0	---	Kootenay	2200	1000	2.85	0	0	---	---













River	Discharge (m³/s)		Depth Bin (m)	Weighted Usable Area (m²)			River	Discharge (m³/s)		Depth Bin (m)	Weighted Usable Area (m²)			
	Columbia	Kootenay		Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout		Columbia	Kootenay		Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout	
Columbia	2037.5	875	14	0	0	---	Kootenay	2200	250	3.5	0	1,559	---	---
Columbia	2037.5	875	14.5	0	0	---	Kootenay	2200	250	4	0	2,230	---	---
Columbia	2037.5	875	15	0	0	---	Kootenay	2200	250	4.5	0	2,306	---	---
Columbia	2037.5	875	15.5	0	0	---	Kootenay	2200	250	5	0	2,692	---	---
Columbia	2037.5	875	16	0	0	---	Kootenay	2200	250	5.5	0	3,109	---	---
Columbia	2037.5	875	16.5	0	0	---	Kootenay	2200	250	6	0	1,382	---	---
Columbia	2037.5	875	17	0	0	---	Kootenay	2200	250	6.5	0	1,243	---	---
Columbia	2037.5	875	17.5	0	0	---	Kootenay	2200	250	7	0	1,019	---	---
							Kootenay	2200	250	7.5	0	2,098	---	---
							Kootenay	2200	250	8	0	1,550	---	---
							Kootenay	2200	250	8.5	0	1,534	---	---
							Kootenay	2200	250	9	0	1,888	---	---
							Kootenay	2200	250	9.5	0	822	---	---
							Kootenay	2200	250	10	0	271	---	---
							Kootenay	2200	250	10.5	0	32	---	---
							Kootenay	2200	250	11	0	0	---	---
							Kootenay	2200	250	11.5	0	0	---	---
							Kootenay	2200	250	12	0	0	---	---
							Kootenay	2200	250	12.5	0	0	---	---
							Kootenay	2200	250	13	0	0	---	---
							Kootenay	2200	250	13.5	0	0	---	---
							Kootenay	2200	250	14	0	0	---	---
							Kootenay	2200	250	14.5	0	0	---	---
							Kootenay	2200	500	0	48	0	---	---
							Kootenay	2200	500	0.5	223	11	---	---
							Kootenay	2200	500	1	229	29	---	---
							Kootenay	2200	500	1.5	989	261	---	---
							Kootenay	2200	500	2	873	641	---	---
							Kootenay	2200	500	2.5	602	2,310	---	---
							Kootenay	2200	500	3	4	2,522	---	---
							Kootenay	2200	500	3.5	0	2,098	---	---
							Kootenay	2200	500	4	0	2,980	---	---
							Kootenay	2200	500	4.5	0	3,214	---	---
							Kootenay	2200	500	5	0	3,375	---	---
							Kootenay	2200	500	5.5	0	4,498	---	---
							Kootenay	2200	500	6	0	5,288	---	---
							Kootenay	2200	500	6.5	0	2,397	---	---
							Kootenay	2200	500	7	0	1,691	---	---
							Kootenay	2200	500	7.5	0	1,810	---	---
							Kootenay	2200	500	8	0	2,931	---	---
							Kootenay	2200	500	8.5	0	2,066	---	---
							Kootenay	2200	500	9	0	2,768	---	---
							Kootenay	2200	500	9.5	0	1,449	---	---
							Kootenay	2200	500	10	0	748	---	---
							Kootenay	2200	500	10.5	0	27	---	---
							Kootenay	2200	500	11	0	0	---	---
							Kootenay	2200	500	11.5	0	0	---	---
							Kootenay	2200	500	12	0	0	---	---
							Kootenay	2200	500	12.5	0	0	---	---
							Kootenay	2200	500	13	0	0	---	---
							Kootenay	2200	500	13.5	0	0	---	---
							Kootenay	2200	500	14	0	0	---	---
							Kootenay	2200	500	14.5	0	0	---	---
							Kootenay	2200	500	15	0	0	---	---
							Kootenay	2200	1000	0	16	0	---	---
							Kootenay	2200	1000	0.5	276	33	---	---
							Kootenay	2200	1000	1	359	90	---	---
							Kootenay	2200	1000	1.5	437	161	---	---
							Kootenay	2200	1000	2	537	792	---	---
							Kootenay	2200	1000	2.5	247	575	---	---
							Kootenay	2200	1000	3	3	1,396	---	---
							Kootenay	2200	1000	3.5	0	3,567	---	---
							Kootenay	2200	1000	4	0	3,141	---	---
							Kootenay	2200	1000	4.5	0	3,520	---	---
							Kootenay	2200	1000	5	0	3,322	---	---
							Kootenay	2200	1000	5.5	0	3,525	---	---
							Kootenay	2200	1000	6	0	3,441	---	---
							Kootenay	2200	1000	6.5	0	6,171	---	---
							Kootenay	2200	1000	7	0	4,684	---	---
							Kootenay	2200	1000	7.5	0	2,815	---	---
							Kootenay	2200	1000	8	0	1,970	---	---
							Kootenay	2200	1000	8.5	0	2,600	---	---
							Kootenay	2200	1000	9	0	3,177	---	---
							Kootenay	2200	1000	9.5	0	1,824	---	---
							Kootenay	2200	1000	10	0	1,200	---	---
							Kootenay	2200	1000	10.5	0	45	---	---
							Kootenay	2200	1000	11	0	0	---	---
							Kootenay	2200	1000	11.5	0	0	---	---
							Kootenay	2200	1000	12	0	0	---	---
							Kootenay	2200	1000	12.5	0	0	---	---
							Kootenay	2200	1000	13	0	0	---	---
							Kootenay	2200	1000	13.5	0	0	---	---
							Kootenay	2200	1000	14	0	0	---	---
							Kootenay	2200	1000	14.5	0	0	---	---

River	Discharge (m³/s)		Depth Bin (m)	Weighted Usable Area (m²)			River	Discharge (m³/s)		Depth Bin (m)	Weighted Usable Area (m²)		
	Columbia	Kootenay		Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout		Columbia	Kootenay		Chinook, Large Rivers	Chinook, Columbia-Snake	Rainbow Trout
							Kootenay	2200	1000	15	0	0	---
							Kootenay	2200	1000	15.5	0	0	---
							Kootenay	2200	1000	16	0	0	---

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

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