# Pilot Thermal Refuge Enhancement at the Horsetail Creek - Columbia River Confluence

## Feasibility and Preliminary Basis of Design Report (30%)

**SUBMITTED JULY 2021, TO:**
Oregon Watershed Enhancement Board
East Multnomah Soil & Water Conservation District

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# 1. Introduction

## 1.1 INTRODUCTION

The Lower Columbia Estuary Partnership (Estuary Partnership) is evaluating the potential for habitat enhancement at the confluence of Horsetail and Oneonta creeks with the Columbia River, located at Columbia River Mile 138 in the lower Columbia River Gorge. The creeks merge within the Horsetail Creek floodplain and enter the Columbia River together through a single source – a multi-barrel box culvert routed under Interstate 84 (to simplify terminology, in the remainder of the document 'Horsetail Creek' is used to reference to the combined Horsetail and Oneonta tributary inputs to the single confluence zone with the Columbia River, hereby referred to as the 'Horsetail confluence'). The specific goal of this enhancement is to utilize the colder water (relative to the Columbia River mainstem) from these tributaries to provide a thermal refuge zone at the Horsetail confluence for summer-migrating, threatened and endangered Columbia River salmon species. This will be accomplished by creating embankment structures, utilizing natural topography where possible, that will divert warmer Columbia River flow from the Horsetail confluence, thereby allowing cooler Horsetail Creek flow to settle and expand within the sheltered embayment inside the constructed embankments. The desired conditions created by the enhancement would essentially replicate, on a smaller scale, the physical conditions at established, highly utilized thermal refuges located upstream in the Bonneville Dam pool, including Drano Lake, Herman Creek, and Eagle Creek. The project design also incorporates elements such as large wood, riparian vegetation, and topographic variation to provide a complex mosaic of habitats at the site.

## 1.2 COLUMBIA RIVER THERMAL REFUGE BACKGROUND

The importance of cold-water (thermal) refuges above Bonneville Dam to salmon and steelhead migrating through the Columbia River is well documented. Numerous studies (Snyder et al. 2020; Keefer et al. 2018; Lower Columbia Estuary Partnership 2018; Beechie et al. 2012; Keefer et al. 2011; Dominguez 2010; Keefer et al. 2008; Goniea et al. 2006; Haskell et al. 2002) have documented the extensive use of these areas in recent decades by summer migrating adult salmonids, as well as the harmful and potentially lethal effects of water temperatures in the mainstem Columbia River from which they are seeking refuge. In response to growing concerns about the harmful effects of Columbia River water temperatures on summer migrating salmonids the U.S. EPA also recently published an extensive study documenting the available thermal refuge within the entire reach of the Columbia River located within the U.S. (U.S. Environmental Protection Agency 2021). The study defined a minimum temperature differential of 2°C (i.e. at least 2° less than the mainstem Columbia River temperature) as a criterion for what constitutes suitable thermal refuge.

In 2018 the Estuary Partnership completed a similar, smaller-scale study to identify and map existing and potential thermal refuges (applying the same temperature criterion) in the lower Columbia River below Bonneville Dam (Lower Columbia Estuary Partnership 2018). While both the Estuary Partnership and E.P.A studies noted the thermal refuge provided by some of the larger lower Columbia tributaries, including the Cowlitz, Kalama and Lewis Rivers, the Estuary

Partnership study found little to no existing suitable refuge for adult salmon and steelhead between the Lewis River and the next closest suitable upstream refuge at Eagle Creek, located immediately upstream of Bonneville Dam. The distance between the Lewis River and Eagle Creek is approximately 57 miles. To address this gap, the Estuary Partnership study evaluated the potential for existing cold-water sources within this stretch of river to provide thermal refuge through enhancement. These sources include several small tributaries located in the lower Columbia River Gorge within approximately 15 miles of Bonneville Dam. Measurements of discharge, temperature, and proximity to the mainstem migratory pathway for adult salmonids collected in this study suggest that three of these tributary confluence zones (located at Bridal Veil Creek, Horsetail Creek, and Multnomah Creek) could potentially provide suitable refuge through enhancement.

A final phase of the Estuary Partnership study applied 3-dimensional hydrodynamic and water temperature modeling to investigate the feasibility of increasing cold water plume size at these three identified potential refuge zones. Based on the previously established temperature criterion and additional criteria for minimum water depth (1 meter and 0.5 meters for adult and juvenile salmon, respectively) and overall area (1 acre, based on the estimated size of Eagle Creek, the smallest observed thermal refuge zone upstream of Bonneville Dam), this preliminary modeling analysis indicated that suitable thermal refuge areas could indeed be created at each of these confluence zones through strategic placement of flow diversion structures intended to isolate each from mainstem Columbia River flows. The model results indicate that despite low tributary flows of typically 10 cubic feet per second (cfs) or less, each of these confluences has the potential for a significantly larger plume exceeding our minimum size criterion of 1 acre (Lower Columbia Estuary Partnership 2018). Cumulative plume area for the three confluence zones combined could approach that of the ~20-acre thermal refuge at the Herman Creek confluence in the mid-Columbia, where heavy use by summer migrating salmonids was observed by Keefer et al. (2011).

## 1.3 PROJECT OVERVIEW

This project builds on work done in the 2018 Estuary Partnership Thermal Refuge Study, focusing on one of the three potential thermal refuge sites identified in that study - the Horsetail Confluence – for further development as a pilot project. The Horsetail confluence was selected from the three for multiple reasons including: a) extensive knowledge of the site based on previous floodplain restoration that the Estuary Partnership completed here in 2013; b) closest proximity to the fish migration pathway, making it potentially the most likely to be detected and utilized by salmonids; c) smallest overall structures required, making it potentially the most cost-effective and constructable of the three; and d) relative locational stability of the confluence zone due to constraints imposed by the interstate culvert.

### 1.3.1 Project Objectives

To provide additional thermal refuge opportunity for summer-migrating Columbia River salmonids we developed two objectives for this phase of Horsetail Creek– Columbia River Pilot Thermal Enhancement Project:

- Complete a feasibility and restoration alternatives analysis to select a preferred project alternative. In the 2018 thermal refuge study we established preliminary ecological and physical habitat criteria and ran a limited series of hydraulic and temperature model simulations over a narrow range of boundary conditions as a cursory assessment of the potential for thermal refuge to be created through placement of flow diversion structures to isolate the confluence zone from Columbia River flows, thereby enabling a larger 'plume' of cold tributary water to form. In this project phase we assess the effectiveness of this enhancement technique over the full range of site conditions observed during the summer migration period and assess the response of the pilot site to a range of geomorphic, sediment, and flow conditions, for three selected alternative configurations.

- Develop concept (30%) designs for the preferred alternative.

#### 1.3.2 Scope of Work

This report summarizes work that the Estuary Partnership and engineering sub-contractor Inter-Fluve have jointly completed to assess the feasibility of a thermal refuge enhancement project at the Horsetail Confluence. The field reconnaissance portion of the feasibility assessment included topographic and bathymetric survey and water stage measurement at the Horsetail Confluence site, as well as visits to additional analog sites throughout this reach of the Columbia River to better assess geomorphic conditions. Hydrodynamic modeling was used to inform the geomorphic evaluation (Appendix C) and then combined with temperature and morpho-dynamic modeling to help evaluate a suite of alternatives for the site. A preferred alternative was identified, and preliminary designs and an order-of-magnitude cost estimate have been prepared and are described in this report.

# 2. Site Characteristics

Baseline hydrologic and geomorphic assessments are included as Appendices B and C. This section provides a general overview of the site characteristics and previous work that has been done at the site. Additional background information related to the site can be found in documents related to prior work done at the adjacent Horsetail Creek Floodplain site (see Section 2.2 below), specifically the Baseline Technical Memorandum that constitutes Appendix A of the feasibility report completed for that project (Inter-Fluve and Lower Columbia Estuary Partnership 2010).

## 2.1 GENERAL DESCRIPTION

The proposed project site is located at the Horsetail Confluence, located near mile 138 of the Columbia River, eight miles downstream from Bonneville Dam, and two miles upstream of Multnomah Falls (Figure 1). With respect to the public land survey system, the site is located within Section 4, Township 1N, R4E, WM. The Horsetail Confluence area falls within hydrogeomorphic reach H of the lower Columbia River Estuary (Simenstad et al. 2011), and within the U.S. Forest Service Columbia River Gorge National Scenic Area.

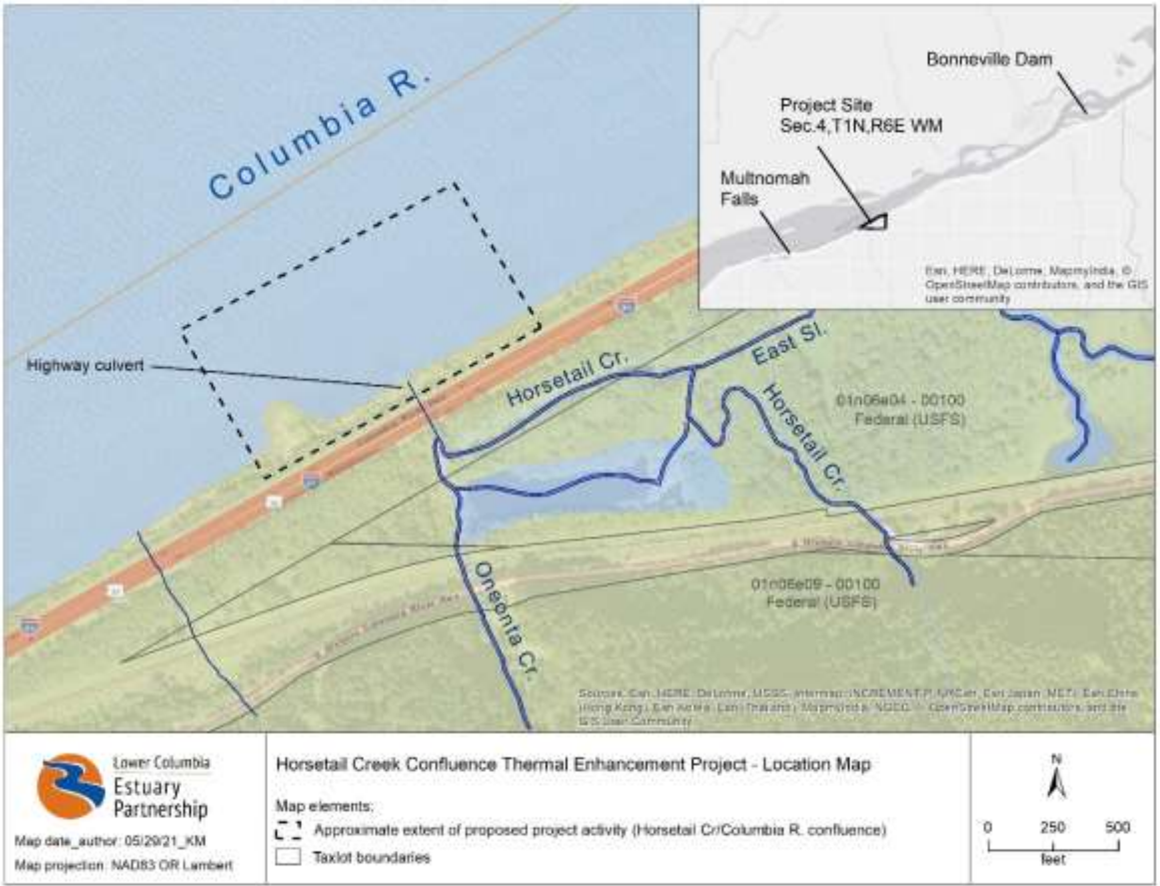



***Figure 1 - Site location map.***

Horsetail Creek enters the Horsetail confluence via a group of five concrete box culverts 6 feet wide by 6.5 feet tall that was routed under Interstate-84 during construction that was completed in the 1960s (Figure 2). The culverts have a compound slope, with a nearly flat lower portion at the confluence end and a steeper upper portion at the floodplain entrance. The average slope is 1.5%. As mentioned in the Introduction, this culvert conveys all flow from the Horsetail Creek floodplain, including contributions from both the Horsetail and Oneonta Creek watersheds. Ownership at the confluence location includes the Interstate Highway 84 right-of-way for land above the high-water line, and Oregon Division of State Lands for the riverbed below the high-water line.

***Figure 2 - Confluence zone of Horsetail Creek and the Columbia River, showing the highway culvert outlet and surrounding landforms. View is looking to the south from over the Columbia River.*** *Note: PVC structures surrounding each culvert barrel are an array of PIT tag antennas that were installed in 2013 after floodplain restoration occurred. This equipment documents salmonid use of the site by recording tagged individuals that access the site through the culvert.*

The landform within the highway right-of-way consists of large road grade material (gravel, cobble, and larger rock) angling steeply to the river, that is sparsely populated with shrub vegetation where finer grained deposits have allowed it to take root (Figure 2). The shoreline and near-shore zone consist of a shallow bench of combined river derived sands and coarser materials derived from the numerous alluvial fans that existed along this shoreline prior to construction of the highway. Emergent herbaceous and aquatic vegetation are present here, with the relative amounts of each shifting in response to Columbia River flow and its reworking of deposited materials. Immediately downstream of the confluence zone, a remnant alluvial fan has persisted after highway construction. At the confluence zone, a small delta has formed from a combination of materials deposited by Horsetail Creek via the highway culvert, and the Columbia River (Figure 3). Within this delta, a small, isolated embayment is currently present during periods of low Columbia River flow. This area retains cooler water discharged by the Horsetail Creek culvert during the summer, when the higher elevation delta formations divert warmer Columbia River flow away. The current embayment is too small (< 0.2 acres) and too shallow (< 0.5-meter depth) to provide useable thermal refuge for adult salmonids, however it illustrates the concept of creating a suitable thermal refuge zone via placement of similar, but much larger, embankment structures that would enclose a larger, and deeper embayment.

***Figure 3 - 2018 Google Earth image showing the landforms and vegetation patterns at the nearshore interface of the proposed project site.***

### 2.2 PREVIOUS WORK

In 2013, LCEP and Inter-Fluve completed the Horsetail Creek Floodplain Enhancement Project (Horsetail Phase 1), which impacted roughly 36 acres within the Horsetail Creek floodplain, immediately south of the proposed project site and Interstate 84. A significant part of that effort was aimed at improving stream temperatures within the floodplain, through extensive revegetation as well as eliminating a stream diversion and restoring Oneonta Creek's historic alignment. A second phase of floodplain revegetation began in 2020, which enhances ~31 additional acres to the east of the initial project location. Results from these previous project phases will complement the proposed thermal refuge work at the confluence zone, by providing cooler water discharged through the culvert, which would increase the quality of refuge provided. More information about this work can be found in the final report (Lower Columbia Estuary Partnership 2012) and online here.

# 3. Feasibility and Alternatives Evaluation

### 3.1 DATA COLLECTION

The following data were collected to inform hydrologic, geomorphic, and hydraulic model assessments conducted as part of this study.

### 3.1.1 Topographic and bathymetric data

An existing lower Columbia Digital Terrain Model (U.S. Army Corps of Engineers 2010) was supplemented with onsite bathymetric and topographic data collection to provide an updated and improved surface elevation model for site evaluation, physical model simulations, and design. Bathymetric and topographic data (Figure 4) was collected on July 9, 2019. Bathymetric data was collected by Solmar Hydro, using a high- resolution multi-beam sonar device. Minimum required water depth for multibeam data collection was approximately 1 meter. In shallower water and landward of the waterline, topographic data was collected by LCEP and Inter-Fluve, using RTK GPS. Bathymetric and topographic survey were combined into one 3-dimensional surface representation that was utilized for hydraulic modeling analysis and earthwork quantity estimates.

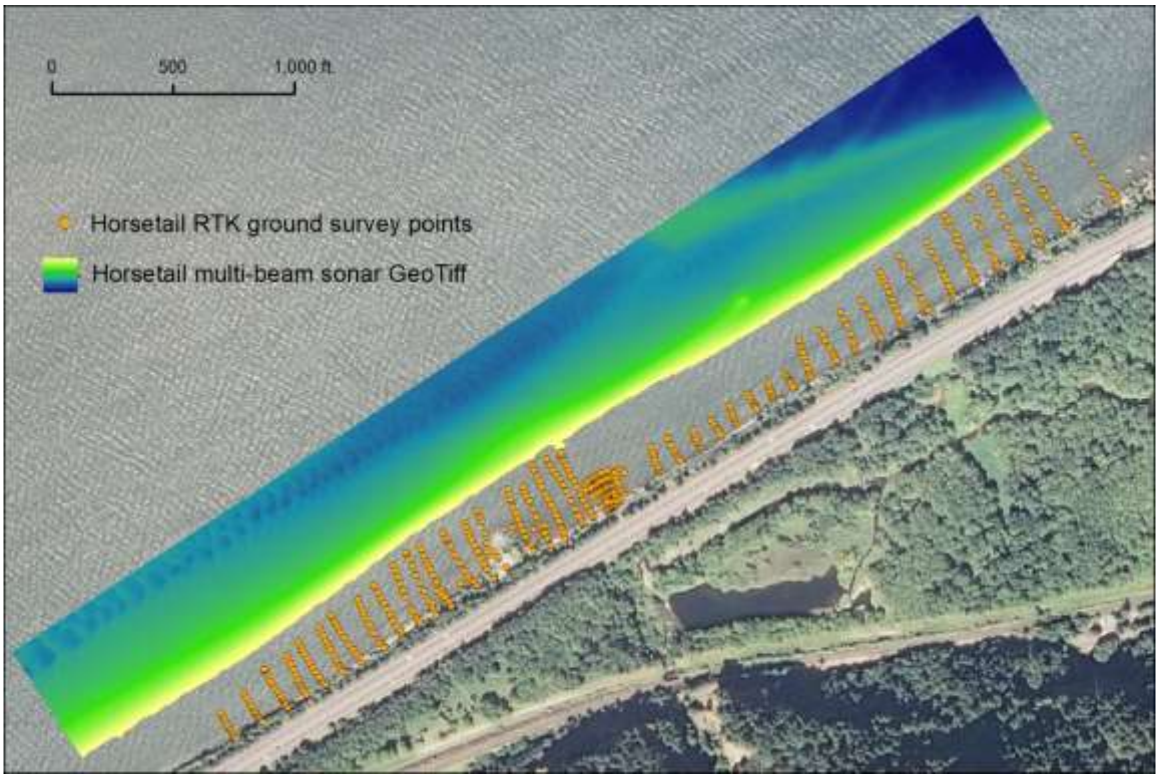



***Figure 4 - Extent of bathymetric (multi-beam sonar) and topographic (RTK GPS) data collected for the proposed project.***

### 3.1.2 Aerial imagery

Historical aerial images of the site from the U.S. Army Corps of Engineers, spanning the period from 1939–1996, were available from LCEP from prior project work. Additional imagery was obtained from Google Earth for more recent years.

### 3.1.3 Historical bathymetric data

Bathymetric sounding data and dredging records from 2011–2018 spanning several miles upstream and downstream of the project site were obtained from the U.S. Army Corps of Engineers to help inform analysis of sedimentation patterns in this reach of the Columbia River.

### 3.1.4 Local sediment supply

Multiple data sources were used to help analyze potential sediment issues arising from hillslope derived sediments from the Horsetail and Oneonta Creek watersheds, including: the 2010 Baseline Technical Assessment compiled during the Horsetail Phase 1 project (Inter-Fluve and Lower Columbia Estuary Partnership 2010); inspection and maintenance records for relevant I-84 underpass culverts in the lower Columbia River Gorge; and visual observations of sediment patterns at the culvert inlet and outlet during numerous field visits to the site from 2013–2021.

### 3.1.5 Analog Site Assessment

A field visit consisting of visual observations at six locations in the lower Columbia Gorge with similar physical characteristics as the project site was conducted in September 2019. The purpose of the visit was to observe sediment deposition patterns and physical site characteristics that could be applicable for design of the proposed project. Details of these site assessments and observations are described in Appendix 6.3.

### 3.1.6 Columbia River Stage

A continuous stage monitoring device (Hobo U20 pressure sensor) was installed on May24, 2019 into an existing housing attached to the western edge (Columbia River side) of the existing Interstate 84 highway culvert. Stage data was collected through December of 2019. Previous stage data collected at this location during the Horsetail Phase 1 project was also used in this study.

## 3.2 SITE HYDROLOGY AND STAGE-DISCHARGE RELATIONSHIP

Hydrology at the Horsetail confluence, where the enhancement project is proposed, is governed primarily by 1) Columbia River discharge from Bonneville Dam; and 2) tributary flows from the Horsetail and Oneonta Creek watersheds (and to a lesser extent the smaller Eastern Slough watershed) discharged through the Interstate 84 culvert. The characteristics of these two primary sources are summarized in the following sections. A complete assessment of Columbia River stage and the stage-discharge relationship that was established for this feasibility assessment is included as Appendix B.

### 3.2.1 Tributary Watershed Hydrology

The following information related to hydrology of the Horsetail Creek, Oneonta Creek, and Eastern Slough watersheds is taken from the Horsetail Phase 1 project Baseline Technical Assessment Memorandum completed in 2010 (Inter-Fluve and Lower Columbia Estuary Partnership 2010). Since that time no significant hydrologic changes to these watersheds have been noted. The extensive 2017 Eagle Creek Fire heavily impacted these watersheds in other ways but based on field assessments by LCEP and Inter-Fluve, no changes to the hydrology have been observed. The three watersheds contributing tributary flow to the proposed project site are shown in Figure 5.

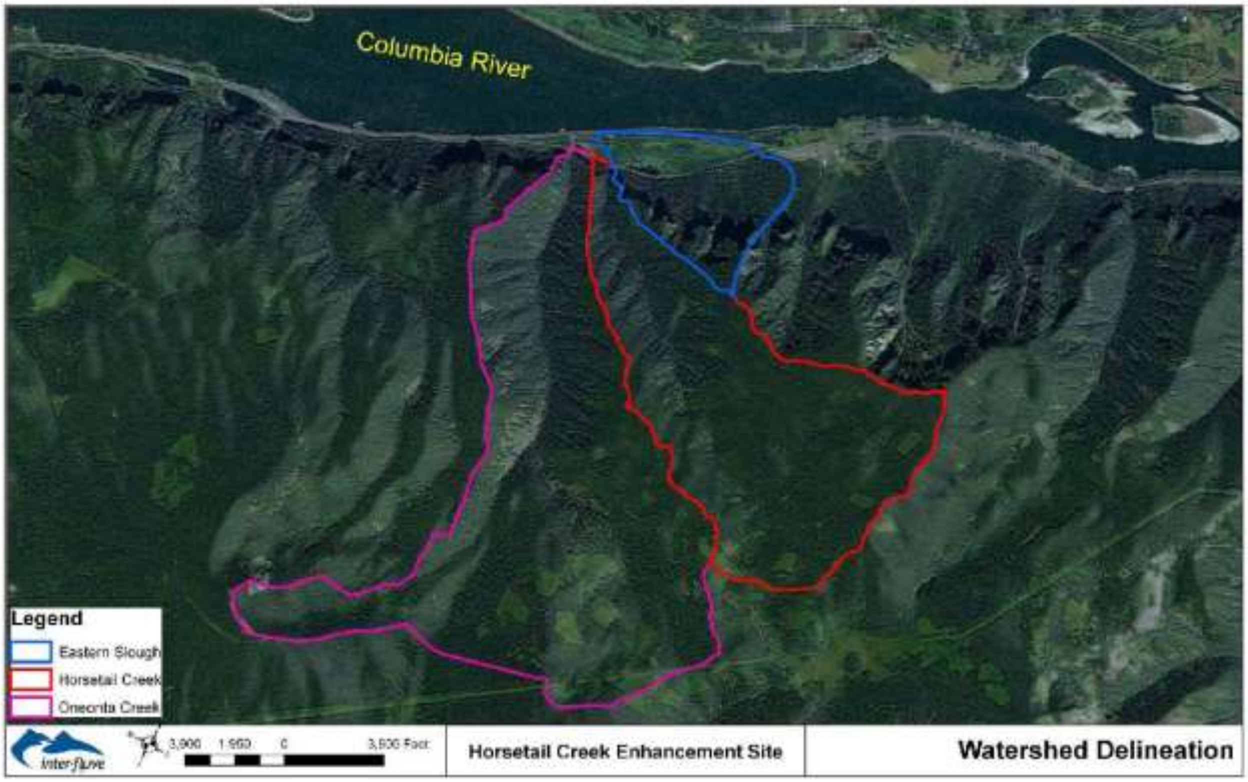



***Figure 5. The three watersheds that provide flow to the Horsetail Creek floodplain and Horsetail Confluence project site: Horsetail Creek; Oneonta Creek; and the Eastern Slough.***

**PEAK FLOWS**

Peak tributary flows are relevant to the proposed project due to: 1) the risks they present with regard to compromising structure stability and compromising the created embayment (due to infilling from potential sediment transport); and 2) potential positive aspects of enhancing scour at the site, thereby flushing finer Columbia River-derived sediment deposits that may settle within the constructed embayment following high water events.

The site is located in a transitional climactic zone between western and eastern Oregon. Local topographic factors (i.e., location against the steep Columbia Gorge valley wall, near the axis of the Cascade Range) lead to substantial variability in precipitation within these watersheds. Winter rainstorms dominate the flood flow hydrology at the site. Although the watersheds are generally lower in elevation than the typical elevation range for rain on snow events (4000 feet), the unique topography and air circulation patterns in the area lead to periodic heavy snow falls which may lead to this type of flooding, in addition to purely rainfall-generated floods. The watersheds are forested and were heavily impacted by the September 2017 Eagle Creek Fire.

Horsetail and Oneonta creeks are un-gaged streams, with no applicable nearby gaging station to enable estimation of peak flows based on observed data. Therefore, peak flows were estimated using regional regression equations, which are developed based on statistical modeling of gage data over broad physiographic areas. Estimated peak flows for the Horsetail, Oneonta and Eastern Slough watersheds are shown in Table 1. A full explanation of the methods used to derive these is provided in the 2010 Baseline Technical Memorandum (Inter-Fluve and Lower Columbia Estuary Partnership 2010).

***Table 1 - Peak flow estimates (from the USGS and the Oregon Water Resources Department (OWRD)) for the three sub-watersheds contributing flow to the proposed project site. Values are in cubic feet per second (cfs).***

| Flow Event | Horsetail Creek | | | Eastern Slough | | | Oneonta Creek | | |
|---|---|---|---|---|---|---|---|---|---|
| | USGS | OWRD | Avg. | USGS | OWRD | Avg. | USGS | OWRD | Avg. |
| 1-year | Extrapolated | | 263 | Extrapolated | | 56 | Extrapolated | | 399 |
| 2-year | 337 | 376 | 356 | 83 | 76 | 79 | 477 | 604 | 541 |
| 5-year | 483 | 515 | 499 | 120 | 105 | 112 | 691 | 833 | 762 |
| 10-year | 584 | 610 | 597 | 147 | 125 | 136 | 836 | 987 | 911 |
| 25-year | 721 | 730 | 725 | 184 | 150 | 167 | 1035 | 1181 | 1108 |
| 50-year | 828 | 820 | 824 | 213 | 169 | 191 | 1190 | 1326 | 1258 |
| 100-year | 936 | 909 | 922 | 242 | 188 | 215 | 1346 | 1470 | 1408 |

**SUMMER FLOWS**

Summertime flow and temperature are the two primary physical characteristics of tributary inputs that will influence thermal refuge quality at the proposed project site. Flow measurements were collected at different locations in Horsetail and Oneonta creeks as part of the Horsetail Phase 1 project in 2010, 2012, and 2014, and again as part of the LCEP Thermal Refuge Study in 2015 and 2016 (Lower Columbia Estuary Partnership 2018). Results are shown in Table 2. It should be noted that flow was significantly re-routed in the floodplain as part of the Phase 1 project and thus patterns evident during pre and post restoration are not consistent. Due to current stream and culvert configurations measurements of the combined streamflow to the project site is not straightforward and was not completed during this study. Prior measurements for the individual streams, however, are adequate to assess the range of tributary input flow to be expected at the confluence zone and estimates based on these values have been applied in project modeling.

***Table 2 - Flow measurements recorded during previous studies for the tributary streams feeding the project confluence zone. Values are in cubic feet per second (cfs).*** *Note: flow contributions from the Eastern Slough watershed are minimal during the summer relative to Horsetail and Oneonta creeks, and typically too low to reliably measure.*

| | | July | | August | | | | September | | October |
|---|---|---|---|---|---|---|---|---|---|---|
| **Stream** | **Station** | 2010 (7/16) | 2016 (7/20) | 2012 (8/13) | 2014 (8/14) | 2015 (8/11) | 2016 (8/5) | 2010 (9/15) | 2012 (9/12) | 2015 (10/01) |
| Horsetail | u/s of gravel pond outlet | 6.2 | 3.3 | 3.2 | 2.7 | -- | -- | 2.6 | 2.1 | 1.2 |
| | Highway reach | 9.3 | 3.7 | 6.7 | 3.9 | 1.8 | 2.7 | 2.8 | 2.5 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Oneonta | u/s of gravel pond diversion | 3.3 | 3.1 | 1.7 | 1.5 | -- | -- | 1.1 | 1 | 0.6 |
| | d/s of gravel pond diversion | 0.6 | 2.6 | -- | 0.8 | -- | 1.2 | 0.2 | -- | 0.3 |
| Estimate of combined flow entering Horsetail Confluence zone | | 9.9 | 6.3 | > 7 | 4.7 | > 2 | 3.9 | 3 | > 3 | 1.3 |

### 3.2.2 Columbia River Hydrology

Columbia River hydrology dominates conditions at the Horsetail confluence, with flows on the order of hundreds of thousands of cubic feet per second (cfs) far exceeding tributary contributions that range from single digits to just a few thousand cfs under extreme flood conditions. For the proposed project, an understanding of Columbia River hydrology is essential for design aspects including alignment and elevation of the diversion structures, anchoring of structures and additional habitat features, and extent of excavation required at the site to maintain the defined depth criteria for adult and juvenile salmon suitability. Much of the following information related to Columbia River stage is taken from the Horsetail Phase 1 Project Baseline Technical Assessment Memorandum completed in 2010 (Inter-Fluve and Lower Columbia Estuary Partnership 2010). That study described general characteristics of Columbia River stage and established relationships between Bonneville Dam stage and stage at the Horsetail confluence and floodplain, which are summarized here. Additional work during the current study included an expanded assessment of these stage relationships based on more recent data. Those results are also summarized here and described fully in Appendix B.

The Columbia River experiences tidal variation from the mouth of the river to Bonneville Dam. At upstream locations such as near the Horsetail confluence, the tidal signal is diminished during periods of high discharge from the dam (such as the spring freshet), and most pronounced during lower flow periods in the summer and early fall. The signal can also be obscured by manipulation of the outflow from Bonneville Dam. This type of hydropower peaking is common during summer months when flow is ramped up and down daily to accommodate power needs. Typical Columbia River stage near the project site is illustrated in Figure 6, which shows the combined effects of diurnal ocean tide and daily power peaking on the water surface profile. This data was recorded in 2008 at Columbia River mile 131, seven miles downstream of the Horsetail confluence. The Phase 1

Horsetail Creek Floodplain Baseline Assessment estimated the tide range local to the site to be approximately 1.5 feet and noted an average daily stage fluctuation of 2 feet and maximum daily fluctuation of 5 feet over the study period (04/01/10-09/29/10). These results are consistent with the observed conditions shown in Figure 6.

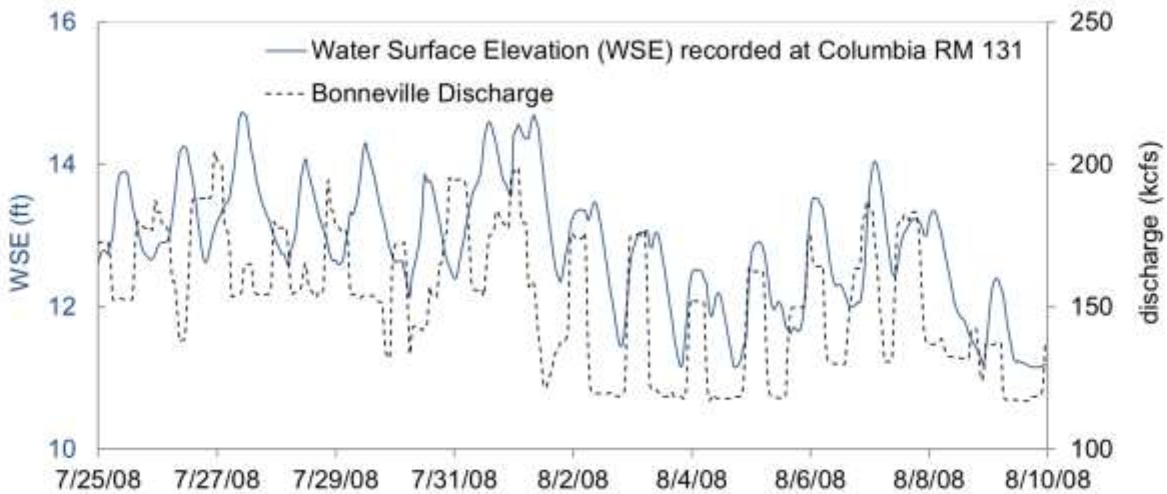



***Figure 6 - Typical summer stage profile for the lower Columbia River near the project site, illustrating the combined effect of diurnal tidal influence and daily power peaking. Power peaking is illustrated directly in the included Bonneville Dam discharge profile, shown in black on the secondary (right) axis.***

Stage data recorded using a Hobo U20 pressure sensor installed in the housing mounted at the culvert outlet was used to develop a correlation between mainstem stage at the site with the long-term USGS gage station for the Columbia River below Bonneville Dam (14128870). This was done in both the 2010 Phase 1 Horsetail Creek Floodplain Baseline Assessment as well as for the current study. Results from the current study are shown in Figure 7.  For the older study, a single relationship was established for the full flow range, whereas for the current study separate curves were fitted for the low-flow (baseflow) and higher flow (spring freshet) periods to obtain closer overall fit.

To assess the full range of Columbia River stage that might be expected during spring, summer, and fall, we downloaded daily stage data for the 26-year range spanning 1990–2017 and calculated percent exceedance values for this timespan. Results are illustrated in Figure 8, for the 5%, 50%, and 95% exceedance values and selected years of interest representing higher, lower, and average flow years (Figure 8).

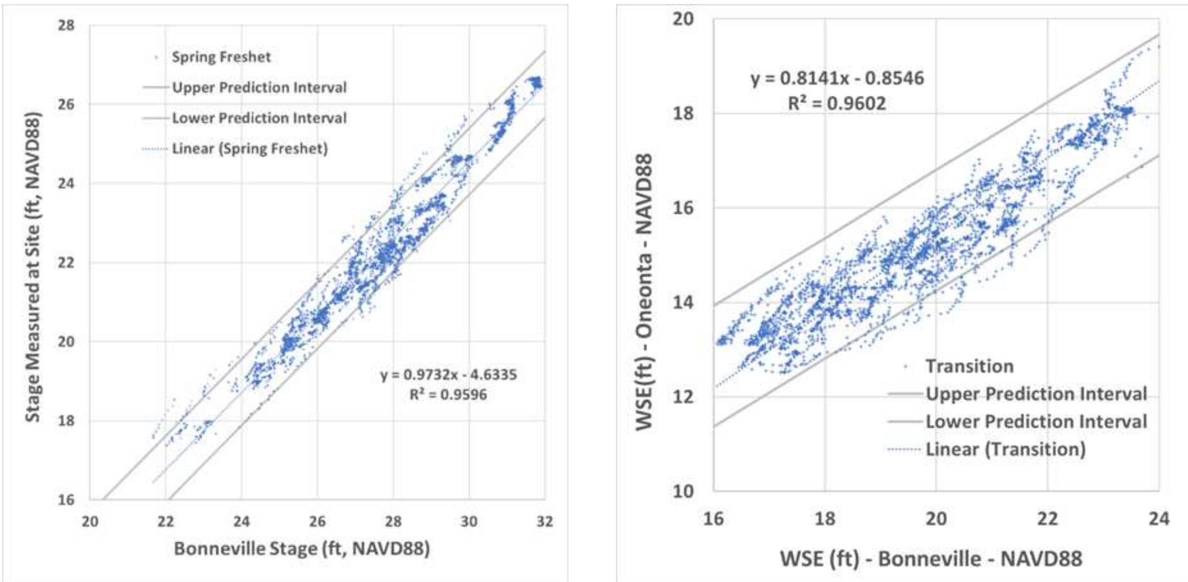



*Figure 7 - 30-minute state data at USGS gage #14128870 compared to measured stage at the Horsetail confluence project site, during: the spring freshet period from May 24–June 8 2019 (left); and the baseflow transition period of June 24–30 2019 (right).*

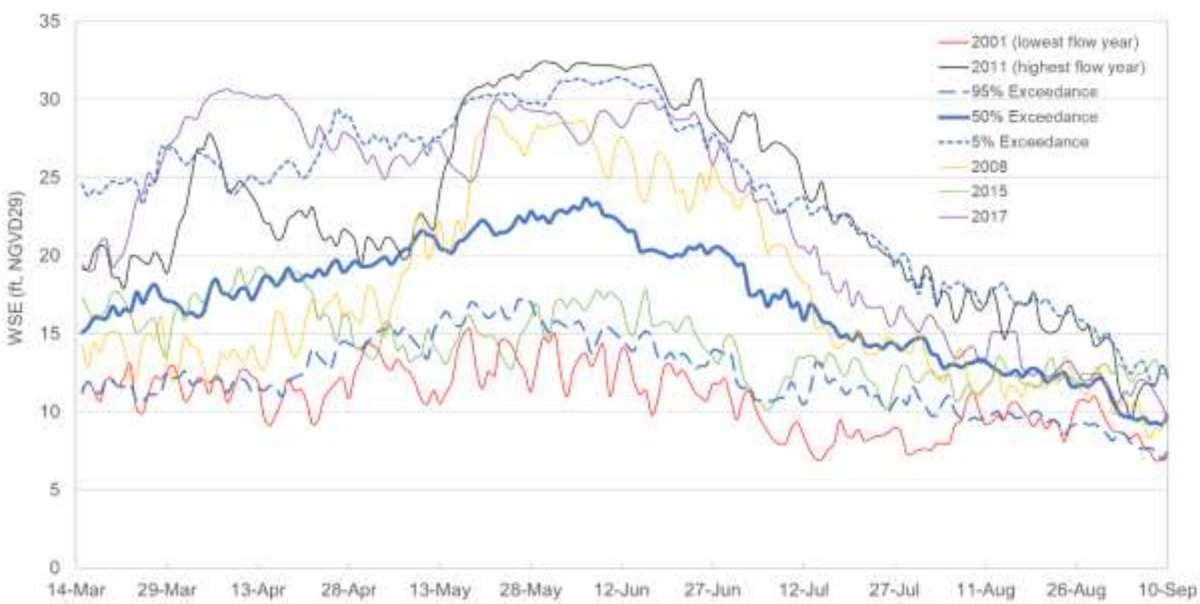



*Figure 8 - Summertime daily water surface elevation (WSE) at USGS Columbia River gage #14128870 below Bonneville Dam for selected years and percent exceedances for the range covering 1990–2017.*

For hydraulic, temperature, and sediment modeling we established a relationship between Columbia River stage at our downstream model boundary (4 miles downstream of the Horsetail confluence) and discharge from Bonneville Dam, over the range of flows extending from baseflow to the 100-year flood magnitude (1% flood return interval). Results are summarized in Figure 9 and described fully in Appendix B.

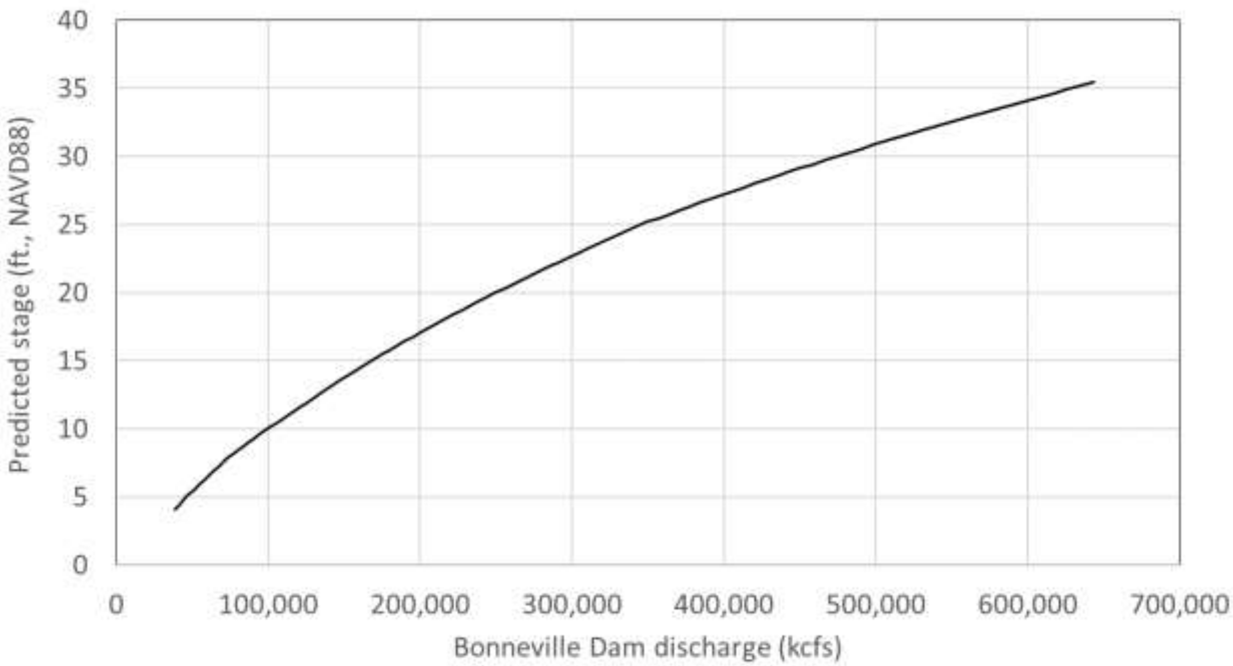



***Figure 9 - Columbia River stage-discharge curve for the project model downstream boundary (Columbia RM 134, 4 miles downstream of project site).***

## 3.3 GEOMORPHIC CONSIDERATIONS FOR LONG-TERM SITE STABILITY

### 3.3.1 Introduction

A geomorphic analysis was conducted as part of this study to assess the overall risk of site degradation due to infilling from Columbia River and Horsetail Creek-derived sediments, and to inform preliminary design of the thermal refuge embayment. The overall volume of the embayment will determine the quantity of thermal refuge provided, and any infilling from sediment would reduce overall volume, and corresponding refuge habitat, over time. Knowledge of current and anticipated future sedimentation patterns at the site allow us to predict whether a) sedimentation rates will be too great to maintain adequate thermal refuge over the targeted 25-year lifespan of the project; or b) sediment rates will be low enough such that they can be compensated for in the design of the embayment, allowing some sediment to accumulate while still providing adequate thermal refuge capacity over the design lifespan. The primary lines of evidence supporting the geomorphic analysis were as follows:

1. Field Observations from analog site visits during the baseflow period (September 2019)
2. Analysis of repeat annual bathymetric surveys of the USACE navigation channel near the project site from 2014 to 2019.
3. Analysis of depositional patterns visible in historical aerial photos of both analog sites and of the project location.
4. Examination of flow patterns, velocity magnitude and shear stress magnitude in preliminary hydraulic simulations at both analog sites and the project site over a range of higher flows. These simulations will be used to provide insight into the relationship between these variables and observed zones of deposition.
5. Interviews of USACE navigation staff and ODOT field maintenance crews to understand the frequency of nuisance sand deposits along this portion of the I-84 corridor.
6. Sediment and morpho-dynamic (SM) model simulations of sand transport in the lower Columbia River project reach.

### 3.3.2 Conclusions

The complete geomorphic analysis is included as Appendix C, except for item 6 above which is described separately in the 'Sediment Transport and Morpho-dynamic Model' section (Section 3.5) below. Results from the SM model were limited in scope, as discussed below, but were mostly consistent with conclusions derived from the geomorphic analysis components 1-5, which are summarized here.

- Columbia River sand

While rigorous quantification of sand movement under existing conditions was beyond the scope of this analysis, observations and lines of evidence described above suggest that the general character of this reach of the Columbia River with respect to sand movement is generally dominated by transport through the reach, though localized bank and near-bank deposits do occur. Sand deposition along the margins is a common occurrence, but the deposition is most likely to result in topographic changes that are transient. This is consistent with observations of sand deposits at the project site, which have been noted following spring freshet events that are relatively large in magnitude. These deposits do not persist, and typically are transported away during the following late fall and early winter, when increased tributary flows in response to significant rain events act to flush them back into the river. Major, persistent blockages of culverts in this reach from Columbia River sand have not been noted and are not common. However, the potential for sand deposition to reduce volume of the proposed constructed embayment exists and must be carefully considered in the project design. Based on the relatively small and transient patterns of sand deposition that have been observed, we believe that by optimizing structure design to minimize bedload sediment deposition and optimizing embayment size to accommodate sediments that are expected to deposit during higher flow years, a project that will provide adequate thermal refuge for salmon over the targeted lifespan of 25 years is achievable.

- Sediment delivery from Horsetail/Oneonta Creeks

Bedload supply to the Horsetail confluence from Horsetail and Oneonta creeks is presumed to be dominated by Oneonta Creek, due to the very low grade (0.09%) of the highway reach of Horsetail Creek compared to the higher Oneonta Creek grade (1.8%). Sediment delivery to the confluence zone, through the Intersate-84 culvert, is episodic, and a function of the higher flows required to mobilize sediments derived from the upstream canyon and watershed, via mass wasting events. The Eagle Creek Fire in 2017 has likely increased sediment supply from the watershed, however the magnitude of this increase, storage potential, and efficiency of delivery to the confluence project location is unknown.

Results of the sediment transport analysis for Oneonta Creek (see Appendix C for details) suggest that the watershed is capable of delivering the amount of sediment currently stored in the confluence zone during relatively moderate peak flow events. However, these results are misleading because they do not account for sediment supply. Oneonta, being a steep canyon creek, is undoubtedly supply limited, meaning that it has excess transport capacity and thus can transport more sediment than is typically supplied to the channel. Therefore, these results are better thought of as sediment transport potential. The amount of sediment delivered to the confluence is limited by the amount of sediment supplied to the alluvial fan reach. This point is emphasized by examining the aerial photographic record, which does not provide evidence for the highly dynamic setting that would result from frequent sediment deposits. These results suggest that a thermal refuge embayment may be susceptible to episodic sediment inputs and should consider bedload transport to optimize the design life of the embayment. Any future phases of design should ideally:

1. Measure bed samples to understand Oneonta Creek grain size distribution.
2. Perform a reconnaissance of the upper watershed to understand the impacts of the Eagle Creek fire on sediment production and delivery.
3. Update existing models of Oneonta Creek to more clearly understand how hydraulics may affect sediment delivery to and evacuation from a potential embayment.
4. Estimate annual sediment loads for Oneonta Creek.

## 3.4 HYDRAULIC AND TEMPERATURE MODEL

The hydraulic and temperature model used in this feasibility assessment is the same model that was developed in the LCEP thermal refuge study (LCEP 2018, Tuflow 2020a, Tuflow 2013). Setup and verification of the model is described in LCEP 2018. Major updates to the model for this study included reducing the model domain (Figure 10) to increase simulation times and efficiency; increasing grid resolution in the vicinity of the project site (Figure 11) for improved topographic and temperature resolution; and incorporating updated bathymetric and topographic data collected at the project site (Figure 4, Section 3.1.1).

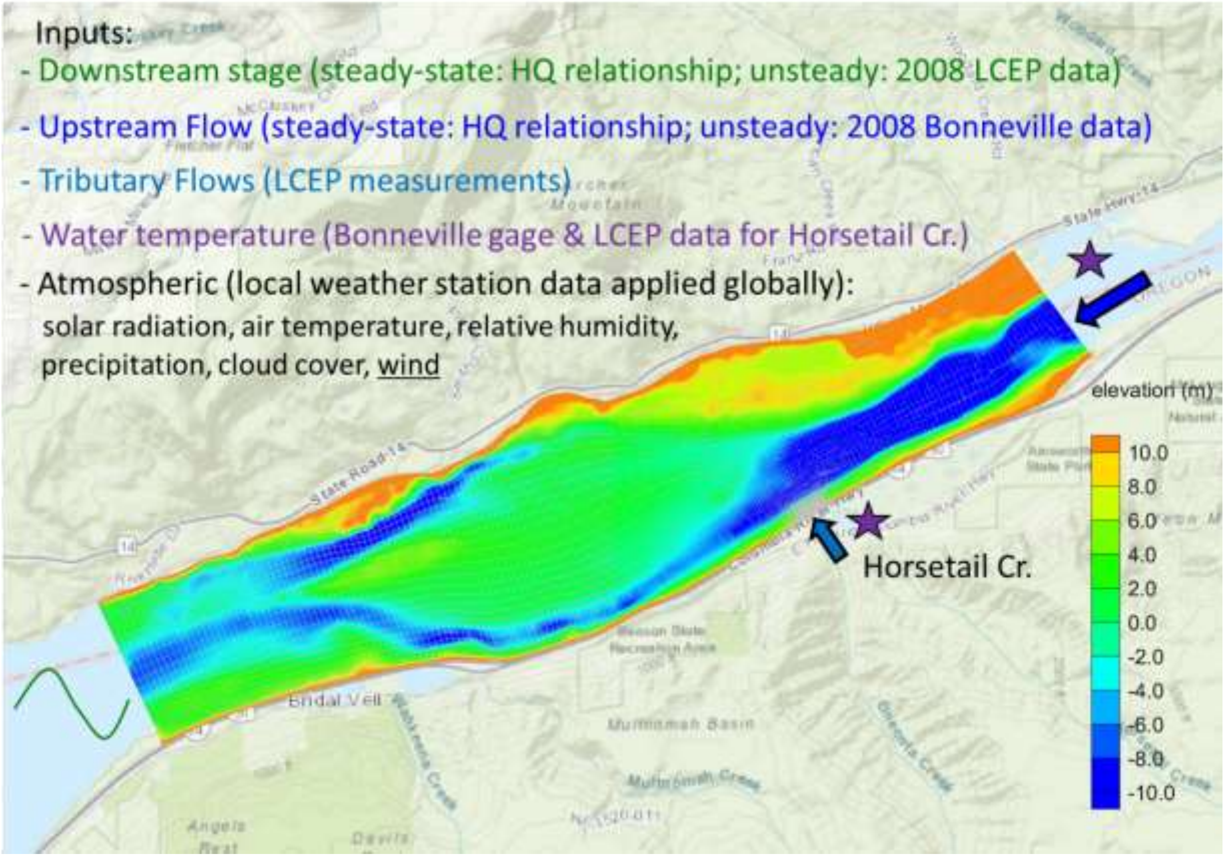



***Figure 10 - Grid extent (domain) and model boundary inputs for the revised Horsetail confluence Tuflow FV 3D hydraulic and temperature model.***

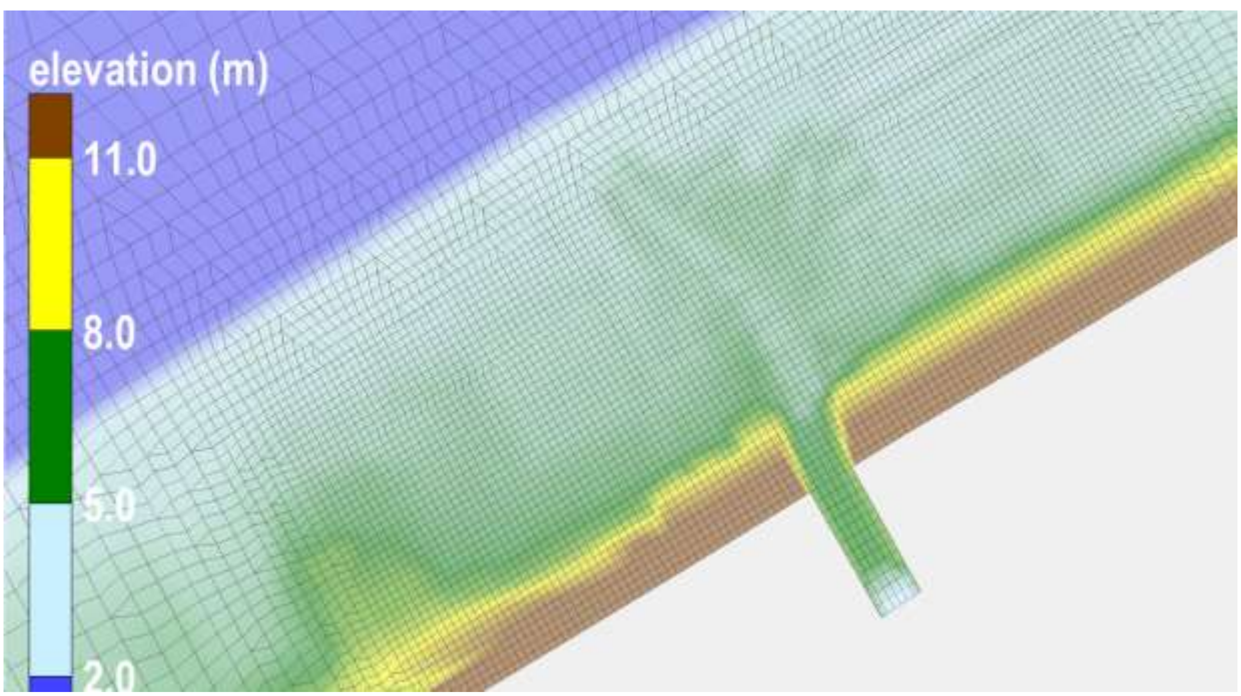



***Figure 11 - Tuflow FV model grid at the project site, showing 1-meter cell resolution. Existing condition topography is shown.***

### 3.4.1 Model Boundary Forcing – unsteady-state

Boundary conditions used to force the model were not adjusted significantly from previous simulations run for the LCEP Thermal Refuge Study (LCEP 2018). We ran unsteady simulations (i.e. time varying stage and discharge applied at the downstream and upstream model boundaries, respectively) in order to assess the dynamic characteristics of the thermal plume, which responds to changes in tributary and mainstem flow and temperature, as well as atmospheric conditions (solar radiation and wind). We selected a time period for the unsteady simulations for which we had available river stage data (2008, from LCEP Ecosystem Monitoring Program data collected at Sand Island near Rooster Rock, at Columbia River mile 131), and which captures the full range of flows that are expected to occur in the mid-July through early September time period, when salmon would reasonably be expected to seek out thermal refuge. We determined that flow range to be approximately 120,000–175,000 cfs, based on evaluation of long-term (1990–2017) records of Bonneville dam daily discharge data. Figure 12 shows results of that analysis, with the 50% exceedance flow falling within this range during most of that period. Also included in Figure 12 is discharge data for 2008, which was used for modeling due to the availability of stage data near the site as mentioned above. We selected a segment of that data from July 31 – August 4, 2008, for use in model simulations, because it captures the full range of desired flows within a relatively short time frame (5 days), thereby minimizing the required model run time (Figure 13).

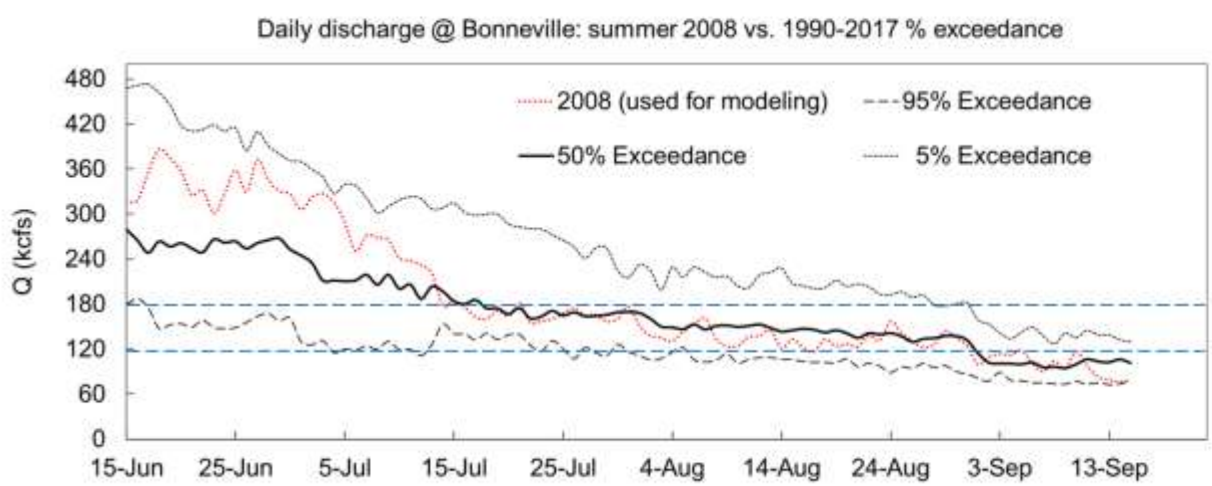



***Figure 12 - Daily discharge (Q) from Bonneville Dam from 1990–2017, showing 10, 50, and 95% exceedance values and 2008 data. Dashed lines indicate the range of flows typical of the summertime period of interest (i.e. the 50% exceedance range from approximately mid-July to early September.***

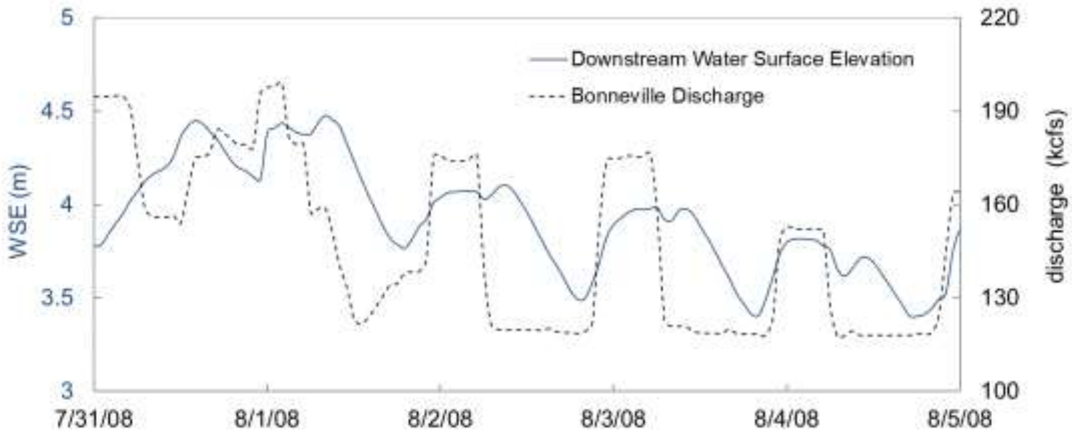



***Figure 13 - Mainstem stage (WSE) and discharge applied at downstream and upstream model boundaries respectively, for the unsteady condition. Discharge (dotted line) ranges from 120–190 kcfs, covering the desired range of flows for evaluation.***

Real-time temperature data for the unsteady condition was available for the Columbia River from the Columbia River DART online data portal. For Horsetail Creek input temperature, we substituted time series data collected during the 2015–2017 LCEP thermal refuge study, since no data was available from 2008. This is a valid substitution since we only require estimated temperature values that would reasonably be expected during the summer period of interest. Similarly, since real-time discharge measurements are not available for Horsetail Creek, we applied values based on previous measurements taken at the site (Table 2) in the unsteady model. Assuming tributary flows slowly decrease throughout the summer dry season we estimated an average rate of decrease per day based on observations taken at the beginning and end of the season and applied the calculated values for the period selected for the unsteady simulation. During this period from July 31–August 5 we estimated discharge to decrease from 5.5 cfs to 4.2 cfs. Water temperature (for both the mainstem and Horsetail Creek), and tributary discharge forcing values applied in the unsteady model (at the locations shown in Figure 10) are shown in Figure 14.

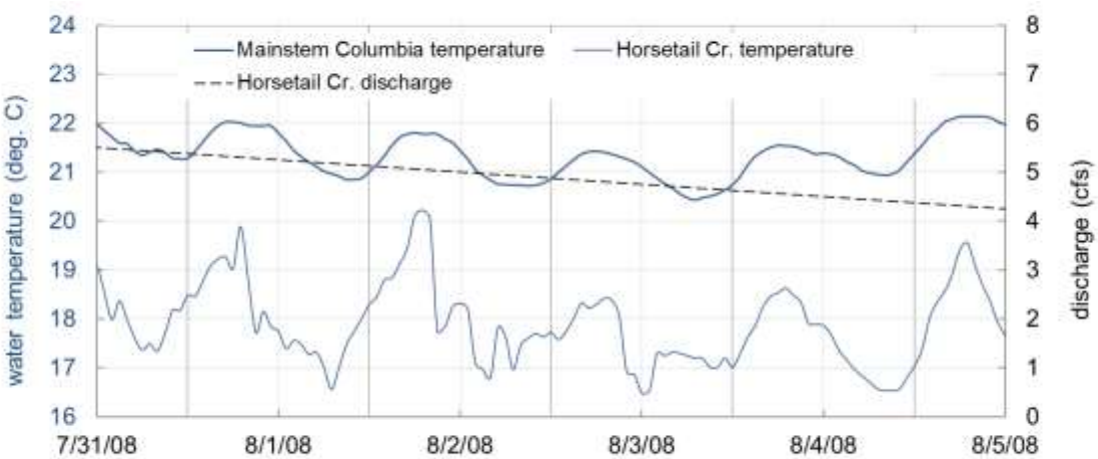



***Figure 14 - Water temperatures and tributary discharge applied at model boundaries (as shown in Fig. 10) for the unsteady condition.***

### 3.4.2 Model Boundary Forcing – steady-state

In addition to the unsteady model simulations discussed above, we ran steady state simulations (i.e. constant flow and stage) for two purposes: 1) rapid evaluation of temperature/depth/detection criteria when optimizing structure orientations for each project restoration Alternative; and 2) evaluation of bed shear stress, and corresponding implications for sediment deposition and scour potential, for the various project Alternatives. To optimize structure orientation for temperature performance we ran simulations for the minimum and maximum flow levels of the summertime range of interest, 120,000 and 175,000 cfs, respectively. To evaluate bed shear, we simulated various combinations of tributary and mainstem peak flood values. These are shown in Table 3 which summarizes the extent of hydraulic and temperature model simulations that were completed as part of this study. Each simulation was run for the complete suite of proposed project Alternatives. Results are summarized in the Alternatives Assessment section below.

***Table 3 - Extent of hydraulic and temperature model simulations completed for the feasibility and 30% design assessment.***

| Simulation | Upstream Boundary Input | Downstream Boundary Input | Tributary Input | [1]Atmospheric Inputs | Purpose |
|---|---|---|---|---|---|
| 1. Steady – high baseflow | 175,000 cfs | Corresponding stage based on HQ relation | 5 cfs flow, estimated diurnal temperature | None | Optimize structure orientations for temperature/detection performance |
| 2. Steady – low baseflow | 120,000 cfs | Corresponding stage based on HQ relation | 5 cfs flow, estimated diurnal temperature | None | Optimize structure orientations for temperature/detection performance |
| 3. Unsteady | Bonneville discharge (flow): 7/31–8/4 2008 | Corresponding Columbia R. stage at Sand Island for same period, adjusted to boundary location | Estimated flow and temperature based on 2015-2016 data | Solar radiation, air temperature, precip, relative humidity, wind | Assess 'real-time' temperature and detectability for optimized Alternatives. Supplements Steady-state analysis. |
| 4. Steady – base + 1-Yr.Trib. flow | 175,000 cfs | Corresponding stage based on HQ relation | Estimated Peak 1-Year Flow | None | Evaluate scour potential for a Horsetail Creek 1-year flood event |
| 5. Steady – base + 2-Yr.Trib. flow | 175,000 cfs | Corresponding stage based on HQ relation | Estimated Peak 2-Year Flow | None | Evaluate scour potential for a Horsetail Creek 2-year flood event |
| 6. Steady – base + 5-Yr.Trib. flow | 175,000 cfs | Corresponding stage based on HQ relation | Estimated Peak 5-Year Flow | None | Evaluate scour potential for a Horsetail Creek 5-year flood event |
| 7. Steady – base + 10-Yr.Trib. flow | 175,000 cfs | Corresponding stage based on HQ relation | Estimated Peak 10-Year Flow | None | Evaluate scour potential for a Horsetail Creek 5-year flood event |

| | | | | | |
|---|---|---|---|---|---|
| 8. Steady – base + 100-Yr.Trib. flow | 175,000 cfs | Corresponding stage based on HQ relation | Estimated Peak 100-Year Flow | None | Evaluate scour potential for a Horsetail Creek 10-year flood event |
| 9. Steady – 2 Yr. + 1 Yr. Trib. flow | 390,000 cfs (Q2) | Corresponding stage based on HQ relation | Estimated Peak 1-Year Flow | None | Evaluate scour potential for combined Horsetail Creek 1-yr. and Columbia R. 2-yr. flood event |
| 10. Steady – 2 Yr. + 2 Yr. Trib. flow | 390,000 cfs (Q2) | Corresponding stage based on HQ relation | Estimated Peak 2-Year Flow | None | Evaluate scour potential for combined Horsetail Creek 2-yr. and Columbia R. 2-yr. flood event |
| 11. Steady – 2 Yr. + 5 Yr. Trib. flow | 390,000 cfs (Q2) | Corresponding stage based on HQ relation | Estimated Peak 5-Year Flow | None | Evaluate scour potential for combined Horsetail Creek 5-yr. and Columbia R. 2-yr. flood event |
| 12. Steady – 2 Yr. + 10 Yr. Trib. flow | 390,000 cfs (Q2) | Corresponding stage based on HQ relation | Estimated Peak 10-Year Flow | None | Evaluate scour potential for combined Horsetail Creek 10-yr. and Columbia R. 2-yr. flood event |
| 13. Steady – 2 Yr. + 100 Yr. Trib. flow | 390,000 cfs (Q2) | Corresponding stage based on HQ relation | Estimated Peak 100-Year Flow | None | Evaluate scour potential for combined Horsetail Creek 100-yr. and Columbia R. 2-yr. flood event |
| 14. Steady – 100 Yr. + 10 Yr. Trib. flow | 640,000 cfs (Q100) | Corresponding stage based on HQ relation | Estimated Peak 10-Year Flow | None | Evaluate scour potential for combined Horsetail Creek 100-yr. and Columbia R. 100-yr. flood event |

Notes:

1. Atmospheric data sources included local weather data obtained from nearby stations and estimates of shortwave and longwave solar input radiation based on latitude of the project site.

## 3.5 SEDIMENT TRANSPORT AND MORPHO-DYNAMIC MODEL

A sediment transport model with the capability to dynamically adjust bed elevations in response to hydraulically forced movement of bed and suspended load materials was developed to help inform the risk of infilling of the proposed project embayment from mainstem Columbia River sediment. The intent of this modelling was to provide an additional line of evidence as part of the geomorphic analysis. The model used is included in the Tuflow FV modelling package, as an add-on module to the hydraulic modeling engine.

### 3.5.1 Model setup

Full model setup is complex and beyond the scope of this document, with numerous options that must be defined for transport, deposition, and erosion rates, bed layer composition, and sediment input rates. Model setup is summarized in Tables 4 and 5. A complete description of the Tuflow Sediment Transport module can be found in Tuflow 2020b.

***Table 4 - Sediment Transport and Morpho-dynamic model setup: transport parameter assignments.***

| Model Parameter | Selected Option/Input | Notes |
|---|---|---|
| Sediment Fraction | Based on Bed Material (see Table 5) | Sediment makeup of a specific layer within the bed. Each layer can have varying amounts of sediment types. |
| Sediment Layers | Based on bed material (see Table 5) | Any bed material can have a single, or multiple, layers. |
| Bed roughness | Nikuradse bed roughness height, ks | Fixed bed roughness height specified. |
| Bed shear model | Default | Selected the default option. |
| Settling model | VanRijn84 | Particle settling velocity determined by Van Rijn formula. Appropriate for natural sand systems. |
| Deposition model | Unhindered (ws) | Uses settling velocity (ws) determined by settling model. |
| Erosion model | VanRijn84 | Corresponding stage based on HQ relation. |
| Bed load model | Soulsby - VanRijn | Showed highest sensitivity of all bedload options. |
| Critical stress model | Soulsby Egiazaroff | |
| Sediment Input concentrations (mg/L) | Sands: 35 | Sediment concentration input at model boundary. |

***Table 5 - Sediment Transport and Morpho-dynamic model setup: bed composition.***

| Bed Material | # of Layers | Layer Material Composition |
|---|---|---|
| Sand | 1 | Layer 1: 25% very fine sand (0.1 mm); 45% fine sand (0.2mm); 30% coarse sand (1.0mm) |
| Cobble | 2 | Top Layer: 15% very fine sand (0.1 mm); 15% fine sand (0.2mm); 15% coarse sand (1.0mm); 55% cobble (100 mm)<br>Bottom Layer: 100% cobble (100 mm) |
| Armor | 2 | Top Layer 1: 15% very fine sand (0.1 mm); 15% fine sand (0.2mm); 15% coarse sand (1.0mm); 55% armor (600 mm)<br>Bottom Layer: 100% armor (600 mm) |

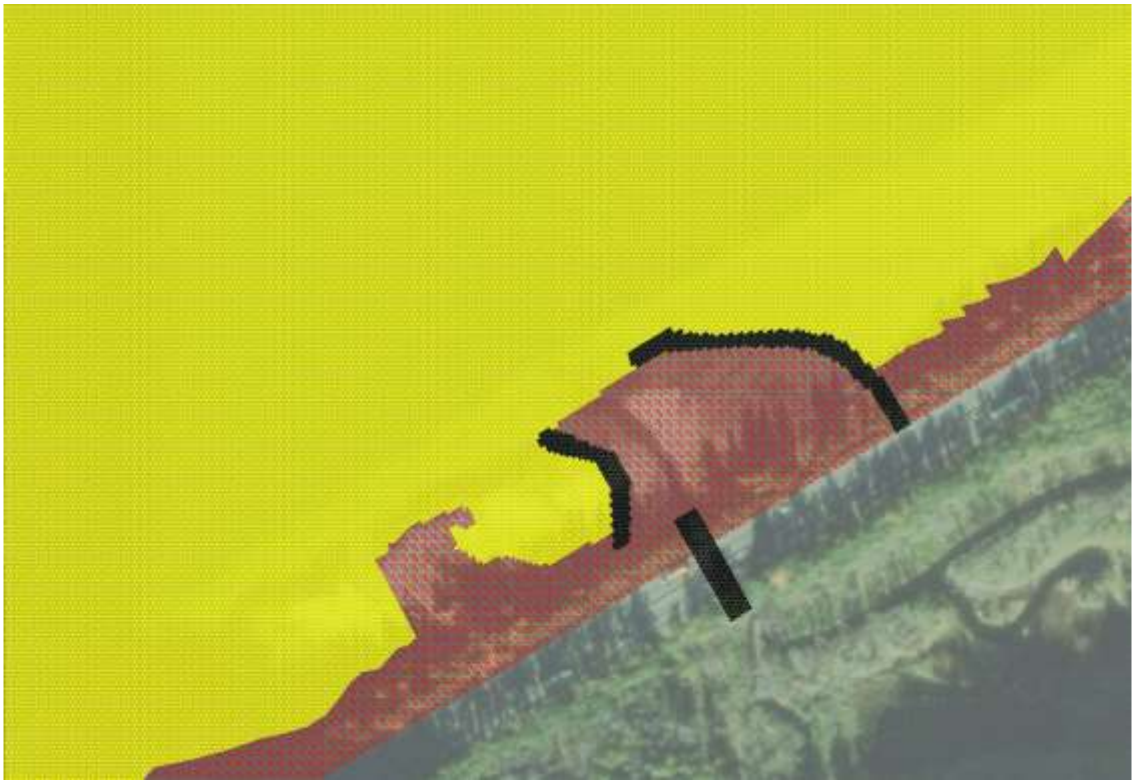


***Figure 15. Bed material assignments (from Table 6) for the Tuflow FV hydraulic and sediment transport models. Yellow areas = "Sand"; red hatched areas = "cobble"; black areas = "armor", applied to the proposed structures and the culvert. Proposed project Alternative 1 is shown.***

### 3.5.2 Model application

The sediment/morpho-dynamic (SM) modeling objective was to attempt to predict whether the proposed constructed embayment would trap Columbia River derived sediments over a range of flow conditions. Because a thorough setup, calibration and verification of the SM model was beyond the scope of this project, we compared results of a variety of input parameter values and selected the most sensitive values for our final model performance evaluation. In other words, we set the model up to most easily move and trap sediment and tested to see if the embayment would fill using those corresponding inputs in our evaluation.

The SM model receives input from the hydraulic model at each time step, calculates the resulting erosion and deposition, determines the change in bed elevation, and feeds the result back to the hydraulic model to be used in the subsequent time step. Due to the highly dynamic hydraulic conditions in this reach of the lower Columbia River we applied an unsteady model simulation to most effectively capture the range of conditions encountered. We ran a long term (7-month) simulation, using the same available 2008 stage data from LCEP's Sand Island monitoring station. Stage and discharge for the respective downstream and upstream boundaries are shown in Figure 16.

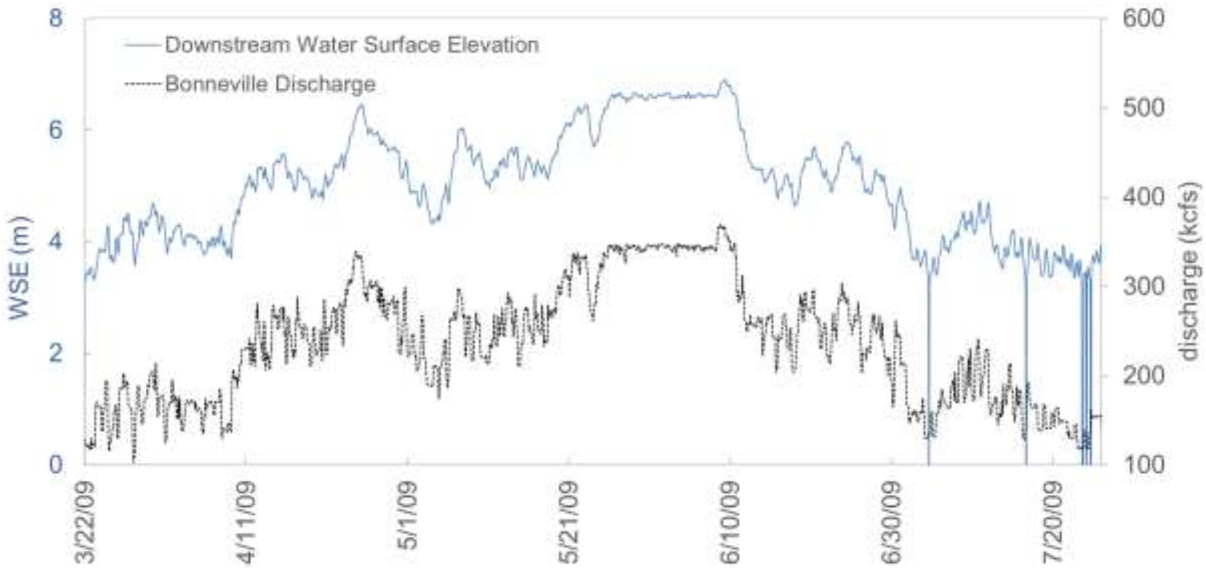



***Figure 16. Hydraulic model boundary forcing conditions used for the long-term (7-month) sediment transport-morpho-dynamic model simulation.***

### 3.5.3 Model results

Setup and calibration of the SM model proved to be more complex and time consuming than what was budgeted for the project, and thus its use as part of this study was limited. We ran just one long-term simulation for a single project Alternative (Alternative 1), applying the boundary conditions shown in Figure 16, which were the only data we had available. Peak flow during this period was 350,000–370,000 cfs (during the Columbia River freshet period from May 26–Jun 9, 2008), which is slightly less than our estimated 2-Year Peak Flow of 390,000 cfs (the modeled flow magnitude which results in river stage values that match the 50% exceedance stage profile calculated by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers 2004)). Overall change in bedform for this 7-month spring–early summer simulation that includes the high-flow freshet period is shown in Figure 17. Bed aggradation immediately upstream and downstream of the embankments, and significant bed scour of approximately 2 meters is seen along the steeper gradient between the shallow near-shore zone and the navigation channel. Based on observed bathymetric changes in this reach of river (U.S. Army Corps of Engineers 2010–2019) these values are greatly exaggerated, particularly in light of the relatively modest freshet event that was simulated. This is expected however, as model parameters were adjusted for maximum sensitivity and resulting bedform changes. Aggradation of approximately 1–1.5 meters of sediment can be seen at the embayment entrance however this is likely overestimated as well. Predicted bedform changes within the embayment itself are minimal despite overtopping of the embankments during the freshet period, suggesting that transport of sediment over the designed structures and subsequent deposition in the embayment may not occur at these flow magnitudes. LCEP is continuing to develop the SM model after completion of this project phase, and this effort will include further calibration and verification as well as simulation of higher magnitude freshet events that are likely to move larger quantities of sediment.

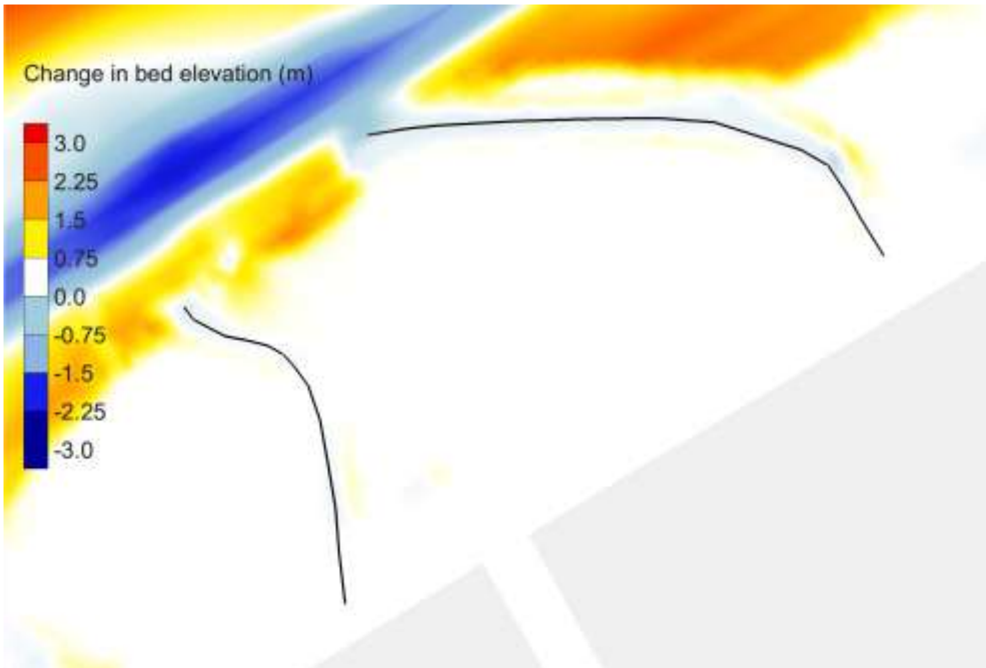



***Figure 17. Sediment and morpho-dynamic model result showing modeled changes in bedform at completion of the 7-month simulation, for restoration Alternative 1. Black lines indicate locations of the flow diversion structures included in this Alternative.***

## 3.6 SOCIAL, INFRASTRUCTURE, AND ECOLOGICAL CONSTRAINTS AND STAKEHOLDER OUTREACH

Potential project constraints were identified to provide guidance for the development and evaluation of restoration alternatives. These constraints were developed based on site observations, data collection and analysis, and discussions with project stakeholders and others with subject matter expertise.

### 3.6.1 U.S. Army Corps of Engineers (COE)

A virtual meeting was convened on July 11, 2020, with the COE to identify potential project constraints associated with the Corps' 408 permitting process and related Corps' infrastructure requirements. COE representatives included individuals from the Portland District's 408 permitting, Navigation, and Environmental Stewardship departments. The following bullet points summarize outcomes of the meeting:

- Federal navigation guidelines require a minimum distance of 400 feet to be maintained between any proposed project infrastructure and the Columbia River mainstem navigation channel, which is located near to the Oregon shoreline in the vicinity of the proposed project.

- A full COE 408 process review would be required for permitting if either of the following two circumstances could potentially occur: project construction impacts any local COE infrastructure; or project construction results in any hydraulic changes to the federal navigation channel. The project would be exempt from this process if it can be demonstrated that neither of these would occur.

As the project is currently designed, none of these constraints present an obstacle to project implementation based on the analysis conducted in this study. Restoration alternatives were designed to meet the 400’ navigation channel buffer width, and modeling has shown that the preferred Alternative would meet thermal refuge criteria that have been established for the project with these design structures (see Section 3.9.1 below). A full 408 process review would likely make project implementation cost-prohibitive, however analysis indicates that this process would not be required. No COE infrastructure has been noted in the vicinity of the project, and a hydraulic model analysis comparing results for each restoration Alternative to the Existing Condition shows no change in water surface elevation, current velocity, or shear stress in the navigation channel when design structures are present. Based on feedback from Corps of Engineers representatives it is expected that submittal of this information for a pre-408 review in later stages of the project will fulfill the requirement for a 408 exemption.

### 3.6.2 Oregon Department of Transportation (ODOT)

Federal Interstate 84 and the Horsetail Creek culvert in the vicinity of the project are under the jurisdiction of ODOT. Due to complications from the COVID-19 pandemic, stakeholder engagement with ODOT did not occur during this project phase, contrary to the original plan. The project team currently plans to initiate this conversation in summer or fall 2021, at which time the 30% concept design can be reviewed. Based on ODOT’s review of project Alternatives brought forward during the Phase 1 Horsetail Creek Floodplain project in 2010 we anticipate the primary constraint to implementing the proposed project will be the potential increase in river stage associated with the constructed diversion structures under high flow conditions. Analysis of model simulations run during this phase do not show any appreciable water surface rise with the proposed design, and so we presume that this constraint will not limit project implementation. However, we are not currently aware of other potential constraints associated with this stakeholder.

### 3.6.3 Oregon Division of State Lands (DSL)

Submerged and submersible lands below the high tide line are under the jurisdiction of the DSL in Oregon. In conversations with DSL prior to the project, no significant permitting constraints were noted for a project that would be designed with structures whose highest elevations do not exceed the 2-Year flood elevation. The current design places embankment structure elevations slightly higher than the minimum required elevation to prevent overtopping when the range of summertime design flow is at its maximum (i.e. ~175,000 cfs). Columbia River stage under these conditions is approximately 5.0 meters, or 16.4 feet, relative to the NAVD88 datum (Figure 18). The estimated 2-Year flood elevation at the site is approximately 7.5 meters, or 24.5 feet, as determined in the Horsetail Phase 1 study (Inter-Fluve and Lower Columbia Estuary Partnership, 2010). This is well above the design elevation for the proposed embankment structures, and thus we do not anticipate any permitting constraints related to DSL jurisdiction. The project team plans to engage DSL in a review of the 30% project design concept in summer or fall of 2021, for further guidance.

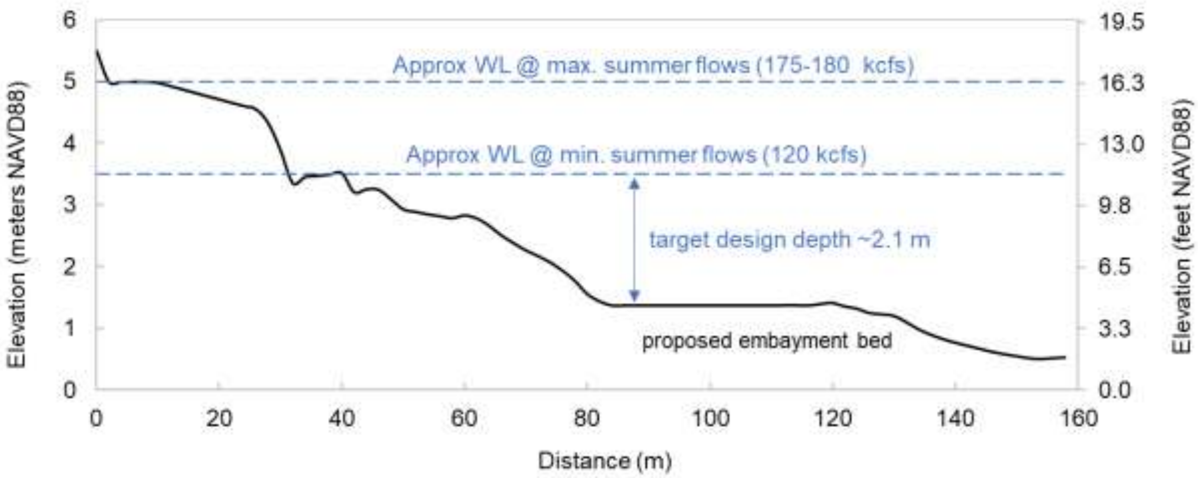



***Figure 18. Approximate elevation cross section for the proposed project, overlain with simulated Columbia River stage at proposed project site over the design flow range. Proposed embankment diversion structures would be built to approximately 5.5–6.0 m, to prevent overtopping at the highest predicted stage for this flow range (5.0 meters, 175,000 cfs).***

## 3.7 ALTERNATIVES ASSESSMENT – PERFORMANCE GOALS, OBJECTIVES AND CRITERIA

Project goals were developed by the design team to reflect intended habitat enhancement provided by the project, as well as its performance related to interaction with riverine process and adjacent infrastructure. Specific objectives related to each goal were developed by the design team, in coordination with project stakeholders.

3.7.1 Goal 1 - **Provide sustainable cold-water refuge at the Horsetail Confluence for adult and juvenile salmonids migrating through the mainstem Columbia River.** The availability of thermal refuge provided will be targeted for the summer period when Columbia River temperatures exceed 20°C, typically from mid-July through early-September.

***Objectives***

1a. Maintain core zone of thermal refuge (defined as any area where [1]depth is > 2.0 m and [1]temperature is > 2° C lower than temperature in the mainstem Columbia) that has a minimum area of 1.0 acre and is persistent 24 hours daily.

1b. Maintain transition zone of thermal refuge (defined as any area where [1]depth is > 2.0 m and [1]temperature is > 1° C lower than temperature in the mainstem Columbia) that has a minimum area of 1.5 acre and is persistent 24 hours daily.

1c. Coldwater plume (defined as water at least 0.5 degrees C cooler than surroundings) is detectable within the existing mainstem Columbia River migration zone (defined as water with depth > 2 m but < 10 m) 24 hours per day.

1d. Thermal characteristics defined in 1a-1c to be met during summer periods when Columbia River mainstem temperature exceeds 20°C and flow is less than 175,000 cfs.

Notes:

1. Targeted overall water depth within Core and Transition zones is 2 meters however the water column is expected to be thermally stratified and the targeted temperature may not be met at all depths. See Section 3.9.1 for discussion of how thermal refuge quality (Objectives 1a and 1b) was assessed.

3.7.2 Goal 2 **– Increase area suitable for use by juvenile and adult salmonids.** Habitat elements will be designed to provide year-round habitat for juvenile salmonids migrating down the mainstem Columbia River, as well as juveniles originating from the Horsetail/Oneonta system. The embayments will have areas with depths sufficient to provide habitat for migrating adult salmonids.

***Objectives***

2a. Maintain adequate water depth (2 meters) in at least 0.5 acres of the embayment at flow of 120,000 cfs to encourage use by adult salmonids.

2b. Maintain adequate cover, with placement of large wood structures or equivalent, to provide predator protection and increase both summer and overwinter rearing habitat for juvenile salmonids.

2c. Minimize range of flows during which the embayment topography creates adverse current fields which may deflect juvenile salmonids away from the site and access to the interior floodplain.

2d. Maximize amount of natural shoreline to the extent possible, by minimizing shoreline armoring, and/or creating living shorelines consisting of vegetation over a protective armoring layer that forms the foundation of the embankment topography.

3.7.3 Goal 3 – Construct an embayment that is resilient to sediment dynamics. The constructed embayment will be designed such that maintenance due to nuisance sedimentation is minimized to the degree possible, and that target habitat values will remain intact with expected gravel inputs from upstream.

***Objectives***

3a. Provide sufficient volume within the embayment such that design criteria (1a, 1b) continue to be met after 25 years of anticipated infilling of sediment.

3b. Design embankment topography so that hydraulic conditions favorable to the evacuation of sand at the outlet of the embayment occurs for a 2-year event (or greater) on the Columbia.

3c. Design embankment topography so that hydraulic conditions favorable to the evacuation of sand within the embayment (and particularly at the outlet) occur for a 2-year event on Horsetail/Oneonta Creeks coupled with a low Columbia River backwater.

3.7.4 Goal 4 – **Develop a project that is stable to hydraulic forces.** Project elements will be designed so that installed wood and stone materials are stable, and that deformable materials continue to provide habitat benefits when subjected to expected hydraulic forces.

***Objectives***

4a. Large stone composing the "stability zone" of the embankments will be stable at the 100-year flood event on both the mainstem Columbia River and Horsetail Creek.

4b. Large wood structures will be stable at the 100-year flood event on both the mainstem Columbia River and Horsetail Creek.

4c. The project will be designed such that any expected adjustments to the embankment-top elevations will continue to allow all other objectives to be met.

3.7.5 Goal 5 – **Develop a project that has no negative impacts on river navigation or adjacent infrastructure.** The project will be developed such that no adverse impacts will be created for the USACE navigation channel in the Columbia River, nor for the Interstate 84 highway embankment.

***Objectives***

5a. The embankment structures shall not encroach within 400 ft of the edge of the USACE navigation channel.

5b. The embankment structures shall not negatively affect visibility within the USACE navigation channel or cause any other serious impediment to navigation of watercraft within the Columbia River.

5c. The embankment structures shall not appreciably alter main channel sediment dynamics in a way that negatively affects the USACE navigation channel.

5d. There should be no detectable change (0.005 m/s maximum difference between modeled results for the existing condition and the preferred alternative) in current velocities within the navigation channel with and without the embankment structures in place.

5d. The embankment structures and associated changes in hydraulic patterns shall not negatively impact the Interstate 84 road prism, including no detectible rise in water surface upstream of the project area.

5e. The embankment structures and associated changes hydraulic patterns shall not cause a change in the frequency of maintenance for the existing multi-barrel box culvert.

## 3.8 RESTORATION ALTERNATIVES CONSIDERED

To address the goals and objectives summarized above for establishment of a thermal refuge embayment, three preliminary Alternative geometries, and several iterations of each Alternative with slightly different diversion structure orientations, were evaluated. Prior to this assessment, temperature modeling was first used to screen different diversion structure compositions, by comparing results for solid structures to those for more porous structure types such as wood-only placements. This initial screening process identified the construction of continuous, solid embankments as the most likely to be successful in creating and maintaining the thermal refuge embayment. This section describes the three preliminary Alternatives, each consisting of solid, continuous embankment structures that divert the warmer Columbia River from the isolated, colder Horsetail Creek inflow, thereby promoting cold-water plume formation.

### 3.8.1 Large Upstream Embayment – Alternative 1

***Description*** – This alternative would create an approximately 2-acre embayment located generally upstream of the Horsetail Creek/Oneonta Creek outlet. The embayment would be created by the construction of two individual embankments: a larger embankment (length ~550 feet) upstream of the existing outlet, and a smaller embankment (length ~ 300 feet) downstream of the existing outlet. Large wood structures would be constructed both within the embankments and within the embayment.

***Benefits, Limitations & Level of Effort*** - This alternative would provide a large embayment to retain cool water inputs for Horsetail/Oneonta Creeks prior to mixing with water from the mainstem Columbia River. A portion of the material used to create the embayments would be generated from excavation or dredging within the embayment footprint. The embayment would provide a thermal refuge zone for both migrating adult and juvenile salmonids. Juvenile salmonids originating for Horsetail and Oneonta Creeks would benefit from the expanded cold-water zone as well the rearing and cover habitat provided by the large wood structures.

This alternative proposes to place ~ 10,500 cubic yards of fill within the two constructed embankments. The downstream embankment serves to limit the amount of back eddy circulation into the embayment from the mainstem, which would allow more warm-water intrusion. A portion of the fill would be composed of heavy material, likely large stone, to provide embankment stability under various hydraulic forces such as shear stress from river flow and waves generated both by wind fetch and boats. Large wood material, stone and planting materials would likely need to be imported to the site by barge, since there is no viable ground access from I-84 in this location.

***Proposed Actions***

- Construction of 2 large embankments to create a thermal refuge embayment east of the Horsetail/Oneonta Creek outlets.
- Dredge/Excavate material for embankment construction from within the 2-acre embayment area.
- Install large wood structures to provide cover habitat for juvenile and adult salmonids.
- Plant native shrubs and trees on embankment to provide shade and increase visibility for watercraft utilizing the area.

### 3.8.2 Large Downstream Embayment – Alternative 2

***Description*** – This alternative would create an approximately 1.9-acre embayment located generally downstream of the Horsetail Creek/Oneonta Creek outlet. The embayment would be created by the construction of a single embankment (length ~ 750 feet), starting upstream of the existing outlet but curving more sharply downstream. Large wood structures would be constructed both within the embankments and within the embayment.

***Benefits, Limitations & Level of Effort*** - This alternative would provide an embayment of similar size to Alternative 1 to retain cool water inputs for Horsetail/Oneonta Creeks prior to mixing with water from the mainstem Columbia River. Similar to Alternative 1, a portion of the material used to create the embayments would be generated from excavation or dredging within the embayment footprint. The embayment would provide a thermal refuge zone for both migrating adult and juvenile salmonids, and an expanded cold-water zone, rearing and cover habitat for juveniles originating upstream. Existing vegetation on the south and west sides of the proposed embankment would provide short term shading and cover benefits.

This alternative proposes to place ~ 5,500 cubic yards of fill within the constructed embankment and takes advantage of an existing higher peninsula to prevent back eddy circulation into the embayment from the mainstem. Material import limitations are similar to Alternative 1 however the level of effort is reduced because the embankment volume is 50% smaller.

***Proposed Actions***

- Construction of 1 large embankment to create a thermal refuge embayment west of the Horsetail/Oneonta Creek outlets.
- Dredge/Excavate material for embankment construction from the 1.9-acre embayment area.
- Install large wood structures to provide cover habitat for juvenile and adult salmonids.
- Plant native shrubs and trees on embankment to provide shade and increase visibility for watercraft utilizing the area.

### 3.8.3 Narrow Downstream Embayment – Alternative 3

***Description*** – This alternative would create an approximately 1.4-acre embayment located generally downstream of the Horsetail Creek/Oneonta Creek outlet. A single embankment (length ~ 650 feet), starting upstream of the existing outlet but curving sharply downstream would be used to create a narrow embayment the follows closely along the I-84 road prism. Large wood structures would be constructed within the embankments.

***Benefits, Limitations & Level of Effort*** - This alternative would provide a smaller embayment than either Alternative 1 or Alternative 2 but would function similarly to retain cool water inputs from Horsetail/Oneonta Creeks prior to mixing with water from the mainstem Columbia River. The footprint of this alternative stays further from the navigation channel than either Alternative 1 or Alternative 2. Similar to the other alternatives, a portion of the material used to create the embayments would be generated from excavation or dredging within the embayment footprint. The thermal refuge and habitat benefits of this alternative are generally similar to the other 2 alternatives. Existing vegetation on the south side of the proposed embankment would provide short term shading and cover benefits.

This alternative proposes to place ~ 10,000 cubic yards of fill within the constructed embankment, with much of the fill being generated from an existing higher peninsula. The location of the inlet closer to the left bank of the mainstem would help to prevent back eddy circulation into the embayment. This orientation may make discovery by migrating salmonids more difficult. Material import limitations and level of effort are similar to Alternative 1.

***Proposed Actions***

- Construction of 1 large embankment to create a thermal refuge embayment west of the Horsetail/Oneonta Creek outlets.
- Dredge/Excavate material for embankment construction from the 1.4-acre embayment area.
- Install large wood structures to provide cover habitat for juvenile and adult salmonids.
- Plant native shrubs and trees on embankment to provide shade and increase visibility for watercraft utilizing the area.

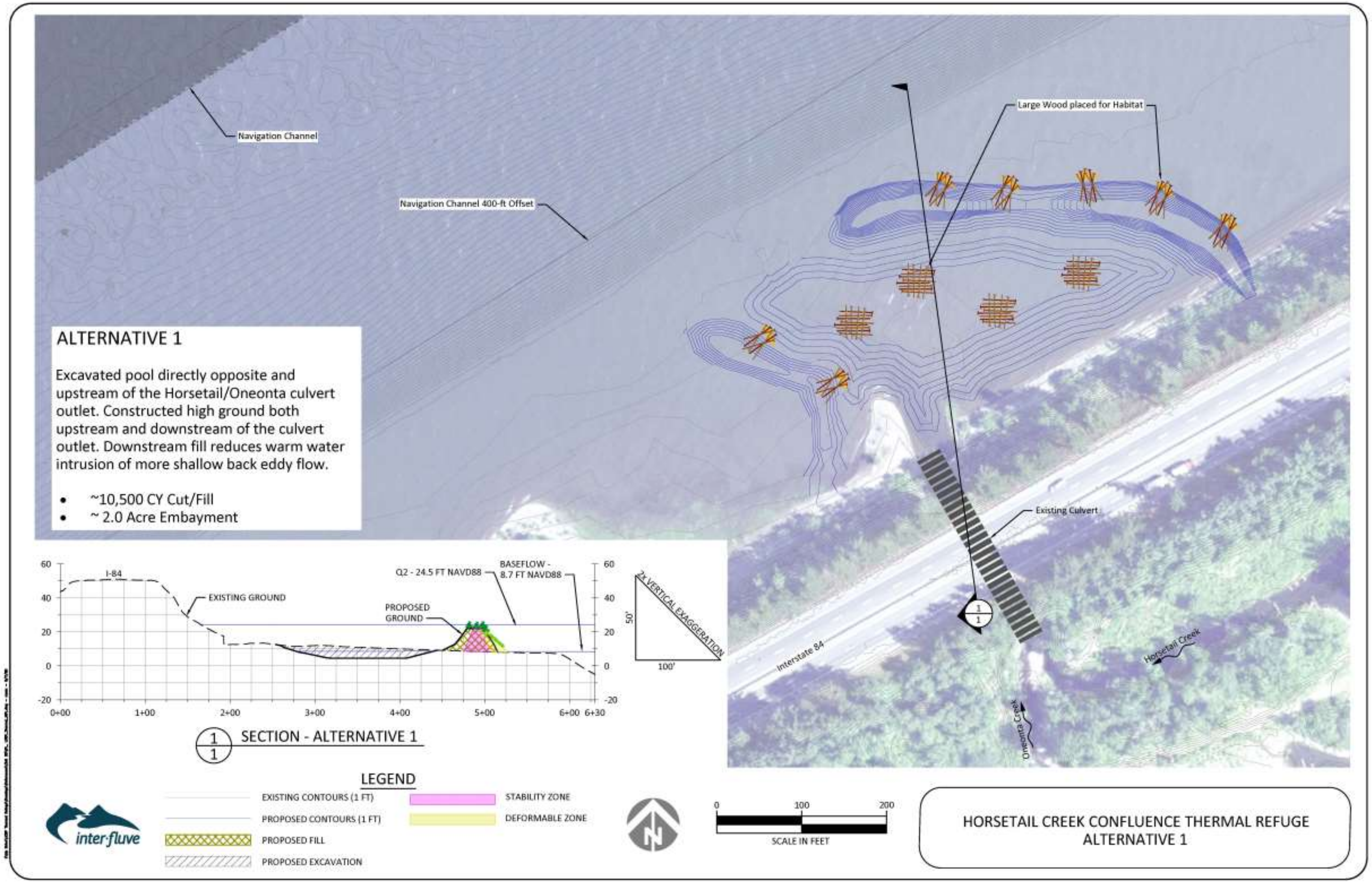



*Figure 15 - Alternative 1 Plan and Profile*

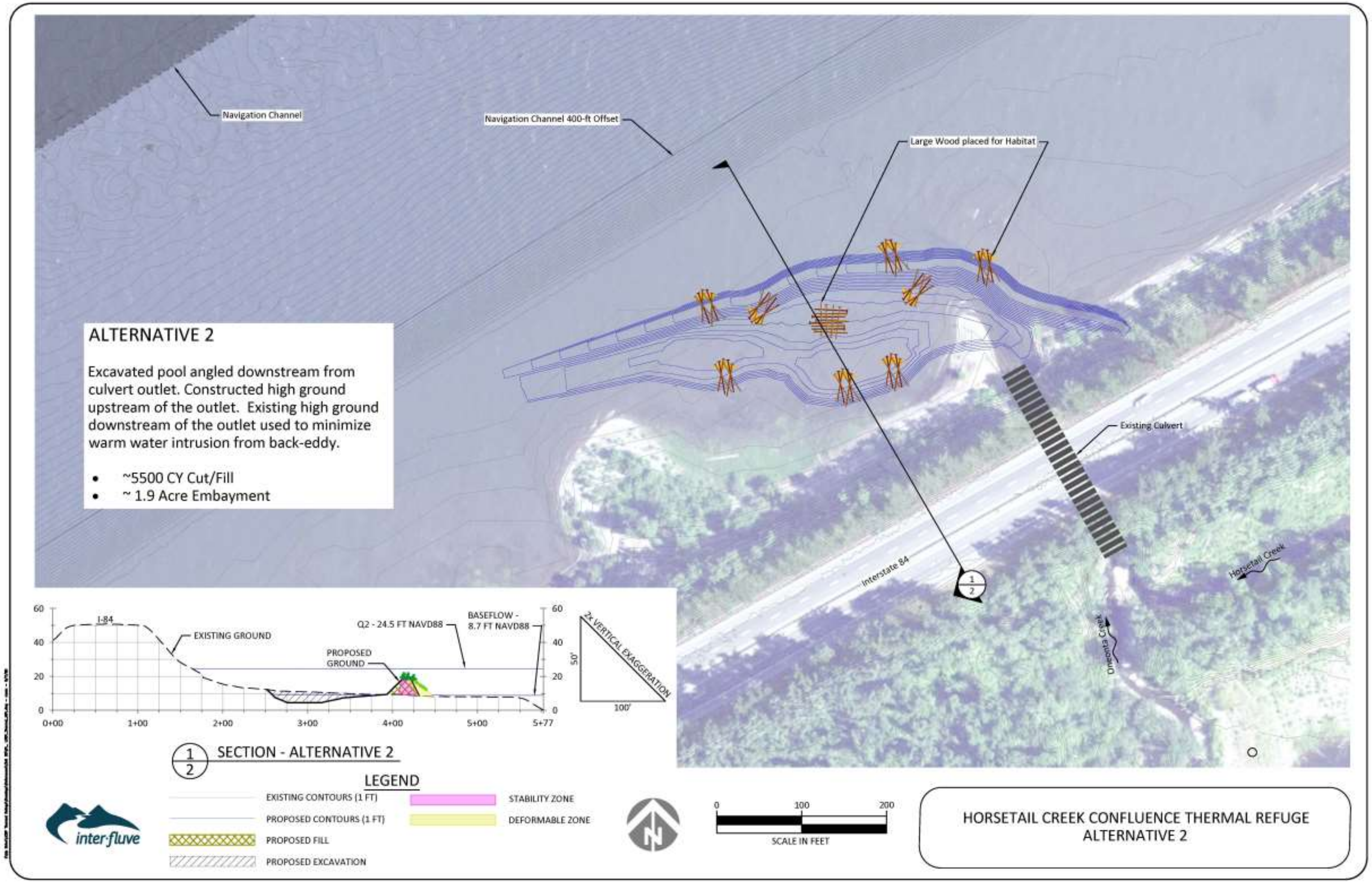



*Figure 16 - Alternative 2 Plan and Profile*

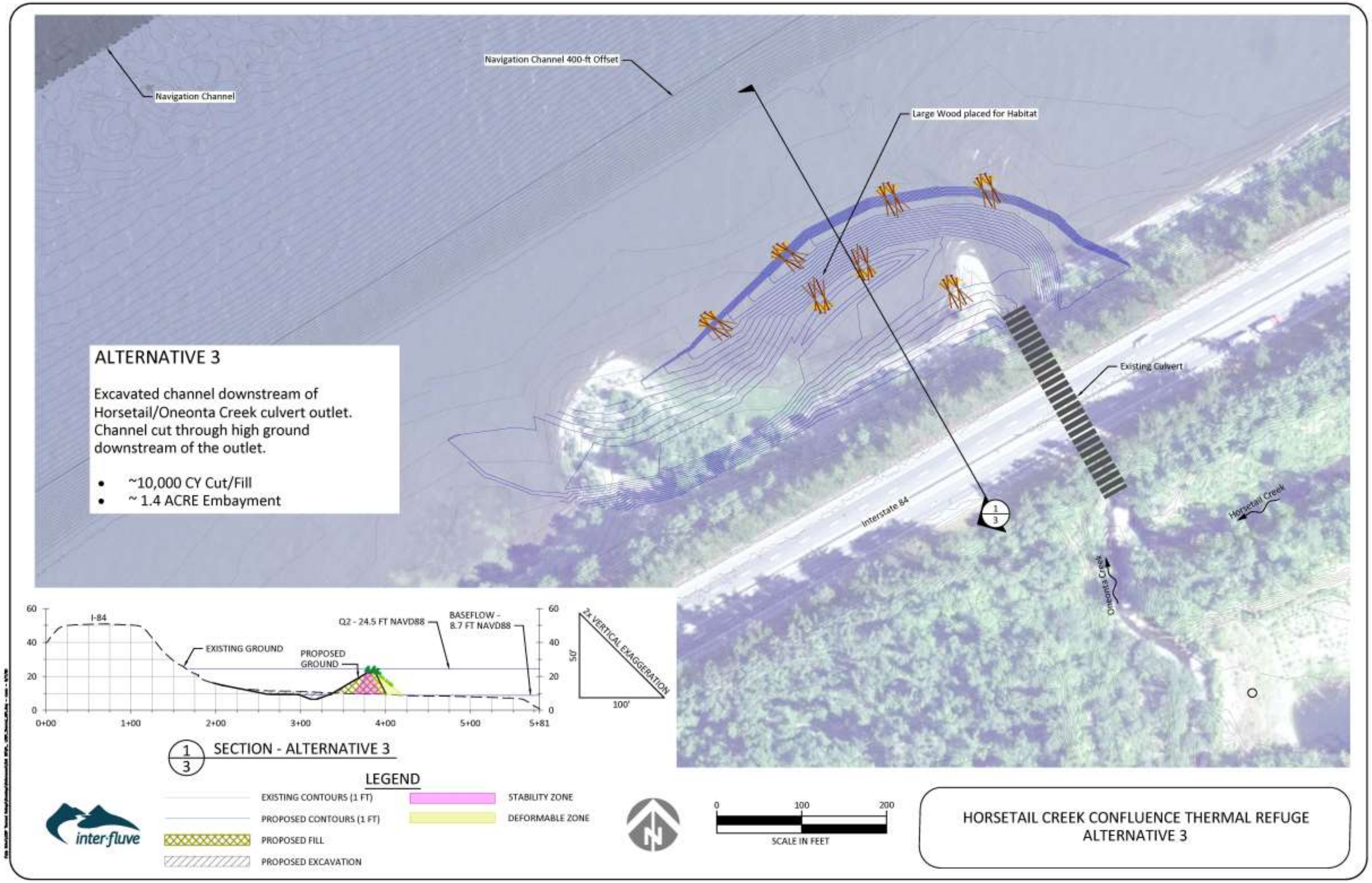



*Figure 21 - Alternative 3 Plan and Profile*

## 3.9 ALTERNATIVES ASSESSMENT – SELECTION OF PREFERRED RESTORATION ALTERNATIVE

Hydraulic and temperature model simulations were run to help inform the selection of a preferred restoration alternative from the three Alternative embankment/embayment geometries presented. We ran unsteady and steady-state hydraulic and temperature simulations covering the range of Columbia River baseflows (120,000–175,000 cfs) expected during the target thermal refuge period, and additional hydraulic simulations of combinations of higher Columbia River and tributary flood magnitudes. We defined scoring metrics based on modeling results to rank the Alternatives. Each metric is mapped to one or more of the design objectives described in Section 3.7. Not every objective was considered in the alternatives analysis as some will apply to any design moving forward and thus not be useful for scoring (such as the stability and infrastructure related objectives). As noted earlier, for each Alternative we initially modeled several preliminary structure alignments to arrive at the optimal performance. We then used these optimized alignments for the Alternatives comparison. This section presents results for the optimized alignments only. Additional detail including results of the preliminary alignment simulations can be found in Appendix 6.4.

### 3.9.1 Goal 1 – Provide sustainable cold-water refuge

Metrics related to Goal 1 are focused on the size, temperature difference (relative to the mainstem Columbia River) and detectability (by salmonids), of the cold-water plume that forms in the proposed embayment. For the analysis we have defined "core" cold-water habitat as that which is 2 °C cooler than the mainstem Columbia River, and has a minimum depth of 2 m. "Transition" cold-water habitat has been defined as that which is 1°C cooler than the mainstem Columbia River and has a minimum depth of 2 m (see Objectives 1a and 1b, Section 3.7.1). Results have been categorized qualitatively using the color codes show below Table 6.

#### *Metric Calculation - Thermal plume size*

Assessment of the plume volume required a 3D modeling assessment to capture thermal stratification of the water column that occurs in these types of embayments when the two distinct water sources meet. Rather than mixing to a uniform temperature, the smaller, colder tributary water tends to sink below the warmer mainstem water forming a colder layer at depth. We noted this stratification during field assessments of Horsetail Creek and the other tributary confluences that we studied in our earlier thermal refuge study (Lower Columbia Estuary Partnership 2018). 2D hydrodynamic models, because they use vertical averaging, cannot capture this phenomenon, which is illustrated in the example vertical profile of the water column shown Figure 22, taken from one of our 3D unsteady temperature model simulations.

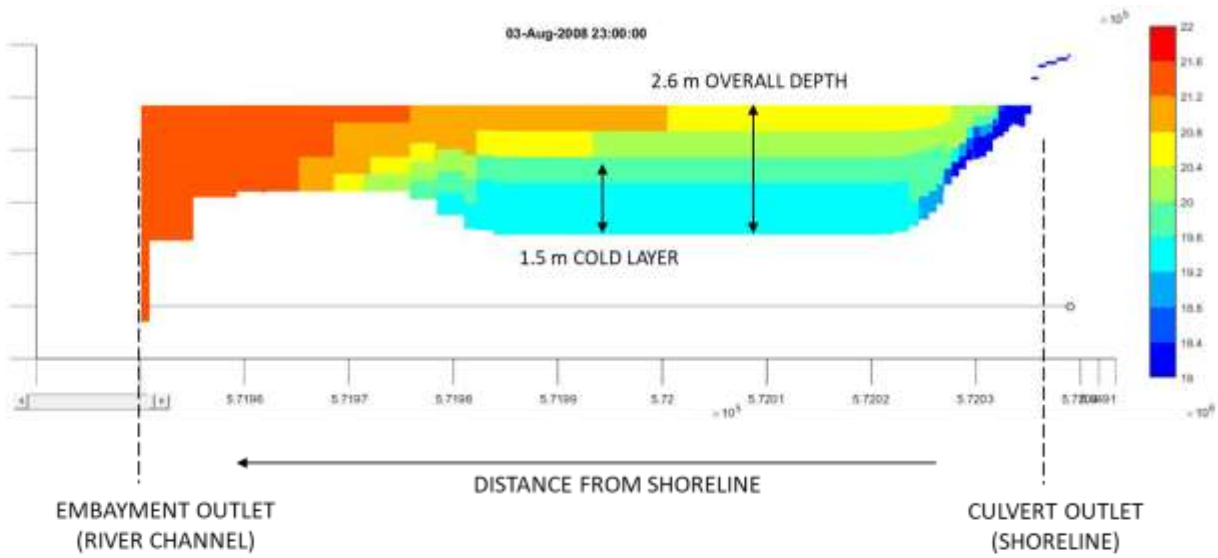



***Figure 22 - Plot of water temperature for a vertical cross section of the created cold-water embayment, taken from a 3D unsteady hydrodynamic and temperature model simulation.***

Objectives 1a and 1b for Goal 1 outlined in Section 3.7.1 define minimum criteria for which we are considering suitable thermal plume area of the proposed project. These include a water depth of 2m, which we believe is the minimum depth needed to attract and retain adult salmonids for any extended period based on research studies related to Columbia River Chinook salmon and steelhead migratory behavior (Johnson et al. 2010; Johnson et al. 2007; Johnson et al. 2005; Keefer et al. 2006). Because the water column can be expected to be thermally stratified, and therefore unlikely to uniformly maintain a temperature that is 2 degrees colder than the mainstem Columbia R. (core thermal refuge criteria, as defined in Objective 1a), we questioned what the minimum 'cold-water' depth might be to attract and retain adult salmonids. Conversations with Matt Keefer (Keefer, personal communication 2021b), a researcher who has studied salmonid use of mid-Columbia River thermal refuges extensively, suggested that a 'thinner' cold-water layer within an adequately deep (>2 meters, based on the literature cited previously) embayment that might be warmer overall would be likely to provide significant habitat benefits, however he did not provide an estimate of what that layer thickness would be. Based on these communications, we chose to evaluate thermal plume quality using the deepest 20% of the water column. To calculate core (Objective 1a) and transitional (Objective 1b) thermal refuge sizes, we measured overall area of this bottom layer which was at least 2 degrees or 1 degree lower, respectively, than the uniform mainstem temperature for each of the temperature model simulations.

### *Metric Calculation - Detectability*

As part of the goal of establishing suitable thermal refuge for migrating salmon at the project site, we include criteria in Objective 1c for ensuring that the design will result in creation of a thermal plume that is detectable by migrating salmon. If these fish cannot detect a negative temperature signal as they pass by the site, it is unlikely that other queues would make them aware of the embayment's existence and therefore they would be unlikely to use it. Consequently, the design must be capable of extending the cooler signal of the plume into the adult migration zone so that they can detect it and be attracted to the refuge. Because of the large degree of uncertainty about the migratory pathway of juvenile Chinook salmon (the species most likely to be migrating through the project reach during the summer period of interest) pathways in this reach of the Columbia River (Carter et al. 2006, Section 2.2.2), we focus on the better understood migratory behavior of adult salmonids, which has been described by Keefer and others (Johnson et al. 2010; Johnson et al. 2007; Johnson et al. 2005; Keefer et al. 2006) and proceed with the assumption that criteria set forth for adults will be sufficient for juvenile detection as well. Based on that information, most adult salmonids migrating upstream in the lower Columbia River do so in a zone parallel to the shoreline that is 2–10 meters deep. Additional communication with Matt Keefer (Keefer, personal communication 2021a) revealed that these fish are also extremely adept at queuing into very subtle changes in temperature, although he did not specify an exact value.

Based on the information above, we assessed detectability through our model simulation results by measuring the distance from the 0.1° and 0.2° thermal gradient contours to the 2-meter depth contour (i.e. the presumed shoreward limit of adult salmon migration), as well as the overall length along the migration corridor where the gradient exists. These measurements are illustrated in Figure 23. Ideally, the temperature gradient should exist <u>within</u> the migratory corridor (distance of 0 or less), but its distance from the shoreline will fluctuate based on the dynamics of the plume, which respond to both Columbia River and Horsetail Creek flows as discussed earlier.

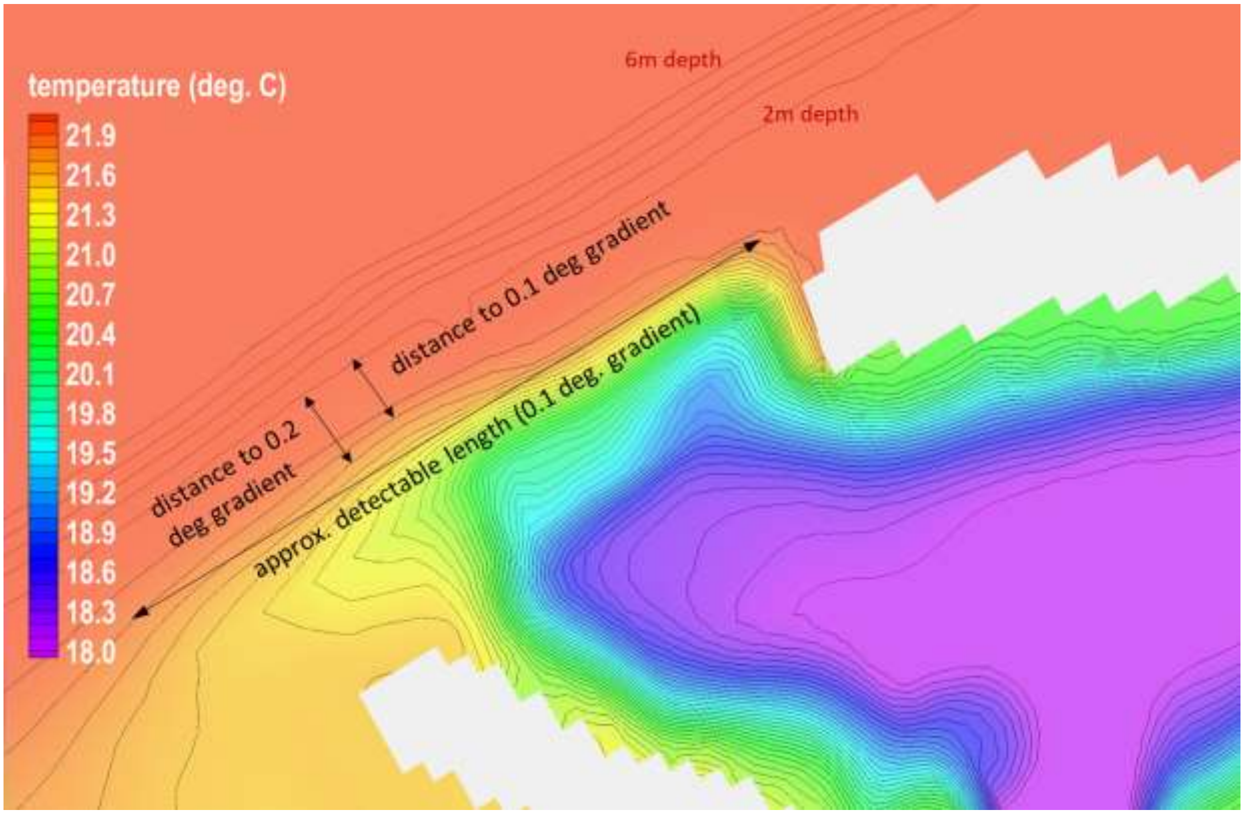



***Figure 23 - Method for measuring detectability of the created thermal refuge plume from simulated temperature model results.***

### *Goal 1 Metrics Assessment (Figures 24–25 and Table 6)*

Figure 24 illustrates temperature performance within the created embayment for the unsteady model simulation using the unsteady boundary conditions described in Section 3.4.1. These include time-varying flow, water temperature and atmospheric conditions, essentially simulating a typical summertime period of 5 days. Results can be compared to the Goal 1 Objectives of maintaining core and transitional thermal refuge zones over the range of summertime conditions. As shown in the plot (Figure 24, bottom), temperature near the bed remains colder relative to temperature at mid-depth and at the surface. Bed temperature at the location chosen (Figure 24, top) remains at least 1 degree cooler than the Columbia R. mainstem for most of the simulation period, and at least 2 degrees cooler at much of the simulation period. The plot shown is for Alternative 1. Results for Alternatives 2 and 3 were nearly identical and thus not included in this report.

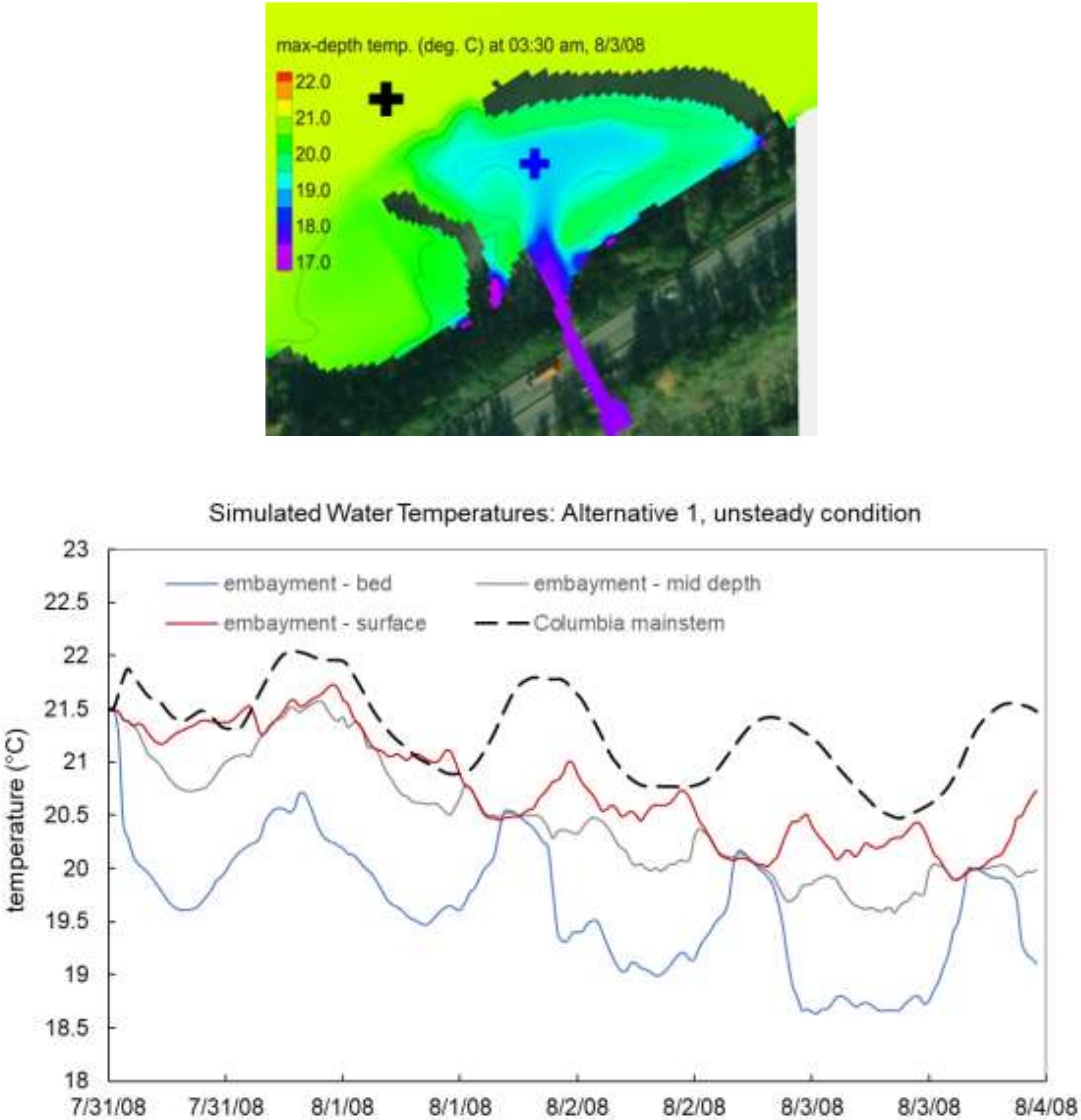



**Figure 24. Temperature performance within the created embayment for the unsteady model run applied to Alternative 1. Data output locations (for the mainstem Columbia and within the thermal plume) are shown in the top image.**

As shown in Figure 25 for the steady-state model analysis, Alternative 3 performs well for both core and transition cold water habitats at the lowest Columbia baseflow (120,000 cfs) but is outperformed by Alternatives 1 and 2 at the highest baseflow (175,000 cfs). Alternative 2 forms the largest transition cold water refuge plumes. Alternative 1 develops an adequately sized plume over the full baseflow range of 120,000–175,000 cfs. The edge of the plume was assumed to be the location where the water was 0.1 °C cooler than surrounding water for the purpose of this analysis. Due to its alignment along the I-84 road prism, Alternative 3 performs poorly with respect to detectability, while Alternative 2 slightly outperforms Alternative 1.

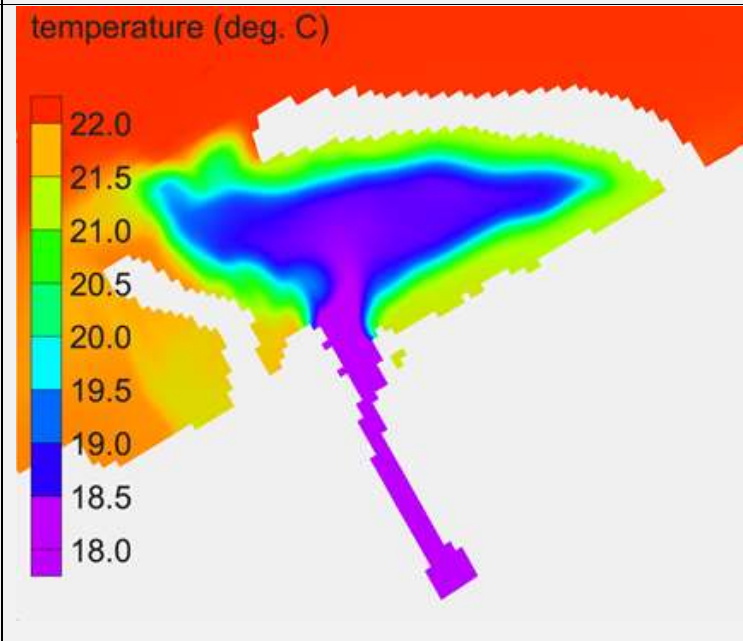
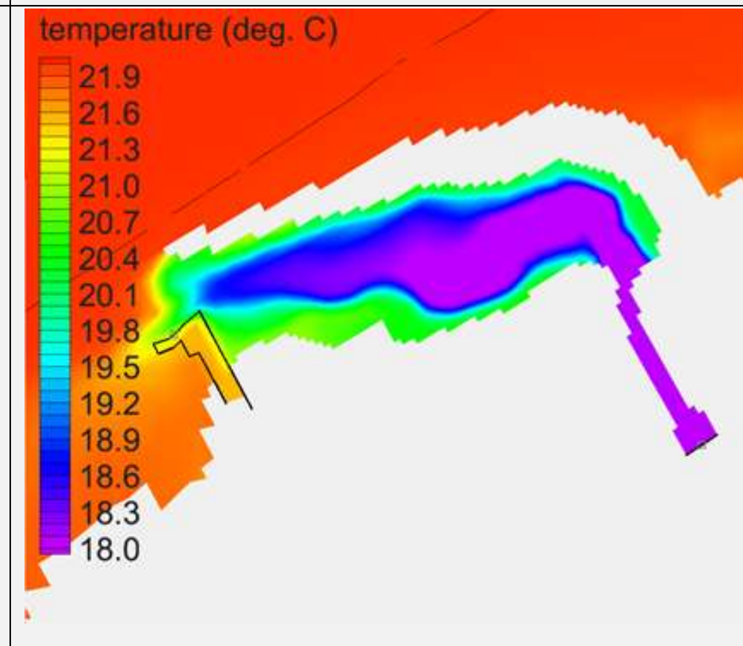
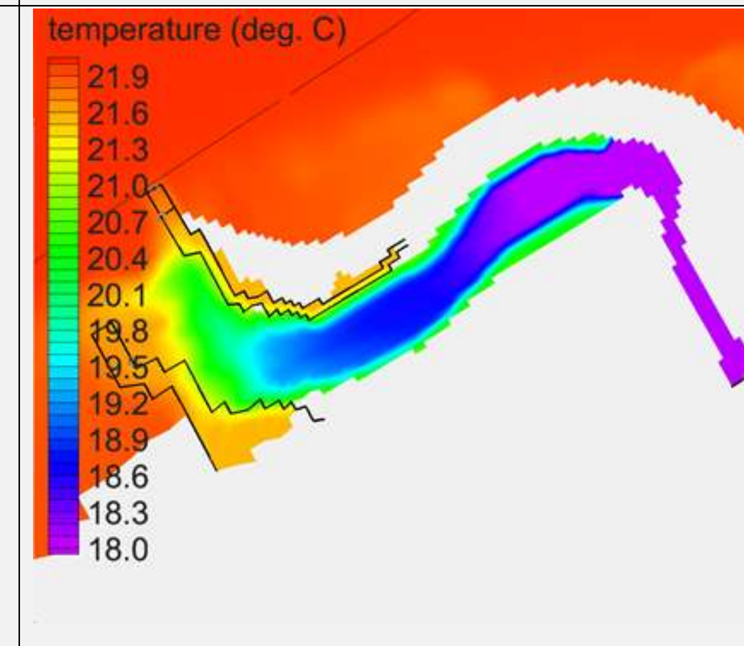
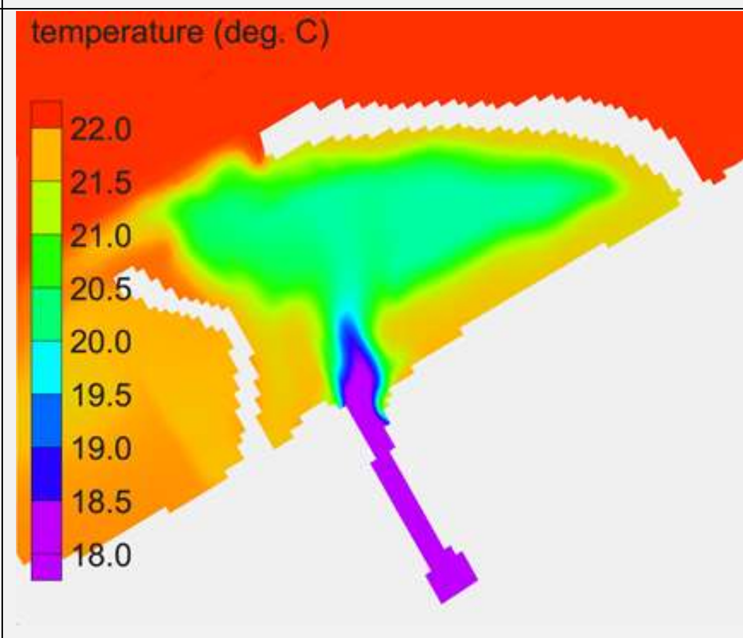
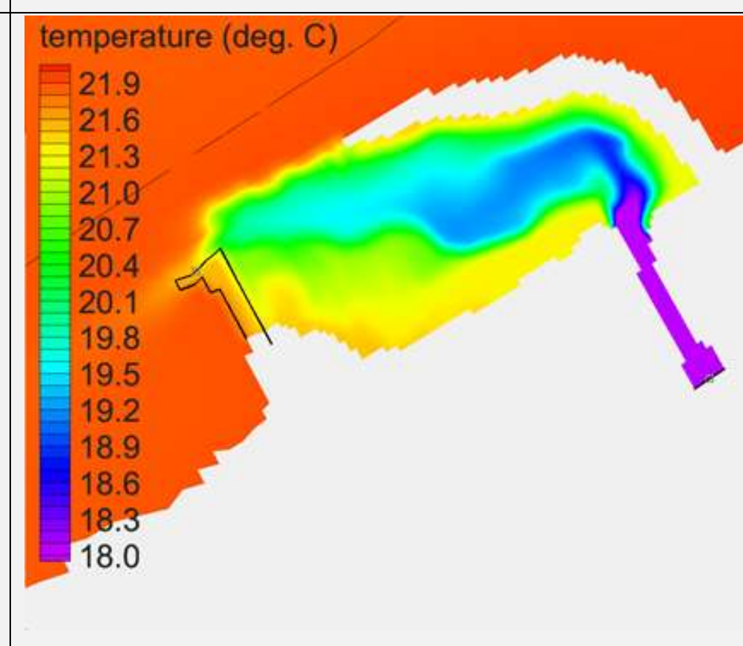
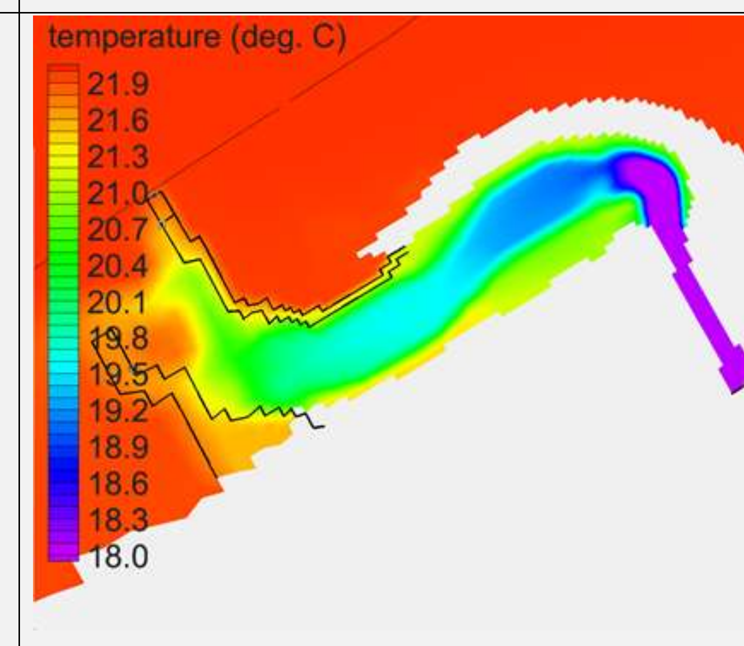
| Alternatives Analysis – Goal 1 Temperature Model Simulation Results | | | |
|---|---|---|---|
| | **Alternative 1** | **Alternative 2** | **Alternative 3** |
| Model Results @ Steady-state low baseflow<br><br>(Columbia River = 120,000 cfs) |  |  |  |
| Model Results @ Steady-state high baseflow<br><br>(Columbia River = 175,000 cfs) |  |  |  |

*Figure 25 - Goal 1 model results: Steady-state temperature model results for optimized structure alignments for Alternatives 1–3. Model used the input boundary conditions described in Section 3.4.2 and titled 'Steady – high baseflow' and 'Steady – low baseflow' (Simulation Nos. 1 and 2 respectively) in Table 3. Black lines in some figures indicate embankment structures that were added to optimize performance for the particular Alternative.*

***Table 6. Goal 1 Alternative Analysis.***

| Alternatives Analysis - Goal 1 Metrics | | | | |
|---|---|---|---|---|
| **Objective** | **Metric** | **Alternative 1** | **Alternative 2** | **Alternative 3** |
| 1a/1d: Core thermal zone provided over summer baseflow conditions. (2°C cooler, 2m depth) | Maximum core zone plume size (acres) @ 120,000 cfs Columbia River flow | 0.78 acres | 0.75 acres | 0.78 acres |
| 1a/1d: Core thermal zone provided over summer baseflow conditions (2°C cooler, 2m depth) | Maximum core zone plume size (acres) @ 175,000 cfs Columbia River flow | 0.69 acres | 1.17 acres | 0.74 acres |
| 1b/1d: Transition thermal zone provided over summer baseflow conditions. (1°C cooler, 1m depth) | Maximum transition zone plume size (acres) @ 120,000 cfs Columbia River flow | 0.78 acres | 0.75 acres | 0.86 acres |
| 1b/1d: Transition thermal zone provided over summer baseflow conditions (1°C cooler, 1m depth) | Maximum transition zone plume size (acres) @ 175,000 cfs Columbia River flow | 1.46 acres | 1.56 acres | 1.00 acres |
| 1c/1d: Thermal zone is detectible within adult salmonid migration corridor (defined by depth between 2m and 10m) over summer baseflow conditions | Distance from plume to migration corridor @- 120,000 cfs Columbia River flow | 26 ft | 10 ft | 39 ft |
| 1c/1d: Thermal zone is detectible within adult salmonid migration corridor (defined by depth between 2m and 10m) over summer baseflow conditions | Distance from plume to migration corridor @ 175,000 cfs Columbia River flow | 49 ft | 26 ft | 105 ft |

**KEY**

| | |
|---|---|
| Dark green | Very much accomplishes objective |
| Light green | |
| Light yellow | Somewhat accomplishes objective |
| Light orange | |
| Orange | Does not accomplish objective |

### 3.9.2 Goal 2 – Useable habitat area and access for juvenile and adult salmonids

Metrics related to Goal 2 are focused on access and habitat quantity. We analyzed velocities at the mouth of the embayment, related to the potential for the formation of velocity barriers to juvenile salmon, and found that all the Alternatives performed equally with respect to this access metric. A detailed writeup of that analysis can be found in Section 3.9.5. Shoreline length was utilized as a proxy for juvenile habitat potential. Alternative 2 provided a slightly longer shoreline than either Alternative 1 or 3 (Table 7).

### 3.9.3 Goal 3 – Resilience to sediment dynamics

Metrics related to Goal 3 are focused on the ability of hydraulics within the constructed embayment to redistribute nuisance sand deposition, extending the design life of the structure and minimizing the risk of fish access issues in the future. The threshold for mobilization of sand was assumed to be approximately 1.3 $N/m^2$ (~ .03 $lb/ft^2$ – Fischenich 2001).

*Metric Calculation – Inlet Sand Mobilization*

As outlined in Goal 3, our objective is to create an embayment that will be resilient to sediment dynamics. This will be accomplished by minimizing potential sedimentation if possible, excavating extra volume from the embayment in certain areas to allow for strategic collection of sediment that does deposit, and optimizing the placement of embankments to promote bed scour and removal of deposited sediment during tributary flood events that typically occur from late-fall through spring (Objective 3c). To evaluate potential for high tributary flows to mobilize sand at the inlet for each project alternative, we compared bed shear results from hydraulic model simulations of 1-year, 2-year, 5-year, and 10-year Horsetail Creek flood magnitudes. We presume that Alternatives which generated the highest bed shears directed in such a way that would promote removal of sediment will be the most resilient to long-term accumulation of sediments within the embayment.

*Goal 3 Metrics Assessment (Table 7 and Figure 27)*

Hydraulic model results for simulations applying high Columbia River flows (~ Q2) in combination with high tributary flows through the culvert suggest that the hydraulics necessary to move sand in this scenario are not generally present for Alternative 1–3, due to dissipation of tributary energy by the Columbia flows which overtop the structures at this stage (**Error! Reference source not found.**7, upper). However, because high tributary flows almost always occur in the late fall–spring rainy period, during which Columbia River flows are typically low (Figure 26), this scenario is not likely to occur. Model results of the higher likelihood scenario of lower flows on the Columbia River combined with an annual high flow through the culvert suggests considerably more capacity to evacuate sands for Alternatives 1 and 3. Alternative 2 performs the most poorly due to dissipation of energy coming out of the culvert on the embankment (**Error! Reference source not found.**7, lower).

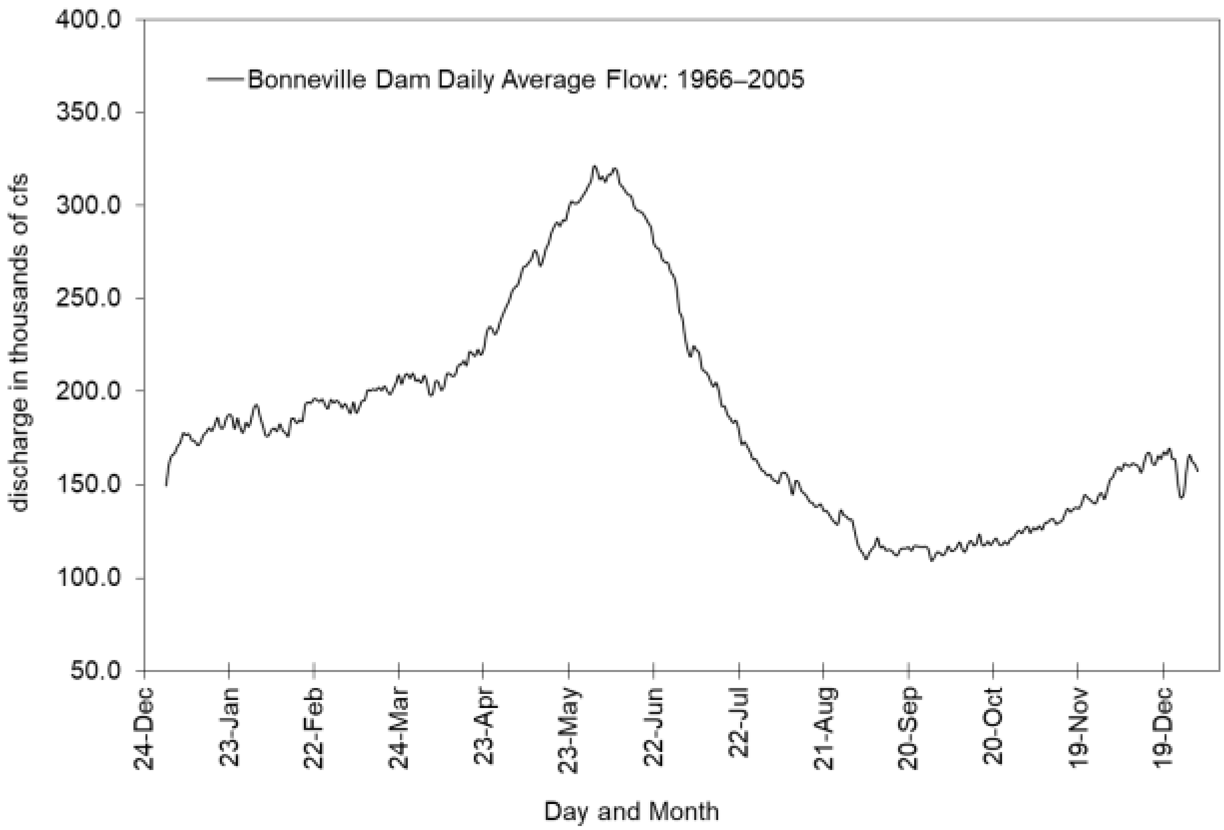



**Figure 26. Daily average Columbia River flow measured at the output of Bonneville Dam, averaged over the years 1966–2005. Flow is typically low during late fall through spring, when tributary peak flows are most likely to occur (due to rain events).** Data source: University of Washington Columbia Basin Research - Columbia River online data access in real time (DART)

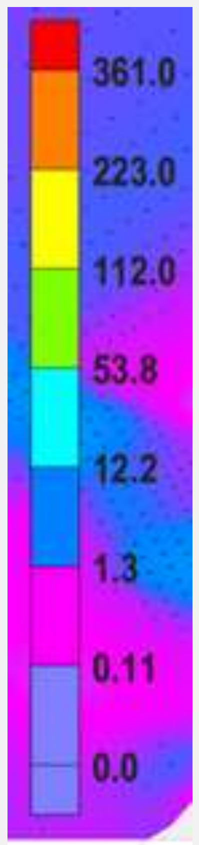
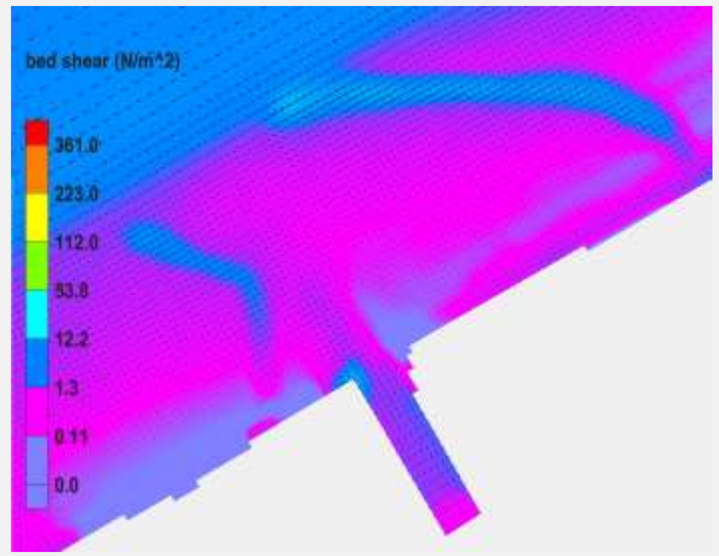
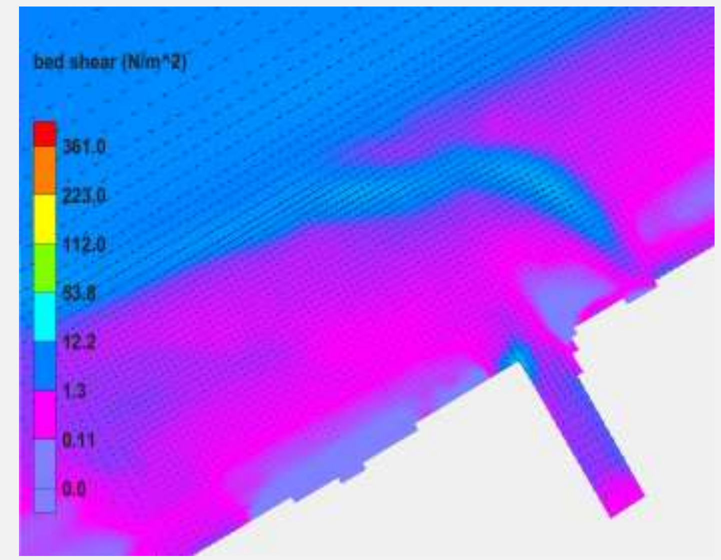
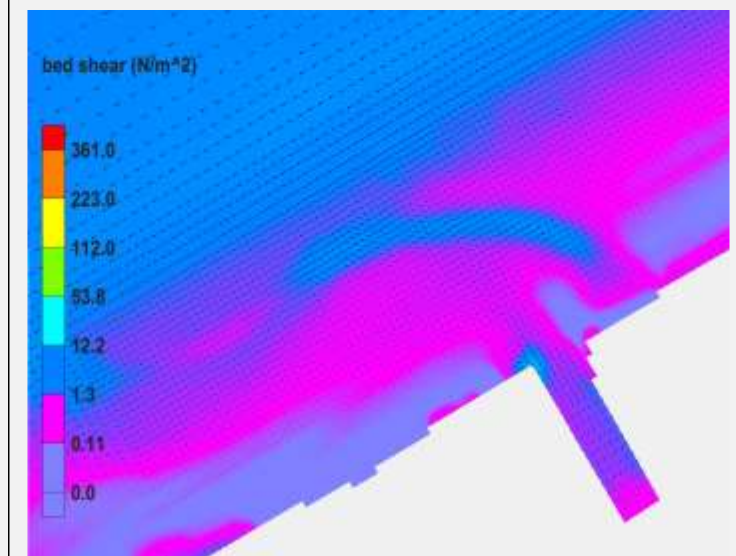
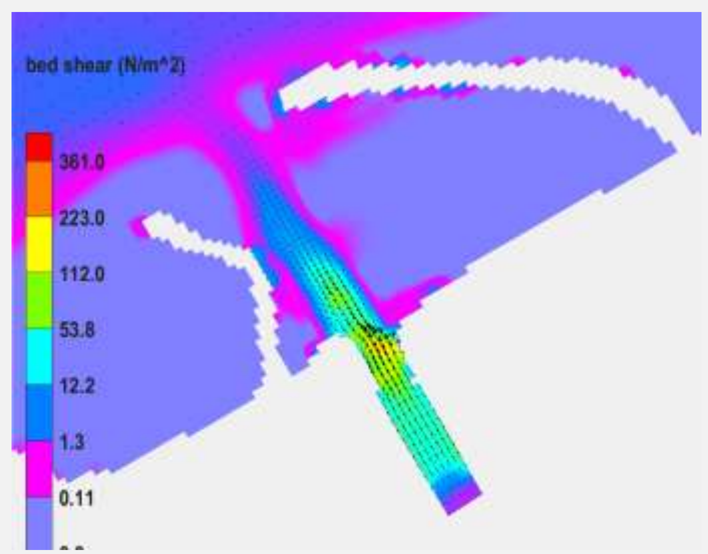
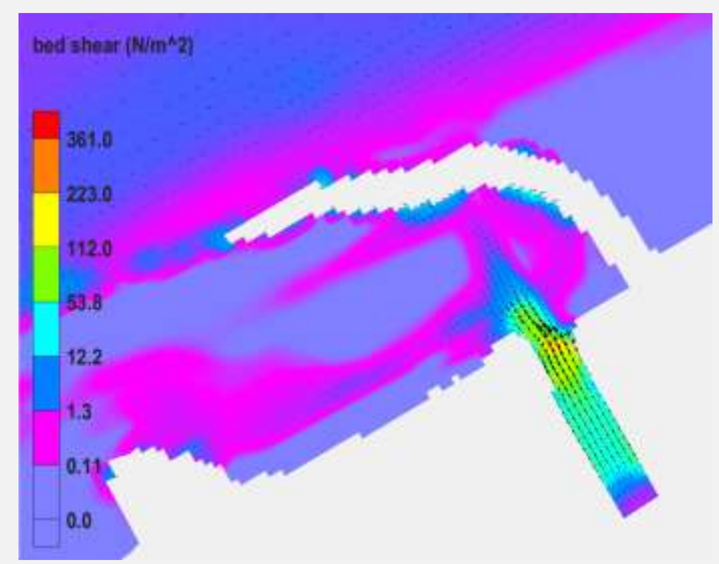
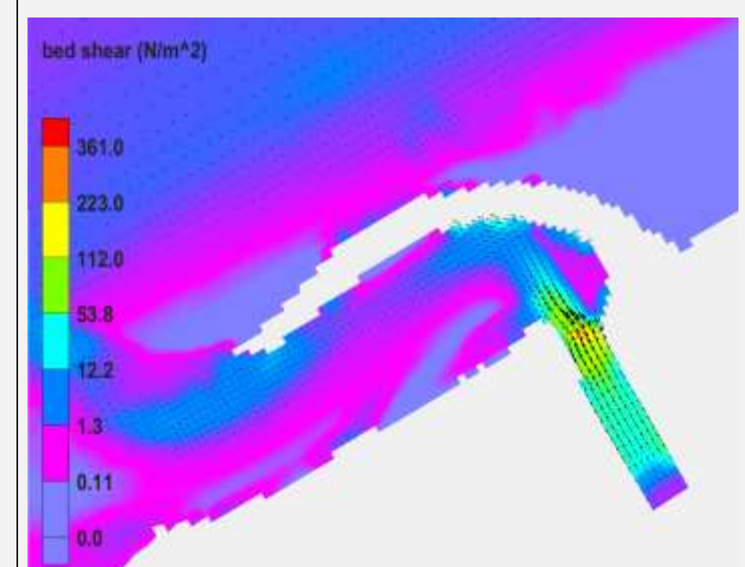
<table>
<tr><th colspan="5">Alternatives Analysis - Goal 3 Model results</th></tr>
<tr><th>Objective</th><th></th><th>Alternative 1</th><th>Alternative 2</th><th>Alternative 3</th></tr>
<tr><td>Model Results - 390,000 cfs Columbia River Flow (~Q2) and 720 cfs from Horsetail/Oneonta (Q1)</td><td rowspan="2">Bed Shear ($N/m^2$)<br></td><td></td><td></td><td></td></tr>
<tr><td>Model Results - 175,000 cfs Columbia River Flow and 720 cfs from Horsetail/Oneonta (Q1)</td><td></td><td></td><td></td></tr>
</table>

***Figure 27 - Goal 3 model results: Steady-state hydraulic model results for predicted bed shear stress for Alternatives 1–3. Model used the input boundary conditions described in Section 3.4.2. Results shown in the top row are for Simulation #9 in Table 3; results shown in the bottom row are for Simulation #4 in Table 3***

***Table 7. Goal 2 and 3 Alternative Analysis Summary.***

| Alternatives Analysis - Goal 2 and 3 Metrics | | | | |
|---|---|---|---|---|
| **Objective** | **Metric** | **Alternative 1** | **Alternative 2** | **Alternative 3** |
| 2c: Minimize deflection of juvenile salmonids away from site and interior floodplain accessibility | current velocity at embayment entrance zone (ft/s) | 1.5 ft/s | 1.5 ft/s | 1.5 ft/s |
| 2d: Maximize natural shoreline habitat | Shoreline Length (ft) | 2200 ft | 2540 ft | 2185 ft |
| 3b: Design embankment topography to allow for evacuation of sand to occur at a 2-year or greater flow event on the Columbia River (Q1 in Horsetail/Oneonta) | bed shear stress | 1.3 $N/m^2$ | 1.0 $N/m^2$ | 12.0 $N/m^2$ |
| 3c: Design embankment topography to allow for evacuation of sand to occur at a 2-year or greater flow event on Horsetail/Oneonta creeks coupled with low Columbia River flows (175K cfs) | bed shear stress | 12.0 $N/m^2$ | 1.0 $N/m^2$ | 20.2 $N/m^2$ |

**KEY**

| | |
|---|---|
| (dark green) | Very much accomplishes objective |
| (light green) | |
| (light yellow) | Somewhat accomplishes objective |
| (light orange) | |
| (orange) | Does not accomplish objective |

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### 3.9.4 Selection of a preferred Alternative

The design team reviewed the model results and metric calculations to consider the selection of a preferred alternative. Alternative 3 was excluded from further consideration due to two factors: 1) the distance of the mouth of the embayment, and resulting detectable thermal signal, relative to the migration corridor in the mainstem Columbia River was deemed too great; and 2) potential challenges in constructability related to its proximity to the I-84 road prism. Alternative 2 performed well with respect to plume size and detectability, but poorly with respect to the potential of high flows to scour nuisance sand from the inlet of the embayment. Alternative 1 performed moderately well in both the Goal 1 and Goal 3 metrics.

Rather than selecting Alternative 1 or 2, we opted for a hybrid design that captures elements, and advantages, of both. The preferred alternative (detailed in Section 4) includes embankment structures that have been optimized for thermal refuge size and detectability; habitat features; and bed scour potential for elimination of sediment. As for Alternative 2, existing natural topographic features are utilized to the extent possible to optimize the cut-fill balance and associated project cost. The major improvements, relative to Alternatives 1 and 2, are summarized as follows:

1. Longer Shoreline – a more complex shoreline to provide more potential opportunity for juvenile habitat.
2. Larger embayment – moving the downstream embankment to tie into the existing high ground allow for expansion of the constructed embayment, with cool water zone located both upstream and downstream of the culvert.
3. Slightly extended upstream embankment – focused on delivering cold water further out into the main channel to improve detectability for migrating salmonids.

Model results for the preferred alternative are illustrated in Figure 28 and can be compared to the results shown above in Figures 25 and 27 for Alternatives 1–3. Table 8 summarizes the Alternatives Analysis for the preferred alternative based on model simulations and can be compared to Tables 6–7 for Alternatives 1–3.

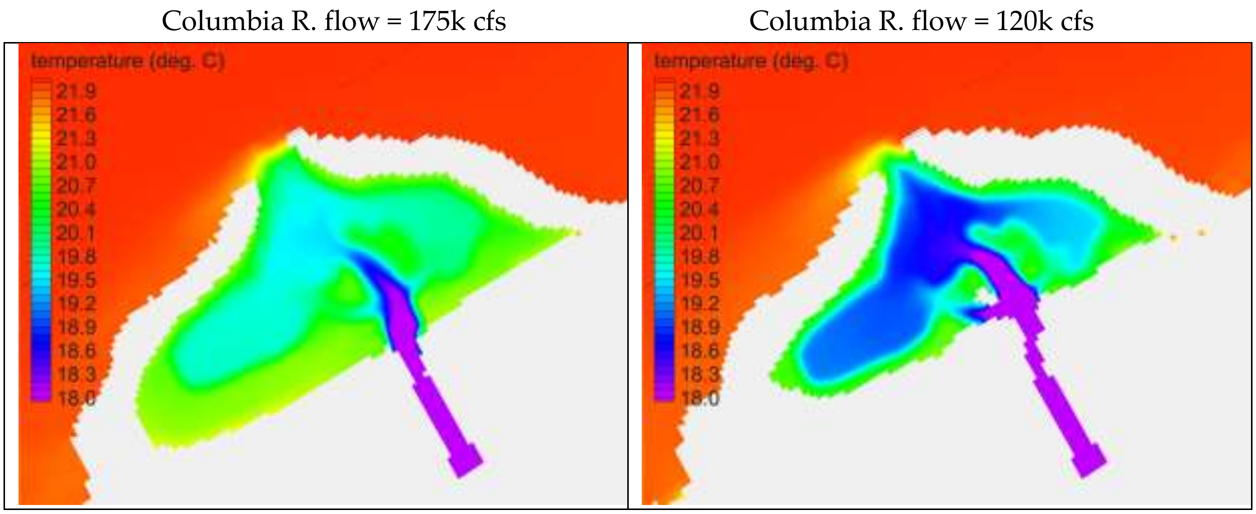



***Figure 28a. Steady-state temperature model results for the preferred alternative, with simulations #1 (left) and #2 (right) in Table 3 applied.***

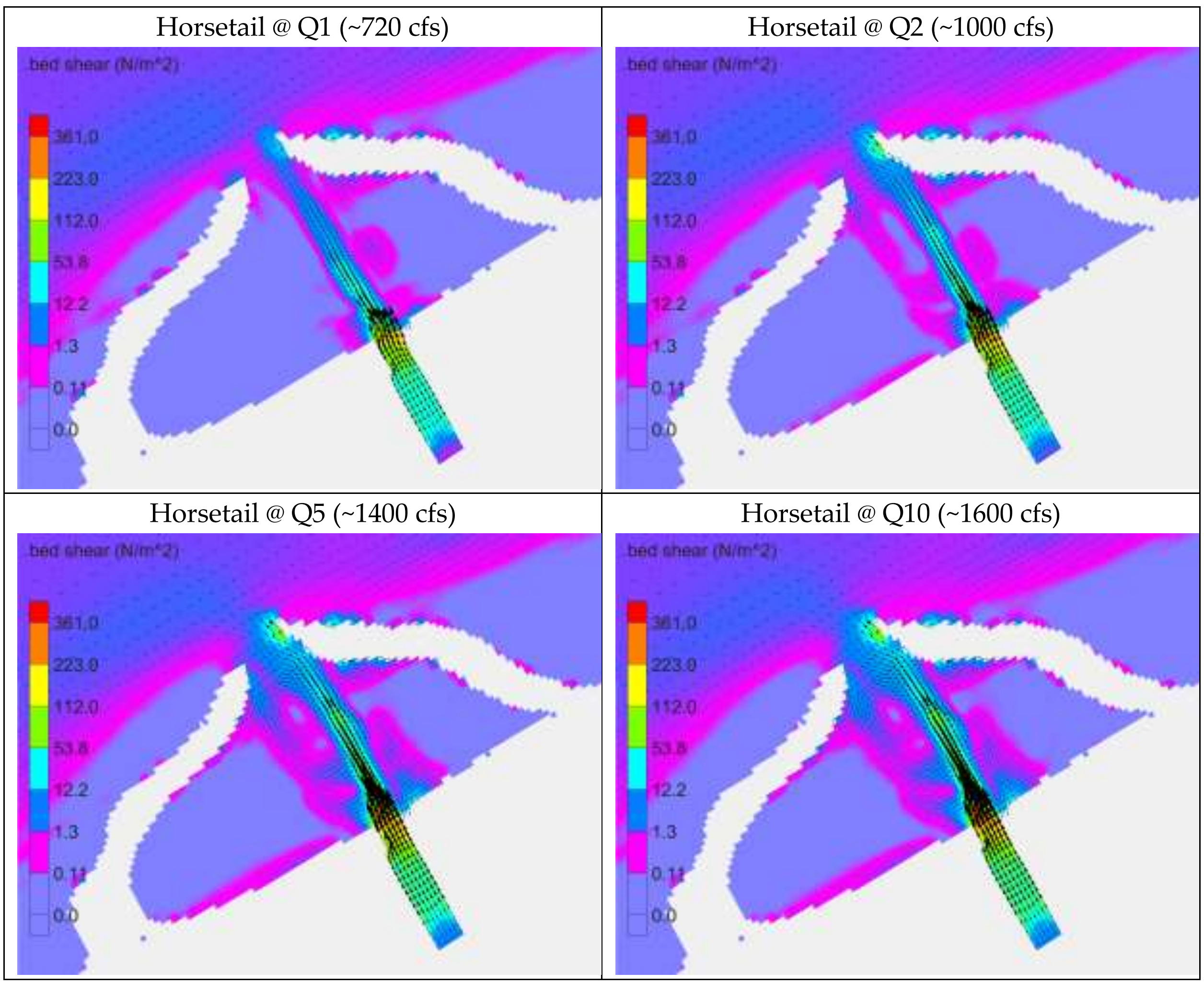



***Figure 28b. Steady-state bed shear model results for the preferred alternative, with simulations #4 (top left), #5 (top right), #6 (lower left), and #7 (lower right) in Table 3 applied.***

**Table 8: Goals 1–3 summary for the preferred alternative.**

| Alternatives Analysis - Goal 1 Metrics | | |
|---|---|---|
| **Objective** | **Metric** | **Preferred Alternative** |
| 1a/1d: Core thermal zone provided over summer baseflow conditions. (2°C cooler, 2m depth) | Maximum core zone plume size (acres) @ 120,000 cfs Columbia River flow | 1.14 acres |
| 1a/1d: Core thermal zone provided over summer baseflow conditions (2°C cooler, 2m depth) | Maximum core zone plume size (acres) @ 175,000 cfs Columbia River flow | 1.35 acres |
| 1b/1d: Transition thermal zone provided over summer baseflow conditions. (1°C cooler, 1m depth) | Maximum transition zone plume size (acres)@ 120,000 cfs Columbia River flow | 1.85 acres |
| 1b/1d: Transition thermal zone provided over summer baseflow conditions (1°C cooler, 1m depth) | Maximum transition zone plume size (acres) @ 175,000 cfs Columbia River flow | 2.3 acres |
| 1c/1d: Thermal zone is detectible within adult salmonid migration corridor (defined by depth between 2m and 10m) over summer baseflow conditions | Distance from plume to migration corridor @ 120,000 cfs Columbia River flow | 0 (plume extends to migration zone) |
| 1c/1d: Thermal zone is detectible within adult salmonid migration corridor (defined by depth between 2m and 10m) over summer baseflow conditions | Distance from plume to migration corridor @ 175,000 cfs Columbia River flow | 0 (plume extends to migration zone) |

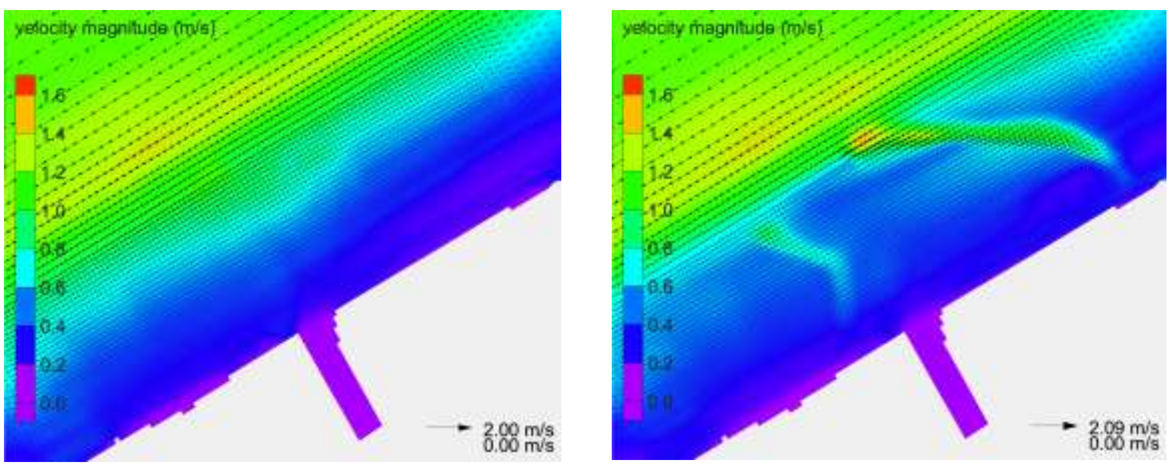
| Alternatives Analysis - Goal 2 and 3 Metrics | | |
|---|---|---|
| **Objective** | **Metric** | **Alternative 1** |
| 2c: Minimize deflection of juvenile salmonids away from site and interior floodplain accessibility | current velocity at embayment entrance zone (ft/s) | 1.5 ft/s |
| 2d: Maximize natural shoreline habitat | Shoreline Length (ft) | 2800 ft |
| 3b: Design embankment topography to allow for evacuation of sand to occur at a 2-year or greater flow event on the Columbia River (Q1 in Horsetail/Oneonta) | bed shear stress | 1.3 $N/m^2$ |
| 3c: Design embankment topography to allow for evacuation of sand to occur at a 2-year or greater flow event on Horsetail/Oneonta creeks coupled with low Columbia River flows (175K cfs) | bed shear stress | 20.2 $N/m^2$ |

### 3.9.5 Evaluation of Objective 2d – Potential Deflection of Migrating Juvenile Salmon

During the grant proposal review process, reviewers expressed concern that if implemented, the thermal refuge concept being evaluated in this project could potentially generate adverse current velocity fields that would negatively impact juvenile Columbia River salmonids migrating downstream. This would occur as velocities increase and are directed away from the shoreline in the vicinity of the upstream embankment structure, overwhelming the ability of juvenile salmonids to reach the interstate culvert and ultimately gain access to rearing opportunities in the Horsetail Creek floodplain. To address this concern, we established the objective of minimizing potential deflection of these fish during the peak migration time of spring through early summer (including the spring freshet) and analyzed hydrodynamic model results to evaluate the potential for deflection during this period as well as the low-flow summer period that we are targeting for providing thermal refuge. Because each alternative can be optimized for this objective through design changes, none offers advantages over the others and thus these results are presented here rather as part of the alternatives assessment.

- Peak migration period (spring freshet)

For all alternatives, embankment structures have been designed to overtop at flow magnitudes that exceed the maximum value (~175,000 cfs) for the targeted summer period for providing thermal refuge. Columbia River flows are typically significantly larger than this during the spring and early summer freshet period when most juvenile salmonids are migrating downstream, which means that these fish will be routed over the structures rather than around them, and thus remain close to the shoreline and potential floodplain access through the culvert. Model results shown in Figure 29 confirm this and suggest floodplain access might even be enhanced during this period, due to decreased current velocities present within the created embayment behind the upstream diversion structures. Based on these results we do not anticipate any negative impacts on the ability of juvenile salmon to access floodplain habitats in the vicinity of the proposed project.



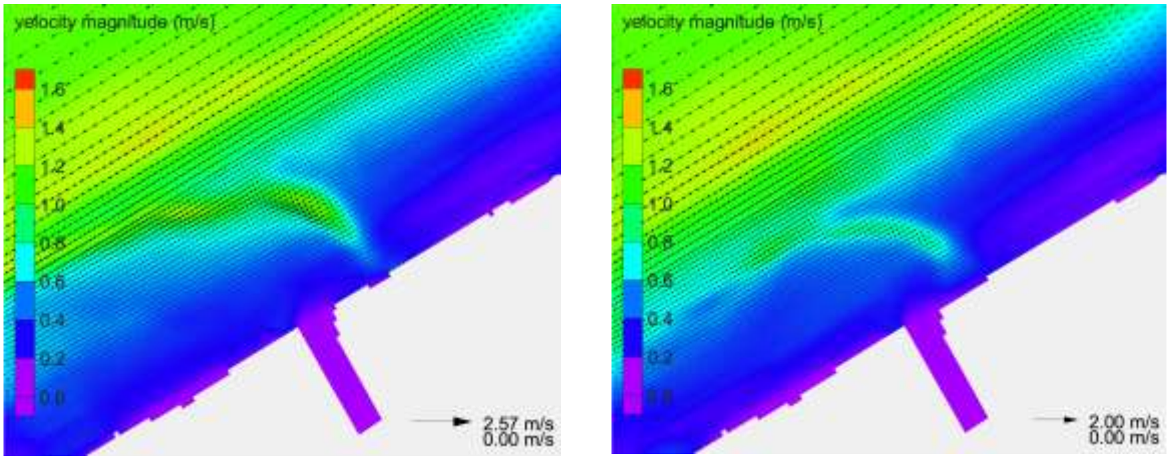



***Figure 29a - Simulated current velocity field in the project area for high flow conditions. Steady-state analysis, Columbia R. flow = 390,000 cfs.*** *Top left: existing condition; top right: Alternative 1; bottom left: Alternative 2; bottom right: Alternative 3.*

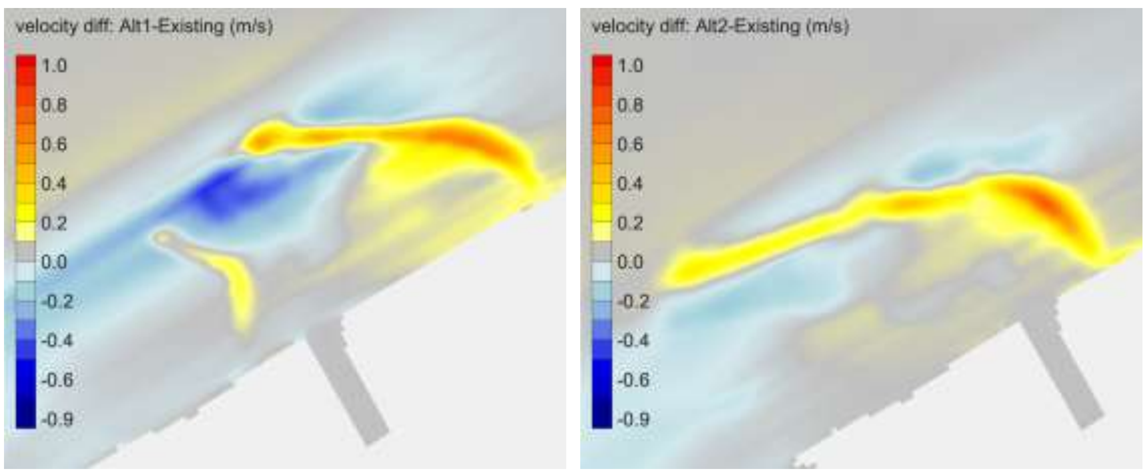



***Figure 29b - Difference in simulated current velocities between the Existing Condition and Alternatives 1/2.*** *Blue shades indicate decreased velocities, yellow/orange/red shades indicate increased velocities, relative to the Existing Condition. Left: velocity difference for Alternative 1 minus Existing; right: velocity difference for Alternative 2 minus Existing.*

- Thermal refuge migration period (summer)

Constructed embankment structures will be designed to provide thermal refuge in the summer and will thus deflect Columbia River flows and migrating juvenile salmonids around them during this period. The following lines of evidence, however, suggest that conditions created by the project will not appreciably impact the ability of these fish to access the floodplain relative to existing conditions:

1) Existing topography

Existing topographic conditions result in water depths ranging from 0 to 1.3 meters over the targeted flow range of 120,000–175,000 cfs for the summer period. This means that during a significant portion of the summer the project site is already either exposed or very shallow, limiting the amount of time that juveniles are provided reasonable access to the interstate culvert. This is confirmed by the summertime Google images shown in Figure 30, as well as model results for the existing condition shown in Figure 31.

***Figure 30 - Recent Google Earth Imagery taken during summer months, showing exposed riverbed in vicinity of project area.*** *Left: image from 7/23/19; right: image from 9/3/2018.*

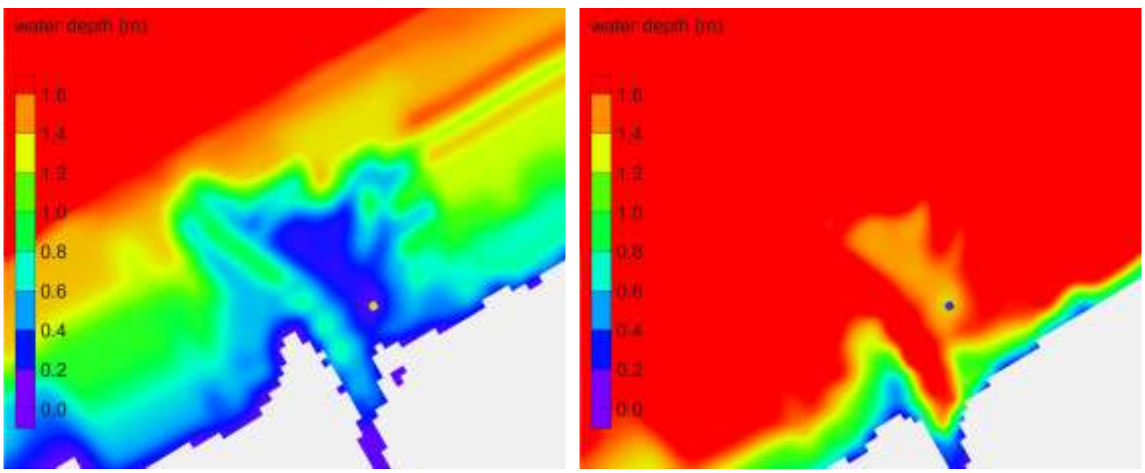



***Figure 31 - Simulated water depths in the project vicinity under existing conditions. Steady-state analysis.*** *Left: Columbia R. flow = 120,000 cfs; Right: Columbia R. flow = 175,000 cfs.*

2) Modeled current velocity field

Simulated velocities of flow directed around the constructed embankments, shown in Figure 32, do not show significant increases in magnitude nor changes in direction. Therefore, it is expected that fish migrating close to the shoreline would remain close to these structures, detect the thermal gradient and easily be able to enter the embayment, and potentially the culvert and floodplain habitat.

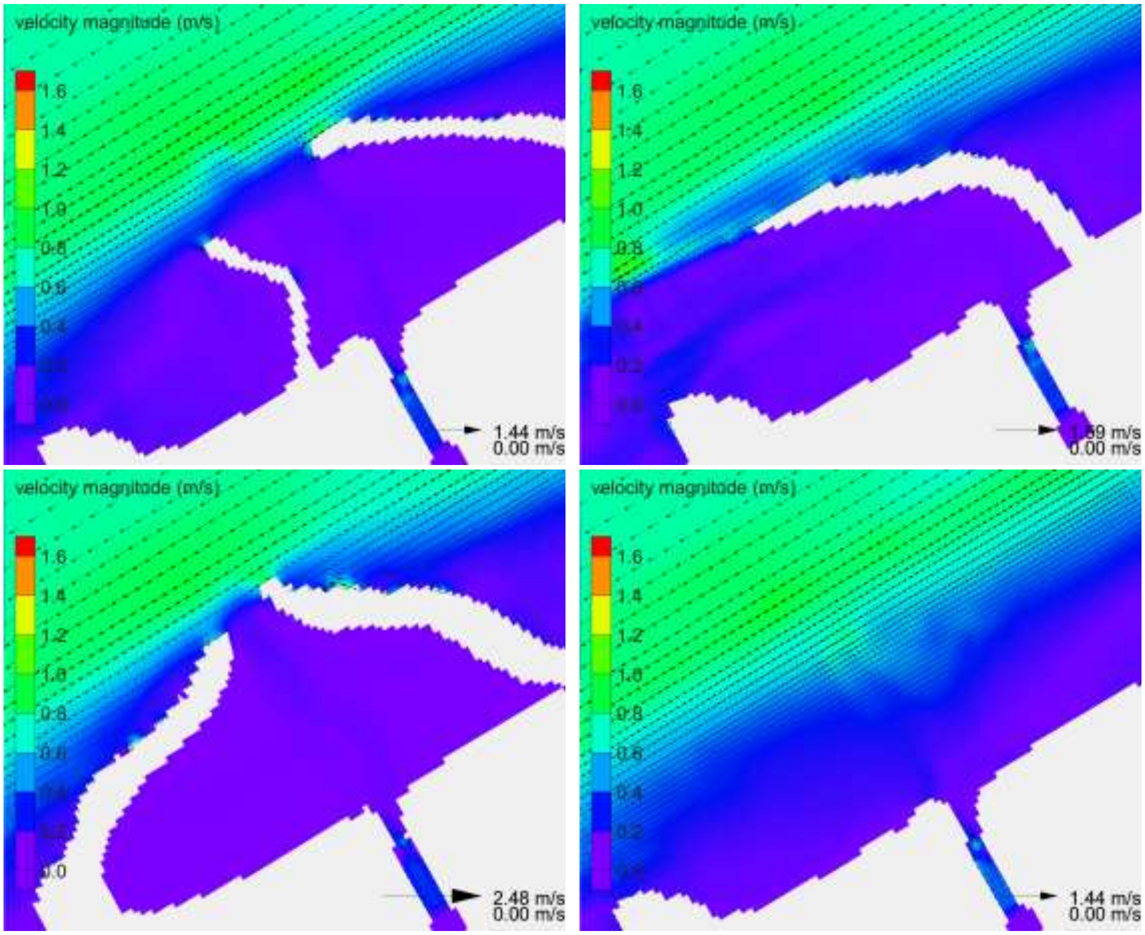



***Figure 32 - Simulated current velocity field in the vicinity of the proposed embankment structures. Steady-state analysis with Columbia River flow = 175,000 cfs.*** *Top left: Alternative 1; top right: Alternative 2; bottom left: preferred Alternative (30% concept design); bottom right: Existing condition (included for reference)*

3) Literature review

We searched relevant literature to try to determine the most likely depth and distance from the shoreline that juvenile salmonids migrating downstream through the project reach are utilizing. As noted earlier, Carter et al 2006 (the most recent and comprehensive source that we could locate) suggests a significant degree of uncertainty as to where Chinook, steelhead, and sockeye smolts migrate in the Columbia River estuary, based on their data and an associated literature review. Within the Bonneville Reach, where the proposed project is located, the most likely locations noted in this study included the channel margins and the navigation channel proper. If this is the case it is unlikely that embankment structures created by this project would impede the migration of these fish since they would barely extend out to the channel margin, due to limits imposed by U.S. Army Corps of Engineers navigation requirements (see Section 3.6.1).

# 4. PRELIMINARY DESIGN

## 4.1 PRELIMINARY DESIGN ELEMENTS

The chosen alternative borrows features from each of the three alternative trial designs to form a new composite design. We rearranged the embankments, modified the embayment, and re-distributed the wood materials to try and get increased benefit for adult and juvenile fish. The reasoning for modification to each of these components and a description of their revisions is discussed in more detail below.

### 4.1.1 Embankments

***Description***

Embankment orientation and placement borrows from the modeling efforts conducted for the three trial alternatives. The placement borrows heavily from option 1 with two embankments but reorients their locations to provide an increased embayment area with additional diversity in internal features. The embanks also have a more refined sectional profile with the riverward sides having much gentler slopes to improve wave erosion resistance and provide increased benefit to downstream migrating juveniles that use shallow gravel slopes for foraging in the early spring.

Each of the two embankments will be composed of three separate layers. The first two layers are similar in character to rubble mound jetty structures described in USACE EM 1110-2-2409. The first layer is core material, which will be well graded sand/gravel of a size that is consistent with gravel sediments native to the system. The second armor layer will be designed for wave heights of ~ 3 feet and consists of a 36" layer of riprap with a median size of 16" and maximum diameter of 24" (ODOT Class 700). These two layers compose the "stability core" of the embankments. This core will be topped with material dredged from the adjacent embayment to reach the topographic characteristics of the design. For those areas above the normal water surface of the Columbia the intent is to provide a suitable medium for the establishment of native vegetation.

The material removed from the embayment is likely to be initially placed as a slurry of material, which will need to be allowed to drain before shaping to finished grade. The design includes containment berms, which can be filled with the slurry of excavated sand and gravel material and be allowed to drain. The current design utilizes coir wrapped straw bale containment berms as a low-cost strategy, but other similar containment strategies (e.g. coir logs) may be considered in future design phases. These structures will help keep this fill in place in the short to medium term while vegetation is being established. A 12" layer of core gravel material will be placed on the riverward side of the embankments to provide additional resistance to wind derived waves and boat wakes.

***Anticipated Benefits***

- Embankments should provide a complex and vegetated living shoreline emulating natural conditions found along the banks of the Columbia in this area.

- Outer slopes flooded during the late winter and spring should provide foraging habitat for downstream migrating juveniles.
- Interior slopes should provide a range of habitat types (slope and substrate diversity) depending on water level.

***Constructability Considerations***

- Work window – if work is conducted during the winter months, construction will likely occur in depths of 4-6 feet of water. If work is conducted during the summer, construction is likely to occur primarily in depths of 1-2 feet. In either scenario, deeper water would be present at near the outboard tie-in to the Columbia River.
- Substantial turbidity containment suitable for a lotic environment (with tide changes) that includes wind and boat generated waves will be required to isolation the work area.
- Active commercial navigation channel will influence mobilization of equipment, staging, material deliveries and demobilization.
- Construction materials (LWD, gravels, ballast, erosion control fabrics, revegetation) import will be critical, and may need to occur during high water to allow to access by barge.
- Construction of topography at depth will require monitoring of material placements to assure materials conform to design intent.
- It is unknown at this time how much of excavated materials on site will be suitable for embankment construction. Current designs balance the excavation cut with the embankment fill.

### 4.1.2 Embayment

***Description***

The embayment configuration for the preferred alternative takes its primary shape from the trial alternative 1 with some additional details to improve variability/diversity of habitat. The increased diversity comes from the creation of deltaic landforms that mimic some of the current morphology of the site while having the added benefit of distributing Horsetail Creek flows more thoroughly into the embayment. Similar to the increased diversity in planform, is increased diversity in the depth of the embayment. Since the overall project is a pilot study for the evaluation of created thermal refuge, it is important to have a wide range of spatial characteristics. Variability in planform and depth is an effort to provide a range of opportunities. This variability comes with the understanding that while some site-specific locations may be preferred at some period and not others, it's important to have situations that can appeal to a wide range of seemingly suitable conditions through space and time.

Diversity in substrate and topography is believed to also provide a range of habitat that supports fish in different life stages and seasonal needs. LWD placed along the margins of the embayment will mimic the habitats preferred by juvenile rearing. Variable depths will provide diversity in holding habitats supportive of adults seeking thermal refuge.

***Anticipated Benefits***

- The embayment should provide a complex and variable habitat for a range of salmonid life stage needs with a primary focus on providing a thermal refuge for migratory adults.
- Similar to the embankment areas, the deltaic features internal to the embayment should exhibit a vegetated living shoreline, emulating natural conditions found along the banks of the Columbia in this area.
- Interior margins of the embayment should provide a range of habitat types (slope and substrate diversity) depending on water level.
- Depths for adult holding habitat will vary to provide diversity, encourage stratification of the Horsetail Creek's cool water plume and offset any macrophytic growth that may impact depths (overhead cover) with time.

***Constructability Considerations***

- Work window – if work is conducted during the winter months, construction will likely occur in depths of 4-6 feet of water. If work is conducted during the summer, construction is likely to occur primarily in depths of 1-2 feet. In either scenario, deeper water would be present at near the outboard tie-in to the Columbia River.
- Substantial turbidity containment suitable for a lotic environment (with tide changes) that includes wind and boat generated waves will be required to isolation the work area.
- Active commercial navigation channel will influence mobilization of equipment, staging, material deliveries and demobilization.
- Construction materials (LWD, gravels, ballast, erosion control fabrics, revegetation) import will be critical, and may need to occur during high water to allow to access by barge.
- Construction of topography at depth will require monitoring of material placements to assure materials conform to design intent.
- It is unknown at this time how much of excavated materials on site will be suitable for embankment construction. Current designs balance the excavation cut with the embankment fill.

### 4.1.3 Large Wood Structures

***Description***

The large wood structures identified for the preferred alternative have the same design intent for those found in the 3 trial design alternatives. These features provide immediate cover for foraging and rearing juvenile fish. With time, the living shoreline vegetation should be allowed to mature and naturally recruit to augment or replace these placed features.

The bank attached structures will be supported/ballasted mainly by attachment to vertical piles, and partially by burial. Whole trees will be utilized (both treetops with limbs intact and root wads) as components to these structures to provide the greatest habitat benefit. Smaller materials, including branches and finer woody materials will be placed within the main wood members to increase structural complexity.

***Anticipated Benefits***

- The primary roles for the LWD structures will be to provide juvenile rearing opportunities in a range of water depths less than 4 feet, and cover for adults in water depths greater than 4 feet.
- A secondary consideration for the structures is to provide internal structure to the embankments.

***Constructability Considerations***

- Work window – if work is conducted during the winter months, construction will likely occur in depths of 4-6 feet of water. If work is conducted during the summer, construction is likely to occur primarily in depths of 1-2 feet. In either scenario, deeper water would be present at near the outboard tie-in to the Columbia River.
- Substantial turbidity containment suitable for a lotic environment (with tide changes) that includes wind and boat generated waves will be required to isolation the work area.
- Active commercial navigation channel will influence mobilization of equipment, staging, material deliveries and demobilization.
- Construction materials (LWD, gravels, ballast, erosion control fabrics, revegetation) import will be critical, and may need to occur during high water to allow to access by barge.
- FTR attachments may need to be made above water, and then piles driven to depth.

***Stability analysis***

Stability analysis and computations for project elements will follow professional practice guidelines for large wood design (Knutson et. al. 2014 and USBR/ERDC 2016), stream habitat restoration (Cramer 2012), bank treatments (Cramer 2003), and institutional knowledge combined with professional judgment for the design of specific project elements. The project setting includes the I-84 road prism and associated culvert, recreational users (boating primarily), as well as commercial river use. While risk level will be evaluated at future design phases, considering the setting it is assumed that large wood structures will be ballasted to the 100-year flood with a conservative factor of safety. Detailed stability analysis documentation for project elements will be provided at 60%.

## 4.2 PLANNING-LEVEL COST ESTIMATE

A planning-level cost estimate for the project is provided in Table 9. Assumptions underlying these estimated costs are listed below the table.

**Table 9: Planning level cost estimate.**

| Horsetail Creek Thermal Refuge Pilot Project | | | | |
|---|---|---|---|---|
| Preliminary Engineer's Opinion of Probable Costs | | | | |
| July, 2021 | | | | |
| **Item** | **Unit** | **Quantity** | **Unit Cost** | **Subtotal** |
| **General Costs** | | | | |
| Mobilization and demobilization | 1 | LS | $401,000 | $401,000 |
| Environmental controls (SWPPP, hydraulic fluids, etc) | 1 | LS | $100,000 | $100,000 |
| Temporary Access (within the project area). | 1 | LS | $100,000 | $100,000 |
| Cofferdams, Diversions, Dewatering and Water Management | 1 | LS | $200,000 | $200,000 |
| | | | | |
| **Earthwork** | | | | |
| Embankment Armor Material - Import and Temporary Stockpile | 2090 | CY | $52 | $108,680 |
| Embankment Core Material - Import and Temporary Stockpile | 1320 | CY | $35 | $46,200 |
| Embankment Armor Material - Placement | 2500 | SY | $105 | $262,500 |
| Embankment Core Material - Placement | 1320 | CY | $15 | $19,800 |
| Excavation and Placement of in-situ matieral | 29660 | CY | $18 | $533,880 |
| Coir wrapped staw bale bank treatment | 20000 | LF | $10 | $200,000 |
| Gravel/cobble bank treatment | 12000 | SY | $18 | $210,000 |
| | | | | |
| **Large Wood Installation** | | | | |
| Logs with Rootwad - Provision and Preliminary Stockpile | 186 | EA | $800 | $148,800 |
| Logs with Rootwad - Import and On-site Stockpile | 186 | EA | $500 | $93,000 |
| Logs with Rootwad - Installation | 186 | EA | $500 | $93,000 |
| Vertical Snags - Provision and Preliminary Stockpile | 153 | EA | $500 | $76,500 |
| Vertical Snag - Import and On-site Stockpile | 153 | EA | $300 | $45,900 |
| Vertical Sngs - Installation | 153 | EA | $400 | $61,200 |
| | | | | |
| **Revegetation** | | | | |
| Seed and Mulch | 2 | AC | $12,000 | $24,000 |
| Planting | 2 | AC | $40,000 | $80,000 |
| | | | | |
| **Total** | | | | **$2,804,500** |
| | | | | |
| **Total + 30% contingency** | | | | **$3,645,900** |

The planning level cost estimate is based on the following assumptions:

- Gravel cobble bank treatment material will be imported (~ 4000 CY). If in-situ material is encountered, this cost may be significantly reduced.

- Armor and Core material will be delivered and dumped at an off-site temporary staging area. They will then be loaded onto a barge for delivery to the site.
- Excavation and placement of in-situ material unit cost estimate assumes use of a Cutter Suction Dredge is feasible.
- Large wood will be delivered and decked at either a barge loading area, or a location within 5 miles of the project site on the Washington side of the Columbia River, south of SR-14.
- Anchor hardware assumed to be incidental to large wood installation.
- Seeding and planting costs are assumed to be ~ 2 times as high as for similar sites with land-based access, to account for additional handling of plant materials and access costs.
- Seeding and planting is assumed to occur only in the elevation zones most conducive to permanent vegetation establishment (~ 14 ft and above, NAVD88, to be confirmed/refined by future vegetation surveys).

## 4.3 BEST MANAGEMENT PRACTICES THAT WILL BE IMPLEMENTED AND IMPLEMENTATION RESOURCE PLANS

### 4.3.1 Site access staging and sequencing plan

Site access will be by barge. One potential barge loading and staging area upstream of the site has been identified, but others may be utilized. The primary staging area will be the high ground on the downstream side of the site as shown on the construction drawings. The staging area cannot feasibly be located above the ordinary high-water elevation but will be located above anticipated water levels during construction. The plan described above and shown on the drawings is recommended for conformance with the permit requirements; however, a revised plan may be developed by the contractor for review and acceptance by the construction contracting agency. The revised plan may include changes in access routes, methods, staging areas, and sequencing so long as it is in conformance with permit requirements. The construction contractor will be responsible for adherence to and implementation of the accepted plan.

### 4.3.2 Work area isolation and dewatering plan

Work areas during construction will be isolated by the installation of Type 3 turbidity curtains, and de-fished prior to dredging, excavation, pile driving, and large wood placement. Surface water isolation measures may also include bulk bags to route Horsetail Creek away from the active work zone. Dewatering of the site will not be practical, but contractor may use local pumping of water to manage turbidity. The Drawings show recommended work area isolation measures; however, a final plan will be developed by the contractor for review and acceptance by the construction contracting agency. The construction contractor will be responsible for adherence to and implementation of the accepted plan.

#### 4.3.3 Erosion and pollution control plan

The project erosion and pollution control plan will be developed by the contractor for review and acceptance by the construction contracting agency. The construction contractor will be responsible for adherence to and implementation of the accepted plan.

#### 4.3.4 Site reclamation and restoration plan

All temporary construction access measures and staging areas will be returned to pre-project conditions or better. Where revegetation is required to restore pre-project conditions areas will be mulched and seeded with a native species mix.

#### 4.3.5 List of proposed equipment and fuels management plan

The construction contractor will be required to provide a list of proposed equipment and a fuel management plan for review and acceptance by the construction contracting agency. The plan will be reviewed and accepted by the construction contracting agency prior to mobilization. The construction contractor will be responsible for adherence to and implementation of the accepted plan.

### 4.4 CALENDAR SCHEDULE FOR CONSTRUCTION/IMPLEMENTATION PROCEDURES

To be completed in future design phases.

### 4.5 SITE OR PROJECT SPECIFIC MONITORING TO SUPPORT POLLUTION PREVENTION AND/OR ABATEMENT

The Contracting Officer, or their representative, will be on site frequently to monitor the construction Contractor's compliance with the approved pollution prevention plan and document any work done to abate site erosion, turbid water, or chemical spills.

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# 6. APPENDICES

## 6.1 APPENDIX A - PROJECT PLAN SHEETS

See accompanying project drawings: Horsetail Thermal Refuge Pilot Project: 30% Design Plans

## 6.2 APPENDIX B - HYDROLOGY ASSESSMENT

See accompanying file

## 6.3 APPENDIX C - GEOMORPHIC ASSESSMENT

See accompanying file

## 6.4 APPENDIX D - ALTERNATIVES PRELIMINARY MODELING ASSESSMENT

See accompanying file