Technical Memorandum

To: Tony Meyer, Lower Columbia Fish Enhancement Group

Authors: Bill Norris

Date: May 31, 2015

Re: Ives Island – Habitat Enhancement

Ives Island – Curious Gorge Guidebook

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1 Introduction

This technical memorandum describes the results of the technical analyses that have been conducted in support of the 60% design submittal for the Ives Island, Habitat Enhancement Project. The project design has been developed to increase quality and quantity of spawning habitat for Lower Columbia River chum and Chinook salmon.

The Lower Columbia chum salmon population are listed as threatened under the Endangered Species Act (ESA). The Hamilton Creek ESU is unique in that it is the only population known to spawn in side channel habitat of the main stem Columbia River. Additionally, the upriver bright (URB) Chinook population that spawns below Bonneville is the only known URB population in the lower Columbia River, and is also threatened under the ESA (Tomaro et al. 2007).

Fluctuations in water levels occasionally dry out redds in the project area despite minimum flow targets that were established in 2001 to prevent dewatering from occurring (SOR 2001-12). The project intent is to increase resiliency of these critical spawning habitats by increasing inundation at low flows. Strategies to fulfill the project intent were developed in the preliminary design and presented to stakeholders. The general measured response from stakeholders focused on improving chum spawning habitat, while avoiding impacts to existing spawning areas located in the project site including URB Chinook spawning habitat.

This 60% design submittal provides enhanced access to an intermittently used spawning area through a backwater connection. This intermittently used spawning area can be cut off from a backwater connection by a high spot on the gravel bar under certain hydraulic conditions. This work could potentially be followed up by subsequent enhancements pending positive monitoring results gathered from observation tubes installed as part of this 60% design.

1.1 PROJECT AREA

The project is located on the Columbia River near river mile (RM) 144, 2.5 miles downstream of Bonneville Dam, at the confluence with Hamilton Creek. A location map is provided in Figure 1. Ives Island lies between the confluence with Hamilton Creek and the Columbia River main stem. Pierce Island is located downstream of Ives Island, and Beacon Rock is downstream of both islands on the Washington side of the Columbia River. Pierce National Wildlife Refuge (PNWR) is located north of Ives Island on the mainland Washington shoreline. A smaller island or exposed gravel bar is expressed at lower Columbia River flows between Ives Island and PNWR. Chum spawning occurs most consistently between the (small island) exposed gravel bar and PNWR, downstream of the confluence with Hamilton Creek. Chum spawning may also occur between the (small island) exposed gravel bar and Ives Island and other areas when flow and tailwater conditions allow. Chinook spawning generally occurs along the margins of Pierce and Ives Islands closer to the mainstem Columbia River.

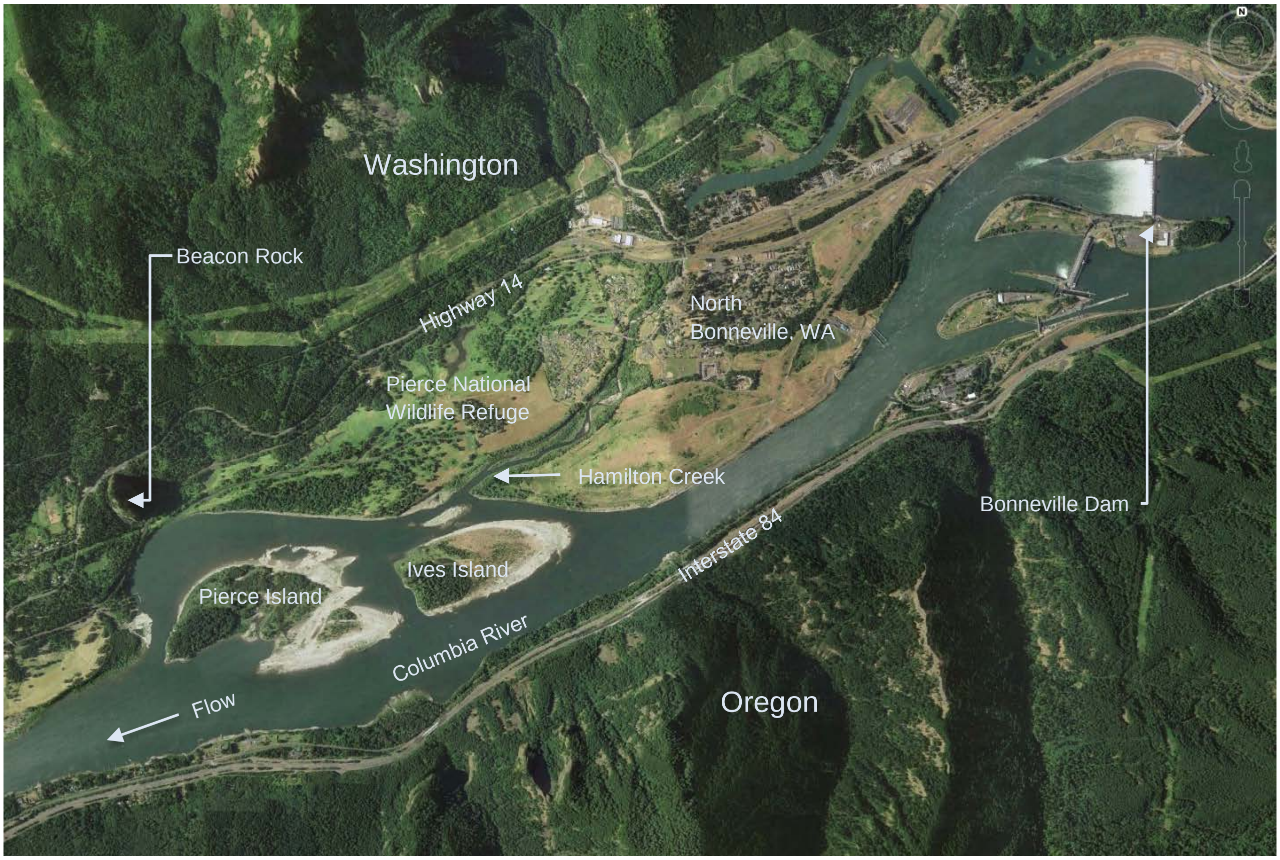

Figure 1, Location Map (adapted from Google Earth)

1.2 PROJECT OBJECTIVES

The project intends to increase quality and quantity of spawning habitat for Lower Columbia River chum and Chinook salmon by lowering bed surface elevation at the downstream end of the South Channel depicted in Figure 2. The South Channel is heavily used by chum salmon when it is inundated (Figure 2). Fluctuations in water levels occaisionally dry out redds in the project area, and lowering bed surface elevation will improve resiliency by increasing inundation during low flows.

1.3 PROJECT COMPONENTS

The project entails lowering bed elevations of the South Channel gravel bar to allow flow into existing spawning areas at a broader range of flows (Figure 2). The design has been developed based on stakeholder input, and hydraulic and habitat modeling.

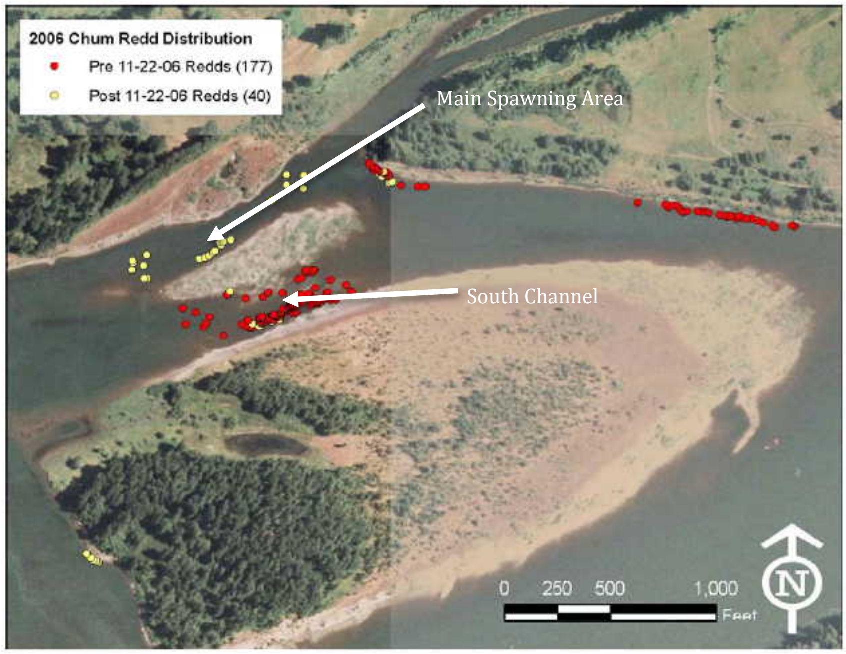

Figure 2, Chum salmon redd locations in 2006 (source: USFWS and ODFW)

In-stream flows downstream of Bonneville Dam have been negotiated to be above 120 kcfs starting in the month of November in part to support chum spawning at the Ives Island site. Therefore, this design focuses on providing resiliency with regard to spawning at the project site at the 120 kcfs flow. Some project alternatives provided additional spawning areas in the South Channel, identified in Figure 3, at flows of 120 kcfs and higher. While some project alternatives provided water to spawning areas at lower flows, down to 85 kcfs. Project stakeholders requested that preliminary design alternatives be scaled back, as described below, during a meeting held on, July 8, 2014, to reduce the potential impact to existing spawning habitat.

The final project design includes reducing the elevation of a portion of a gravel bar to connect a mapped spawning area to the Columbia backwater under specific hydauilc conditions. The backwater connection will enhance access and reduce the potential for stranding. This backwater connection includes an excavation cut of approximately 400 cubic yards (CY). The material to be excavated includes spawning sized substrate, which has limited supply in the Lower Columbia River due to the presence of upstream dams. As such, the excavated material will be deposited in a deeper portion of the river, adjacent to the cut, to promote spawning. The excavation cut and fill also includes fine grading to create dimples and hummocks in the excavated surface. The dimples and hummocks will create fine scale hydraulics that are anticipated to promote spawning activity. In addition, the final design includes ground water monitoring tubes to gather temperature data near the project site. Water temperatures observed in spawning gravels near the project site can be 2 to 5 degrees Celcius higher than surface water (Arntzen, 2009). The elevated water temperatures in spawning substrates promote faster incubation times for fertilized eggs. The ground water monitoring tubes may help identify locations of warmer groundwater inputs for future spawning enhancements.

2 Geomorphic Setting

Columbia River flows are highly regulated by dam releases. The dams trap sediment that would otherwise be transported downstream to the lower river and Ives Island project site. River flows downstream of Bonneville dam are characterized as "sediment starved." As a result, the main stem of the Columbia River has downcut and channel boundaries are now comprised of coarser material that armor underlying sediments. Peak flows have also been reduced as compared to pre-dam conditions. Thus, it is unlikely that gravel bars hydraulically controlling flows around Ives Island will change significantly over time. Hamilton Creek continues to discharge smaller (sand and silt) sediment to the project site. The Columbia River will periodically transport smaller size class sediments during high sustained flows that typically occur during spring freshets.

3 Design Development

3.1. PRELIMINARY DESIGN ALTERNATIVES

Stakeholder input helped in developing project alternatives. A meeting was held at the site on September 26, 2013. This first meeting included representatives from: BPA, NOAA, USFWS, WDFW, WDNR, ODFW, LCFRB, Cowlitz Tribe, USGS, and LCFEG. The main concern expressed at this first meeting was to avoid impacts to the Main Spawning Area identified in Figure 3. This concern help establish efforts to deliver water to the South Channel at increased frequency.

Preliminary design alternatives are discussed in Appendix A as scenarios 1, 2, and 3. There were four project alternatives including a no-action alternative evaluated as part of the preliminary design from which the 60% design has been developed. The preliminary design no-action alternative provides a base condition, evaluated at Columbia River flows of 120 kcfs. Scenario 1 was developed to deliver flow to the South Channel (as identified in Figure 3) when Columbia River flows are as low as 85 kcfs. This was accomplished by reducing the elevation of the gravel bars at the Upper Control (as identified in Figure 3) and the South Channel. The scenario 1 design alternative assumed that if flow through the Main Spawning Area at 120 kcfs remained unchanged, impacts to the Main Spawning Area would be avoided. Several iterations were required to deliver flow to the South Channel at 85 kcfs, yet not change flow through the Main Spawning Area at 120 kcfs. This was accomplished by creating an approximately 30 feet wide excavation cut (bottom width) through the Upper Control and modeling excavation of the South Channel to meet design criteria. Scenario 2 included excavation cuts through the Upper and Lower hydraulic controls to deliver water to the Main Spawning Area at Columbia River flows as low as 85 kcfs. No excavation of the South Channel was proposed under scenario 2. Scenario 3 included an excavation cut at the South Channel to increase wetted area at Columbia River flows of 120kcfs. No excavation cut at the Upper Control was proposed for scenario 3. A summary of USGS alternatives analysis is presented in Ives Island Habitat Enhancement (Tiffan et al. 2014) provided in Appendix A.

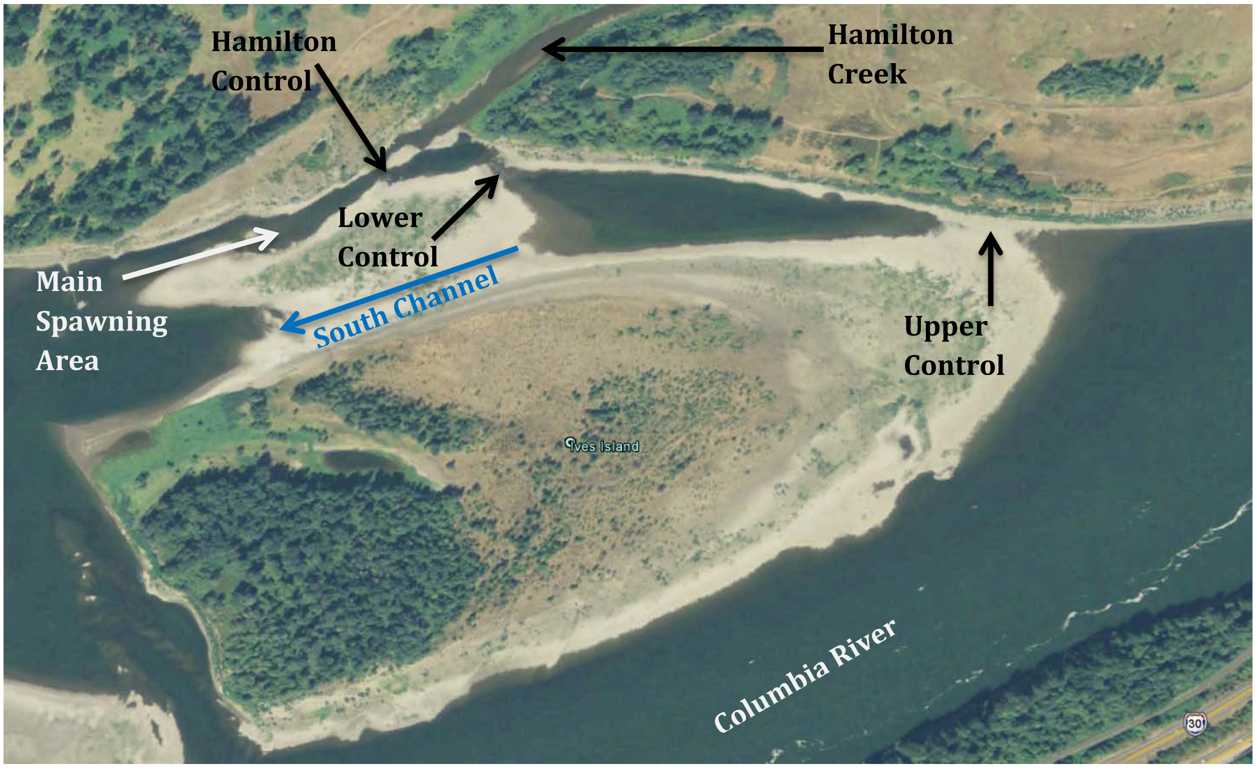

Figure 3, Project Components (source: Google Earth)

3.2. 60% DESIGN OPTIONS

A second stakeholder meeting was conducted on July 8, 2014. The second meeting included representatives from: BPA, NOAA, USFWS, WDFW, LCFRB, Columbia Land Trust, USGS, and LCFEG. Preliminary Design Scenario 3, or a variation thereof, was considered the best alternative since it would have the least impact and was least likely to influence the Main Spawning Area. It was suggested that excavation volumes associated with scenario 3 be reduced to a minimum to allow access to a spawning area at the downstream end of the South Channel. This minimal excavation would provide access from either the upstream or downstream end of the South Channel as shown in Figure 3. This variation of scenario 3 was recommended after preliminary design analyses were performed and became the basis for 60 percent design development.

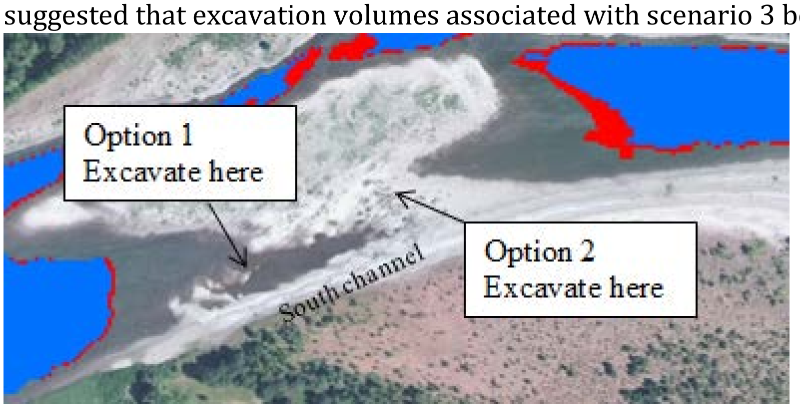

Figure 4, Options to modify preferred alternative (Tiffan et al. 2014).

The third project stakeholder meeting was held on, April 13, 2015, to present designs and modeling of Option 1 and Option 2 shown in Figure 3. Option 1 connects a known chum spawning area at the downstream portion of the south channel to the downstream tailwater. Option 2 extends the 120,000 cfs headwater elevation into the inlet of the South Channel. Both options include an excavated area that is wet for 120,000 cfs model runs at an average tailwater elevation, but dry at the minimum tailwater elevation. Habitat modeling did not show a significant increase in predicted habitat at 120,000 cfs due to shallow depths and near zero velocities. However, habitat areas are expected to increase at higher flows – especially for Option 1 that connects tailwater areas where chum spawning has been observed.

3.3. 60% DESIGN

Option 1 served as the basis for the 60 percent design, which connects a mapped spawning area that is isolated during certain flow and backwater conditions. Twelve different flow and backwater conditions are presented in Site Analyses. The 60% design drawings show an excavated cut inclined plane through the high spot in the gravel bar resulting in 400 CY of excavation cut largely consisting of spawning sized substrates. As this class of sediment is no longer transported into the project area as a result of upstream dams, it is considered desirable to place the excavated material back in the channel to provide habitat value.

Initially it was considered that placement of the excavated spawning gravel could provide an excellent opportunity to enhance Chinook spawning areas through gravel augmentation. However, access around the project site poses some complicating issues, including:

- A rare plant, Columbian Yellowcress (Rorippa columbiae) is found along the shorelines in this area and its presence could restrict access if identified in an access location.
- Several fish wheel remnants exist along the south shoreline of Ives Island, complicating access.
- The best location for gravel augmentation is likely at the mouth of the channel separating Ives Island and Pierce Island. However, the southwesterly tip of Ives Island is a private property parcel where an historic fish wheel is located.
- Access along the westerly shore of Ives Island is complicated by steep slopes, mature trees, rare plants and potential wetland impacts

Due to potential impacts associated with transporting gravel at the project site, depositing the spawning gravel close to its origin is considered to provide the most benefit with least impact (see sheet 3 of the design drawings). However, based on past spawning surveys, chum salmon are more likely to benefit than Chinook salmon from gravel augmentation at this location.

Site access is proposed through PNWR along an existing unimproved road. Construction is anticipated to occur during low water levels and thus, access from the existing unimproved road to the excavation area should be over a dry gravel bar. An historic fish wheel remnant is located on the southerly shoreline of PNWR downstream of the gravel bar access point.

4 Site Analyses

Site topographic and bathymetric surveys were performed by the USGS. The survey information provided input for the River 2D hydrodynamic model that was used to model hydraulics and habitat benefits. Preliminary design modeling scenarios and outputs are discussed in detail in Appendix A.

Habitat modeling for Options 1 and 2 did not show significant predicted habitat increases at 120,000 cfs due to near zero velocities, however chum salmon spawn in low velocity side channels over a wide variety of substrates compared to other salmonids, and have been observed spawning in shallow waters as low as 0.21 m (Geist et al. 2002, Tiffan et al. 2014). Therefore even a small increase in water depth over the South Channel gravel bar could increase spawning habitat significantly, but will not necessaryily show up in habitat modeling output. It is important to note that groundwater flows and upwelling that can dictate where chum spawning occur is beyond the capacity of this model. Thus, habitat modeling was not performed for the 60% design. Habitat modeling is not necessary since water depths can be directly measured from the hydraulic model output and velocity is not necessarily an important factor since chum have been known to spawn during backwatered conditions at this location.

4.1. HYDRUALIC MODEL OUTPUT

Hydraulic modeling was performed for this project with the River 2D hydrodynamic model. Converged model files were provided by the USGS for existing conditions. The USGS existing conditions model files were modified represent proposed conditions. The model was run with following input parameters:

- Columbia River flows of 120,000 cfs, 125,000 cfs and 130,000 cfs
- Hamilton Creek flows of 2 cubic meters per second (cms) and 5 cms
- Low and average Columbia River tailwater elevations.

This produces 12 model runs for existing and proposed conditions. Graphical model output is provided in Figures 5 through 28 for existing and proposed conditions depths comparison. The comparison shows that a backwater connection is created with proposed conditions at some, but not all model runs.

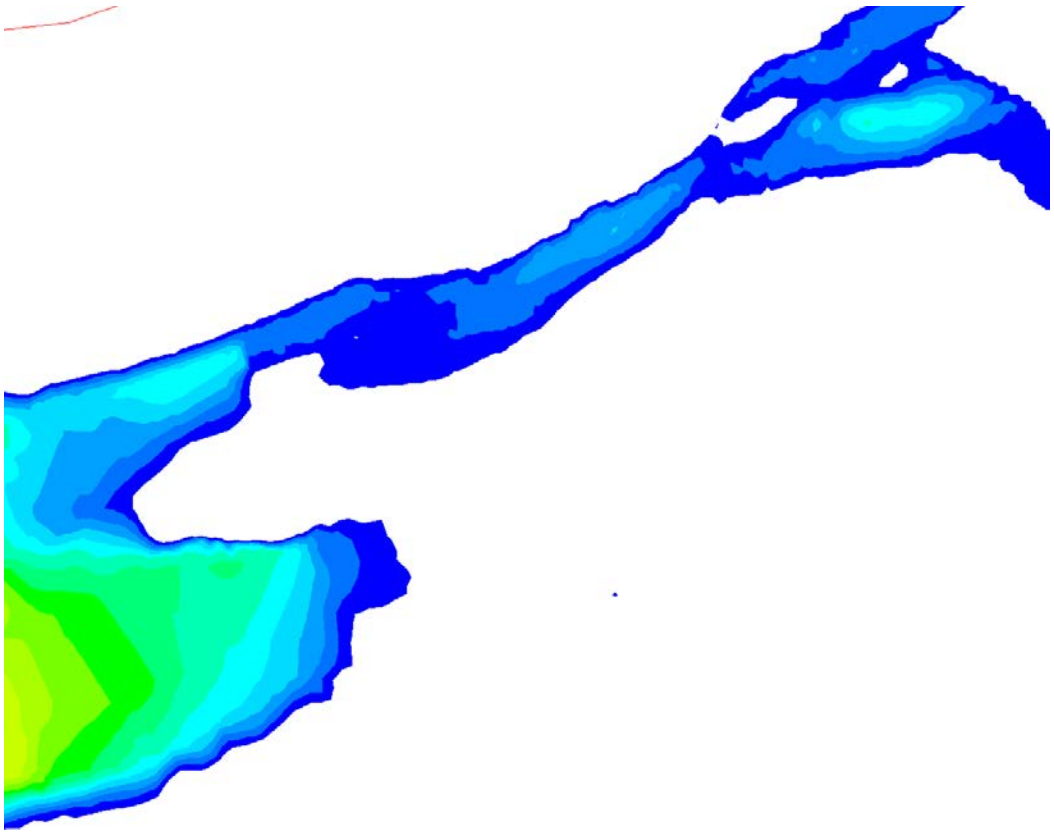

Figure 5, River 2D, 120kcfs, Ham 2 cms, low tailwater, EXISTING

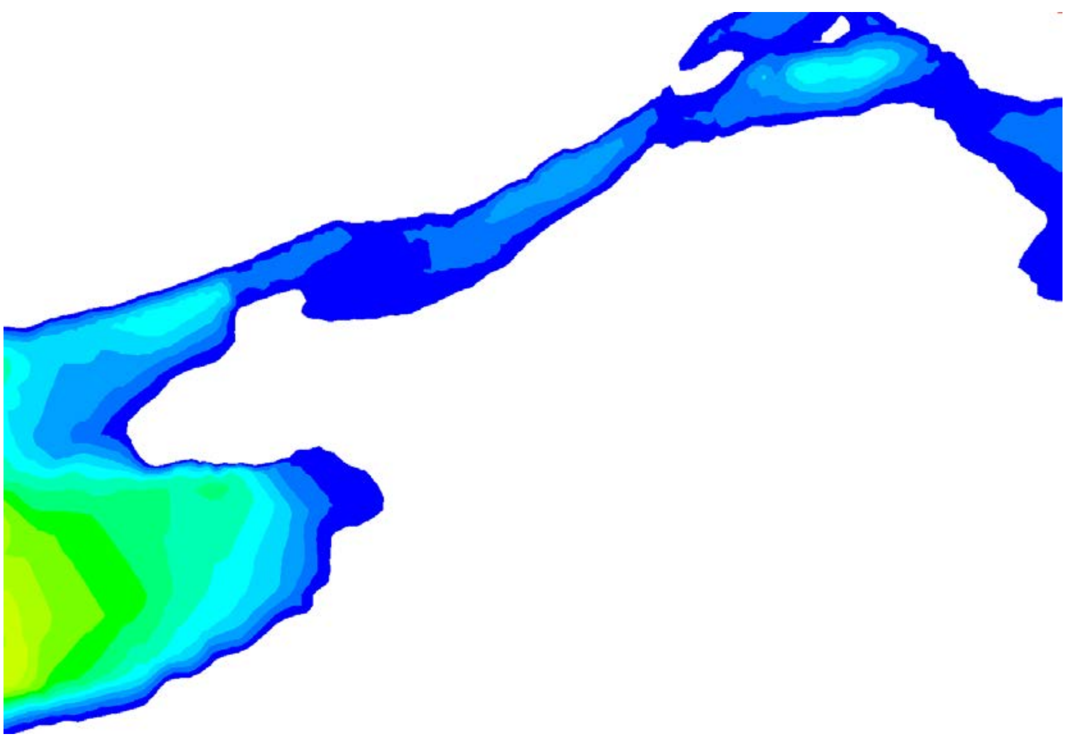

Figure 6, River 2D, 120kcfs, Ham 2 cms, low tailwater, PROPOSED

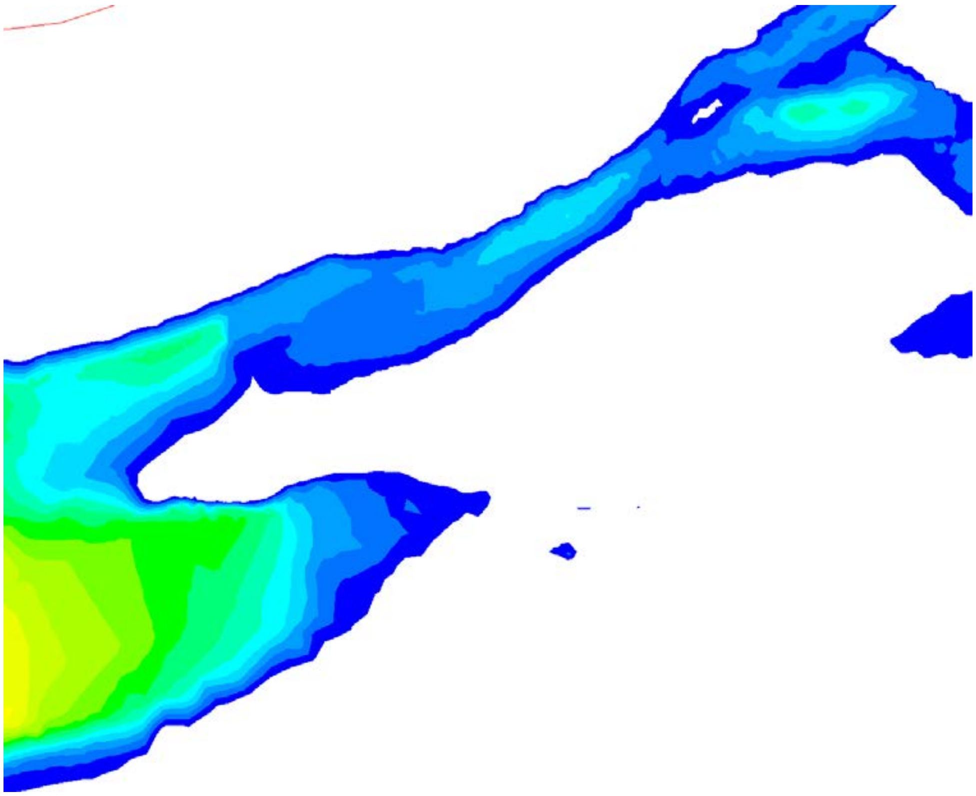

Figure 7, River 2D, 120kcfs, Ham 2 cms, ave. tailwater, EXISTING

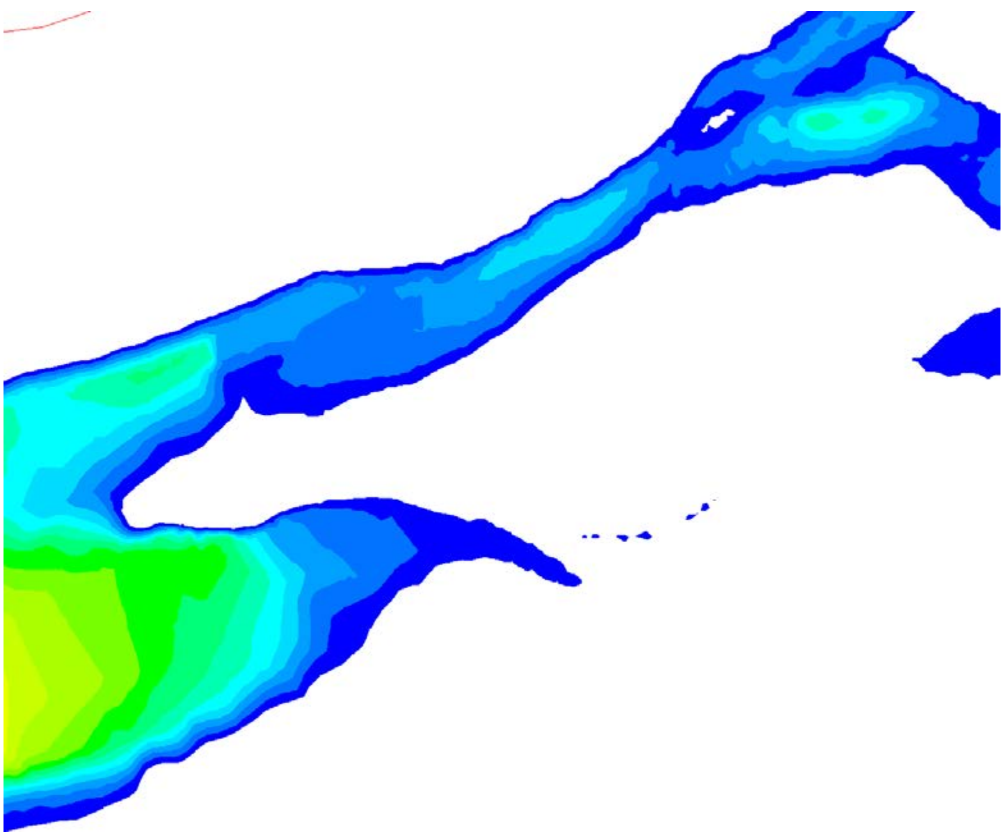

Figure 8, River 2D, 120kcfs, Ham 2 cms, ave. tailwater, PROPOSED

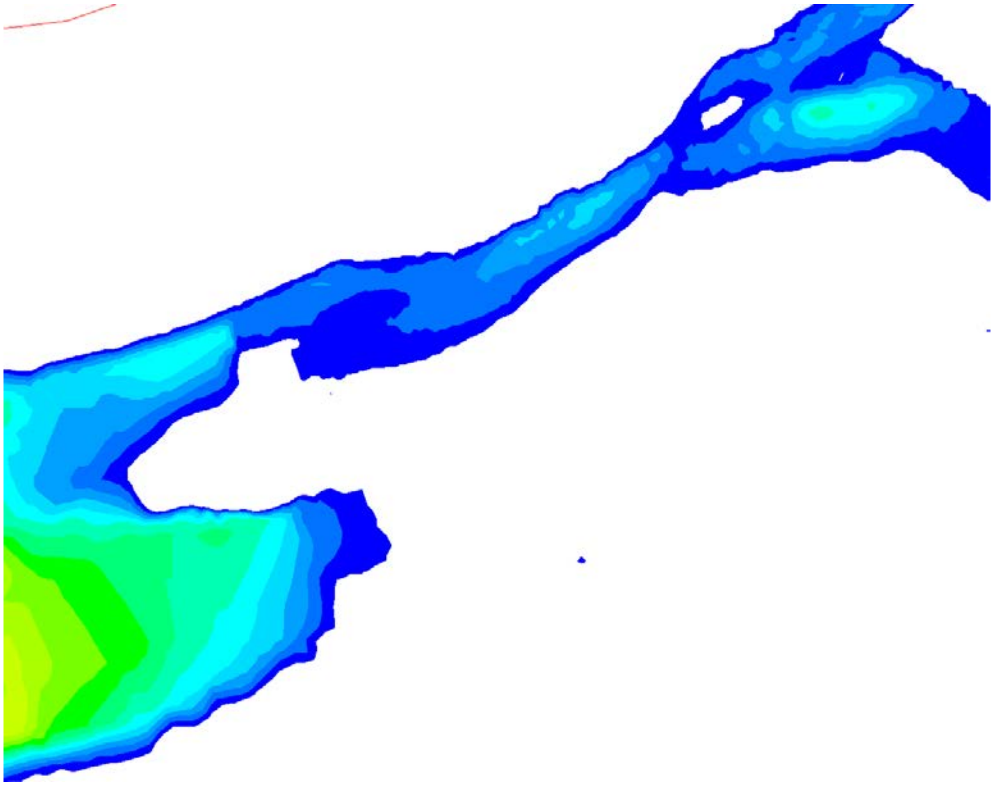

Figure 9, River 2D, 120kcfs, Ham 5 cms, low tailwater, EXISTING

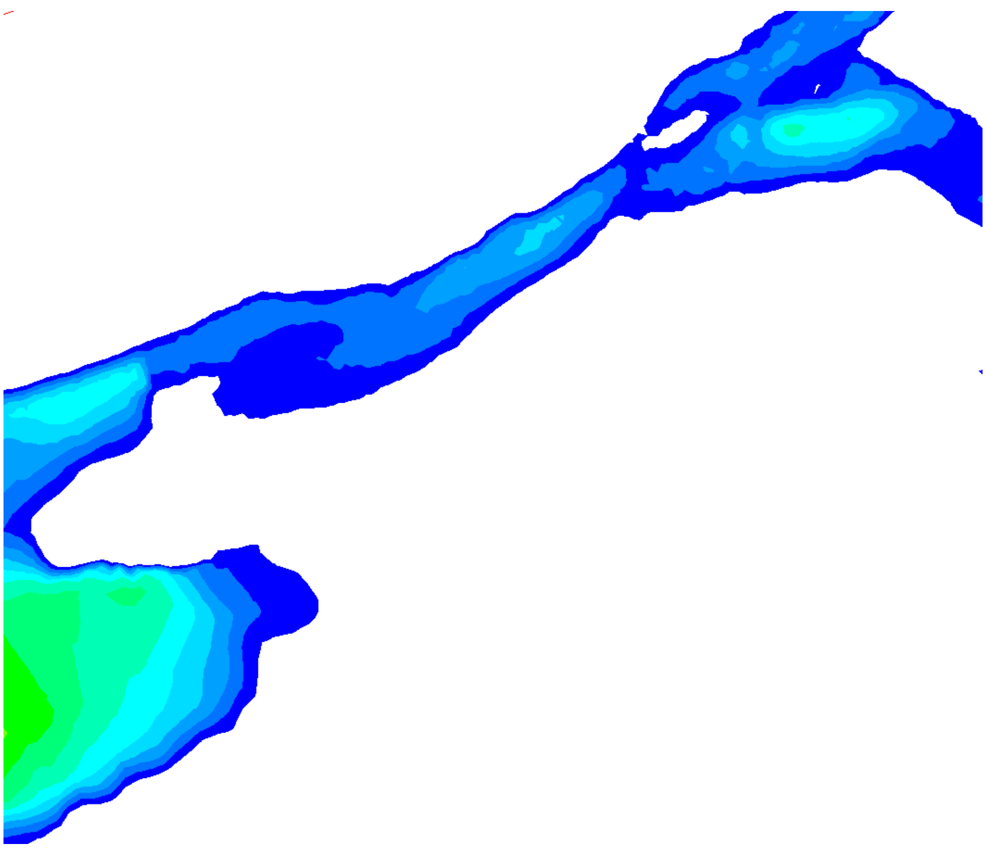

Figure 10, River 2D, 120kcfs, Ham 5 cms, low tailwater, PROPOSED

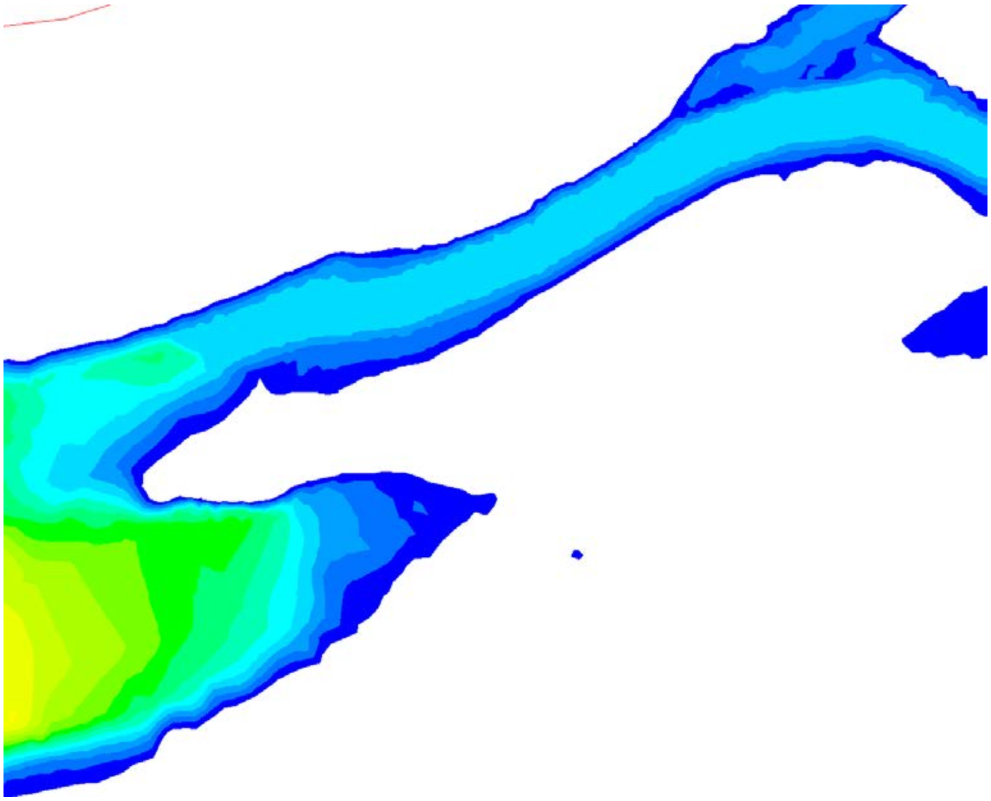

Figure 11, River 2D, 120kcfs, Ham 5 cms, ave. tailwater, EXISTING

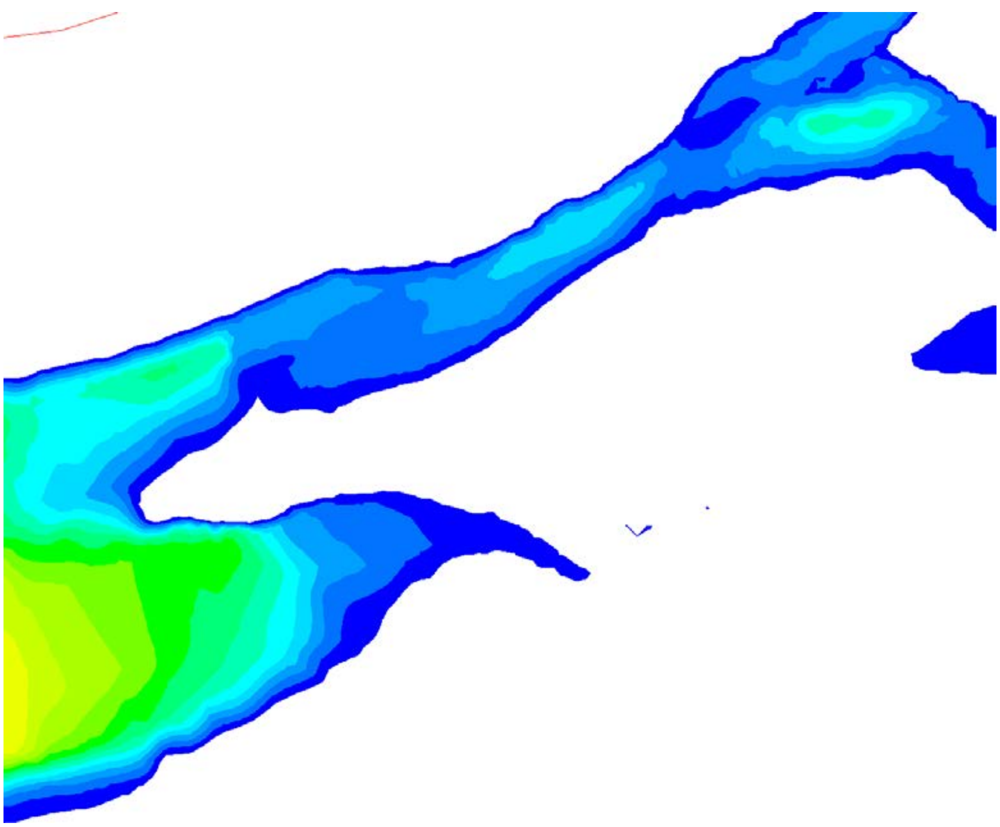

Figure 12, River 2D, 120kcfs, Ham 5 cms, ave. tailwater, PROPOSED

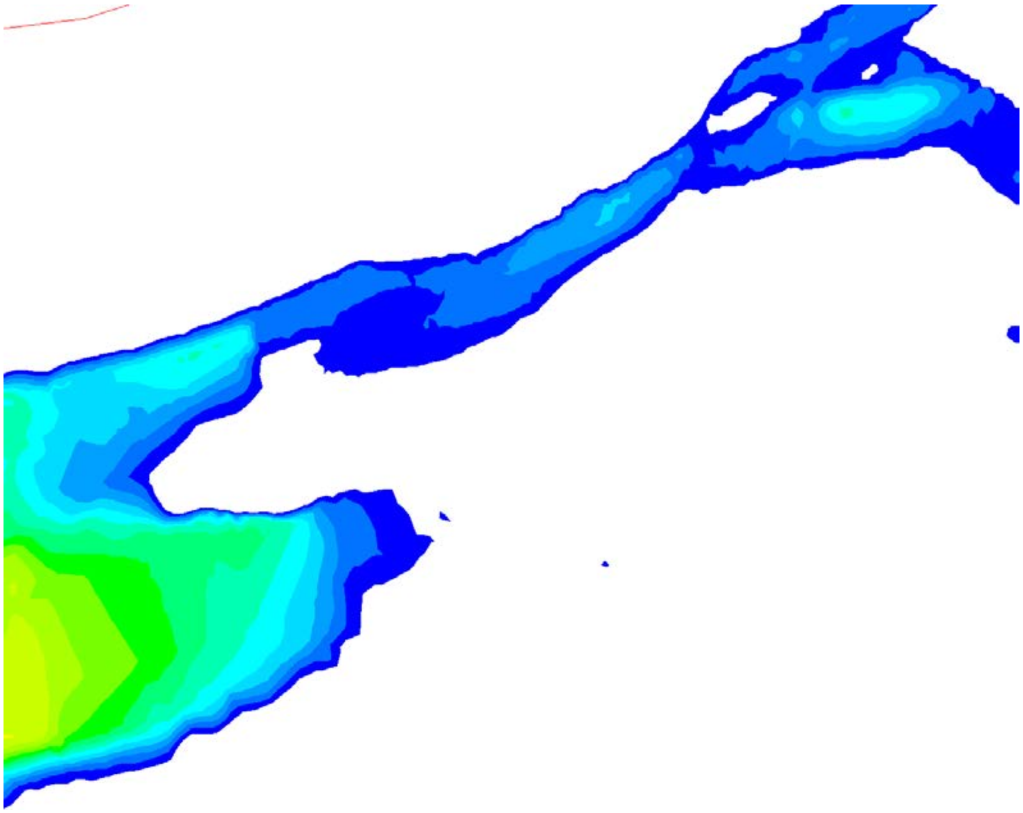

Figure 13, River 2D, 125kcfs, Ham 2 cms, low tailwater, EXISTING

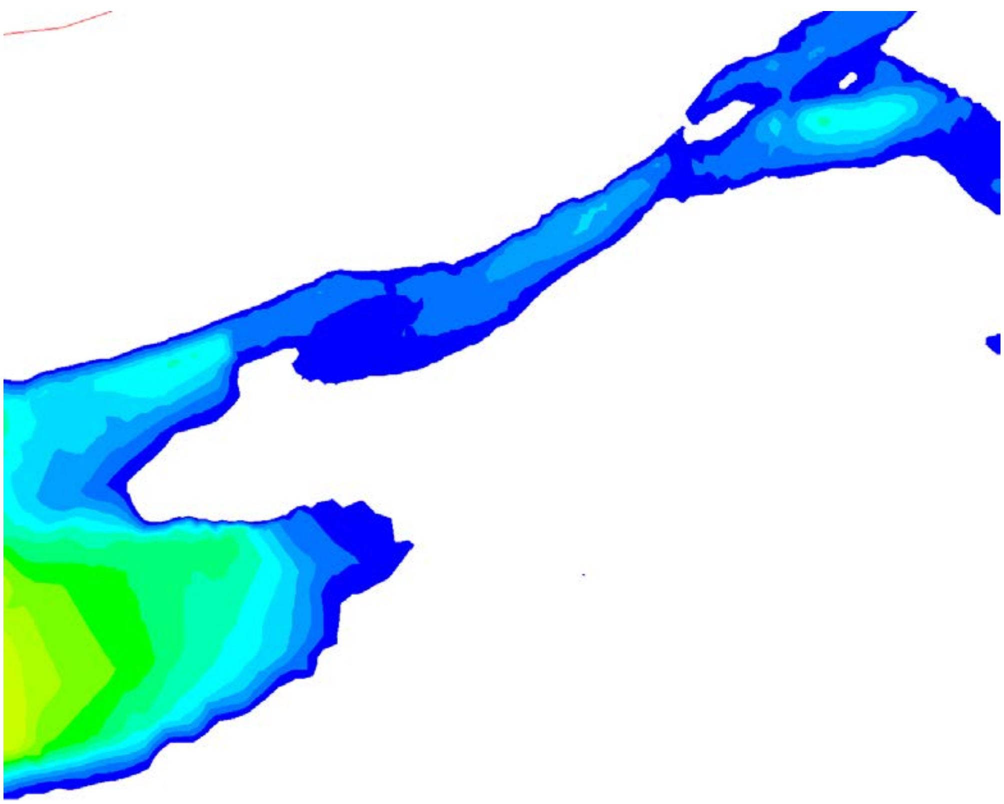

Figure 14, River 2D, 125kcfs, Ham 2 cms, low tailwater, PROPOSED

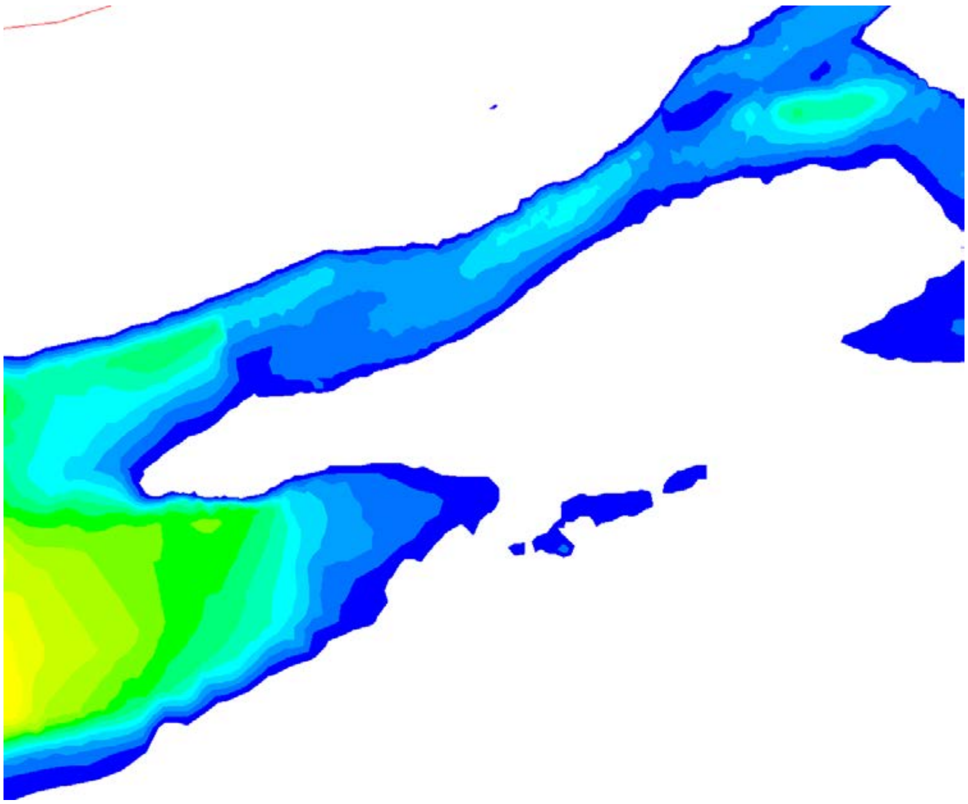

Figure 15, River 2D, 125kcfs, Ham 2 cms, ave. tailwater, EXISTING

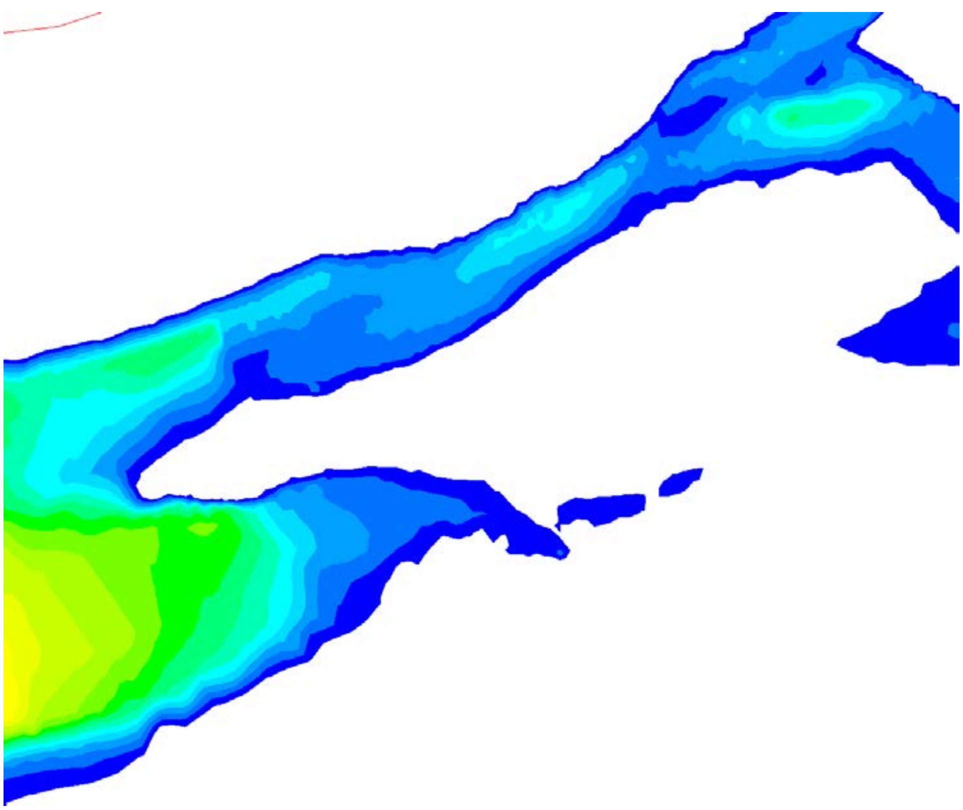

Figure 16, River 2D, 125kcfs, Ham 2 cms, ave. tailwater, PROPOSED

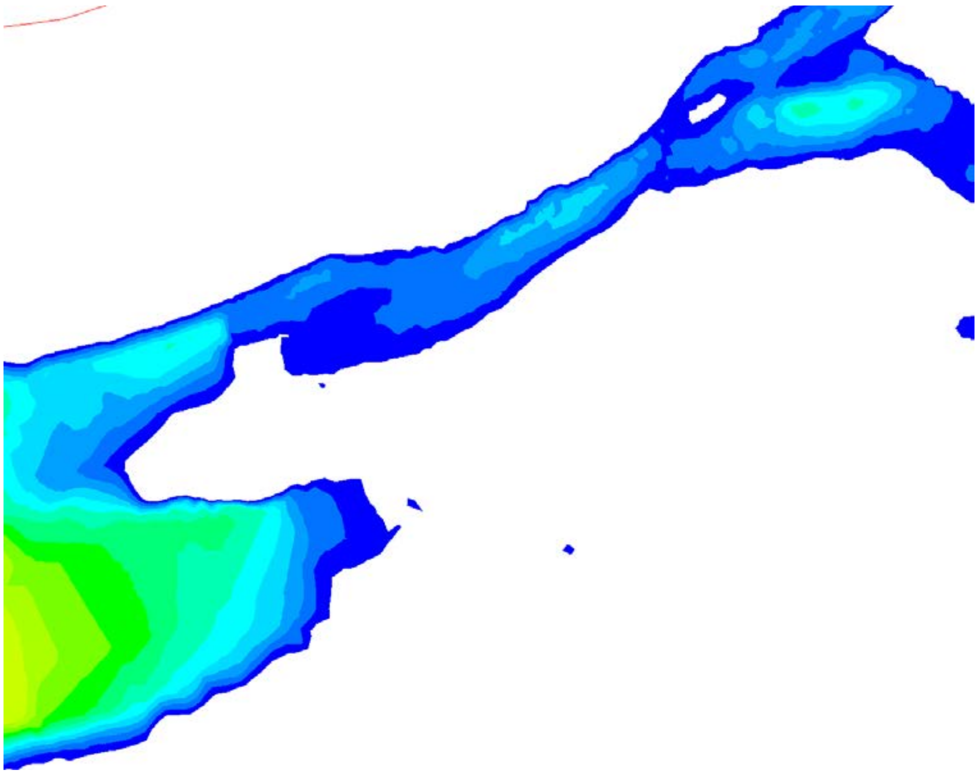

Figure 17, River 2D, 125kcfs, Ham 5 cms, low tailwater, EXISTING

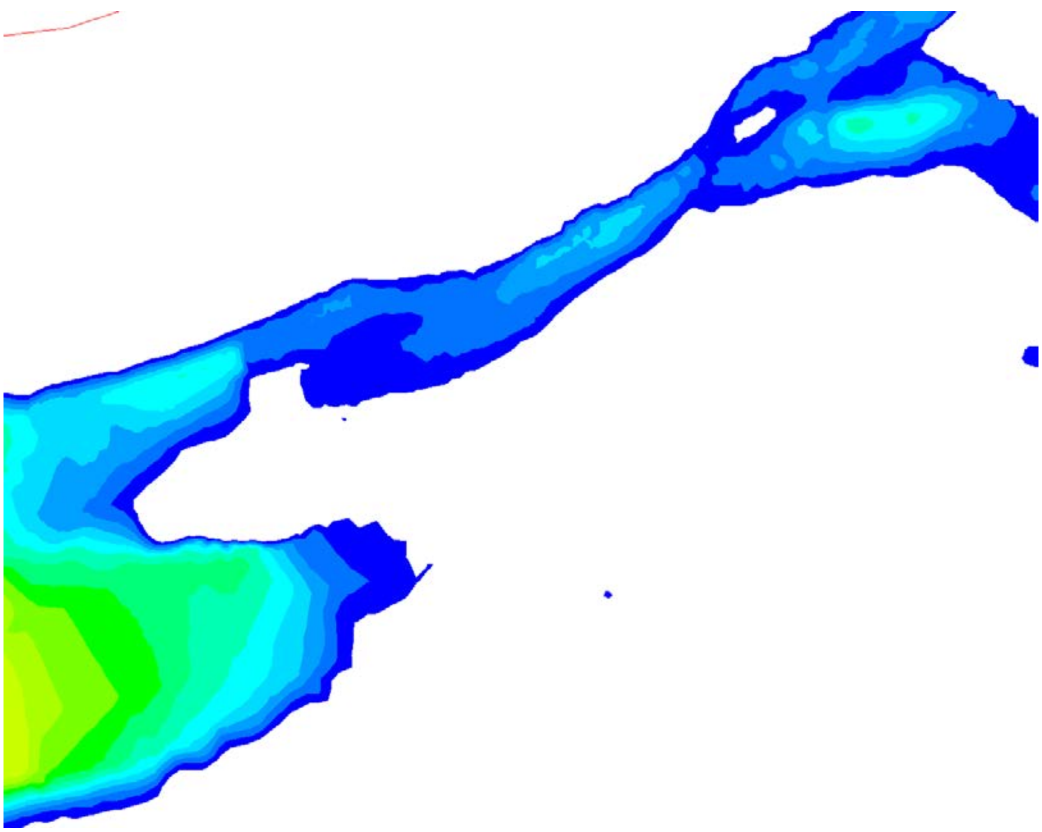

Figure 18, River 2D, 125kcfs, Ham 5 cms, low tailwater, PROPOSED

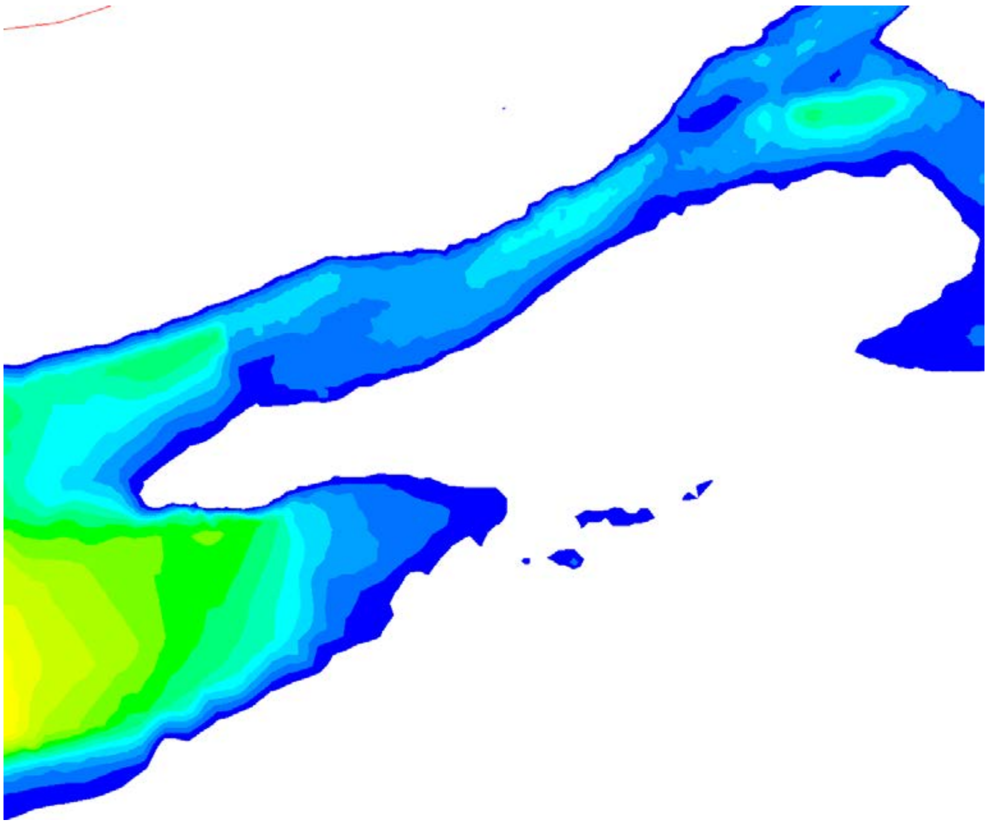

Figure 19, River 2D, 125kcfs, Ham 5 cms, ave. tailwater, EXISTING

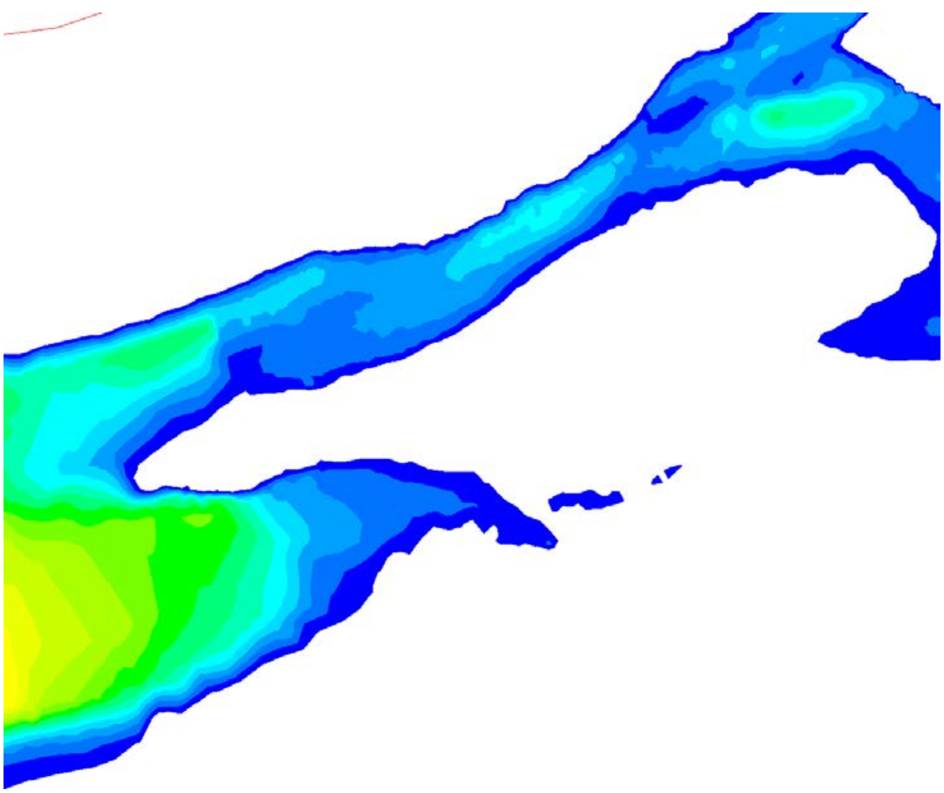

Figure 20, River 2D, 125kcfs, Ham 5 cms, ave. tailwater, PROPOSED

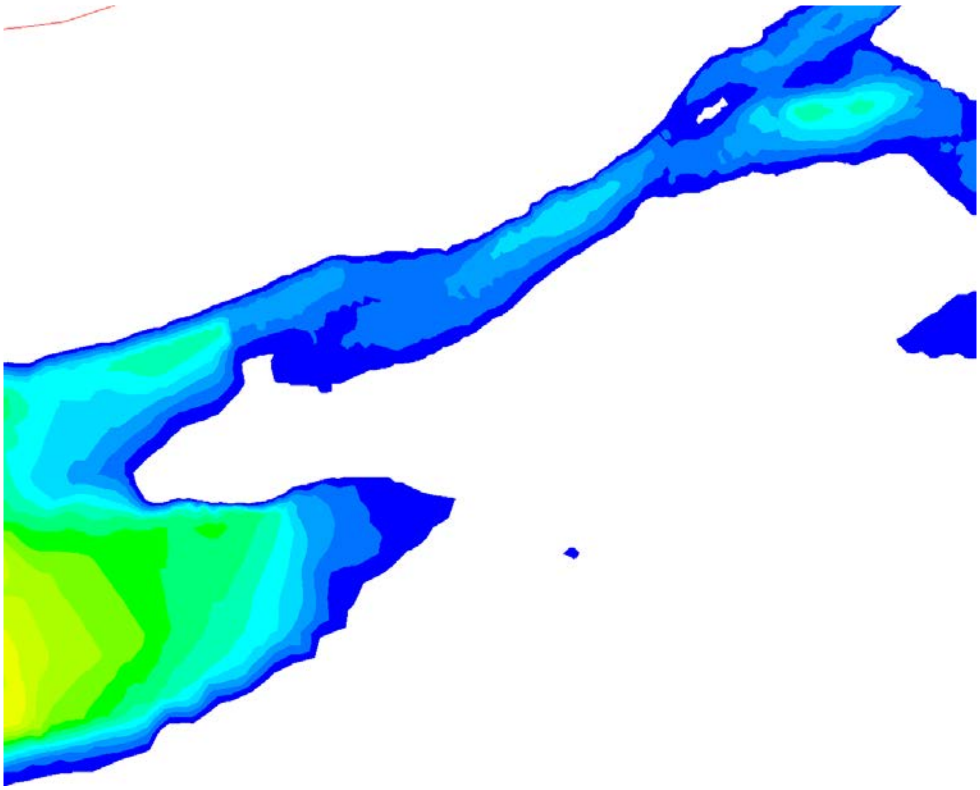

Figure 21, River 2D, 130kcfs, Ham 2 cms, low tailwater, EXISTING

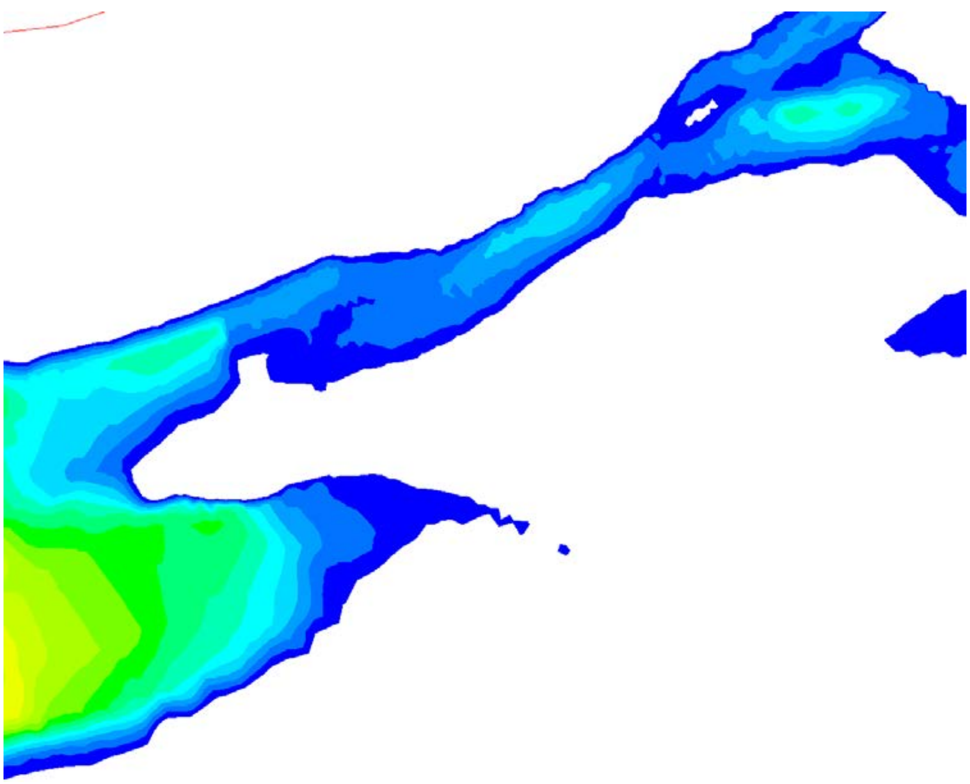

Figure 22, River 2D, 130kcfs, Ham 2 cms, low tailwater, PROPOSED

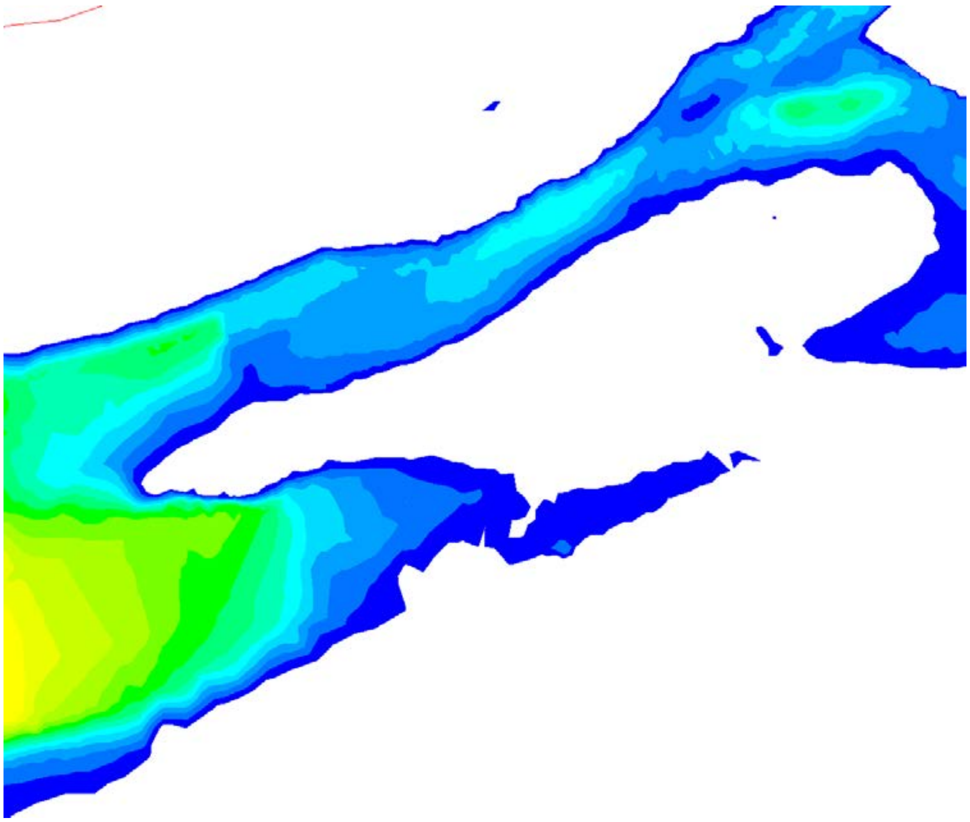

Figure 23, River 2D, 130kcfs, Ham 2 cms, ave. tailwater, EXISTING

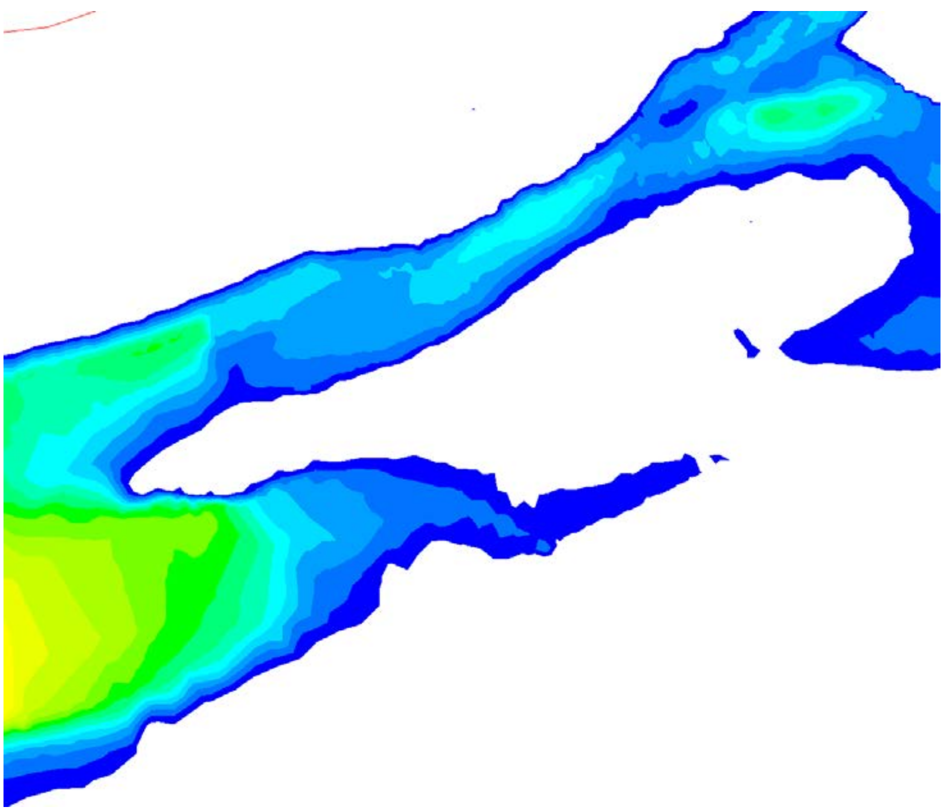

Figure 24, River 2D, 130kcfs, Ham 2 cms, ave. tailwater, PROPOSED

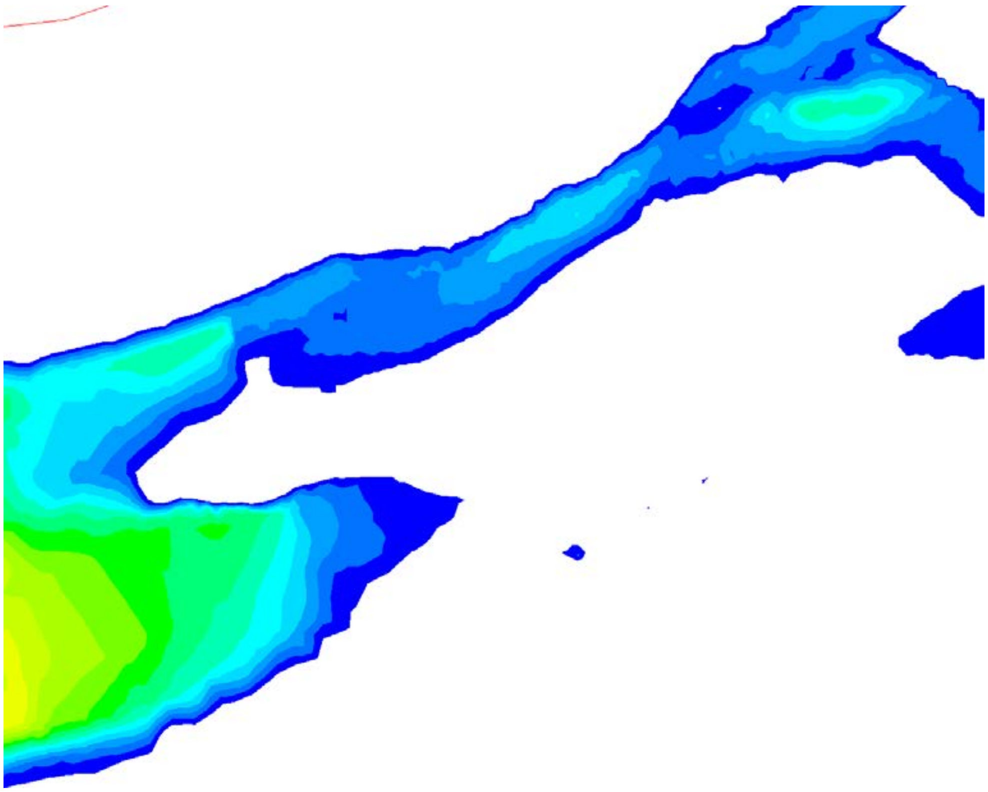

Figure 25, River 2D, 130kcfs, Ham 5 cms, low tailwater, EXISTING

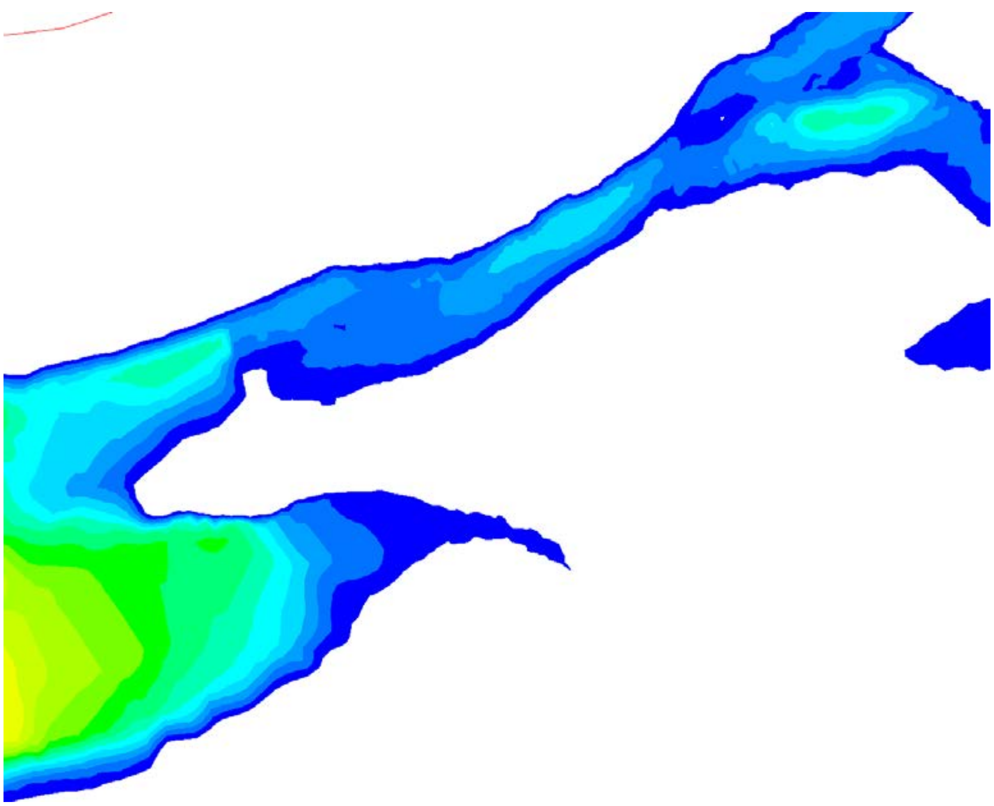

Figure 26, River 2D, 130kcfs, Ham 5 cms, low tailwater, PROPOSED

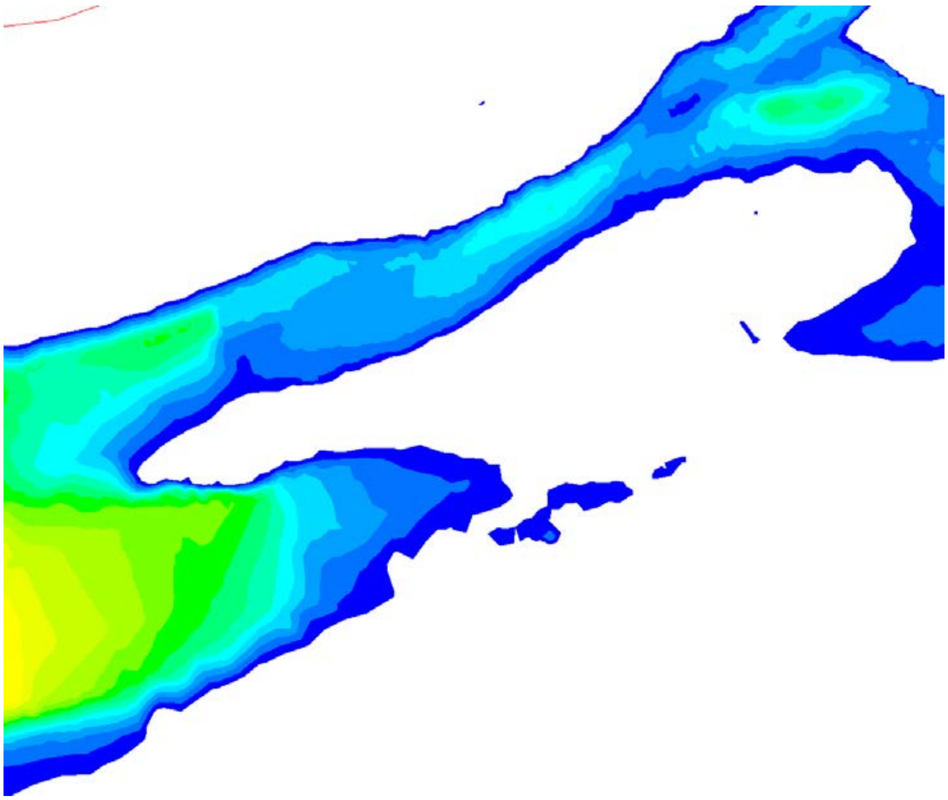

Figure 27, Figure 23, River 2D, 130kcfs, Ham 5 cms, ave. tailwater, EXISTING

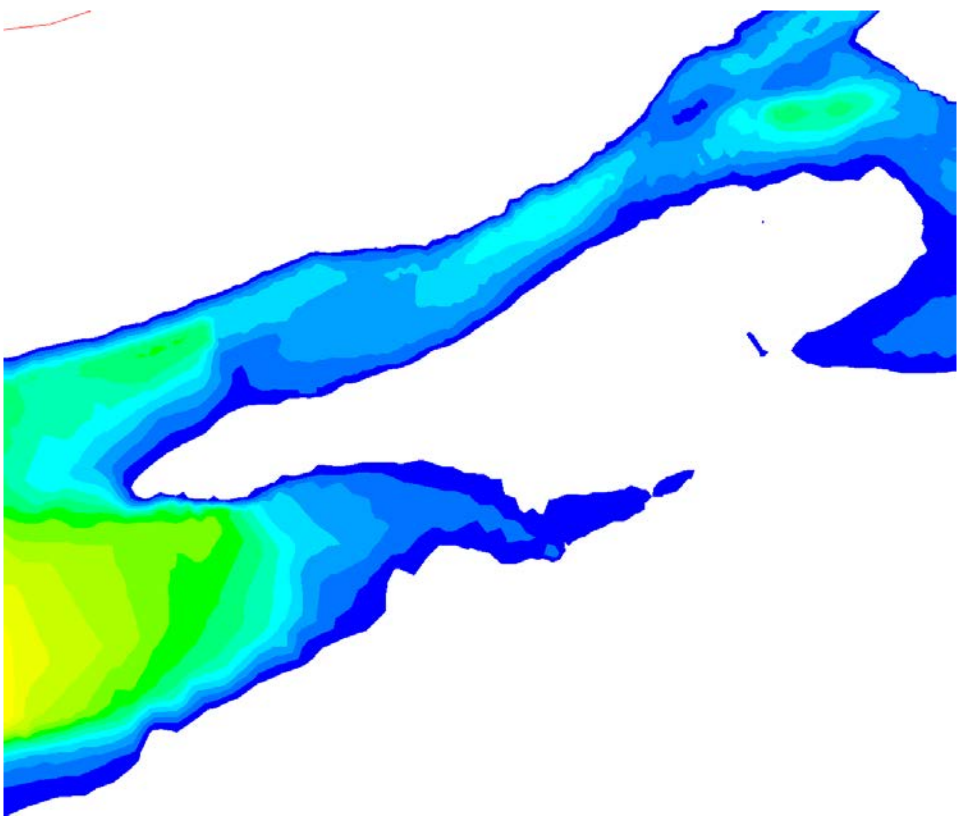

Figure 28, Figure 23, River 2D, 130kcfs, Ham 5 cms, ave. tailwater, PROPOSED

5 Opinion of Probable Cost

An opinion of probable cost was developed based on typical, installed unit costs.

Ives Island Opinion of Probable Construction Cost

No.	Bid Item	Unit	Unit Price	Quantity	Subtotal
General					
1	Mobilization	LS	$5,000	1	$5,000
Erosion and Sediment Control					
2	Access, Erosion Control	LS	$15,000	1	$15,000
Habitat Enhancement					
3	Excavation Cut	CY	$15	400	$6,000
4	Dimple and Hummock Surface	HR	$160	8.0	$1,280
5	Groundwater Observation Tubes	EA	$5,000	9.0	$45,000

Construction Subtotal	$72,280
15% Contingency	$10,842
WA State Sales Tax, 7%	$5,060
Project Total	**$88,182**

6 References

Arntzen, Evan V., Pacific Northwest National Laboratory (PNNL), Temperature and Water Depth Monitoring Within Chum Salmon Spawning Habitat Below Bonneville Dam, Annual Report – October 2007–September 2008, July, 2009.

Geist, K. R., Hanrahan, T. P., Arntzen, E. V., McMichael, G. A., Murray, C. J., and Chien, Y. J. 2002. Physicochemical Characteristics of the Hyporheic Zone Affect Redd Site Selection by Chum Salmon and Fall Chinook Salmon in the Columbia River. North American Journal of Fisheries Management. 22:4, 1077-1085.

System Operational Request (SOR) 2001-12, Boyce, Raymond, Chairperson, Salmon Managers, November 27, 2001.

Tiffan, K.F., 2014, Summary Notes of Ives Island Habitat Enhancement Meeting – July 8, 2014 held in Vancouver, WA, U.S. Geological Survey, Western Fisheries Group, Cook, WA.

Tiffan, K.F., Hatten, J.R. and Batt, T. R., 2014, Ives Island Habitat Enhancement: U.S. Geological Survey, Western Fisheries Group, Cook, WA.

Tomaro, L. M., van der Naald, W., Brooks, R. R., Jones, T. A., and Friesen, T. A. 2007. Evaluation of Chum and Fall Chinook Salmon Spawning Below Bonneville Dam, Annual Report. Oregon Department of Fish and Widldlife. 1-39.

APPENDIX A

Ives Island Chum and Chinook Salmon Spawning Habitat Enhancement

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Introduction

The lower Columbia River downstream of Bonneville Dam supports spawning populations of chum salmon (*Oncorhynchus keta*) and fall Chinook salmon (*O. tshawytscha*). Although most chum salmon spawning in the Columbia River occurs in tributaries, a segment of the population spawns in main-stem habitats in the vicinity of Ives Island about 3.5 km below Bonneville Dam (Figure 1). The spawning area along the north side of Ives Island below the mouth of Hamilton Creek is particularly important to chum and Chinook salmon because riverbed temperatures are 7-11ºC higher than surface water temperatures during spawning (Geist et al. 2002). These areas of upwelling are selected by chum and Chinook salmon because warmer water riverbed temperatures increase egg incubation and development rates and provide suitable water quality even at very low water velocities. In past years, hundreds of redds have been counted in this area (Tomoro et al. 2007). Both lower Columbia River chum salmon and Tule fall Chinook salmon are federally listed as "threatened" (NMFS 1999; USFWS 1999).

Although the Columbia River in this area is unimpounded, water levels are subject to water regulation from Bonneville Dam, outflow from Hamilton Creek, and tidal fluctuations. Seasonally, flows are lowest during early fall and water from the Columbia River typically does not flow into this area until November 1 when fishery managers increase Bonneville flows for chum spawning. Furthermore, during this time Hamilton Creek is often dry until rainfall increases stream flow. Both of these conditions preclude Tule fall Chinook salmon from spawning in this area before November 1, but their potential use of this area if water and habitat were available is currently unknown. This situation is only remedied by the unpredictable arrival of fall rains and by managing Bonneville Dam tailwater elevations, which does not occur until November 1 each year. However, water could be supplied to this important spawning area at lower Columbia River flows by reducing the elevation of certain hydraulic controls that currently preclude water from entering the area.

Garland et al. (2003) showed that water from the Columbia River does not flow into the channel between Ives Island and the Washington shore until flows reach about 120 kcfs. During early fall (September-October), flows are often less than this and can be as low as 75 kcfs (DART 2014). One reason water is prevented from flowing into the key spawning area is that the riverbed elevation at the upstream end of Ives Island is about 3.2 m above mean sea level (MSL) whereas the downstream elevation of the spawning area is about 2.2 m above MSL. Flow could be provided to the main spawning area by lowering the elevation of the riverbed at current hydraulic control points (Figure 1) to allow water to flow through the area at lower Columbia River flows. This action would potentially benefit early-spawning Tule fall Chinook salmon, but could alter habitat conditions for chum salmon when flows are increased on November 1 under existing flow management agreements.

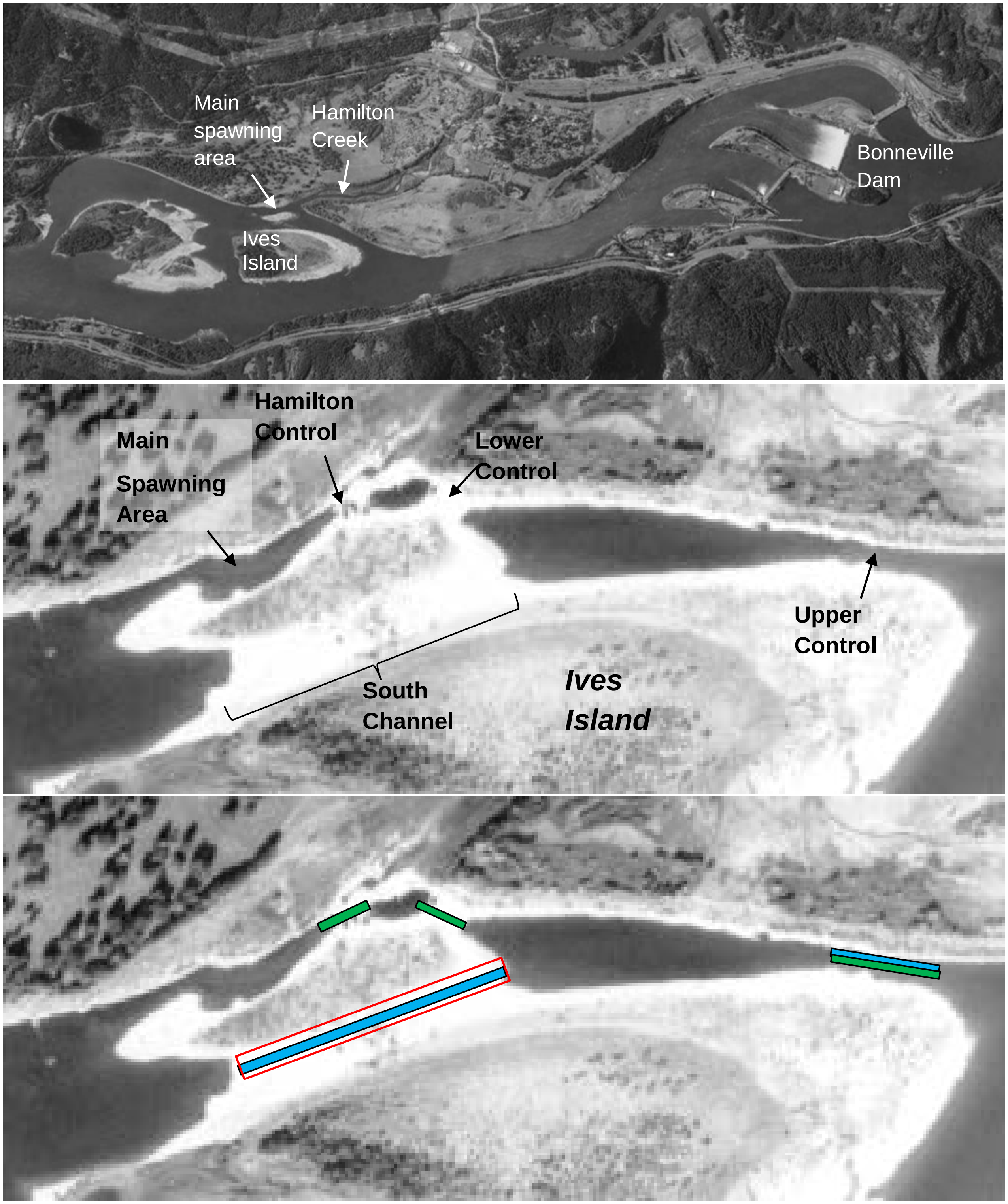


Figure 1. The Ives Island study area in relation to Bonneville Dam (top panel), the main hydraulic controls considered for modification in modeling scenarios (middle panel), and schematics (not to scale) of the excavation scenarios (bottom panel). Scenario 1 is shown in blue, scenario 2 is shown in green, and scenario 3 is shown in red. See text for additional details.

Alternatively, additional chum spawning habitat could be added by modifying riverbed elevations to allow access to spawning areas that currently only exist at flows higher than those provided under normal chum flows (i.e., ~120 kcfs or ~11.5 ft Bonneville tailwater elevation). The area directly adjacent to the north side of Ives Island (hereafter, South Channel), has been used in the past by chum salmon when flows are about 135 kcfs or Bonneville tailwater elevation is about 13.5 ft (Garland et al. 2003). This habitat could be made accessible to chum salmon by either 1) reducing the elevation of upstream controls and channel modification that would allow water to flow into this area at normal chum flows (i.e., ~120 kcfs or ~11.5 ft Bonneville tailwater elevation), or 2) by improving downstream access into this area at normal chum flows and lowering the riverbed to create a blind slough (because no water would flow in from the upstream end. The second option would rely on intergravel flow and upwelling to provide suitable habitat for spawning.

We initially modeled the effects of four different habitat enhancement scenarios on chum and Chinook salmon spawning habitat in the Ives Island area. We conducted a spatially explicit habitat analysis using two-dimensional hydrodynamic modeling and predictive statistical spawning habitat models within a GIS framework. Modeling results were presented at a stakeholder meeting to solicit input for producing a final design. The outcome of that stakeholder meeting was that most thought there was considerable risk associated with the first set of scenarios we modeled. Two new alternative scenarios were suggested which we then modeled and reported on. This report summarizes results on our modeling of the original scenarios as well as the two scenarios suggested at the stakeholder meeting. The blind slough option suggested at the stakeholder meeting is the one selected for design purposes.

Study Area

We focused habitat modeling around Ives Island because our habitat enhancement scenarios would most likely affect the main chum salmon spawning area and the area immediately to the south (i.e., the South Channel; Figure 1). The habitat modeling study area extended from the downstream end of Ives Island (and across to the Washington shoreline) to about 100 m upstream of Ives Island, but did not include the main Columbia River channel. We also included the lower 50 m of Hamilton Creek in the study area for habitat modeling purposes. The study area is generally characterized by a low gradient bed comprised of gravels and cobbles and low to moderate velocities during the fall spawning season. Riverbed temperatures (~20 cm below the substrate surface) can be considerably warmer (up to 9°C) than ambient water temperatures in certain areas (Geist et al. 2002). These areas are preferred by chum salmon, but riverbed temperatures have not been mapped for the entire study area.

Methods

Enhancement scenarios

We evaluated three scenarios to enhance chum and Chinook salmon spawning habitat at Ives Island as well as a base condition. The base condition reflected current habitat conditions without modification and served as a basis for comparison to the enhancement scenarios. Scenario 1involved simulating a cut through the Upper Control and through the South Channel to provide water and spawning habitat to the South Channel (Figure 1). The cut was relatively small, a channel approximately 30 feet wide by 2 feet deep. This scenario was modeled for Columbia River flows of 85 kcfs to simulate a low-flow condition and 120 kcfs to simulate the flow typically provided during the chum salmon spawning period. Scenario 2 involved simulating cuts made through the Upper, Lower, and Hamilton Controls to provide water to the main chum spawning area below the mouth of Hamilton Creek at a low flow (85 kcfs) and at a typical flow (120 kcfs). Scenario 3 was similar to Scenario 1 except the simulated cuts were wider and shallower. Scenario 3 was only modeled for a flow of 120 kcfs.

We also evaluated two additional scenarios (plus base condition) that were the product of a stakeholder meeting at which the first set of modeling scenarios were presented. We refer to these as “options” to keep them distinct from the original set of scenarios we modeled that are described above. Option 1 involved reducing the riverbed elevation at the downstream end of the South Channel to provide access to blind slough to increase chum salmon spawning habitat at a flow of 120 kcfs (Figure 2). This option relies on groundwater upwelling to provide spawning cues and suitable habitat as there would be little to no velocity in the slough. It should be noted that we were very conservative in how we lowered the riverbed elevation (simulated excavation) so as to minimize riverbed disturbance while still allowing fish access to this area. Option 2 involved lowering the riverbed elevation at the upstream end of the South Channel to provide flow through this area at 120 kcfs while minimizing flow reductions to the Main Spawning Area (Figure 2). Again, we took a conservative approach to reducing riverbed elevations in this area. Chum salmon were the focus of options 1 and 2.

Bathymetry

We required a high-resolution, digital elevation model of the study area to conduct hydrodynamic modeling and a GIS-based analysis of chum and Chinook salmon spawning habitat. Most of the bathymetry data for this area was previously collected by Garland et al. (2003). We collected additional data in areas with sparse or no data such as in the South Channel, Hamilton Creek, and in the area typically inundated between the Upper and Lower Controls (Figure 1). Data were collected during roving surveys on foot using a real-time

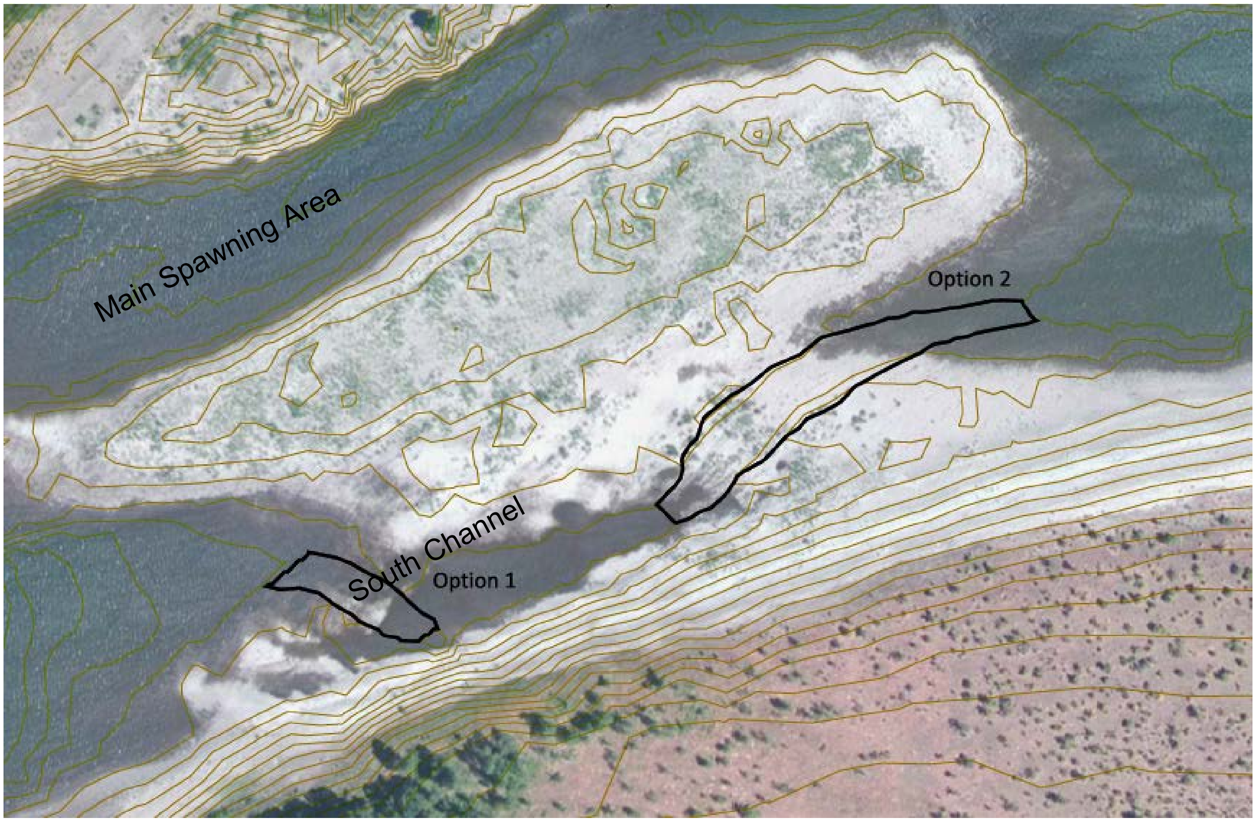


Figure 2. Two alternative chum spawning habitat enhancement options recommended by stakeholders in the South Channel at Ives Island. Option 1 would excavate within the area outlined in black to create a blind slough. Option 2 would excavate within the area outlined in black to provide minimal flow to the South Channel. Both options were modeled at a flow of 120 kcfs.

kinematic GPS (±2 cm elevation accuracy). Data from Garland et al. (2003) and those collected on this project were combined to form a complete bathymetric coverage of the study area.

Hydrodynamic modeling

We used a two-dimensional hydrodynamic model (River2D; Ghanem et al. 1996) to estimate depth-averaged water velocities for Columbia River flows of 85 and 120 kcfs for the first three scenarios and 120 kcfs for options 1 and 2. The 85-kcfs flow was selected to represent a low-flow condition at which water is not provided to the Ives Island area for spawning chum and Chinook salmon. Flows can be this low during September and October and may be more common under future climate change. The 120-kcfs flow was selected because this roughly corresponds to the flow during the chum salmon spawning period when the Bonneville Dam tailwater is held around 11.5 feet, depending on tidal stage.

The hydrodynamic model applies a two-dimensional finite-element method to solve the shallow-water flow equations. Model inputs included riverbed bathymetry with geographic position, elevation, and substrate roughness (height) information, as well as all inflow discharges and the water surface elevation (WSE) at the downstream end of the modeled area. Position, elevation, and riverbed substrate roughness data were then used to create a triangulated mesh of points, or nodes for use in the model. After the computation mesh was generated and smoothed, inflow discharges were assigned to the upper end of the modeled area. For each Columbia River discharge, we modeled Hamilton Creek input discharges of 2 or 5 m^3/s in separate model runs as these flows are typical during the spawning season. Given the tidal influence on WSEs within the study area, we modeled both the minimum and average downstream WSE collected at Warrendale, Oregon for each Columbia River/Hamilton Creek discharge combination. Therefore, for the base condition and the three scenarios, a total of 28 model runs were made. For the two alternative options modeled, a total of 8 model runs were made.

Final channel geometries of simulated excavations were arrived at iteratively for scenarios 1 and 3 and options 1 and 2. It was necessary to balance flows between the main spawning channel below the mouth of Hamilton Creek and the South Channel at the (overall) 120-kcfs modeled flow. This was based on avoiding substantial changes to the main spawning channel, while attempting to increase flow and spawning areas in the South Channel and the 120 kcfs flow. The design of hydraulic controls and modifications to increase flow in the South Channel were based off the assumption that flow through the existing, main spawning channel should remain unchanged. As mentioned earlier, we took a conservative approach to arrive at final channel geometries for options 1 and 2 to minimize simulated excavations.

Habitat models

We used the chum and Chinook salmon spawning habitat models developed by Garland et al. (2003). These logistic regression-based models predict the probability, *Pi*, of redd presence in *i* habitat cells given the habitat characteristics (e.g., depth, velocity, substrate) of each cell as delineated in a GIS. *Pi* can be expressed as a logit function as:

$$P_i = \frac{e^{g(x)}}{1 + e^{g(x)}}$$

where *g(x)* is the linear combination of parameter estimates of the predictor variables. The multivariate model for chum salmon was expressed as:

$$g(x) = 1.21 - 2.38D + 1.34\,V_1 + 1.42V_2 + 0.90V_3$$

where *D* represents depth (m) and $V_{1\text{-}3}$ represent different categories of water velocity (V_1, 0.2-0.3 m/s; V_2, 0.3-0.4 m/s; V_3, >0.4 m/s). Because we modeled velocity as a design variable, an individual variable will assume a value of 1 when its category contains a measure for a given habitat cell, otherwise its value will be 0. Velocities <0.2 m/s served as the reference category.

The multivariate model for Chinook salmon was expressed as:

$$g(x) = -1.41 + 2.44V + 2.59S - 1.04D$$

where *V* represents velocity (m/s), *S* represents substrate , and *D* represents depth (m). Both velocity and depth were continuous variables but substrate was modeled as a design variable and assumed a value of 1 when substrates ranged from 75 to 150 mm, otherwise it assumed a value of 0 when substrates were <75 mm (i.e., the reference category).

Habitat predictions

Chum and fall Chinook salmon spawning habitat was predicted for scenarios 1-3 whereas only chum salmon spawning habitat was predicted for options 1 and 2. We predicted the quantity of chum and fall Chinook salmon spawning habitat for each modeled flow by analyzing the physical habitat data in a GIS, in conjunction with the logistic regression models. GIS coverages were created for habitat variables that were included in our final logistic regression models. Habitat attributes of each GIS cell were used in the logistic regression models to determine the probability of redd presence for each cell. We created probability coverages in GIS and considered habitat cells with probabilities ≥0.6 suitable spawning locations for chum and fall Chinook salmon. We set probabilities to zero in areas where the depth was ≤0.21 m, because we observed no chum or fall Chinook salmon redds in areas this shallow. Additionally, we observed no fall Chinook salmon spawning in water deeper than 4.2 m so we set a maximum spawning depth limit of 6.5 m based upon work by Mueller and Dauble (2000) and Mueller (2001), and assumed no spawning occurred at depths greater than this. We then summed the areas of all cells with probabilities ≥0.6 to determine the total hectares of potential spawning area, which we plotted for each flow and scenario. Finally, we calculated the percent change in potential spawning habitat estimated for each scenario compared to the base condition.

Temperature mapping

We collected riverbed temperature data to determine if warm, subsurface water existed at potential channel excavation sites during mid to late November, 2013. At the Upper Control, 14 transects were established perpendicular to the main axis of the channel and spaced at 10-m intervals. Temperature data were collected at five equally spaced locations along each transect. The same approach was used at the Lower Control except only six transects were established. At the Hamilton Control, fewer data were collected because this area was sampled extensively in the past (Geist et al. 2002). At this site, three transects were established and between three and six locations were sampled along each. A limited amount of sampling was conducted in the South Channel because the area was mostly dry except for a relatively small pool of standing water.

Temperatures were collected with a digital temperature meter (Omega model 450-ATH) connected to a thermistor that extended to the bottom of a 155-cm, perforated GeoProbe drive rod. The accuracy of the thermistor and temperature meter was ±0.15°C. At each sampling location, the drive rod was driven to a depth of 20 cm into the bed. A temperature reading was recorded after a 2-4 min equilibration period. The rod was then removed from the riverbed and the surface water temperature was measured. The water depth as well as a GPS point was collected at each location.

Results

Scenarios 1-3

Chum habitat.—Predicted chum salmon spawning habitat varied by scenario, Columbia River flow, WSE, and Hamilton Creek flow (Figure 3). Habitat areas ranged from 1.3 to 4.1 ha depending on flow and scenario. Scenarios 1 and 3 always produced more chum salmon spawning habitat than the unaltered base condition, but scenario 2 produced more variable habitat results depending flow conditions. Generally, more habitat was predicted at 120-kcfs flow combinations than for 85-kcfs flow combinations (Figure 3).

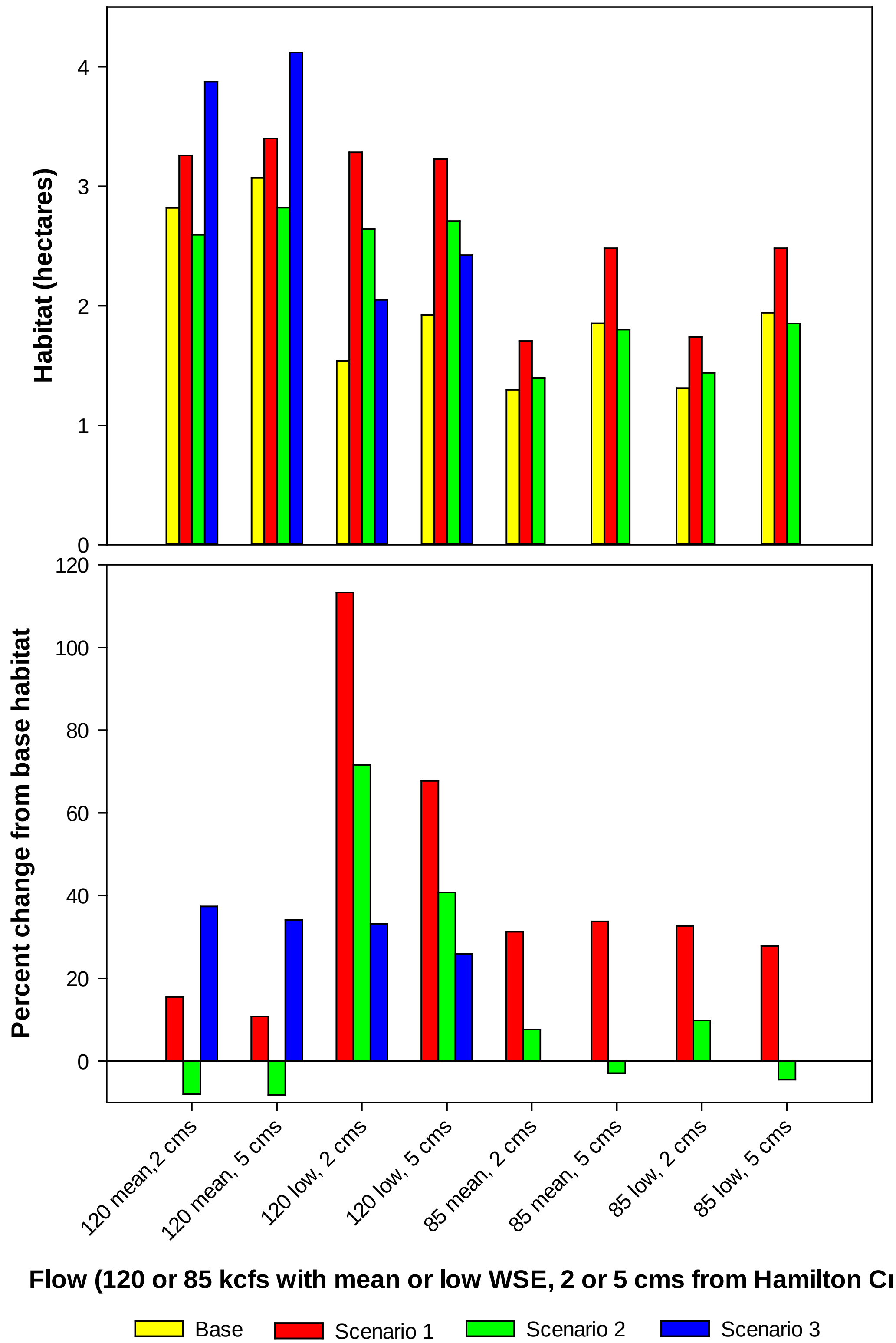


Figure 3. Predicted chum salmon spawning habitat area (top panel) and change in habitat area compared to the base condition (bottom panel) for different habitat enhancement scenarios. Water surface elevation is abbreviated as "WSE" and cubic meters per second as "cms."

The percent change in chum salmon spawning habitat from the base condition varied considerably by scenario and flow combination. Scenario 1 produced 29-34% more habitat at a flow of 85 kcfs regardless of Hamilton Creek inflow and downstream WSE (Figure 3). At a flow of 120 kcfs, downstream WSE had a large effect on percent habitat change for scenario 1. At a mean WSE, habitat increased only 11-16% over base habitat areas, but at a low WSE habitat increased by 68-113% (Figure 3). This was largely due to there being less habitat at the low WSE compared to the mean WSE for the base condition, whereas scenario 1 generally produced the same amount of habitat regardless of flow combination at a Columbia River flow of 120 kcfs.

Scenario 2 resulted in the largest percent gains (41-72%) in chum salmon spawning habitat over base amounts for a flow of 120 kcfs and a low WSE (Figure 3). For this flow, a higher Hamilton Creek discharge resulted in less habitat. For the other flow combinations modeled, less habitat was predicted than the base condition for four of the six model runs. The amount of habitat predicted under scenario 3 was somewhat consistent (26-37%) at a flow of 120 kcfs regardless of Hamilton Creek discharge and WSE (Figure 3). Examples of predicted chum salmon spawning habitat for the different scenarios are shown in Appendix 1.

Chinook habitat.—Predicted Chinook salmon habitat followed the same trend as with chum salmon except that absolute habitat amounts were higher (Figure 4). Habitat areas ranged from 3.0 to 6.5 ha depending on flow and scenario. Scenarios 1-3 always produced more Chinook salmon spawning habitat than the unaltered base condition, except for scenario 2 modeled at 85 kcfs which always produced less. Generally, more habitat was predicted at 120-kcfs flow combinations than for 85-kcfs flow combinations (Figure 4).

The percent change in Chinook salmon spawning habitat from the base condition varied considerably by scenario and flow combination. Scenario 1 produced the most gain in habitat over base conditions compared to the other scenarios. Scenario 1 produced 19-30% more Chinook salmon spawning habitat at a flow of 85 kcfs, which did not vary much with WSE, but habitat was reduced at the higher Hamilton Creek discharge (Figure 4). At a flow of 120 kcfs, habitat area increased from 52 to 66% for scenario 1, and less habitat was predicted at higher WSEs and Hamilton Creek discharges. Scenario 2 produced 28-38% more spawning habitat at a flow of 120 kcfs compared to the base condition. However, less habitat was predicted for all 85-kcfs flow combinations (Figure 4). For scenario 3, twice as much habitat was predicted at 120 kcfs and mean WSE compared to the low WSE at this flow (Figure 4). Discharge from Hamilton Creek had little effect on habitat predicted in this scenario. Examples of predicted Chinook salmon spawning habitat for the different scenarios are shown in Appendix 2.

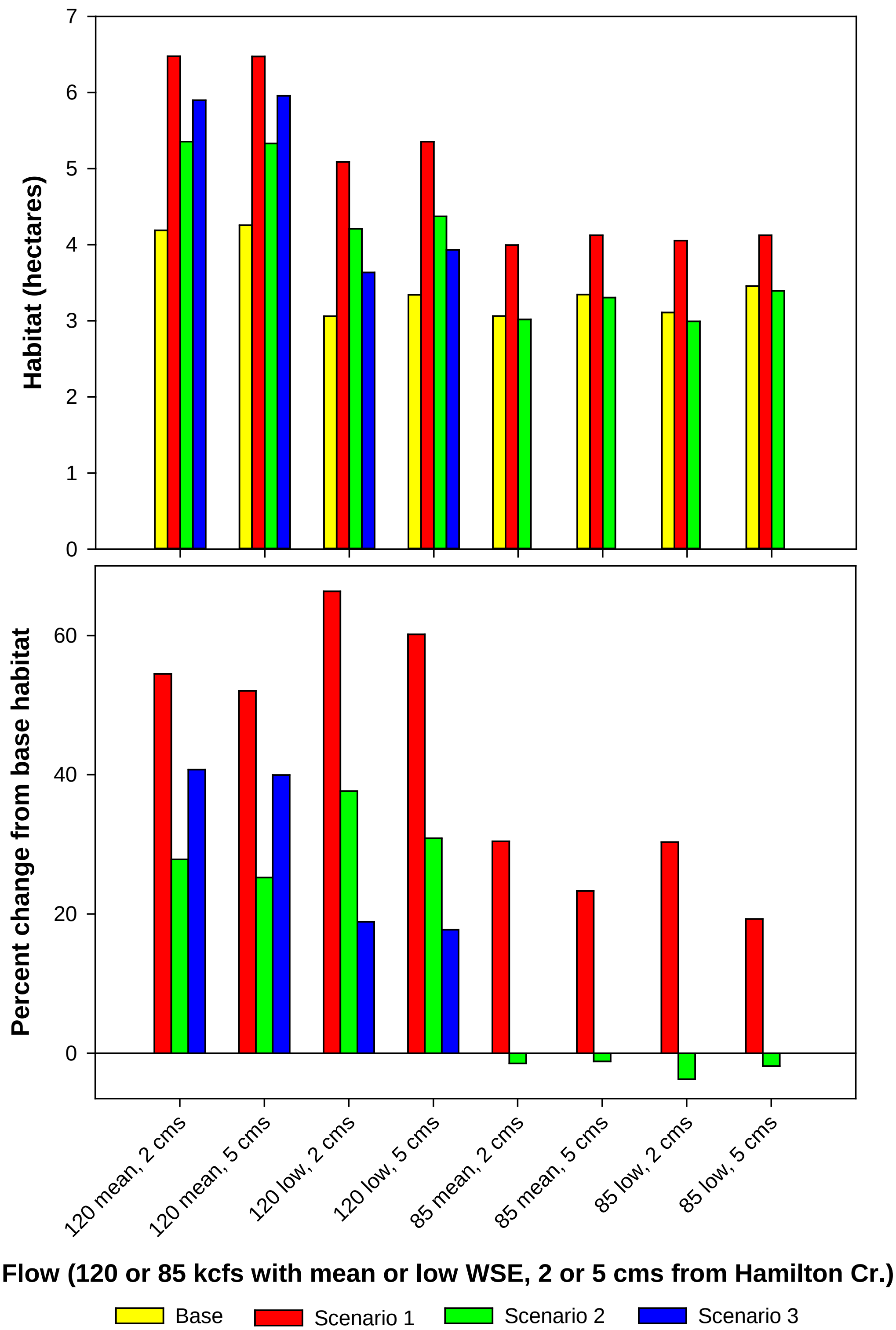


Figure 4. Predicted Chinook salmon spawning habitat area (top panel) and change in habitat area compared to the base condition (bottom panel) for different habitat enhancement scenarios. Water surface elevation is abbreviated as "WSE" and cubic meters per second as "cms."

Options 1 and 2

Chum habitat.—Neither option 1 or 2 produced appreciable amounts of chum salmon spawning habitat in the South Channel compared to the base condition (Figure 5). There were generally only changes of less than 1.5% in habitat area, none of which occurred within the South Channel. Options 1 and 2 did increase the wetted area in simulations involving an average WSE (Figures 6 and 7). Only at the mean WSE was there evidence that the enhancement options would begin to supply water to the intended areas. This did not occur at the low WSE. For option 1, water was supplied to the blind slough as intended, but the depth was not great enough to be considered suitable habitat (Figure 6). For option 2, water flowed through the upper portion of the excavated area, but then went subsurface (Figure 7). It is likely that the lack of suitable chum salmon spawning habitat predicted for options 1 and 2 is the result of conservative excavation simulations and not modeling a high enough Columbia River flow.

Temperature mapping

We collected 70 riverbed and surface water temperature measurements at the Upper Control. Riverbed temperatures averaged 0.3°C warmer than surface waters (range of differences, -0.3 to 0.9°C). Water depths ranged from 15 to 75 cm. At the Lower Control, temperature measurements at 30 locations showed that the riverbed temperatures averaged 0.8°C warmer than surface waters (range of differences, 0.3 to 2.6°C). Water depths ranged from 20 to 60 cm. A total of 13 locations were sampled at the Hamilton Control where riverbed temperatures averaged 0.7°C warmer than surface waters (range of differences, 0 to 2.8°C). A total of 8 locations were sampled in the South Channel. The South Channel only contained a shallow disconnected pool whose temperature was probably strongly influenced by the air temperature. Nonetheless, two riverbed temperature measurements were 13.1 and 13.3°C which were 7.4 and 7.6°C warmer than the surface water temperatures. Other riverbed temperatures ranged from 5.1 to 10.0°C resulting in differentials ranging from 0.6 to 4.4°C.

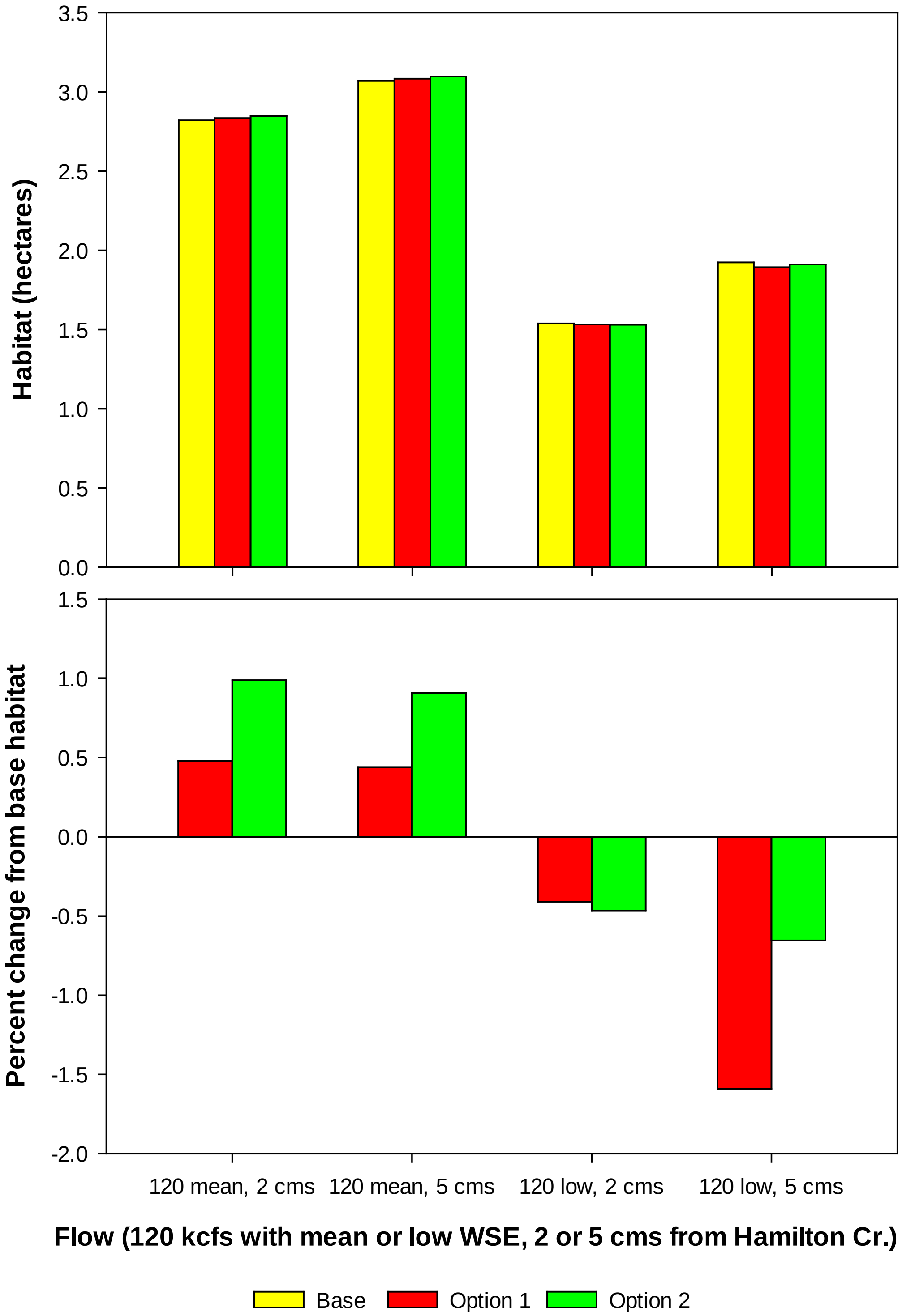
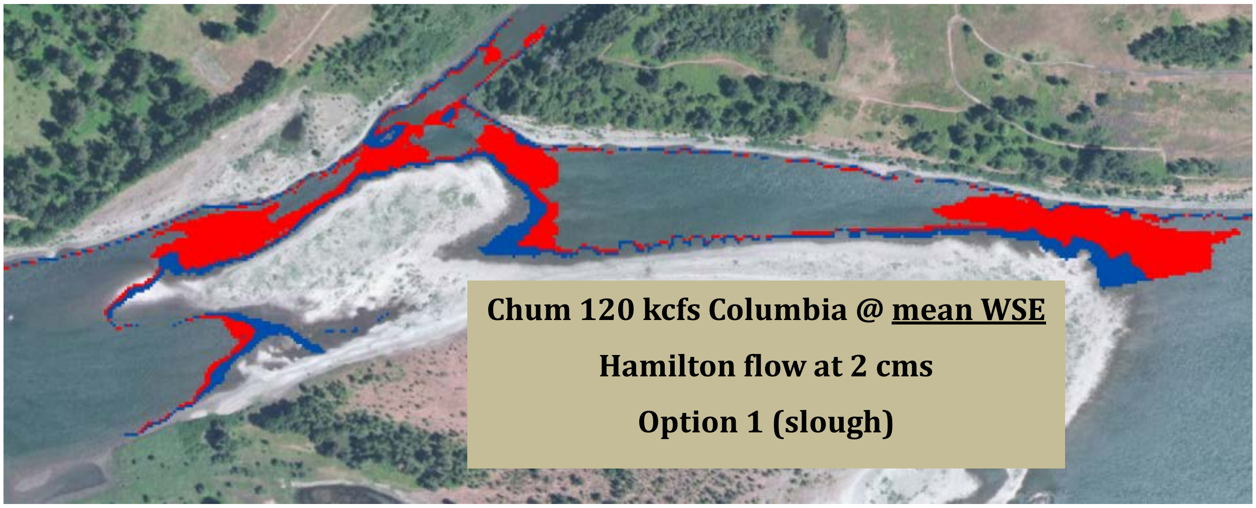


Figure 5. Predicted chum salmon spawning habitat area (top panel) and change in habitat area compared to the base condition (bottom panel) for habitat enhancement options 1 and 2 in the South Channel at Ives Island. Water surface elevation is abbreviated as “WSE” and cubic meters per second as “cms.”



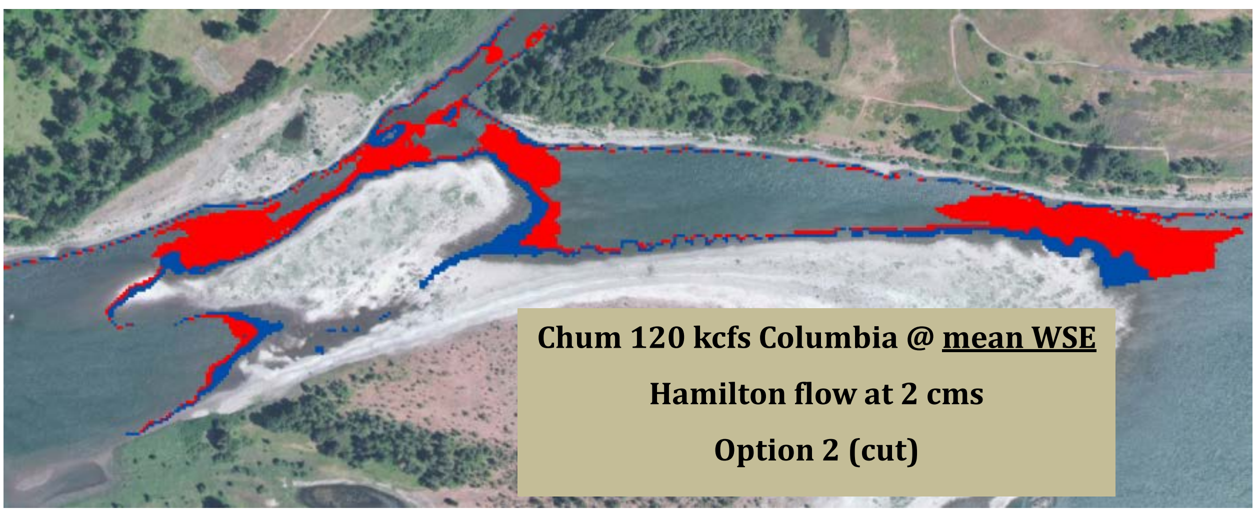
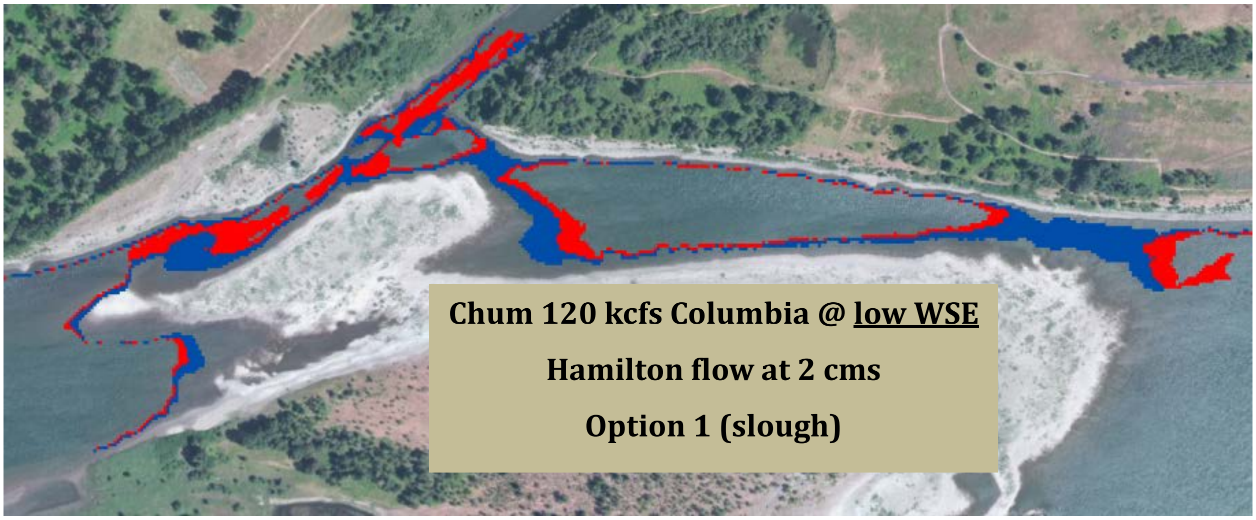


Figure 6. Predicted chum salmon spawning habitat (red areas) and extent of wetted area shallower than 0.21 m (blue areas) for habitat enhancement options 1 (top panel) and 2 (bottom panel) at Columbia River flows of 120 kcfs, mean water surface elevation (WSE), and Hamilton Creek discharge of 2 m^3/s (cms).



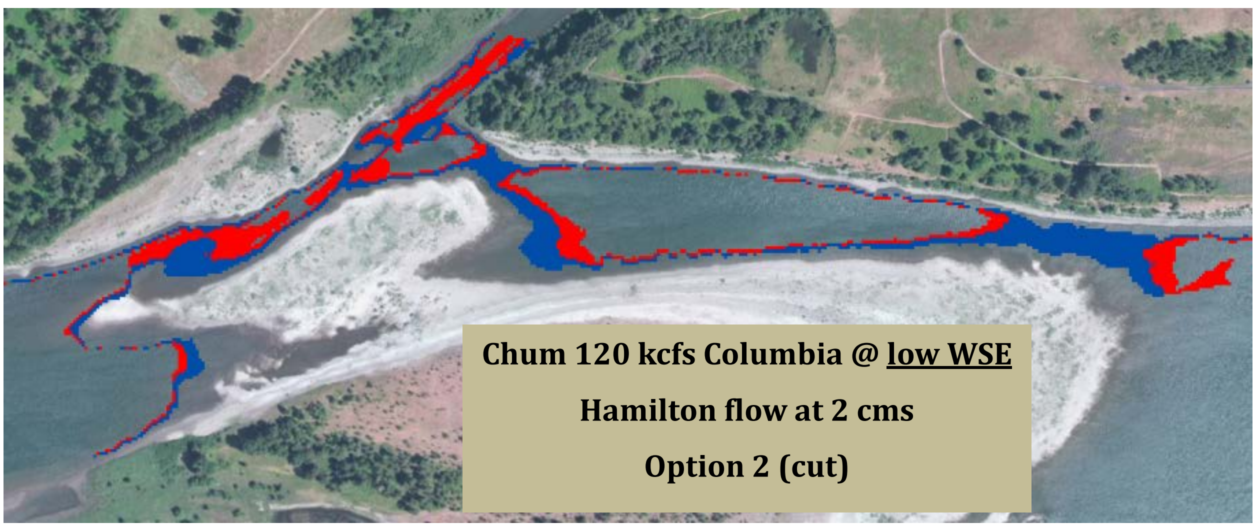


Figure 7. Predicted chum salmon spawning habitat (red areas) and extent of wetted area shallower than 0.21 m (blue areas) for habitat enhancement options 1 (top panel) and 2 (bottom panel) at Columbia River flows of 120 kcfs, low water surface elevation (WSE), and Hamilton Creek discharge of 2 m^3/s (cms).

Discussion

Scenarios 1-3

Most of the habitat enhancement scenarios modeled resulted in an increase in both chum and Chinook salmon spawning habitat compared to current, base conditions. However, many of the model runs resulted in habitat being produced in areas where chum and Chinook salmon have never been observed spawning. This is due to the spawning habitat models not accounting for important redd site selection cues such as upwelling warm water from the riverbed for chum salmon and downwelling for Chinook salmon. Geist et al. (2002) showed that chum salmon selected spawning sites in the Ives Island area that corresponded to locations where warm groundwater upwelled from the riverbed. In fact, chum salmon have been observed spawning at Ives Island where water velocities are zero as long as warm water upwells from the riverbed. The differential between riverbed and surface water temperatures could not be incorporated into the chum habitat model because these data are not available for the entire study area. Similarly, Chinook salmon tend spawn in areas of downwelling (Geist et al. 2002), which our Chinook salmon habitat model could not capture. Nonetheless, the models predicted where suitable habitat existed based on depth, velocity, and substrate which could be used by chum and Chinook salmon if other requisite habitat conditions were present.

One flow scenario that was not modeled was zero flow from Hamilton Creek. Hamilton Creek is often dry in September and October. During this condition, any spawning habitat would be solely supported by flow from the Columbia River. However, under scenario 1 habitat was predicted to occur in the main chum salmon spawning area below the mouth of Hamilton Creek at a flow of 85 kcfs. This could only occur if Hamilton Creek discharged water, which was true in our modeling. Flow scenarios run in which Hamilton Creek was dry likely would have produced different habitats amounts particularly in the main chum spawning area.

The different scenarios modeled represent different levels of risk and complexity. Scenario 1 has the advantage of providing spawning habitat in the South Channel at a flow of 85 kcfs which would otherwise not occur at this flow. Further, this would be the only appreciable habitat in the area if Hamilton Creek was dry and provided no flow to the main chum salmon spawning area. However, when flow is increased to 120 kcfs, the flow must now be split between the South Channel and the main chum spawning channel. This creates a situation where the split flow must be balanced between the two channels so as not to reduce flow to the main spawning area. This complex condition also exists for scenario 3 at this flow. Maintaining this balance necessitated an iterative approach to arriving at the final channel geometries for the simulated excavated channels on the hydraulic controls. Because 120 kcfs was the highest flow modeled, it is unknown how the flow balance between the two channels would be affected at higher flows. In addition, it is unknown how stable over time the excavated channels would be for any of the scenarios given that spring flows in the Columbia River can approach 500 kcfs in some years.

Another risk associated with scenario 2 is the excavation at the Lower and Hamilton Controls where some fish currently spawn. Excavation at these sites could potentially change the suitability of existing spawning habitat and affect both the surface and hyporheic hydrology. Geist et al. (2002) speculated that the riverbed structure and underlying geomorphology probably influence current areas of downwelling and upwelling of warmer groundwater. It is possible that the upwelling groundwater temperature regime could be altered by excavation although we found little temperature difference between riverbed and surface water at these controls. Altering the riverbed under scenario 2 represents an unknown risk to spawning habitat suitability and long-term stability of the channel.

Although Scenario 3 is similar to scenario 1, it probably carries the least risk of the scenarios modeled. The wider, shallower channels may be more stable over time than the narrower, deeper channels of scenario 1. There is also no excavation of the Upper Control in this scenario which reduces the manipulation of the existing landscape. However, there is still the need to balance the flow going through the main chum salmon spawning area and the South Channel. This scenario also produced the most chum salmon spawning habitat compared to the other scenarios. Furthermore, we measured elevated riverbed temperatures in this area suggesting that this area should be preferred by chum salmon. Finally, habitat would still be provided in the South Channel at flows higher than 120 kcfs given that spawning has been observed in the past at higher flows. Of the habitat scenarios we modeled, we believe scenario 3 is the preferred alternative.

Options 1 and 2

Following a stakeholder meeting at which the modeling results of scenarios 1-3 were discussed, it was decided the least risky option for enhancing spawning habitat in the Ives Island area was to lower the elevation of, and provide access into, the downstream end of the South Channel for chum salmon—Option 1. This option creates a blind slough that would rely on intergravel flow and groundwater upwelling to provide suitable spawning habitat. The substrate in this area is suitable for chum salmon (Garland et al. 2003) and areas of warm groundwater exist. This option carries the least risk since no hydraulic controls would be modified and there are no issues relating to balancing flows between two channels. Habitat would also be available in this area at flows higher than 120 kcfs as has been observed in the past. The greatest uncertainty with this design is the extent of warm groundwater input to this area and whether this cue would be sufficient for chum salmon to spawn there despite there being zero velocity.

Although our modeling results did not show the addition of an appreciable amount of chum salmon spawning habitat for option 1, this is likely due to the conservative nature of riverbed alteration. Our approach was to only minimally remove material from an elevated area that prevented fish access to the slough. This resulted in very shallow water within the slough that did not meet the criterion of being habitat. However, flows are managed at slightly higher levels than the 120 kcfs flow that we modeled for both options. This would likely result in more habitat being available in this area for chum salmon given current operations at Bonneville Dam. Our modeling also highlights the sensitivity of chum salmon spawning habitat to downstream water surface elevations that influenced by tides. There was always more habitat predicted at a mean water surface elevation compared to a low water surface elevation because at mean levels more area was wetted and depths were greater.

References

DART (Data Access in Real Time). 2014. Available http://www.cbr.washington.edu/dart/dart.html. (October 2014).

Garland, R.D., K.F. Tiffan, D.W. Rondorf, J. Skalicky, and D.R. Anglin. 2003. Assessment of chum and fall Chinook salmon spawning habitat near Ives and Pierce islands in the Columbia River. 1999-2001 Annual Report to the Bonneville Power Administration, Portland, Oregon.

Geist, D.R., T.P. Hanrahan, E.V. Arntzen, G.A. McMichael, C.J. Murray, and Y. Chien. 2002. Physiochemical characteristics of the hyporheic zone affect redd site selection by chum salmon and fall Chinook salmon in the Columbia River. North American Journal of Fisheries Management 22:1077-1085.

Ghanem, A., P. Steffler, F. Hicks, and C. Katopodis. 1996. Two-dimensional hydraulic simulation of physical habitat conditions in flowing streams. Regulated Rivers: Research and Management 12:185-200.

Mueller, R.P., and D.D. Dauble. 2000. Evidence of deepwater spawning of fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning near Ives and Pierce Island of the Columbia River, 1999. Annual Report to the Bonneville Power Administration, contract DE-AC06-76RLO1830, Portland, Oregon.

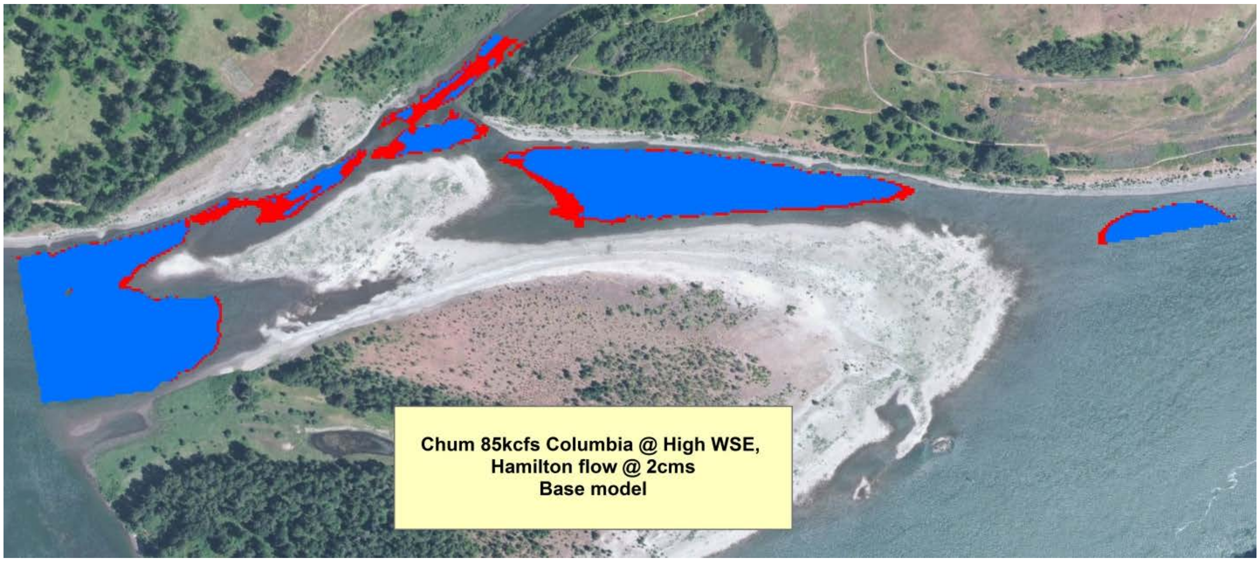
Mueller, R.P. 2001. Deepwater spawning of fall Chinook salmon (*Oncorhynchus tshawytscha*) near Ives and Pierce Island of the Columbia River, 2000. Annual Report to the Bonneville Power Administration, contract DE-AC06-76RLO1830, Portland, Oregon.

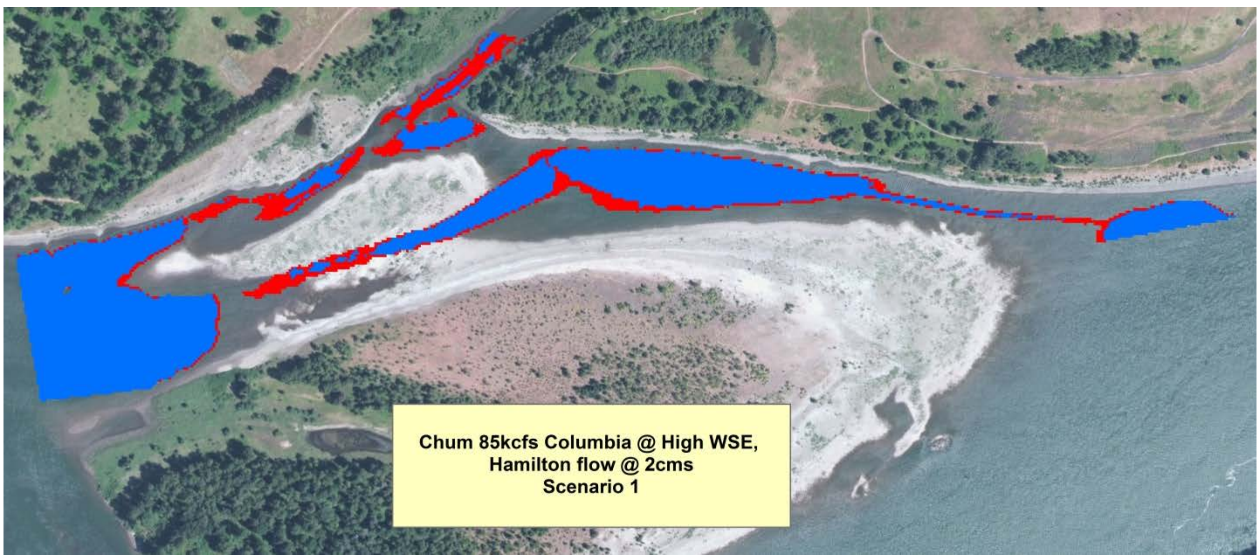
NMFS (National Marine Fisheries Service). 1999. Endangered and threatened species: threatened status of two ESUs of chum salmon in Washington and Oregon. Federal Register 64:14508-14517.

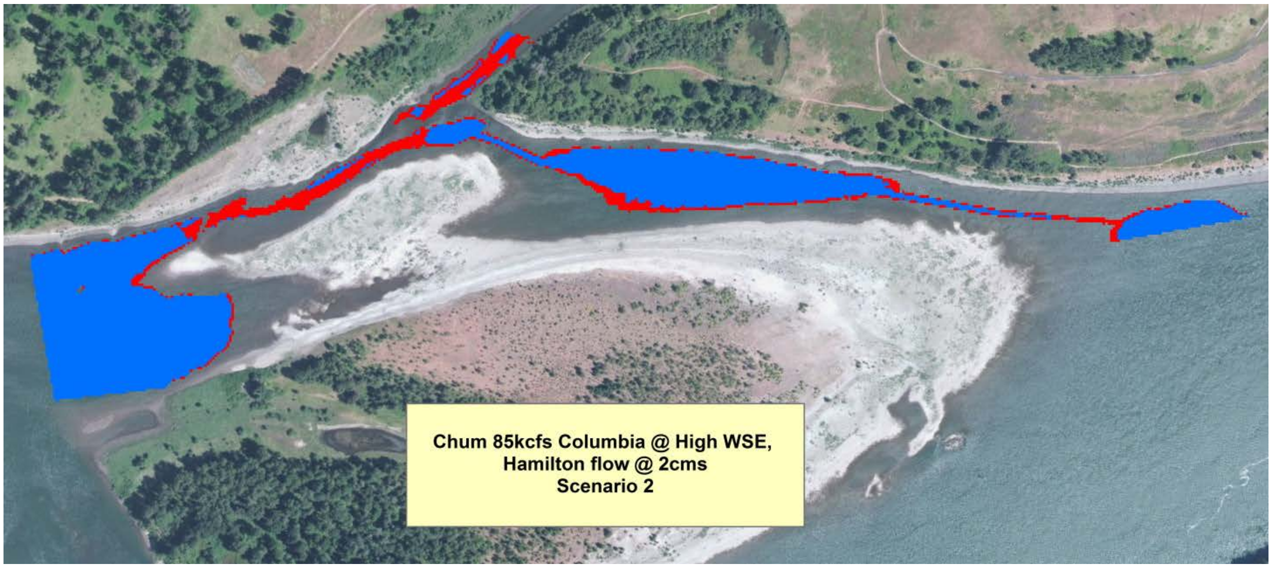
Tomoro, L., W. van der Naald, R. Brooks, T. Jones, and T. Friesen. 2007. Evaluation of chum and fall Chinook salmon spawning below Bonneville Dam. 2005-2006 Annual Report to the Bonneville Power Administration, Project 199900301, Portland, Oregon.

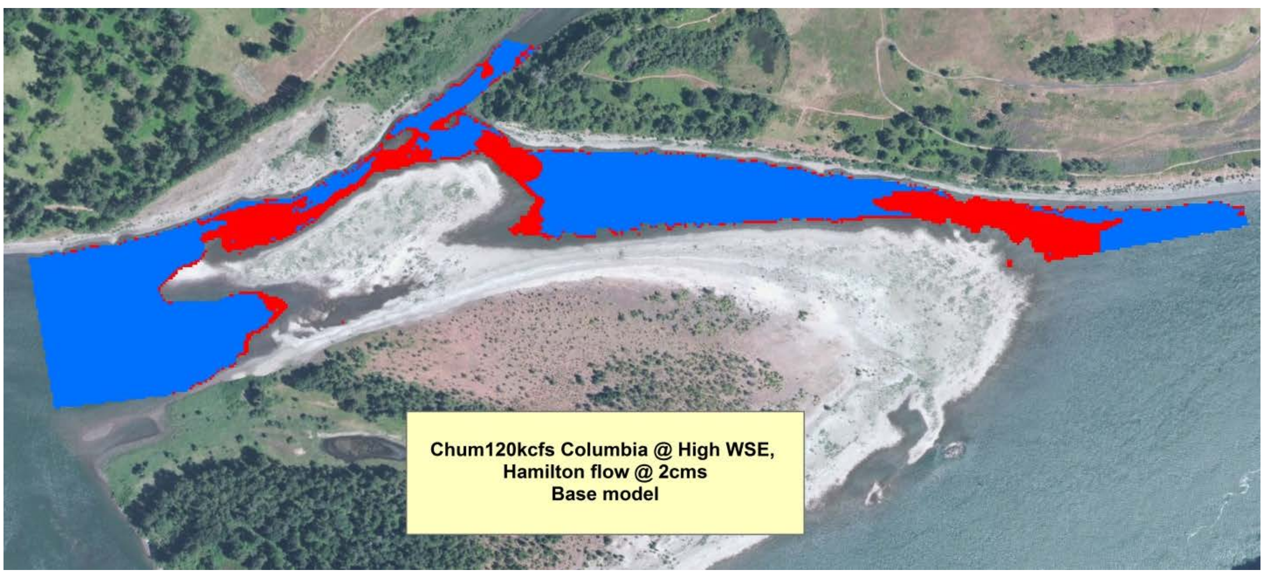
U.S. Fish and Wildlife Service. 1999. Endangered and threatened wildlife and plants; listing of nine evolutionarily significant units of chinook salmon, chum salmon, sockeye salmon, and steelhead. Federal Register 64:41835-41839.

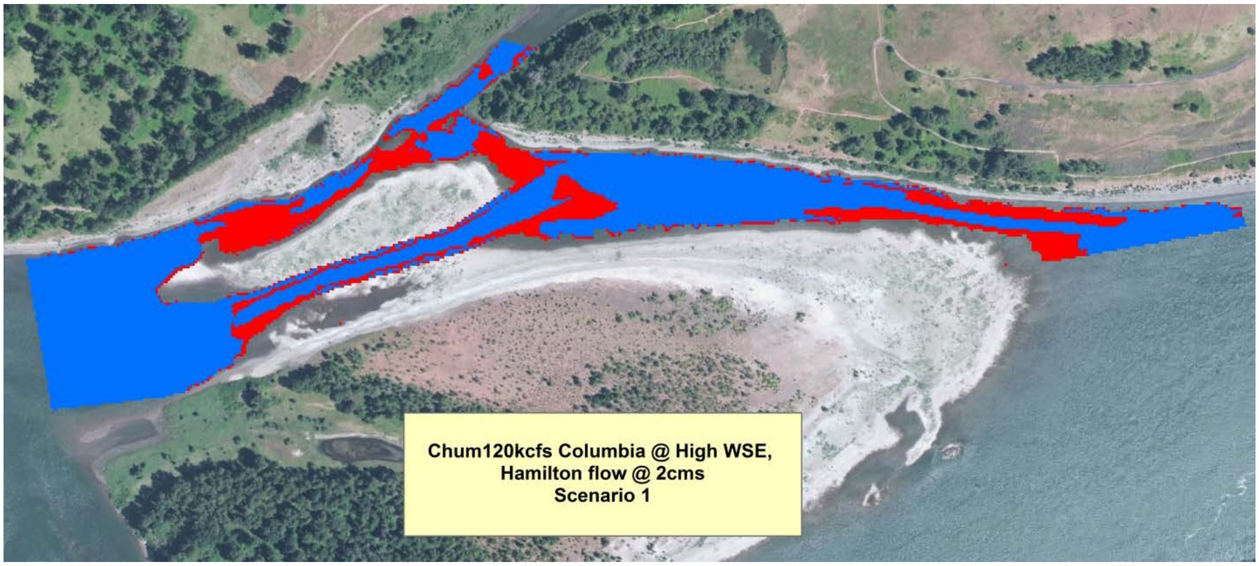
Appendix 1. The following figures show predicted chum salmon spawning habitat (red areas) for different habitat enhancement scenarios. All scenarios were modeled for the Columbia River flows shown on each figure and for average water surface elevations (WSE; shown as "Hi") and a Hamilton Creek discharge of 2 m^3/s ("cms").

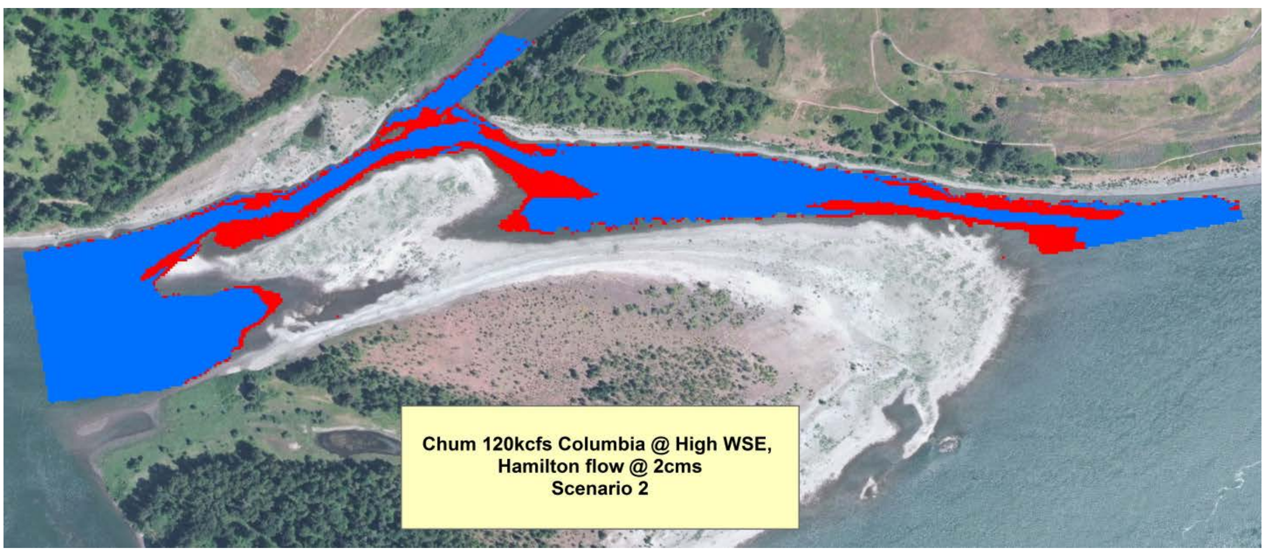


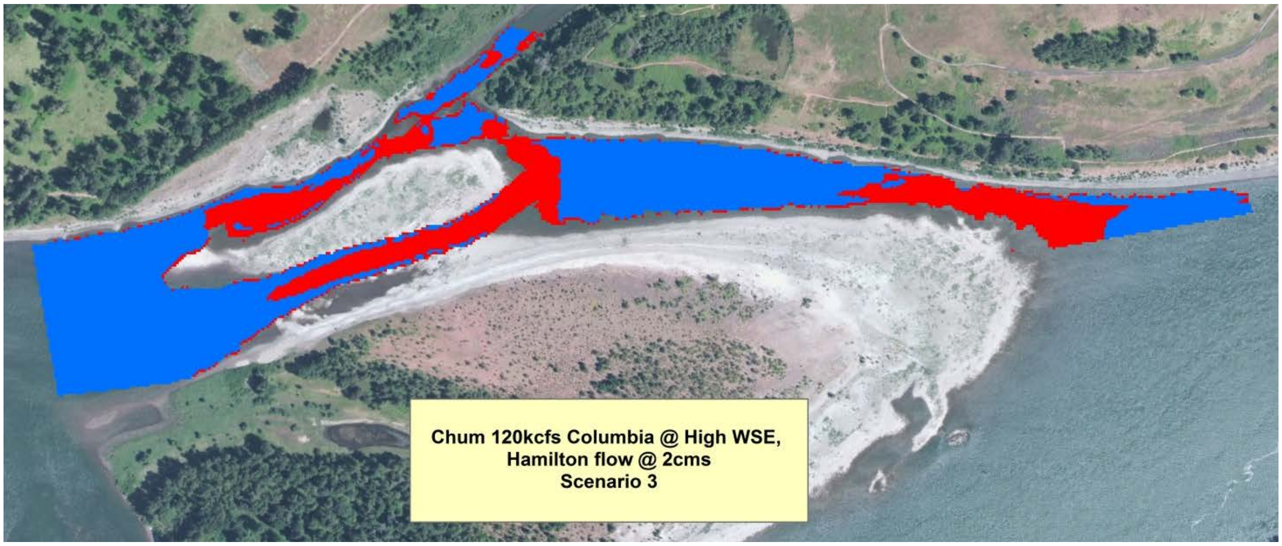



Chum 85kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 2

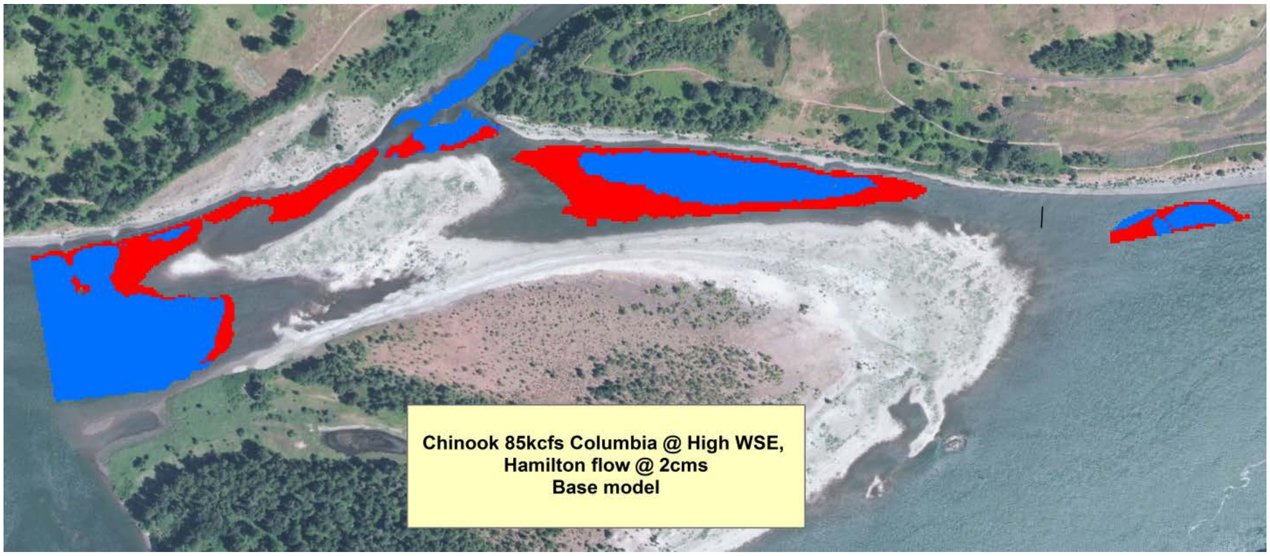

Chum120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Base model

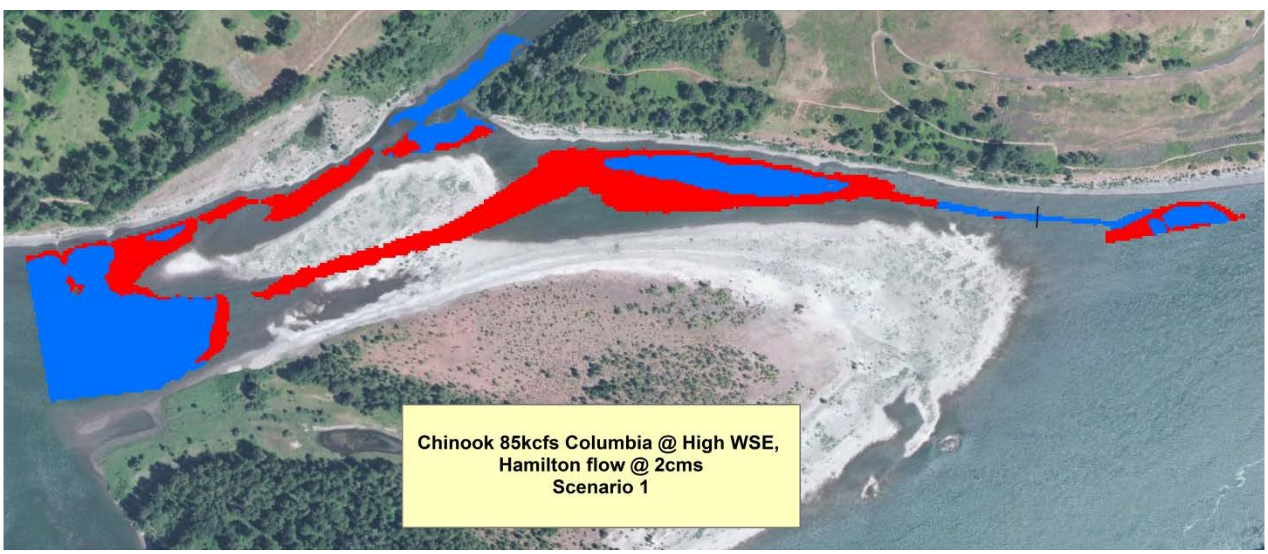

Chum120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 1

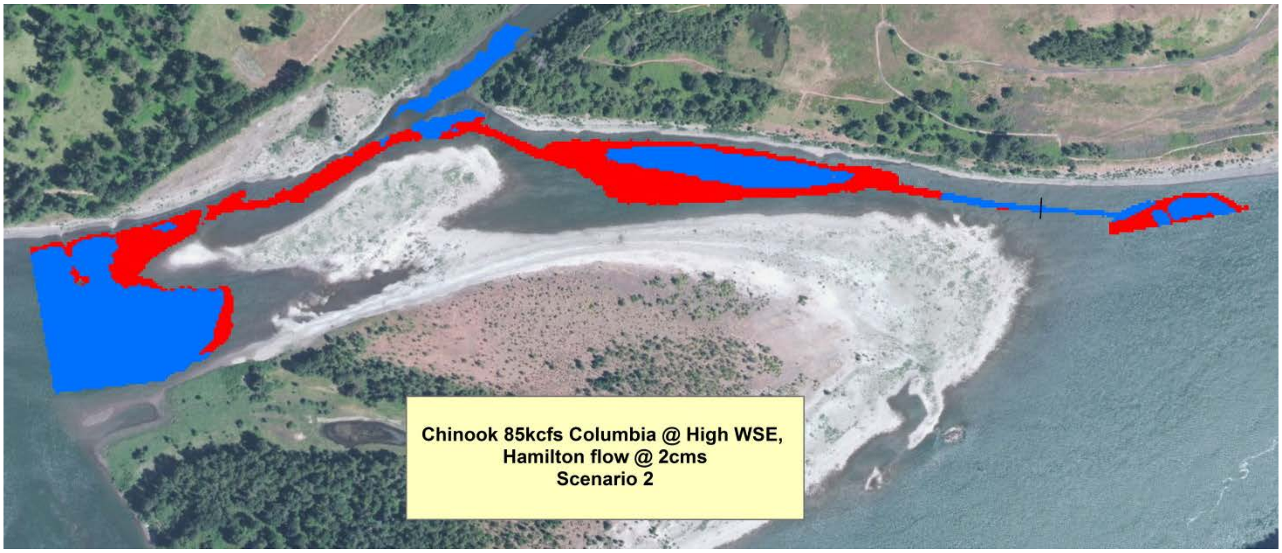

Chum 120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 2

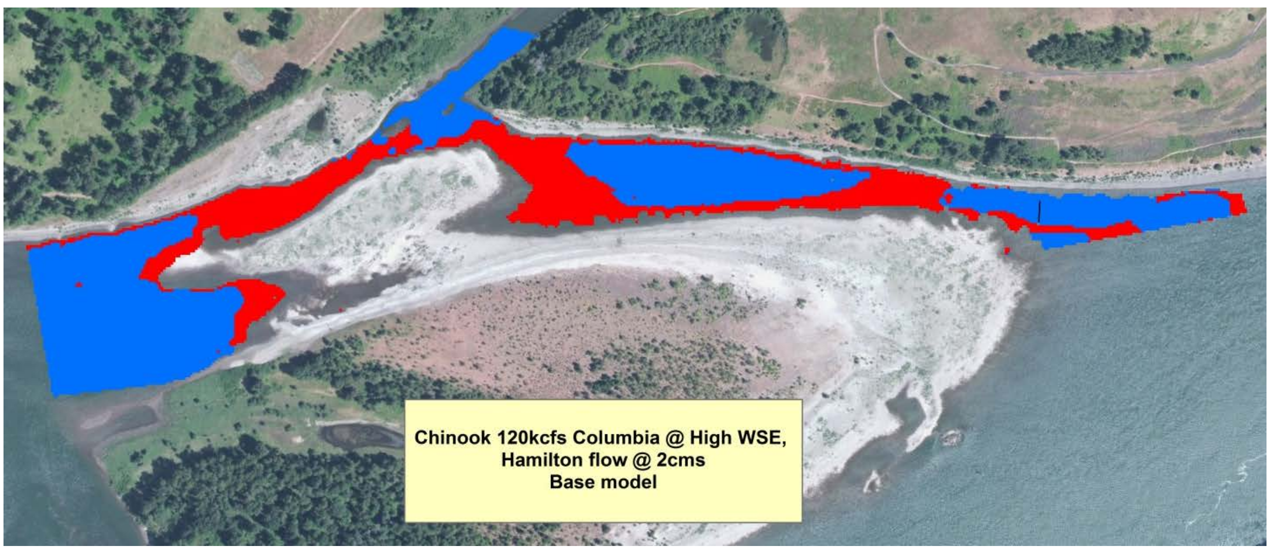

Chum 120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 3

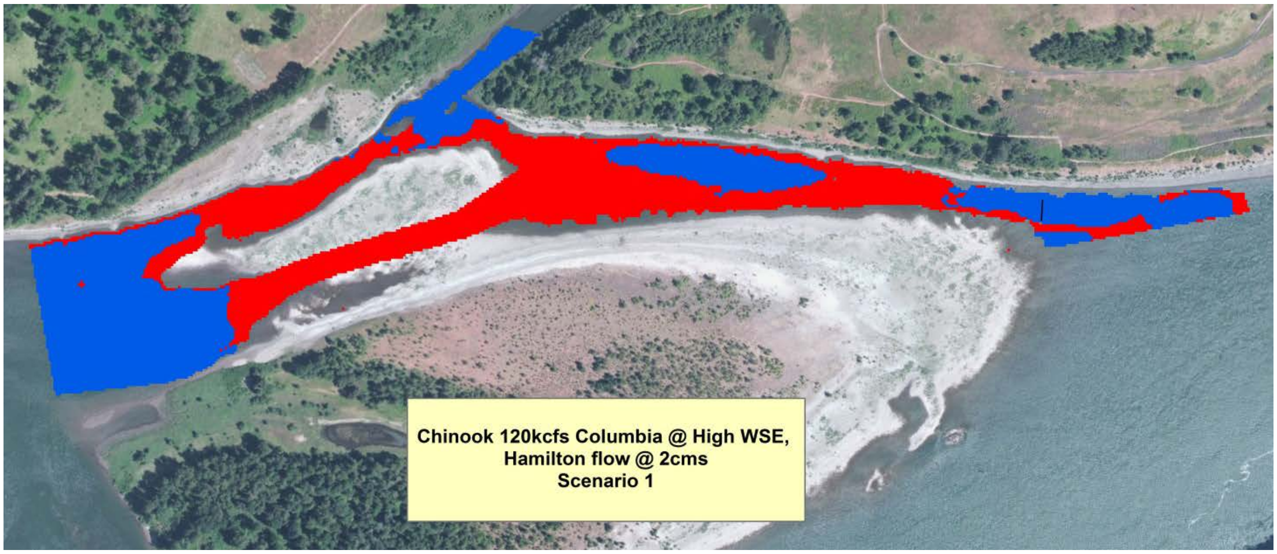
Appendix 2. The following figures show predicted Chinook salmon spawning habitat (red areas) for different habitat enhancement scenarios. All scenarios were modeled for the Columbia River flows shown on each figure and for average water surface elevations (WSE; shown as "Hi") and a Hamilton Creek discharge of 2 m^3/s ("cms").

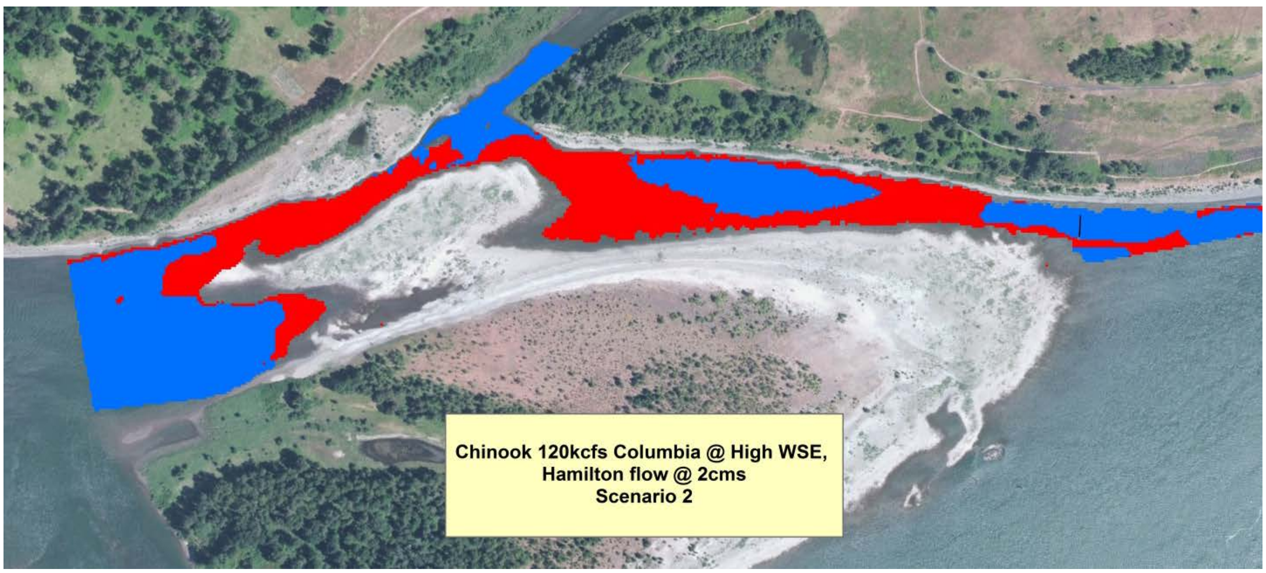


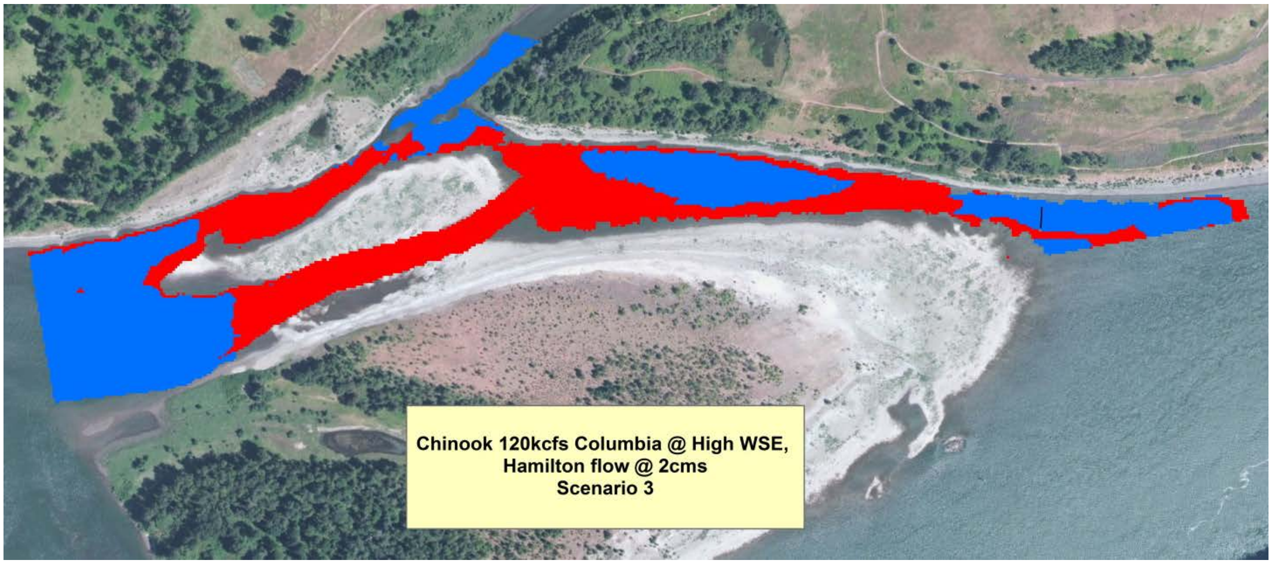



Chinook 85kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 2


Chinook 120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Base model


Chinook 120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 1


Chinook 120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 2


Chinook 120kcfs Columbia @ High WSE,
Hamilton flow @ 2cms
Scenario 3