

IMEQUES ACCLIMATION POND FACILITY STREAM AND FLOODPLAIN RESTORATION

UMATILLA RIVER

BASIS OF DESIGN REPORT 100% DESIGN

PREPARED FOR:



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1.0 PROJECT BACKGROUND

1.1 NAME AND TITLES OF SPONSOR, FIRMS AND INDIVIDUALS RESPONSIBLE FOR DESIGN

Sponsor:

- Jude Love, Confederated Tribes of the Umatilla Indian Reservation (CTUIR) Project Manager

Design Firm:

- Paul DeVries Ph.D., PE, Certified Fisheries Professional, Project Manager/Engineer of Record/Fisheries Scientist/Fluvial Geomorphologist
- Ben Cary, PE CFM, Senior Hydraulic Engineer

1.2 LIST OF PROJECT ELEMENTS THAT HAVE BEEN DESIGNED BY A LICENSED PROFESSIONAL ENGINEER

- Large Wood Structures
- Streambed Boulders
- Floodplain Riprap Removal
- Floodplain Connectivity Pilot Channel Excavation

1.3 EXPLANATION AND BACKGROUND ON FISHERIES USE (BY LIFE STAGE – PERIOD) AND LIMITING FACTORS ADDRESSED BY PROJECT

The project reach is located between the confluence with Meacham Creek and the Bingham Road bridge approximately 1.1 mile upstream (Figure 1). Key fish species of concern using habitat in the reach include spring Chinook Salmon (*Oncorhynchus tshawytscha*) and Endangered Species Act-listed Steelhead (*O. mykiss*), and Bull Trout (*Salvelinus confluentus*). Other native species of interest include resident Redband Rainbow Trout (*O. mykiss*), Mountain Whitefish (*Prosopium williamsoni*), Speckled Dace (*Rhinichthys osculus*), Pacific Lamprey (*Lampetra tridentata*) and Western Brook Lamprey (*L. richardsoni*) (USFS 2001). Most of these species are a First Food for the CTUIR. The reach is an important spawning area for spring Chinook Salmon. The CTUIR's Imeques acclimation pond facility is located within the project reach. Salmon and steelhead smolts are allowed to emigrate directly into the middle of the reach from the facility via its outfall.

Geomorphic processes, floodplain connectivity, and accompanying habitat for these fish species within the reach have been influenced by historic grazing and agriculture, tree harvest/clearing, and river training through riprap placement within the 100-year floodplain. There has been a resulting decrease in channel complexity, lack of instream woody materials, loss of floodplain connectivity and an overall simplification of floodplain processes. The site also encompasses an important anadromous salmonid acclimation facility that is critical towards the restoration of depressed native salmon and steelhead stocks in the basin. As seen in Section 2.3, pool habitat is particularly limiting for holding and spawning adult Chinook Salmon during late summer/early fall months when elevated water temperatures may occur. With climate change, it is possible that summer water temperatures could become less favorable to Chinook Salmon in the reach. In addition, reduced instream habitat complexity has resulted in reduced habitat availability for juvenile steelhead. All of these species and others, including native amphibians, macroinvertebrates, freshwater mussels, and wildlife, can benefit from increased instream habitat complexity and thermal refuge habitat availability, more distributed flood energy dissipation, and a more diverse native vegetation riparian and floodplain forest.

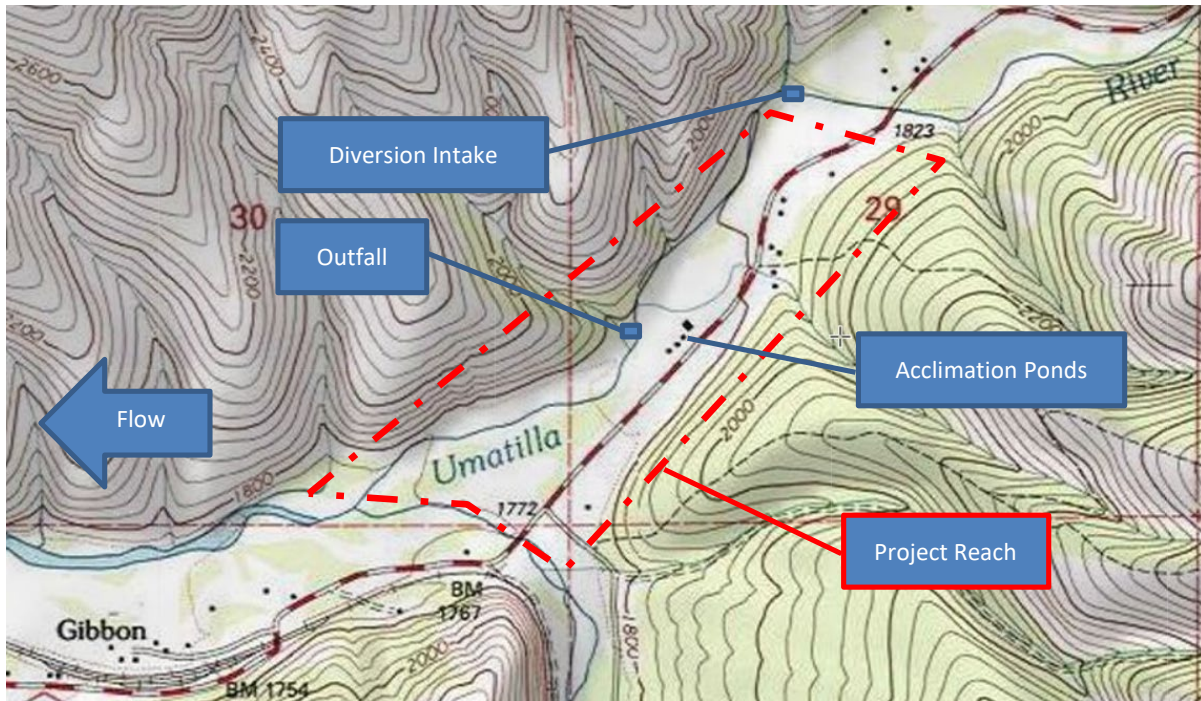


Figure 1. Location of project reach above confluence with Meacham Creek, and acclimation facility features.

1.4 PROJECT ELEMENTS

The CTUIR Department of Natural Resources is coordinating the development of designs for restoring channel and floodplain conditions and processes in the Umatilla River. The CTUIR desires that this project contributes to a riverine system which is shaped and maintained by the dynamic interactions and interconnections of its physical and ecological processes. An over-arching goal is to enhance ecosystem processes capable of producing first foods that sustain the continuity of the Tribe's culture. To accomplish that goal, this project is tied to the CTUIR's Umatilla River Vision (Jones et al. 2011) where the proposed restoration actions directly address and enhance the interconnected nature of the five primary 'touchstones' (hydrology, geomorphology, connectivity, riparian community and aquatic biota) by emulating or facilitating natural riverine processes and habitats. The CTUIR aims to address these limiting factors through direct restoration actions, with the goal of returning it closer to its historic, naturally functioning state, and increase fish habitat quantity and quality. At the same time, the CTUIR has a goal of avoiding increased flood impacts to the integrity and operation of the Imeqes acclimation pond rearing facility needed for recovery of salmon and steelhead stocks in the basin, and create conditions in the river channel that mitigate for coarse sedimentation impacts at the facility river diversion intake. Presently, the facility operation is threatened with inundation and erosion of the pond complex by large floods, and deposition of cobbles and gravels in front of the diversion intake screen thereby requiring periodic maintenance excavation of the riverbed in front of the diversion to ensure inflow needs of the project are met.

The CTUIR intends to accomplish the combined ecosystem restoration project and facility operational security goals by:

- (i) Removing riprap groin structures and bank armoring at selected locations upstream of the diversion to increase floodplain connectivity;
- (ii) Installing large wood debris (LWD) structures within the bankfull channel that create a variety of localized scour pool habitat, instream cover habitat complexity, substrate sorting, and increased roughness to restore and enhance channel migration and floodplain connectivity processes,

- create more defined split channel and vegetated island morphology, and replace the function of removed riprap groins with large wood material;
- (iii) Excavating small floodplain pilot channels to increase floodplain connectivity in a way that helps promote floodplain and riparian vegetation growth and extent, while at the same time not adversely affecting the diversion intake, acclimation ponds, and outfall of the Imeqes facility;
- (iv) Modifying floodplain roughness with LWD logs to reduce avulsion risk towards the acclimation pond complex location; and
- (v) Developing a planting plan to restore a floodplain and upland terrace forest community that more closely resembles historical conditions, reduces avulsion potential, improves wildlife habitat and cultural resources, and provides a future source of large wood to the channel.

1.5 DESCRIPTION OF PERFORMANCE / SUSTAINABILITY CRITERIA FOR PROJECT ELEMENTS AND ASSESSMENT OF RISK OF FAILURE TO PERFORM, RISK TO INFRASTRUCTURE, POTENTIAL CONSEQUENCES AND COMPENSATING ANALYSIS TO REDUCE UNCERTAINTY

Improvements in each River Vision touchstone condition are addressed by the design in the following ways, following the Physical Habitat Monitoring Strategy (PHAMS) framework of Jones et al. (2015):

Hydrology:

- Reconnect surface and groundwaters to increase the diversity of water temperature, increase floodplain storage capacity, and increase summer baseflow, by increasing frequency of floodplain connectivity during spring high flows.

Geomorphology:

- Increase frequency of floodplain connectivity to promote floodplain forest growth by excavating pilot channels at the floodplain edge, increasing instream roughness to raise flood water levels, and installing large wood to split high flows towards floodplain flow paths, and selectively remove riprap bank armoring.
- Increase in-channel habitat diversity by installing a wide range of types and sizes of large wood pieces individually and as small, modular structures to provide local scour pool and object/overhead cover habitat at numerous locations throughout the reach, feeding stations for juvenile salmonids and native fish species, and holding habitat for migrating adult salmon and trout.
- Increase spawning habitat availability by installing large wood pieces and streambed boulders to function as instream structure and in-channel roughness, which lead to additional sorting of spawning-sized gravel deposits in a largely depositional reach.
- Construct in-channel large wood structures and streambed boulder fields that promote local sediment deposition on bars to increase low flow sinuosity and thalweg persistence in front of the existing diversion intake, thereby promoting river processes to keep the intake clear of coarse substrates, and that direct higher flows towards a crib jam on the outside of the bend downstream of the diversion, to promote formation and maintenance of a deeper pool in the reach.

Connectivity:

- Improve hyporheic and groundwater influence on stream channels by increasing floodplain hydrologic connectivity in the manner described above.

Riparian:

- Restoring future native riparian and floodplain forest vegetation by increasing floodplain connectivity, promoting deposition and persistence of gravel bars for cottonwood colonization, and planting native conifer species suited for current land cover conditions, in anticipation of future channel migration.
- Increase future source of LWD for channel geomorphology and beaver habitat creation.

Aquatic Biota:

- Increasing habitat quantity and quality for native fish species through the collective actions identified above. In particular, by constructing numerous smaller large wood structures and distributing them throughout the reach for the same cost as constructing a smaller number of large structures, the project distributes risk and accounts for behavioral (e.g., territorial) and predation factors that can limit carrying capacity of individual pools.

Most of the project reach, which lies entirely within the boundaries of the Umatilla Reservation, encompasses lands owned by BPA and CTUIR. The right bank between the diversion intake and bridge is private property. Flooding and erosion risks are greater upstream of the facility outfall. Downstream of the outfall, there are no private property, structures, or infrastructure at risk. The general strategy to minimize risk upstream of the outfall is to implement low-impact actions that have minimal effect on flood levels and routing of overbank flows that would affect the Imeqes facility and the right bank private property. There are presently no anticipated significant increased flood risks to the bridge and road infrastructure. Hydraulic modeling indicates the low chord of the bridge is more than 5 feet above the predicted 100-year flood water surface elevation (WSE) under existing conditions. The design was developed to minimize the potential for rise caused by planned enlargement of gravel bars opposite and downstream of the diversion intake. Hydraulic simulations using a 2-dimensional HEC-RAS model predict that while there will be localized raising and lowering of the water surface elevation in the vicinity of project actions, the overall areal extent of inundation during the 100-year flood would not change significantly.

1.6 DESCRIPTION OF DISTURBANCE INCLUDING TIMING AND A REAL EXTENT AND POTENTIAL IMPACTS ASSOCIATED WITH IMPLEMENTATION OF EACH ELEMENT

The contractor will be required to adhere to HIP IV conservation measures, which are included directly on the design plans. Instream work will be performed during the normal in-water work window of July 1-August 15. Measures implemented for sediment and erosion control, water management, and fish salvage and protection will involve use of temporary supersack-poly sheeting coffer dams to isolate specific work areas as needed, although most of the work can be performed with minimal disturbance in the channel proper. For example, embedded logs will be installed using a low impact construction technique that minimizes increased turbidity during log placement, where water flows into an excavated trench as the log is placed and then not allowed to flow back out. Small modular log jam structures where the excavation hole for vertical anchor post placement will be surrounded by supersack/sandbag cofferdams where needed; some will be constructed in the dry on gravel bars. Debris logs will be constructed in the dry. Boulder field placement will involve placing boulders onto the streambed and working them into the surface.

Total number of each type of structure depicted on the 90% design plans, and nature and approximate maximum associated areas of disturbance per item are as follows:

- 45 Embedded habitat logs – Rootwad scour hole in channel = 12 ft² / trench excavation in bank = 60 ft²
- 1 Crib jam – Excavation footprint = 1,800 ft²
- 14 Modular post assisted log jam structures – Excavation footprint = 800 ft²
- 156 Debris logs w/ vertical posts – Excavation footprint = 45 ft²
- 162 Streambed Boulders – Placement Footprint = 6 ft² (maximum)

2.0 RESOURCE INVENTORY AND EVALUATION

2.1 DESCRIPTION OF PAST AND PRESENT IMPACTS ON CHANNEL, RIPARIAN AND FLOODPLAIN CONDITIONS

Geomorphic processes, floodplain connectivity, and accompanying habitat for these fish species within the reach have been influenced by tree harvest/clearing, riprap and rock groin placement, and excavation and other bulk earthwork activities at various locations within the 100-year floodplain. These activities have led to limited instream and floodplain habitat complexity, and degraded floodplain connectivity and riparian condition. Current land use in the project reach is primarily the acclimation facility and rural residential. The riprap bank armoring and rock groin placement occurred along the left bank between the diversion intake and the bridge, presumably to protect the property downstream.

2.2 INSTREAM FLOW MANAGEMENT AND CONSTRAINTS IN THE PROJECT REACH

Flows in the project reach are unregulated and subject to negligible diversion upstream. Summer flows appear to reflect an unimpaired hydrology upstream.

2.3 DESCRIPTION OF EXISTING GEOMORPHIC CONDITIONS AND CONSTRAINTS ON PHYSICAL PROCESSES

The Project reach is located between the confluence with Meacham Creek and the Bingham Road bridge approximately 1.1 mile upstream (Figure 1). The channel in the project reach is a relatively steep (less than 1 percent gradient overall) plane bed with cobble and gravel substrates. For the most part, the overall depositional nature of the project reach limits deep pool formation, where most pools are small and in the form of obstruction scour around large wood. Bankfull widths in the upstream portion of the reach are between approximately 100 feet and 130 feet based on cross-section profile morphology in relation to the 2-year flood (see Section 3.6). Empirical predictions of 102 feet (Castro and Jackson 2001) and 113 feet (Lee and Julien 2006) are consistent with observations.

Channel planform predictions based on bankfull channel properties between the diversion intake and the bridge are equivocal, ranging from single channel (Leopold and Wolman 1957; Parker 1976; Ferguson 1987; van den Berg 1995) to borderline braided (Millar 2000, 2005; Eaton et al. 2010). A review of historical aerial photography confirmed that the project reach has been relatively active geomorphically, especially in the downstream half with episodic channel shifts in the vicinity of the outfall and downstream (Figure 2). There is some braiding and more channel migration in the lower half of the reach, which appears to be associated with a concave reach scale slope break in the vicinity of the confluence with Meacham Creek (Figure 3), a high sediment supply, and local flood flow expansion. The zone of instability extends approximately 1,000 feet upstream of the facility outfall, to where extensive erosion of the riparian zone and deposition and splaying of sediments on the floodplain occurred during the flood of record in 2020 (Figure 2).

Locations of existing LWD accumulations and pools were mapped on aerial photographs and locations surveyed in with the Real Time Kinematic Geographic Positioning System (RTK GPS) rover (Figure 4). Large wood accumulations consist primarily of single large trees with rootwads lodged on upper banks, on top of large gravel bars, and that had recently fallen into the channel through bank erosion. Large wood was not found to contribute to significant pool creation, where most pieces appeared to be transient (Figure 5). Accumulations of multiple pieces of large wood were generally absent from the upper reach above the facility outfall.

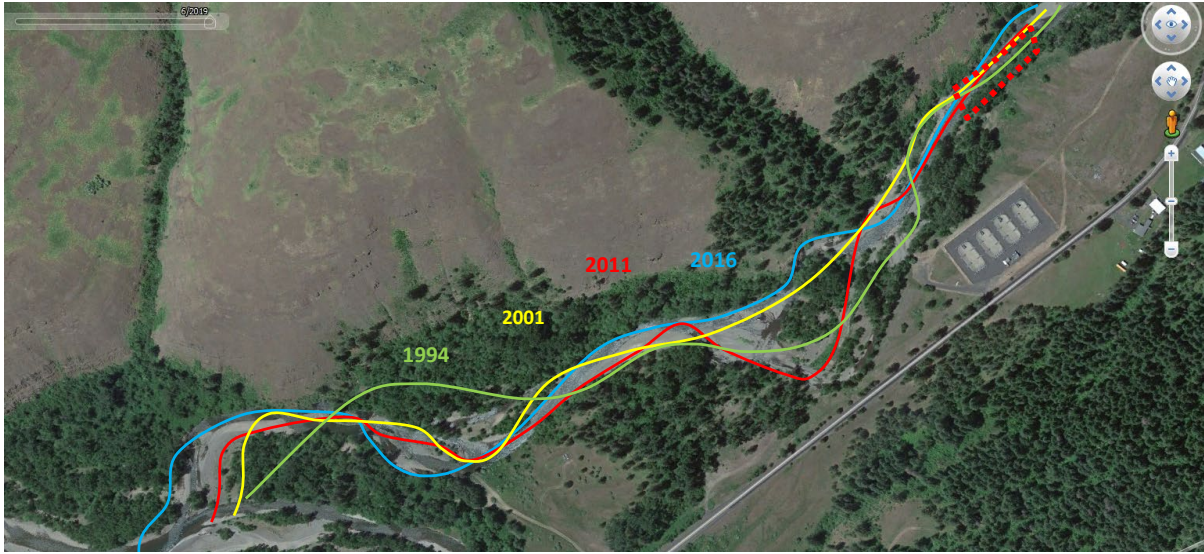


Figure 2. Approximate locations of main channel in lower half of project reach 1994-2019; derived from Google Earth historic aerial photos. Area of erosion that occurred in 2020 and that may affect the ponds is indicated by dashed red polygon.

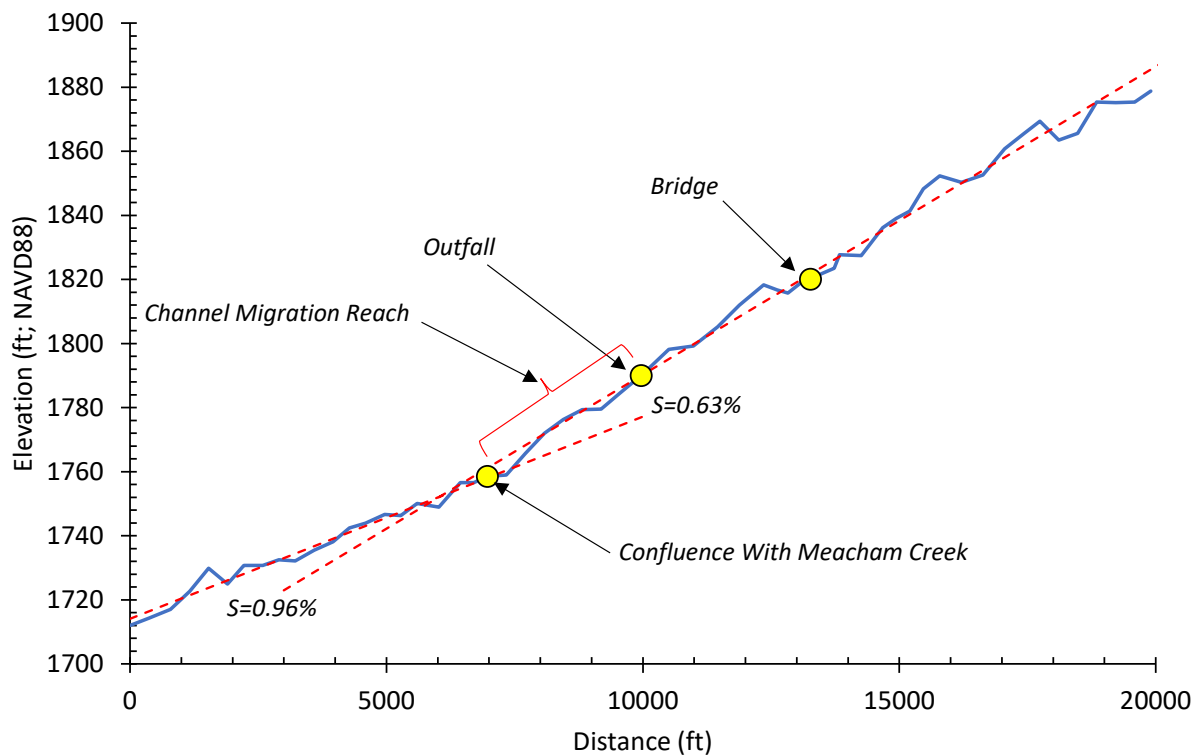


Figure 3. Approximate Longitudinal elevation profile extracted from StreamStats, with locations of significant landmarks and reach slope regression lines indicated.

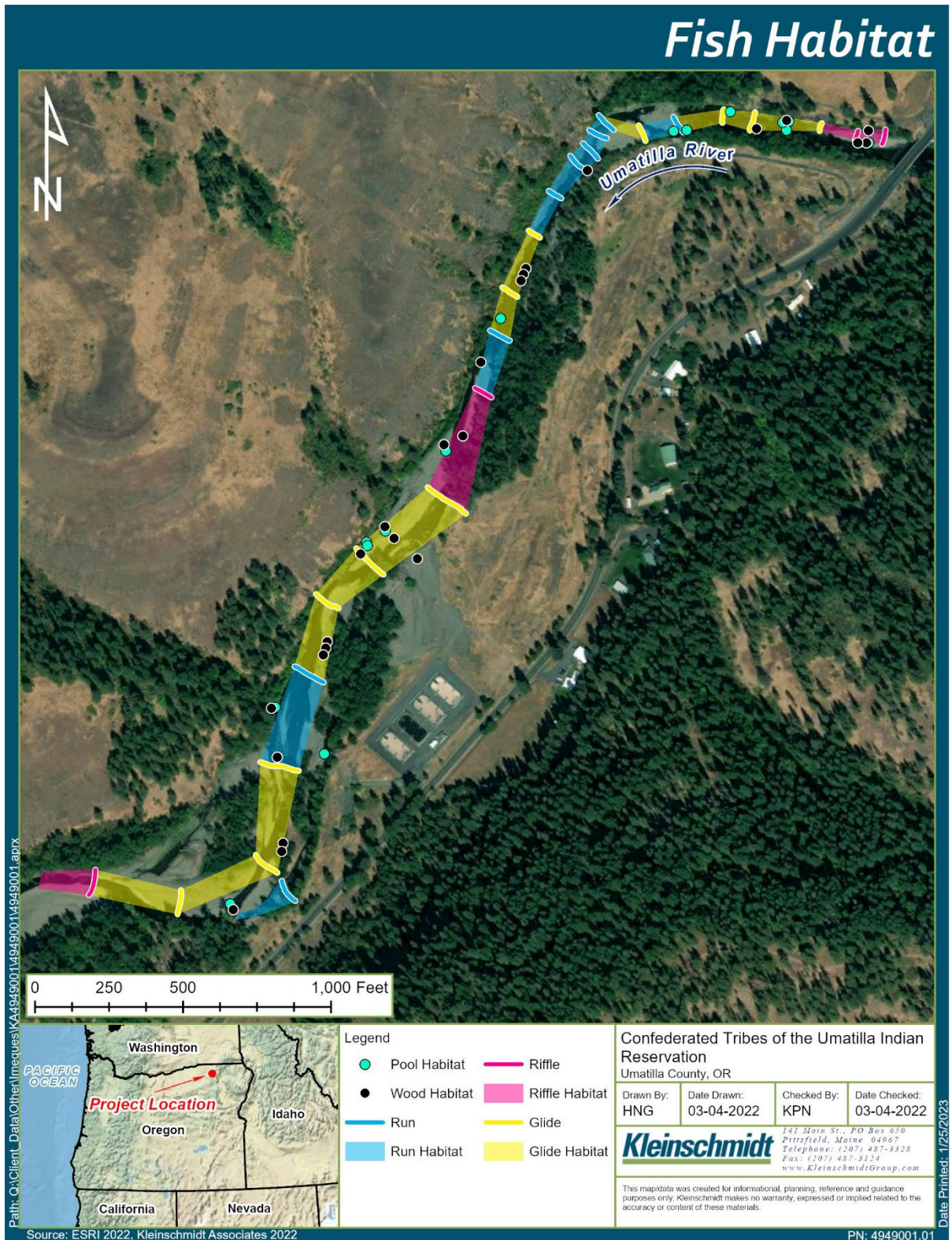


Figure 4. Locations of large wood accumulations, pools, and fish habitat mapped in the field at low flow.



Figure 5. Representative photographs of typical large wood pieces found in the project reach.

2.4 DESCRIPTION OF EXISTING RIPARIAN CONDITION AND HISTORICAL RIPARIAN IMPACTS

The riparian zone is a patchwork of alder, willows, and cottonwood trees and shrubs and bare riverbanks, with a few grand fir and Ponderosa pine observed. The pine are found in more open spaces, whereas the fir are found as undergrowth in more heavily forested patches. The floodplain forest downstream of the Imeqes facility supports a more diverse, predominantly native plant community than the floodplain forest upstream of the facility. Portions of the riparian zone, primarily upstream of the Imeqes facility, have been cleared for land use at higher elevations relative to the channel thalweg. Channel incision along this stretch has increased hydrologic disconnection of the river with the adjacent floodplain, resulting in a less diverse upland forest.

community that supports some non-native species (*Robinia pseudoacacia* and *Rubus armeniacus*). One lower lying area of the left bank riparian forest upstream of the ponds was washed out during the 2020 flood, resulting in an elevated riparian terrace that is further disconnected from the channel and that also supports non-native species (*Phalaris arundinacea*).

2.5 DESCRIPTION OF LATERAL CONNECTIVITY TO FLOODPLAIN AND HISTORICAL FLOODPLAIN IMPACTS

Lateral connectivity is depicted for existing conditions in Figures 6 and 7 for the 2- and 5-year flood, respectively. There is limited opportunity for floodplain connectivity upstream of the diversion intake because of the presence of an older, higher elevation relic terrace. In addition, avulsion potential is limited by riprap placed along the left bank. Lateral connectivity is more extensive currently downstream of the sharp bend in the river below the intake, as evidenced by a low elevation floodplain and deposition of gravel deposits on the floodplain as a splay feature in the direction of the acclimation ponds. This portion of the project reach has greatest sensitivity to actions that would increase floodplain connectivity. Below the outfall, the left bank floodplain is less frequently connected, where a relatively large area thereof is inundated at the 100-year flood. The right bank braided floodplain downstream of the outfall is lower elevation than on river left, and inundated more frequently. This lower, more connected portion of the floodplain also features a relatively large forested wetland and seep that is hydrologically connected to the main channel, and that is more extensively inundated during 2-year flood events.

This project includes partial removal of riprap and excavation of a pilot channel that would engage between the 1.5- and 2-year flood to increase floodplain connectivity. Measures are incorporated in the design to protect the existing buried diversion pipeline from scour, and redirect high flows back to the channel instead of towards the acclimation ponds. Two other opportunities were noted downstream of the outfall for increased engagement of the left bank floodplain at the 1.5- to 2-year flood level that would increase connectivity substantially. In addition, strategic placement of large wood at high flow splits within the lower elevation river right depositional braided reach could increase connectivity across that area.

2.6 TIDAL INFLUENCE IN PROJECT REACH AND INFLUENCE OF STRUCTURAL CONTROLS (DIKES OR GATES)

N/A

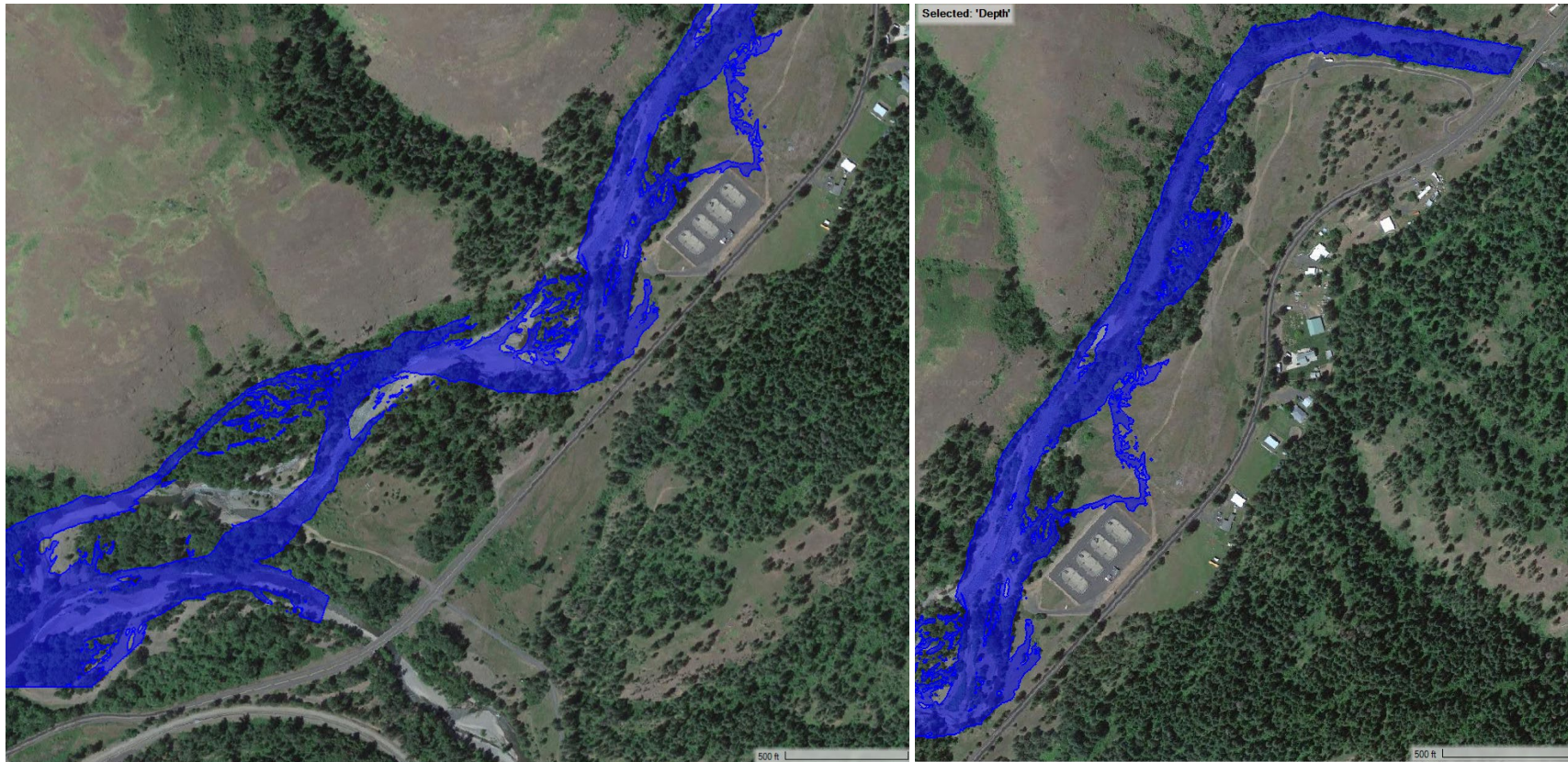


Figure 6. Simulated 2-year flood peak inundation boundaries in downstream (left) and upstream (right) portions of the project reach under existing conditions.

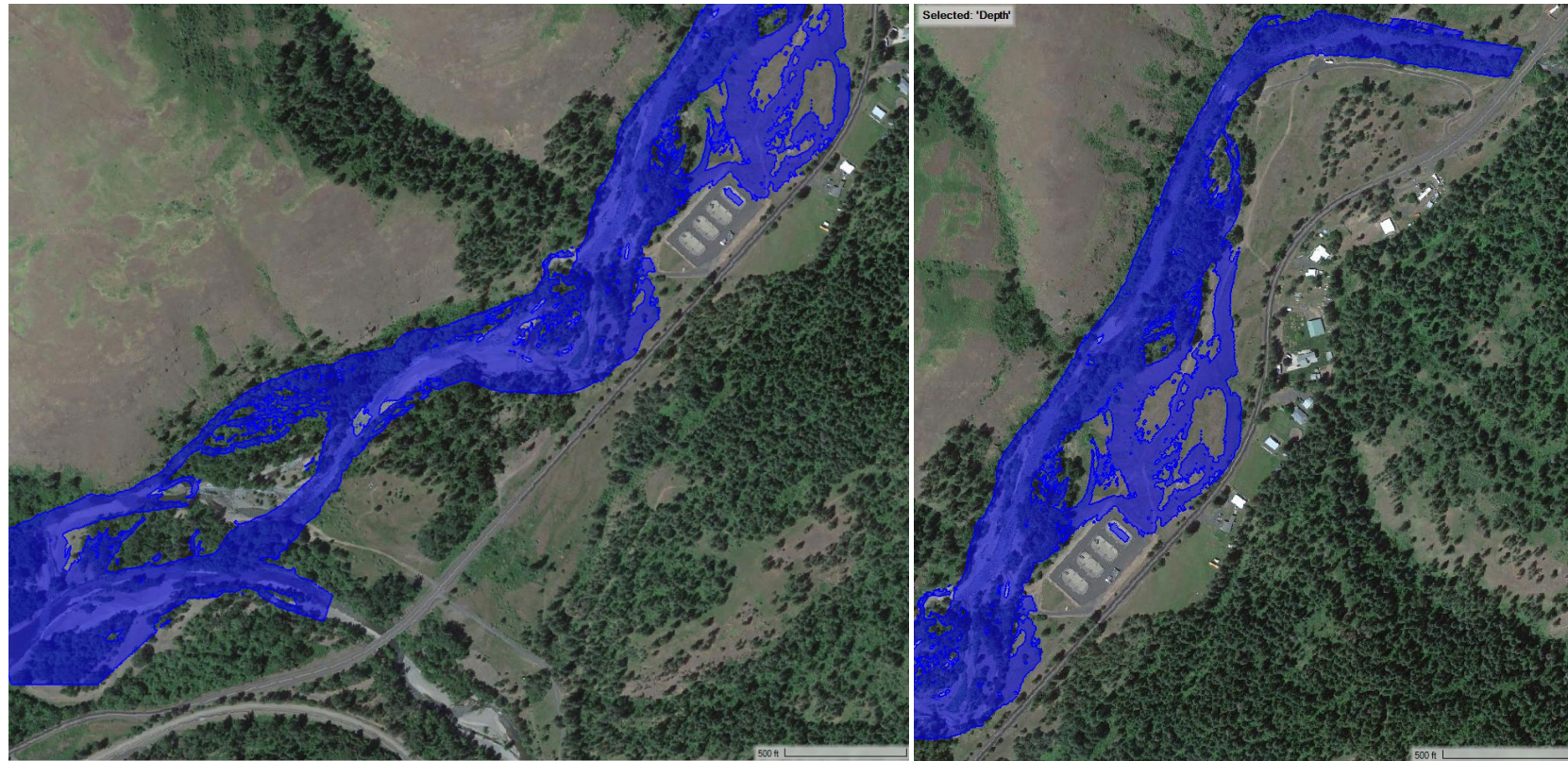


Figure 7. Simulated 5-Year Flood Peak Inundation Boundaries in Downstream (left) and Upstream (right) portions of the project reach under existing conditions.

3.0 TECHNICAL DATA

3.1 INCORPORATION OF HIP IV SPECIFIC ACTIVITY CONSERVATION MEASURES FOR ALL INCLUDED PROJECT ELEMENTS

HIP IV General Conservation Measures and Activity-Specific Conservation Measures are included in the plans as standalone sheets, one for general and the second for fish protection measures. Sheets are also included with project specific measures for temporary erosion and sediment control, water management, and access and staging requirements.

3.2 SUMMARY OF SITE INFORMATION AND MEASUREMENTS (SURVEY, BED MATERIAL, ETC.) USED TO SUPPORT ASSESSMENT AND DESIGN

CTUIR provided LiDAR terrain datasets and corresponding aerial photographs of the project area from collected in 2009, 2016, and 2020. The 2020 data were collected after a significant flood occurred earlier that year. It was necessary to supplement the 2020 LiDAR terrain data with bathymetry data and to ground truth the LiDAR data on the floodplain. Both types of data were necessary for developing a sufficiently accurate hydraulic model and CAD plan base map. Topographic and bathymetric point data were accordingly collected in the field in October 2021 using a RTK GPS rover and base station unit (Figure 8). The base station was set on an arbitrary point, and coordinates and elevations were adjusted based on surveyed control points with known coordinates and elevation identified in facility design plans developed by Montgomery Watson and provided by CTUIR. The design plan datums were NAD83 Oregon State Plane (horizontal) and NAVD88 (vertical). Point coordinates and elevations were collected across hydraulic controls, water surface and thalweg bed elevations along the longitudinal profile, at the corners of specific facility structures with known elevations, and at selected locations on the floodplain. The RTK survey of known as-built elevations of the top corners of the concrete diversion inlet and pond outfall structures indicated that a vertical conversion of 58.22 feet was needed to adjust the RTK survey elevations to match the known elevations of the local concrete structures. The horizontal coordinates of the raw data were converted to NAD83 coordinates through rotation and translation transformations that were calculated to minimize the sum of square errors in surveyed vs. known coordinates of the same control points used to establish the elevation correction.

The RTK data were compared against closest LiDAR point elevation. Most of the data appeared clustered relatively tightly about an average line, but there were several outlier points that were determined to have been collected in a side channel area directly adjacent to the hatchery outlet (Figure 9). This area is situated within a geomorphically active, depositional area upstream of the large-scale slope break (cf. Figures 2 and 3), and thus the topography likely changed after the LiDAR data were collected. After the outliers were removed, the remaining data appeared to have similar variance about an average line across the site elevation range. The corresponding offset appears to be a bias of +1.92 feet. The RTK bathymetry elevations were accordingly adjusted upwards by 1.92 feet prior to blending with the LiDAR data to generate a consistent terrain for the hydraulic model and CAD base map.

The 2020 LiDAR data (NV5 Geospatial, 2021) were combined with the adjusted RTK bathymetric survey data for a CAD base map and to support the development of a two-dimensional (2D) HEC-RAS hydraulic model for design and flood modeling. The CAD base map was adjusted later in 2024 for the 90% design using additional survey data collected by Kleinschmidt and CTUIR staff in December 2023 to reflect more recent changes in bathymetry in the vicinity of the intake associated with annual removal of sediment deposited in front of the intake.

The survey data indicate that average bankfull width is approximately 84 feet upstream of the outfall. The channel is wider downstream of the outfall because of the extensive deposition and channel migration that has occurred there.

Pebble counts were collected at four locations for characterizing the river bottom grain size distribution as it affects calculations of channel stability and sediment transport/deposition patterns in the reach.

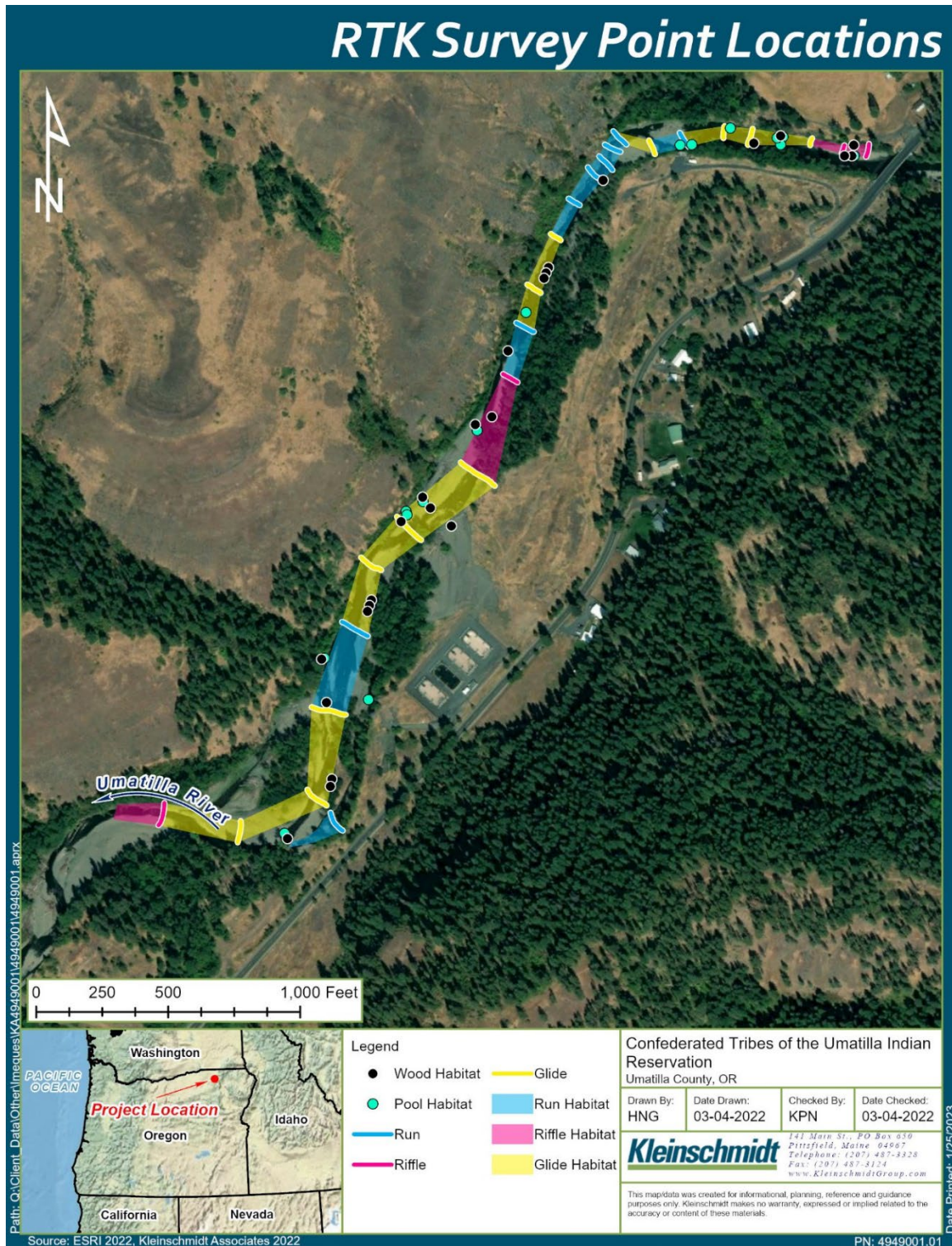


Figure 8. Locations of RTK GPS survey points collected in the field.

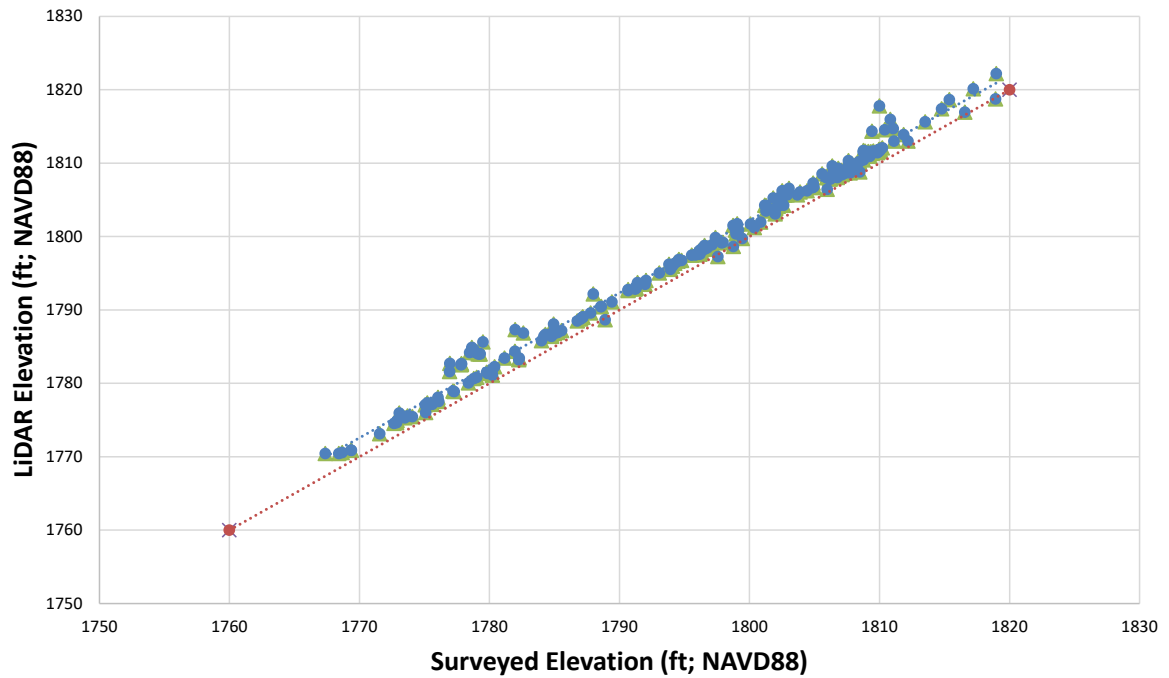
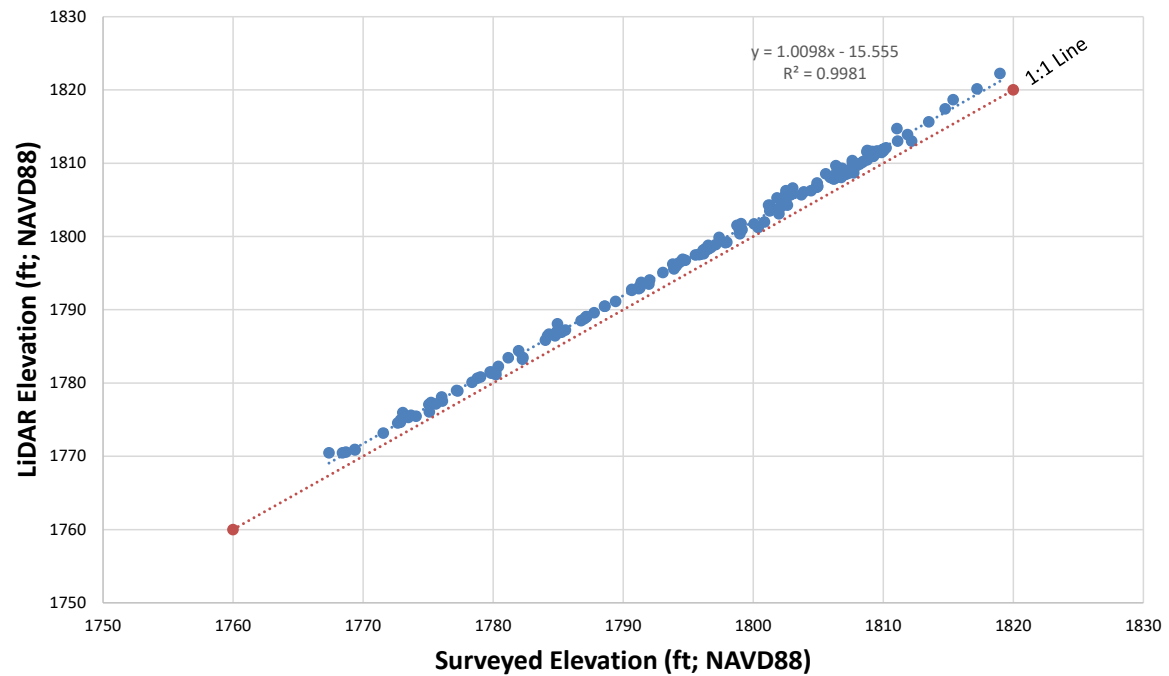


Figure 9. Comparison of RTK-GPS survey data with 'bare earth' LiDAR elevations: All data (top) and Filtered (bottom).

3.3 SUMMARY OF HYDROLOGIC ANALYSES CONDUCTED, INCLUDING DATA SOURCES AND PERIOD OF RECORD INCLUDING A LIST OF DESIGN DISCHARGE (Q) AND RETURN INTERVAL (RI) FOR EACH DESIGN ELEMENT

Hydrologic design flow parameters were estimated for the site using an active USGS gage (Station #14020000, Umatilla River Above Meacham Creek Near Gibbon, OR) located approximately one mile upstream with a period of record starting in 1933. Peak flow magnitudes were estimated for floods over a range of recurrence intervals using the USGS' PeakFQ program based on Bulletins 17B and Bulletin 17C (USGS 2019). Peak flows were first calculated for the USGS gage location and then adjusted to the site based on the drainage area using the correction equation (Cooper, 2006):

$$Q_u = Q_g (A_u / A_g)^a$$

Where Q_u and Q_g , and A_u (134 mi²) and A_g (131 mi²) are the peak flows and drainage areas at the ungaged and gaged locations, respectively. The exponent a was determined using the equations for each recurrence interval in Cooper's (2006) Table 24, where the other terms cancel when calculating the above ratios.

Flood flows were also computed for comparison with regional averages using USGS regional regression equations in the web-based StreamStats facility (USGS 2021), to evaluate for bias/prediction error in the longer interval events.

Daily flow duration curves were developed for the entire year and for the main November 15 – May 31 operation period, using average daily flow data at the gage.

The results were used to define hydrologic design flow parameters for both restoration and facility modification objectives.

3.3.1 PEAK FLOW ESTIMATES

Table 1 summarizes the estimated flood flows in the project reach. The regression estimates are lower than the gage-based estimates and the differences increase with longer recurrence interval (Figure 10). Given this increasing divergence of estimates, the more conservative flood peak estimates derived from the gage data following Bulletin 17C were used for developing designs.

Table 1. Flood magnitudes estimated for various recurrence intervals in the Umatilla River.

Return Period (Years)	Regression Flow (cfs)	B17B Flow (cfs)	B17C Flow (cfs)
100	6,000	6,970	7,220
50	5,220	6,020	6,180
10	3,580	4,030	4,050
5	2,890	3,240	3,230
2	2,020	2,160	2,140

3.3.2 LOW FLOW ESTIMATES

Figure 11 depicts daily flow duration curves for the gage, for various periods during the year. Winter base flows (November–February) are around 150 cfs. Flows during the bulk of the November–May diversion period are higher than this roughly 74 percent of the time, and exceed 80 cfs, thus meeting minimum instream flow requirements does not appear to be an issue for the facility.

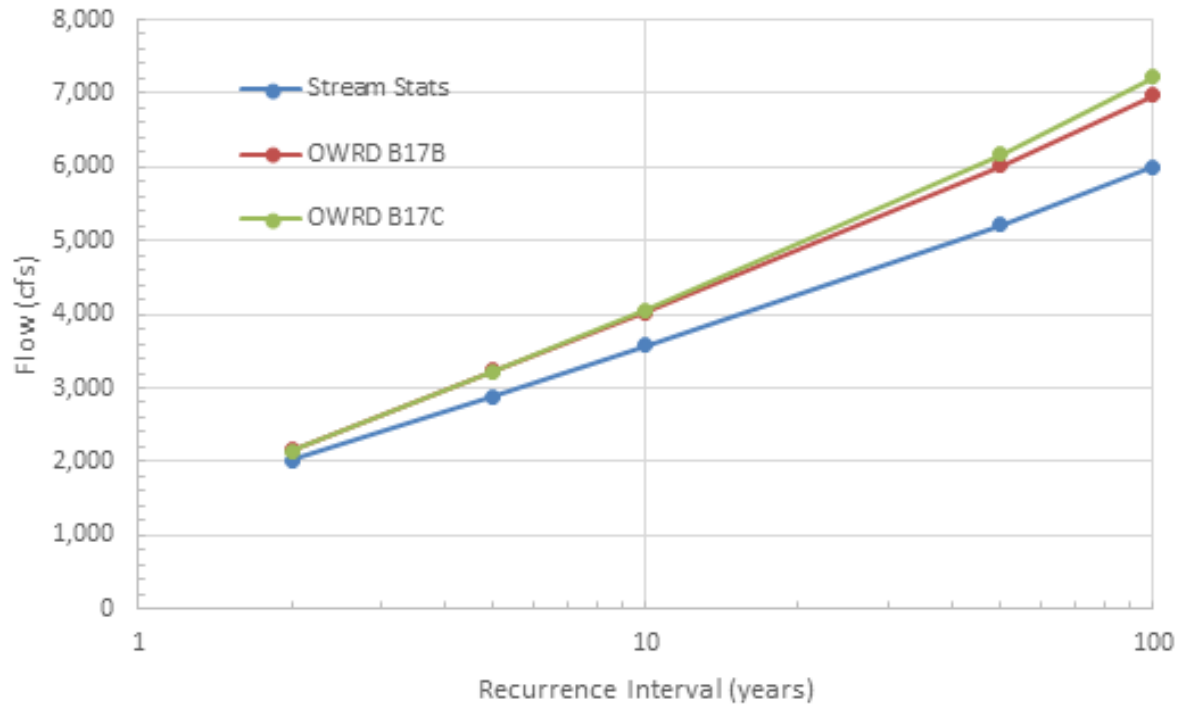


Figure 10. Comparison of peak flow estimates derived using different methods and data.

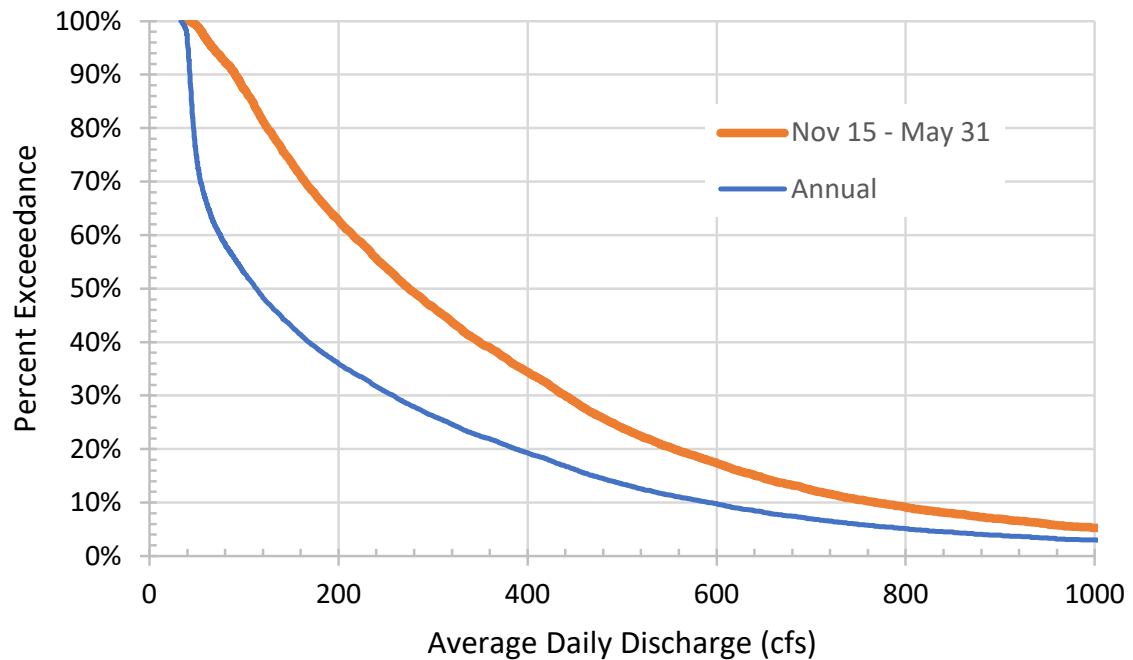


Figure 11. Daily flow duration curves for the USGS gage # 14020000; period evaluated = last 30 years to reflect more recent hydrology.

3.3.3 CLIMATE CHANGE

In using the design flows above, it is noted that peak and flow duration estimates derived from the USGS gage are based on historic climate conditions. Even when basing design function and performance on just the last 30 years of data and using the most conservative estimates of peak flow magnitudes, with climate change it is plausible that the flows may not be representative of Umatilla River hydrology in 20-40 years from now. Modeling assessments of climate change impacts to hydrology in the upper Umatilla River basin are associated with predicted lower volume snowpack, higher winter peak flows, and lower summer base flows. The loss of spring snowmelt is linked to a potential reduction in discharge from April-June, and earlier decrease to base flow in July (Yazzie and Chang 2017; Halofsky et al. 2018). Isaak et al. (draft publication) predicted runoff timing (center of flow mass) of all streams in the Blue Mountains ecoregion as a whole to advance 9 to 23 days earlier in the year, with the larger changes anticipated at higher elevations. This change in runoff timing is expected to co-occur increasingly with periods of maximum summer temperatures, which may be associated with loss of thermal habitat. Fish habitat in the Umatilla River could accordingly be influenced by climate change via increased channel instability associated with increased peak flows, reduced rearing habitat availability through lower summer flows, increased summer water temperatures, increased wildfire risk and its effect on erosion and sedimentation, and increased presence of invasive plant species (BMAP N.D.).

3.4 SUMMARY OF SEDIMENT SUPPLY AND TRANSPORT ANALYSES CONDUCTED, INCLUDING DATA SOURCES INCLUDING SEDIMENT SIZE GRADATION USED IN STREAMBED DESIGN

Pebble counts were collected at four locations for characterizing the river bottom grain size distribution as it affects calculations of channel stability and sediment transport/deposition patterns in the reach. Moving in the downstream direction, PC-1 was collected in the vicinity of the diversion intake, and PC-4 was collected approximately 1,000 feet upstream of the confluence with Meacham Creek. Pebble count grain size distributions are depicted in Figure 12. The data indicate that the project reach contains substrates suitable for spawning by both species, and the reach has been noted by the CTUIR to contain redds of both species. Project elements promoting accumulation and stability of spawning gravels would be considered beneficial.

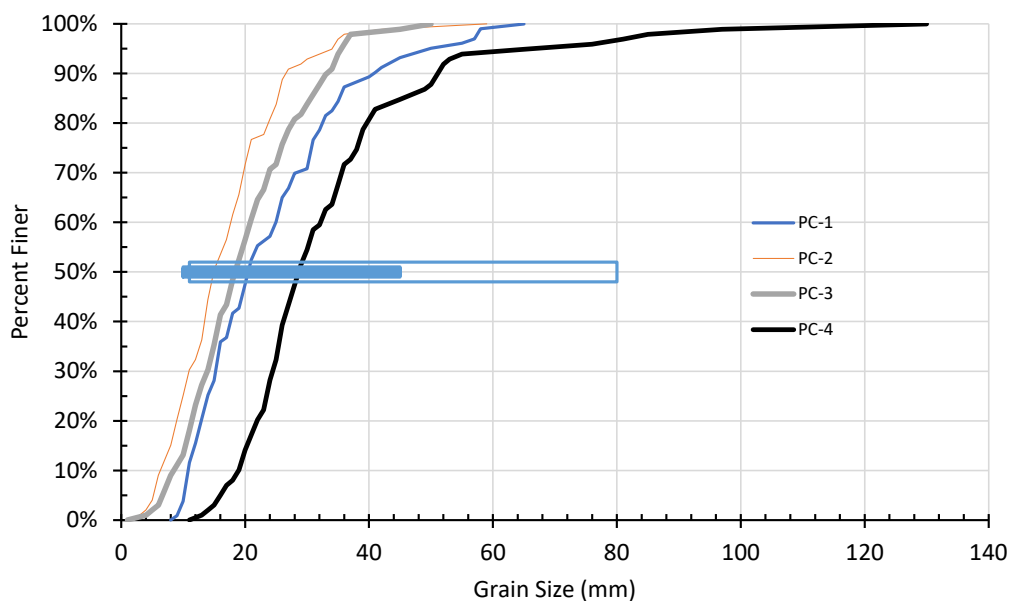


Figure 12. Riverbed pebble count grain size distributions at four locations distributed across the reach. Horizontal bars represent range of D_{50} 's reported by Kondolf and Wolman (1993) as suitable for steelhead trout (filled bar) and Chinook salmon (open bar) spawning.

3.5 SUMMARY OF HYDRAULIC MODELING OR ANALYSES CONDUCTED AND OUTCOMES – IMPLICATIONS RELATIVE TO PROPOSED DESIGN

A depth-averaged two-dimensional (2D) HEC-RAS model was developed for project design and for assessing potential effects of the project. The model geometric domain was set up to encompass the Umatilla River and its floodplain from the Bingham Road bridge to the confluence of the Umatilla River and Meacham Creek. The geometry used represents 'existing' conditions (as of 2020 for the floodplain, and late 2021 for the channel thalweg). Steps in model development and simulation are summarized below.

3.5.1 MODEL TERRAIN

The hydraulic model developed for this analysis relied on both LiDAR data of the Umatilla River floodplain, collected by NV5 geospatial in 2020, and bathymetric survey data of the Umatilla River channel collected by Kleinschmidt in 2021. A merged terrain dataset was generated from the 2020 LiDAR and bathymetric survey to develop an initial base terrain for a 2D HEC-RAS model. The adjusted survey data were used to develop one-dimensional (1D) cross section geometry in the HEC-RAS Model. The shape of each hydraulic control cross section was based on the RTK bathymetric survey points inside of the channel banks and the LiDAR data outside of the channel banks. Large individual rocks or other transect specific anomalies were not included in the model cross section geometry but were accounted for with either increased local Manning's n roughness values or with the implementation of SA/2D connections. Additional cross sections were interpolated between surveyed hydraulic control cross sections using the channel thalweg RTK elevation and an estimated channel bottom shape. The final 1D cross section model geometry was then used to develop a bathymetric terrain surface of the Umatilla River within the study area. This bathymetric surface was merged with the LiDAR data to create a final terrain surface which was used for the 2D hydraulic model. The mosaicked topography/bathymetry DEM was created as a .tif raster with coordinate system NAD_1983_StatePlane_Oregon_North_FIPS_3601_Feet (units=ft).

3.5.2 MODEL GEOMETRY

Model mesh resolution was selected to be approximately 20 feet on the floodplain in areas with mild topographic relief and slow-moving water. The mesh size was made smaller within channels and over floodplain terrain areas with more rapidly varying relief. The mesh size in the vicinity of and between the bank break lines was set to 10 ft, and was gradually relaxed with distance from the channel to the general floodplain mesh size.

The upstream and downstream model boundaries were placed sufficiently far enough away from primary study areas to ensure any errors at the boundary conditions would have negligible numerical influence on simulations within the primary study area.

Manning's roughness values were first assigned to model elements based on a land use layer developed using ESRI's ARC GIS - PRO software. Polygons were delineated for each type of different land cover within the model area using an aerial image taken in 2020 and provided with the LiDAR data by NV5. Each polygon was assigned a specific Manning's n roughness value for the given cover type value, in accordance with professional judgment and data presented by Chow (1959; Table 2).

There were two hydraulic control cross sections located directly upstream of critical project infrastructure where large rocks along the hydraulic control crest needed to be accounted for. Both hydraulic controls were modeled as Storage Area/2D connection (SA/2D connections) which simulated flow over the hydraulic control cross section using the weir equation. An SA/2D connection was used for that that the individual surveyed rocks along the control's crest could be accounted for within the model. The SA/2D connections used the weir equation overflow computational method with a low weir coefficient of 1.0 to simulate conditions close to

normal 2D overland flow. The weir coefficients used at each location were calibrated in order to match observed water surface elevations upstream and downstream of the SA/2D connections.

Table 2. Roughness coefficients applied to major land cover types in the 2D model.

Land Surface Type	Manning's n
Open Space Floodplain	0.06
Heavily Forested Banks	0.18
Overgrown Channel	0.08
Log Jam	0.20-0.25
Channel	0.06-0.13

3.5.3 CALIBRATION

Channel roughness was the primary calibration parameter for the model results and was adjusted on a reach-by-reach basis based on field observation, presence of instream wood or large rock debris, and turbulence with the end goal of matching observed water surface elevations that were collected from the RTK survey. Manning's n roughness of the channel was initially assigned a value of $n=0.06$ based on field observation under flow conditions of 60 cfs (the measured/calibration flow). Roughness values were then adjusted during model calibration in order to match surveyed water surface elevations at the measured discharge. Adjustments were made to the Manning's n roughness values in certain channel areas based on field observations and engineering judgment. Channel reaches with larger instream boulders or LWD and significantly higher turbulence were assigned Manning's n roughness values higher than the default value of 0.09. Slower, flat bottomed channel reaches were assigned lower Manning's n roughness values. Calibration efforts focused on matching the surveyed water surface elevations at the 25 hydraulic control sections and minimizing error sums. Calibration errors are summarized in Table 3.

The calibration values were then further adjusted to estimate bankfull values based on the relative roughness relation of Limerinos (1970), which reflects n values decreasing with increasing flow depth. Equation inputs includes the D84 grain size derived from the pebble count data and estimated bankfull water surface elevations based on surveyed channel geometry. The bankfull channel roughness values developed from the calibrated measured flow values using Limerinos' (1970) equation were averaged to a single value of $n \approx 0.057$. This value was applied across the bankfull channel bed for simulating the 2- year and larger flood peaks.

3.5.4 SIMULATIONS

The HEC-RAS 2D model version simulates unsteady flows and requires initial and boundary conditions for flow and water surface at the upstream and downstream ends of the model domain. The model has the option for simulating hydraulics using one of two solution schemes, a 'Diffusion Wave' approximation and the full momentum equation solution. The diffusion wave approximation is generally stable and runs much faster in obtaining a solution, but neglects flow advection terms from the momentum equation in its formulation. Hence the approximation is more suited for simulating hydraulics of slow-moving water areas such as low gradient floodplains, ponds, and backwater regions where flow advection effects are of second order. The flow advection term in the momentum equations cannot be neglected in channels such as the Umatilla River. Correspondingly for this project, the Full Momentum equation solution was used to provide the most accurate solution.

For all simulations, the downstream boundary condition was approximated by the normal depth with friction slope $S = 0.0088$, which is roughly the average channel slope of the project reach. The upstream boundary

condition was defined using a synthetic inflow hydrograph with gradually increasing flow over the first 5 hours of the simulation. The target flow was then held constant for 5 hours in the simulation to ensure that computed discharges at the upstream and downstream boundaries were the same, to ensure numerical mass conservation. At the end of the 10th hour, the solution was considered steady-state for the selected model flow.

Table 3. Measured vs predicted water surface elevations, from calibrated HEC-RAS model.

Hydraulic Control Section	Surveyed WSE (ft)	Modeled WSE (ft)	Difference (ft)	Hydraulic Control Section	Surveyed WSE (ft)	Modeled WSE (ft)	Difference (ft)
XS1	1,811.8	1,811.7	0.0	XS14	1,798.1	1,798.5	-0.5
XS2	1,811.2	1,811.2	0.0	XS15	1,797.8	1,797.9	-0.1
XS3	1,810.3	1,810.3	0.1	XS16	1,797.8	1,797.7	0.1
XS4	1,809.6	1,809.2	0.3	XS17(L)	1,795.8	1,795.8	0.0
XS5(L)	1,808.4	1,808.6	-0.1	XS17(R)	1,796.0	1,795.5	0.5
XS5(R)	1,808.7	1,808.6	0.1	XS18	1,792.6	1,792.6	0.0
XS6(R)	1,808.1	1,808.2	-0.1	XS19	1,788.9	1,788.6	0.3
XS6(L)	1,808.2	1,808.3	-0.1	XS20	1,786.9	1,786.9	0.0
XS7	1,806.8	1,807.3	-0.5	XS21(L)	1,786.7	1,786.3	0.4
XS8	1,804.3	1,804.7	-0.4	XS21(c)	1,786.7	1,786.7	0.0
XS9	1,803.2	1,803.1	0.1	XS21(r)	1,786.7	1,786.7	0.0
XS10	1,802.0	1,802.2	-0.2	XS22	1,780.3	1,780.2	0.1
XS11	1,800.9	1,800.9	0.0	XS23	1,777.0	1,776.7	0.2
XS12	1,799.9	1,799.7	0.2	XS24	1,774.6	1,774.5	0.1
XS13	1,798.5	1,798.7	-0.2	XS25	1,771.3	1,771.4	0.0

3.5.5 IMPLICATIONS OF MODELING RESULTS TO DESIGN

The HEC-RAS model results were used initially to evaluate the general feasibility of proposed conceptual design elements, where the flows derived in Section 3.3 were modeled to predict WSE and mean channel velocity. Identification of project elements was based in part on reviewing simulation results for both the 2- and 5-year peak flood events, which indicated when and where floodplain connectivity was more vs. less frequent (Figures 6 and 7), and where velocities are greater vs. slower in the bankfull channel and on the floodplain (Figures 13 and 14). The predicted inundation extents indicate where floodplain connectivity would require the least amount of floodplain earthwork and instream modifications. The predicted velocities indicate where floodplain channels are most vulnerable to erosion and thus may be potential avulsion pathways, and where instream structures and substrates are more vs. less vulnerable to scouring. Similar maps were generated for the 100-year flood for use in stability design and assessing risks to the Imeques facility (Figures 15 and 16). Velocity and depth predictions were also used for designing stable wood and boulder placements in the 60% design.

The model terrain and roughness representations were subsequently modified to represent the 90% design. Bathymetry was adjusted to reflect the proposed design elevation contours in the vicinity of the intake, and at balanced cut and fill locations on the floodplain associated with floodplain connectivity-focused project elements. The hydraulic effect of large wood placements was simulated in HEC-RAS using a higher local value of Mannings n roughness coefficient (details provided in Section 3.5.6). Corresponding model simulations were used to evaluate potential for site-wide changes in the 100-year WSE and to check stability design of instream project elements.

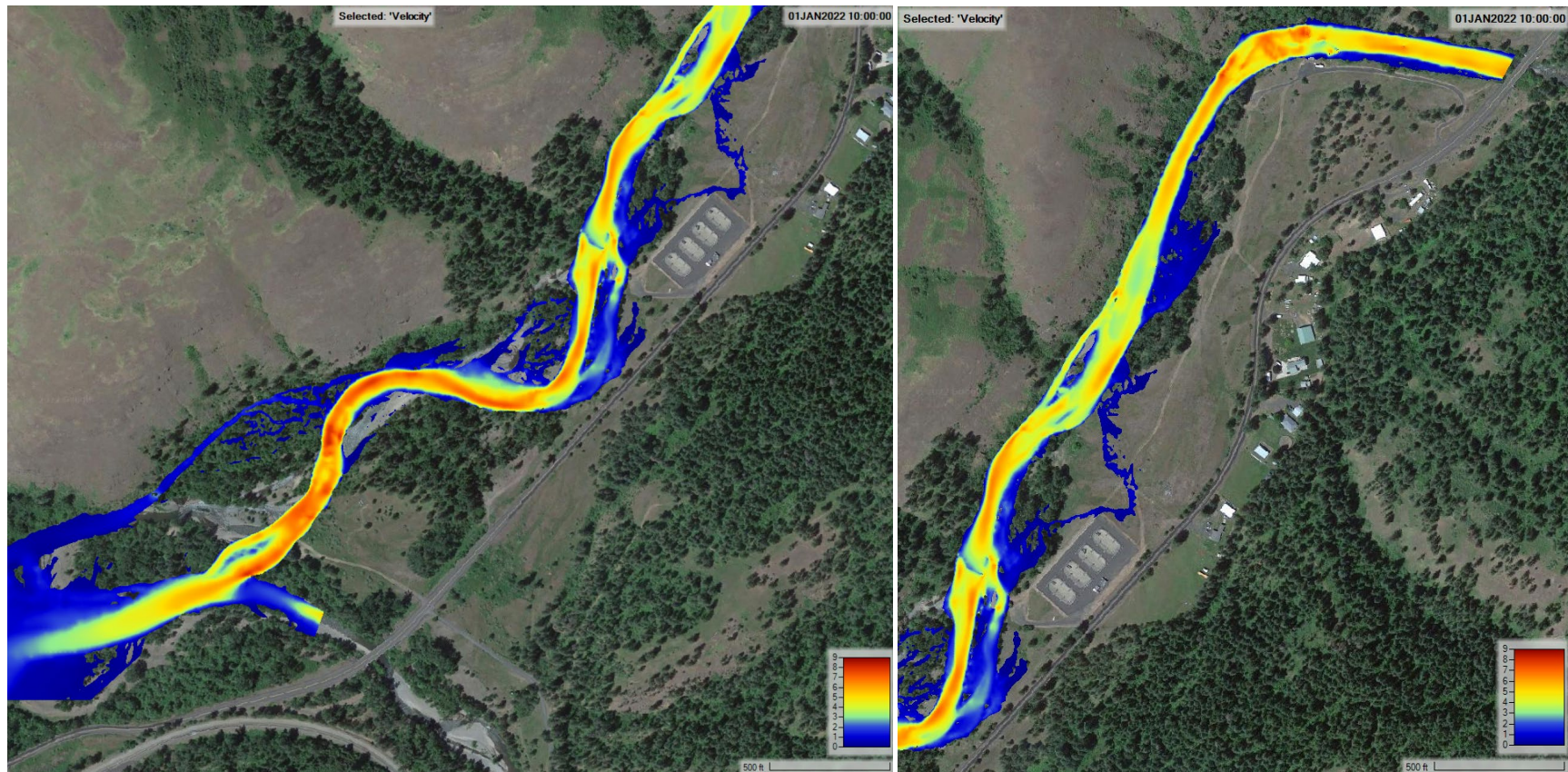


Figure 13. Simulated 2-year flood peak velocities in downstream (left) and upstream (right) portions of the project reach under existing conditions.

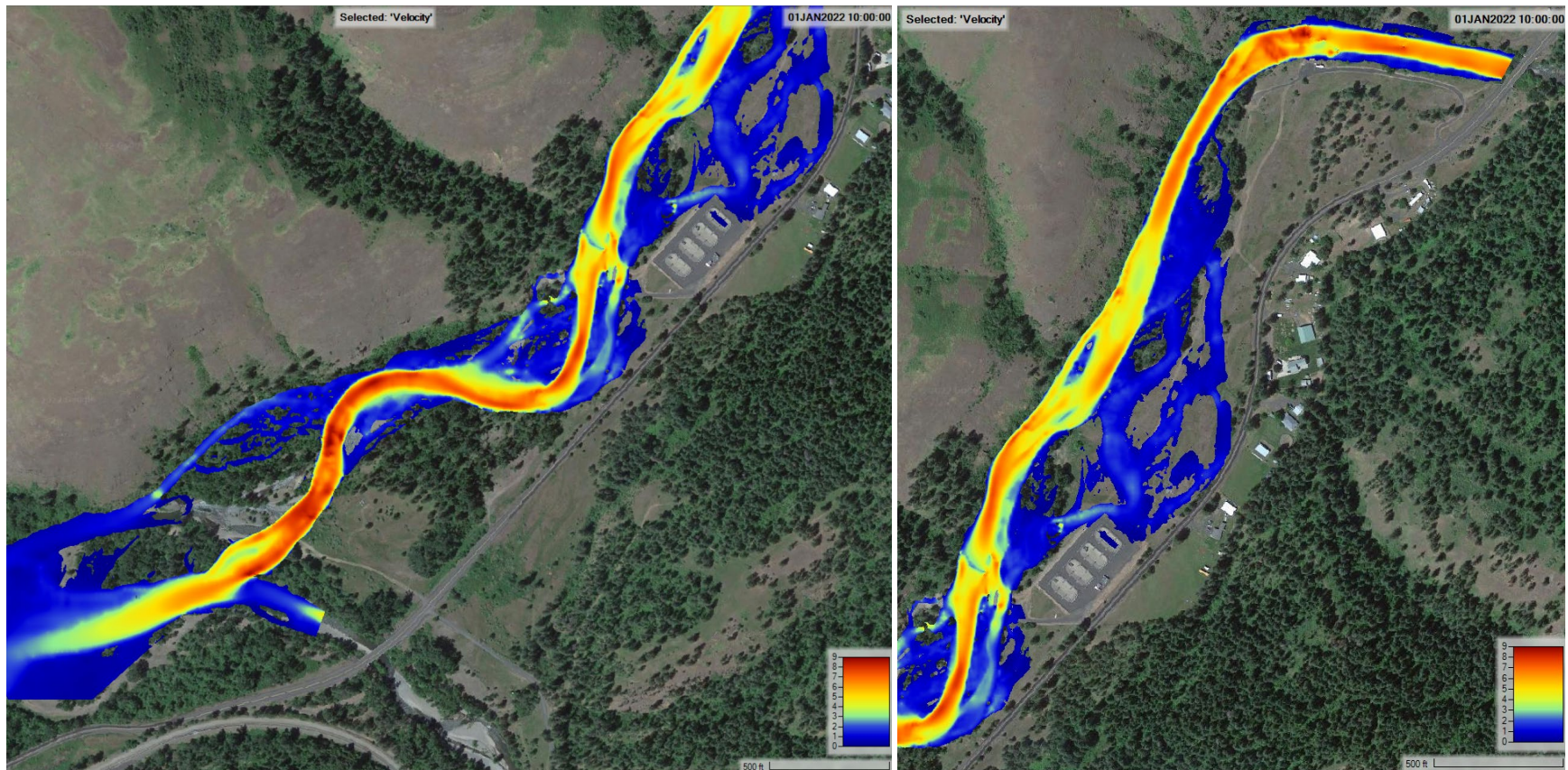


Figure 14. Simulated 5-year flood peak velocities in downstream (left) and upstream (right) portions of the project reach under existing conditions.

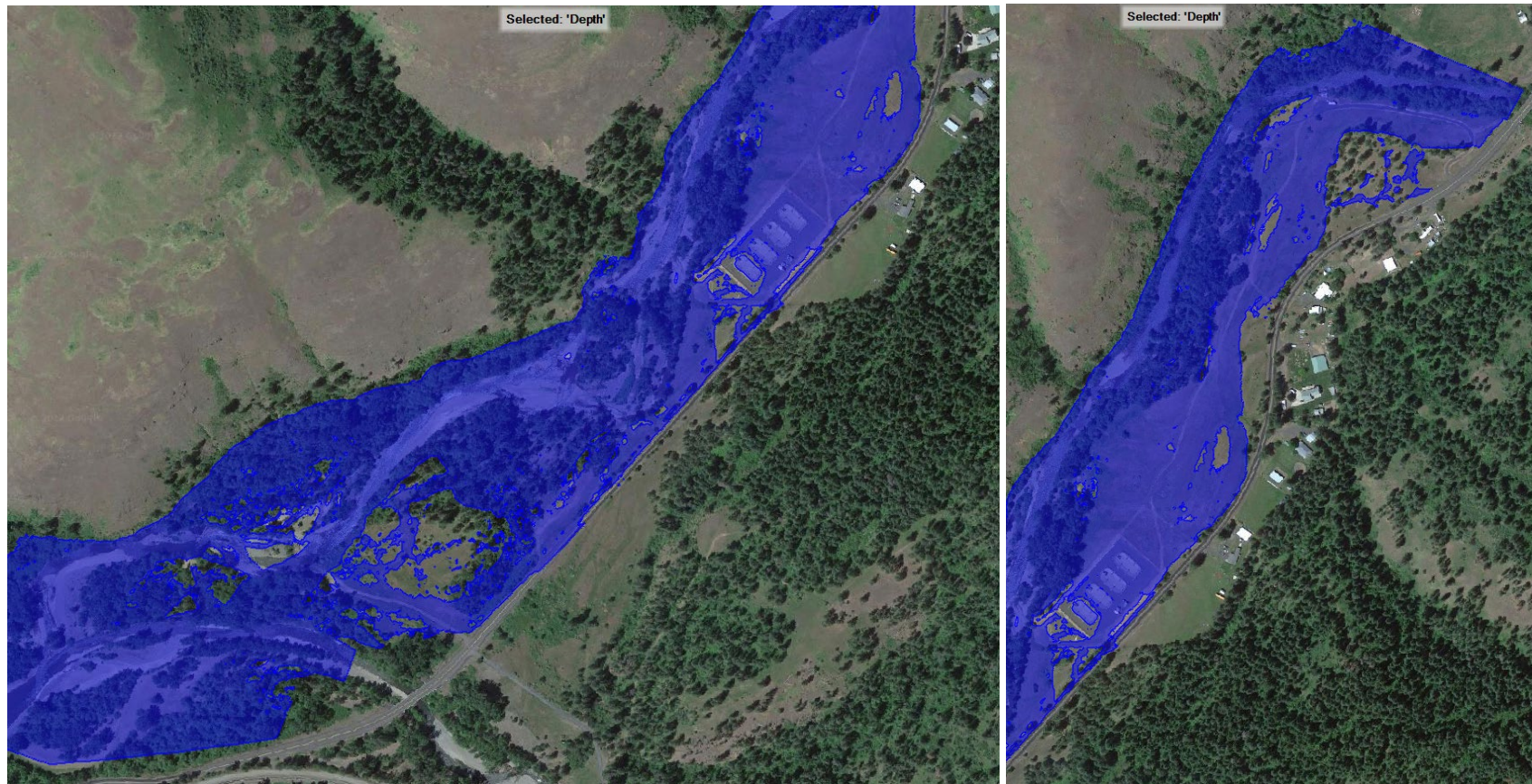


Figure 15. Simulated 100-year flood peak inundation boundaries in downstream (left) and upstream (right) portions of the project reach under existing conditions.

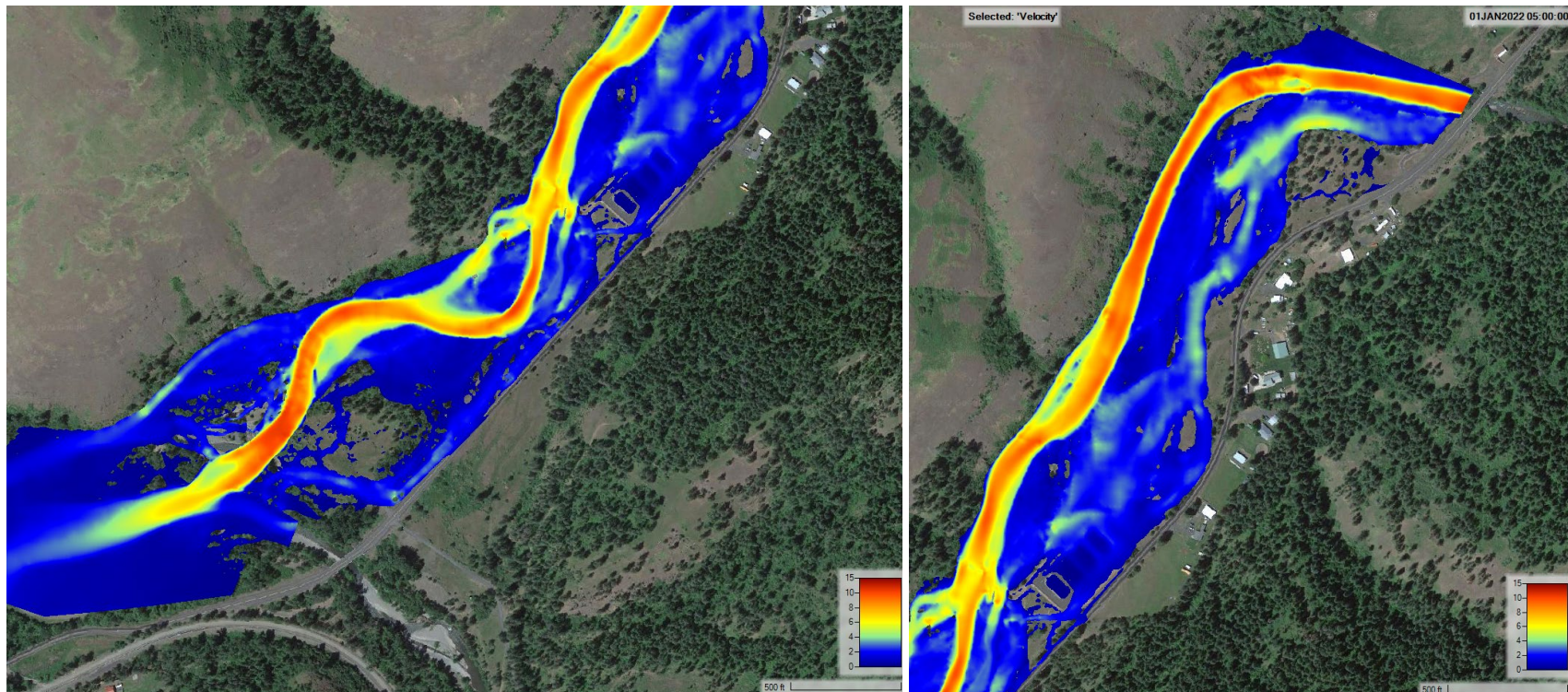


Figure 16. Simulated 100-year peak velocities in downstream (left) and upstream (right) portions of the project reach under existing conditions.

IMPLICATIONS TO INSTREAM HABITAT COMPLEXITY DESIGNS

The key objectives of increased instream habitat complexity were identified as (a) creating deeper pools, (b) providing instream cover, and (c) working with channel planform maintenance processes. These objectives can be attained through use of large wood material (LWM), and habitat boulders. Figure 17 indicates general locations where LWM and boulders can be implemented to achieve these objectives. Rationales are summarized succinctly below.

The governing reach scale flooding and geomorphic characteristics and field observations imply that large, deep pools will be difficult to create and maintain except possibly at sharper bends in the river where bend scour processes dominate. At other locations, smaller pools will most likely be associated with scouring around appropriately sited large wood pieces or accumulations. One location for potential large pool creation that could potentially persist over time was identified in discussion with the CTUIR, along the right bank (looking downstream) where the river turns a hard left below the diversion intake. LWM can be best placed for providing longer-term instream cover and creating small scour pools in the upper half of the project reach, upstream of the facility outfall and active channel migration zone. This reach is less depositional than downstream, and thus LWM is less likely to become buried and more likely to maintain small scour pools. However, the flood modeling results indicates that the lower portion of this reach should have wood placements that have a minimal effect on flood levels, to avoid increasing floodplain connectivity that would increase risk of channel migration towards the acclimation ponds facility.

It is clear that the reach in the vicinity of and below the outfall is more dynamic, where habitat complexity is provided in the form of multiple channels that facilitate gravel sorting for providing spawning habitat in particular. In addition, maintenance of more stable split channels can reduce risk of scouring of redds by spreading out flood flow energy. Channel splits accordingly can be enhanced or maintained through placement of larger, more defined LWM structures at island and mid-channel gravel bar apices that split flows and provide a lee zone for sediment deposition and vegetative colonization.

IMPLICATIONS TO FLOODPLAIN CONNECTIVITY DESIGN

The CTUIR is primarily interested in increasing floodplain connectivity along the left bank to benefit floodplain forest restoration efforts. The left bank floodplain is generally inundated at higher flood flows than the right bank floodplain except in the vicinity of the Imeques acclimation ponds facility. The hydraulic model simulations indicated that left bank areas in other locations in the project reach are generally not connected at even the 5-year flood (Figure 7). However, the LiDAR terrain indicates the presence of floodplain flow paths that could become connected at the 2-year flood with minimal excavation of pilot channels at their head, at three locations.

Three constraints were identified that may limit the extent to which floodplain connectivity could be achieved at the locations identified, for which the design includes elements that address them accordingly:

- A relic upper floodplain terrace and a levee at the upstream end of the reach limits connectivity of much of the floodplain from upstream, directing flow back towards the river (Figure 18). Pilot channels excavated through the terrace would not be expected to persist, and would likely refill over time. Moreover, the terrace serves as natural overbank flood training for the facility, redirecting flows that otherwise would add more substantially to flood impacts at the acclimation ponds. Thus the terrace was left undisturbed and targeted for upland forest plantings.

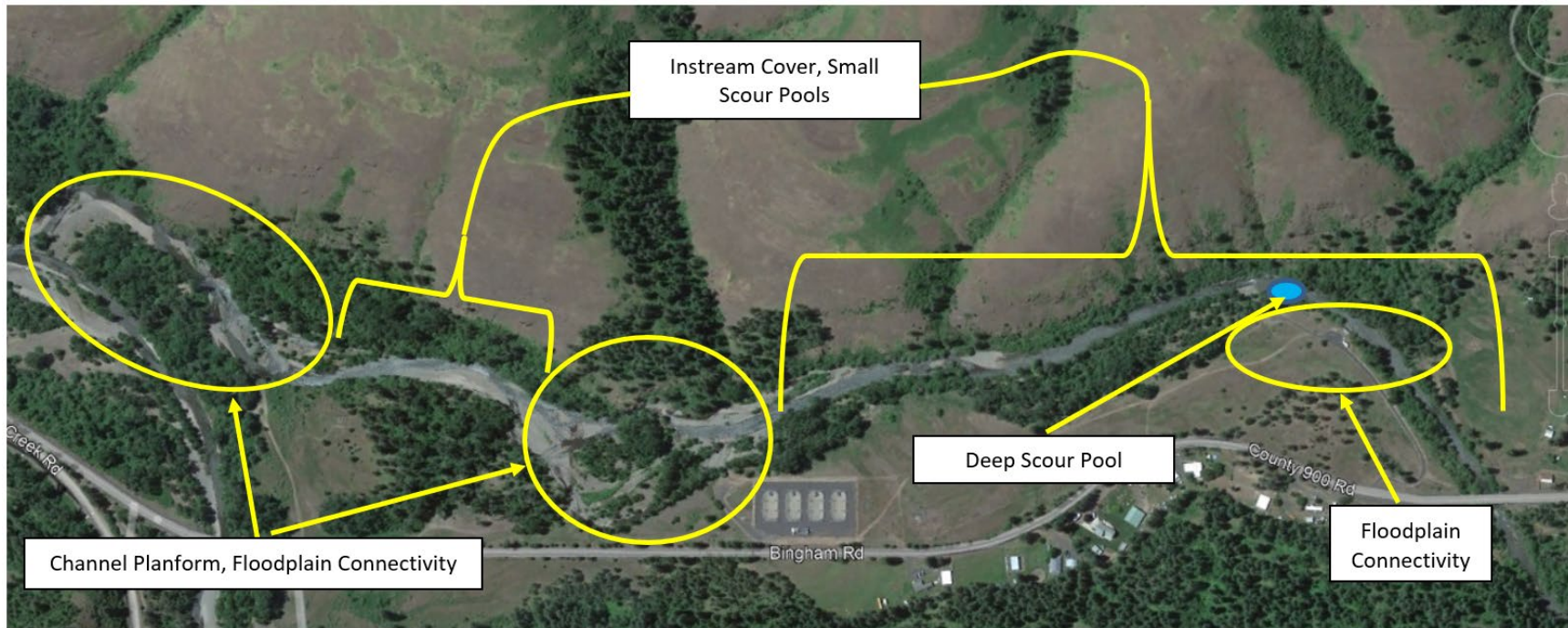


Figure 17. Proposed locations and habitat-related objectives of LWM placement within the project reach. A riverbend crib jam is proposed to create the deep scour pool. Small modular log jams and debris and sediment trapping log placements are proposed for promoting sediment deposition, split flow and floodplain connectivity enhancement. Small, embedded logs protruding out in the channel on the riverbed are proposed for creating distributed pockets of juvenile rearing habitat without substantially increasing flooding risk to the acclimation pond facility.

- The 30-inch diameter pipe runs under the floodplain from the diversion to the water headbox. The top of the pipe is approximately 7 feet below ground at the intake, and becomes progressively shallower moving towards the headbox, where it sits approximately 3 feet below ground. Placement of a coarse cobble armor layer was prescribed to protect the pipe from avulsion along the enhanced floodplain flow path created as part of floodplain connectivity project elements.
- The area with greatest connectivity potential in the reach upstream of the outfall has floodplain swales directed towards and then away from the acclimation pond area. Measures were designed to redirect overbank flows and promote natural floodplain deposition and native plant establishment in front of the upstream side of the pond fence line to prevent potential avulsion in the vicinity of the facility.

Project elements that were designed to increase floodplain connectivity included:

- Pilot channel cuts to increase frequency of overbank flood flows along relic swales on the floodplain;
- Increasing instream roughness with limited placements of large wood to raise upstream water levels locally in the vicinity of floodplain flow paths during more frequent, lower magnitude floods; and
- Adding log structures along the channel margin to promote flow splits between channel and floodplain and potentially increase conveyance locally.

Initial hydraulic model results suggested that the first two elements would have higher likelihoods of increasing floodplain connectivity. Two locations were identified at the upstream end that become engaged when flows are between the 5- and 10-year flood levels, one of which corresponds to the location of the existing diversion intake (Figure 18). That location will not be modified, to preserve operation of the intake. The hydraulic modeling predictions of water levels indicate that excavation of an approximately 3 feet deep pilot channel at the other, upstream location would result in engagement of the floodplain downstream at approximately the 2-year flood. The area of floodplain benefitting from connectivity is restricted primarily to the area outlined in Figure 18, however. Areas farther downstream are connected already at the 2- and 5-year floods (Figures 6 and 7). Importantly, increased connectivity at this location could add to floodwaters impacting the acclimation ponds, and thus debris logs were added to the design to minimize increased flows in the direction of the ponds and protect them from erosion.

The hydraulic modeling predictions depicted in Figures 6 and 7 indicate that much of the remainder of the floodplain upstream of the facility outfall is inundated at the 5-year flood. This indicates that significantly increased instream roughness in the river channel upstream of the outfall could be associated with increased connectivity at the 2-year flood. The predicted velocity magnitudes are low (Figure 13), and the route over the floodplain represents a longer flow path such that the risk of avulsion over the floodplain is low. Nonetheless, minor flood protection log placements and earthwork on the floodplain is included in the design to redirect higher velocity floodplain flows away from the acclimation facility by strategically promoting longer term deposition.

Although modeling results depicted in Figure 7 indicate that the 5-year flood does not overtop the left bank downstream of the acclimation facility, two floodplain flow paths were discerned on the LiDAR terrain model that could be connected at the 2-year flood with minimal excavation of pilot channels on the left (looking downstream) riverbank. The connectivity would increase groundwater recharge and more frequent flow of water for enhanced spring growth of floodplain vegetation in the existing forest terrace. These locations are along the outside of a bend, and thus are at risk of eventually filling in again through accumulation of wood debris and deposition of fine sediments forming a natural levee. Benefits would be expected over the near term, say on the order of 5-10 years depending on observed flood frequencies and magnitudes.

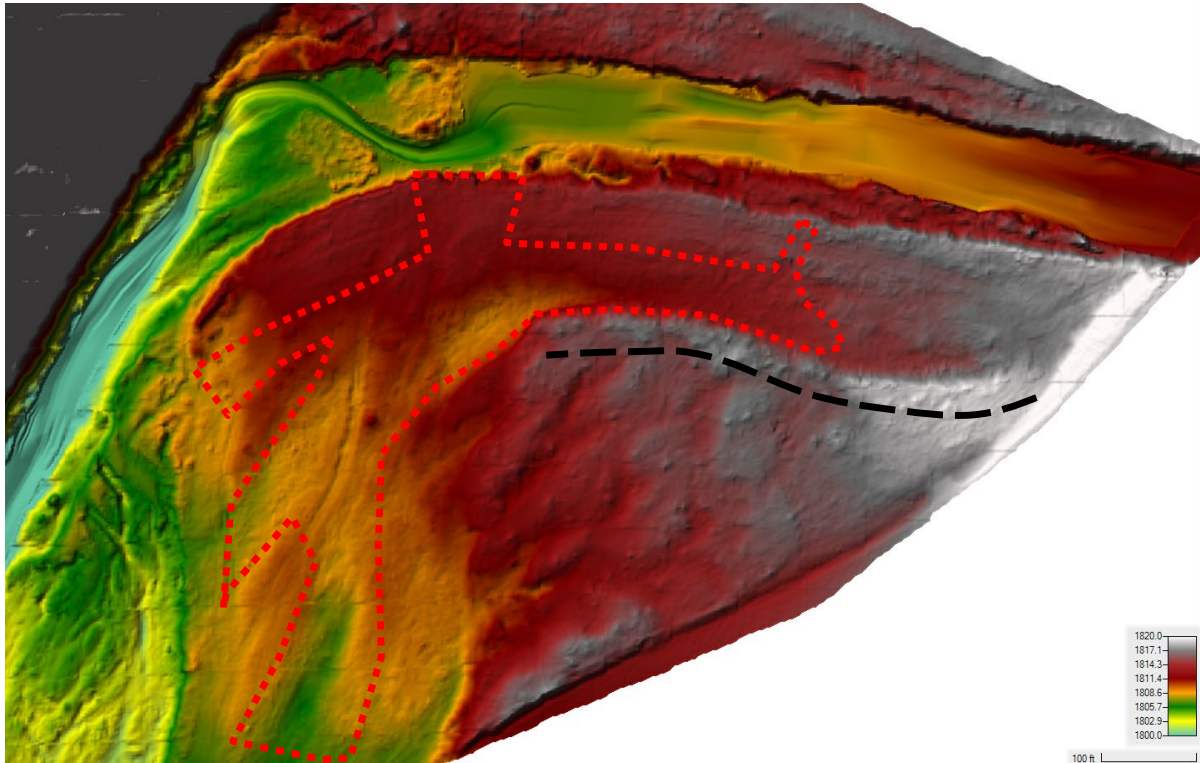


Figure 18. High ground near upstream extent of project reach that appears to represent a relic upper floodplain terrace (dashed line) and a levee that was natural and/or anthropogenic in origin (outlined by solid line) Locations of potential pilot channels, and the corresponding area of floodplain where reforestation would most directly benefit from the associated enhanced connectivity are delineated by the dotted polygon outline.

3.5.6 PREDICTED HYDRAULICS WITH DESIGN

Flood hydraulics were evaluated for with-project conditions by modifying the terrain topography where excavation is proposed, and by approximating the effect of project elements on channel roughness over the general areas expected to be affected hydraulically by groupings of logs and boulders as follows:

- Embedded Logs, PALS, Crib Jam along channel margin = Manning's n increased by 0.01 over existing;
- Debris Log fields: Manning's n increased to 0.11;
- PALS with Debris Logs: Manning's n increased to 0.15; and
- Boulder Fields: Manning's n increased by 0.01 over existing.

Wood placement along the channel margin is expected to blend in hydraulically with the riparian zone roughness and thus have minor additional impact on channel roughness overall. Boulder fields were also estimated to have minor additional impact on roughness based on work of Pagliara and Chiavaccini (2006). Debris log (with and without PALS) field effect on roughness was estimated based on comparing relationships developed by Darby (1999), Stone and Shen (2002), and Musleh and Cruise (2006).

Figures 19-21 depict the inundation extents and velocity fields simulated for the 2-, 10-, and 100-year flood peaks under with-project conditions after construction. It can be seen that increasing floodplain connectivity increases velocities over the floodplain as well. The simulation includes a small berm around the northeast perimeter of the ponds, and the figures show the berm protecting the ponds from smaller flood events but not significantly altering the 100-year flood extent on the floodplain. A protective armor layer of cobble is indicated for where the increased connectivity follows over the pipeline and intake access road.

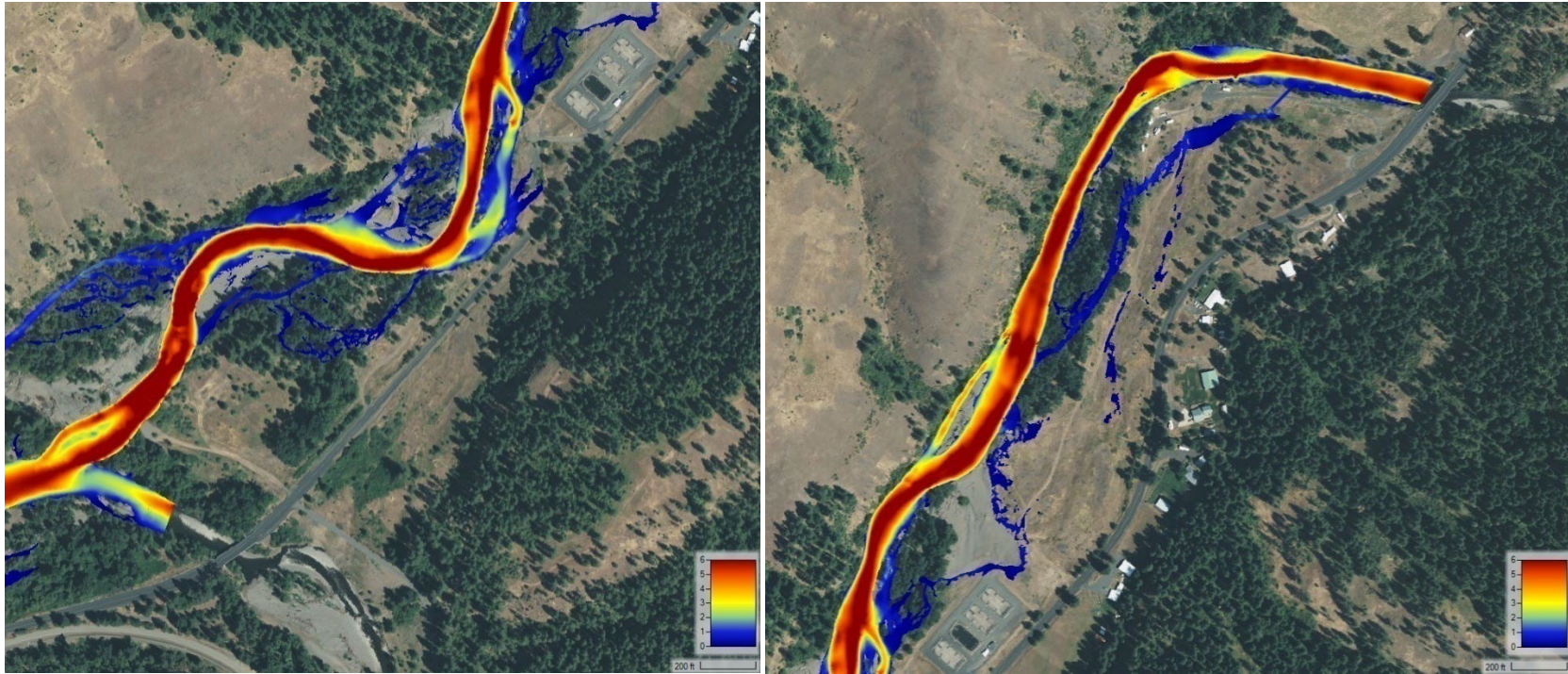


Figure 19. Simulated 2-year flood peak velocities in downstream (left) and upstream (right) portions of the project reach under proposed conditions. Velocity legend truncated at 6 ft/s to show greater resolution on the floodplain.

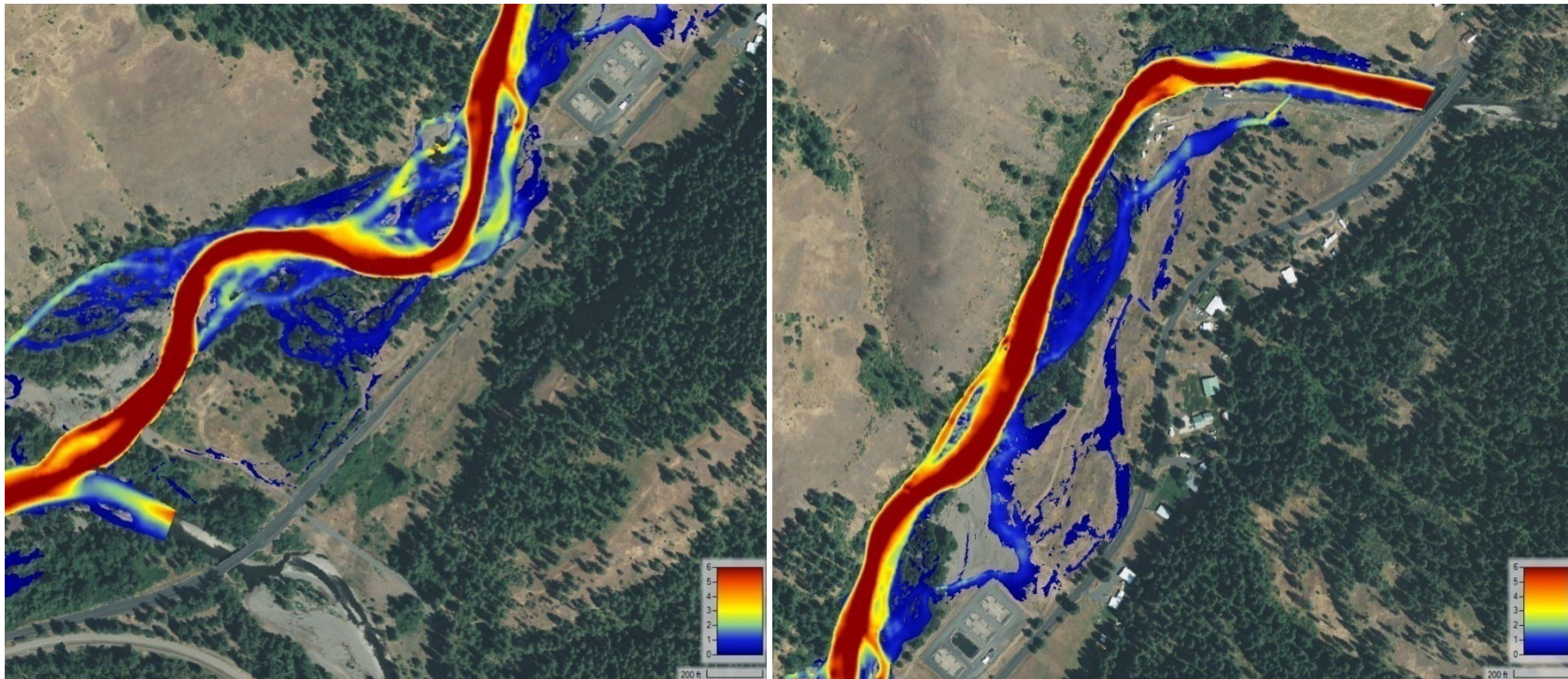


Figure 20. Simulated 5-year flood peak velocities in downstream (left) and upstream (right) portions of the project reach under proposed conditions. Velocity legend truncated at 6 ft/s to show greater resolution on the floodplain.

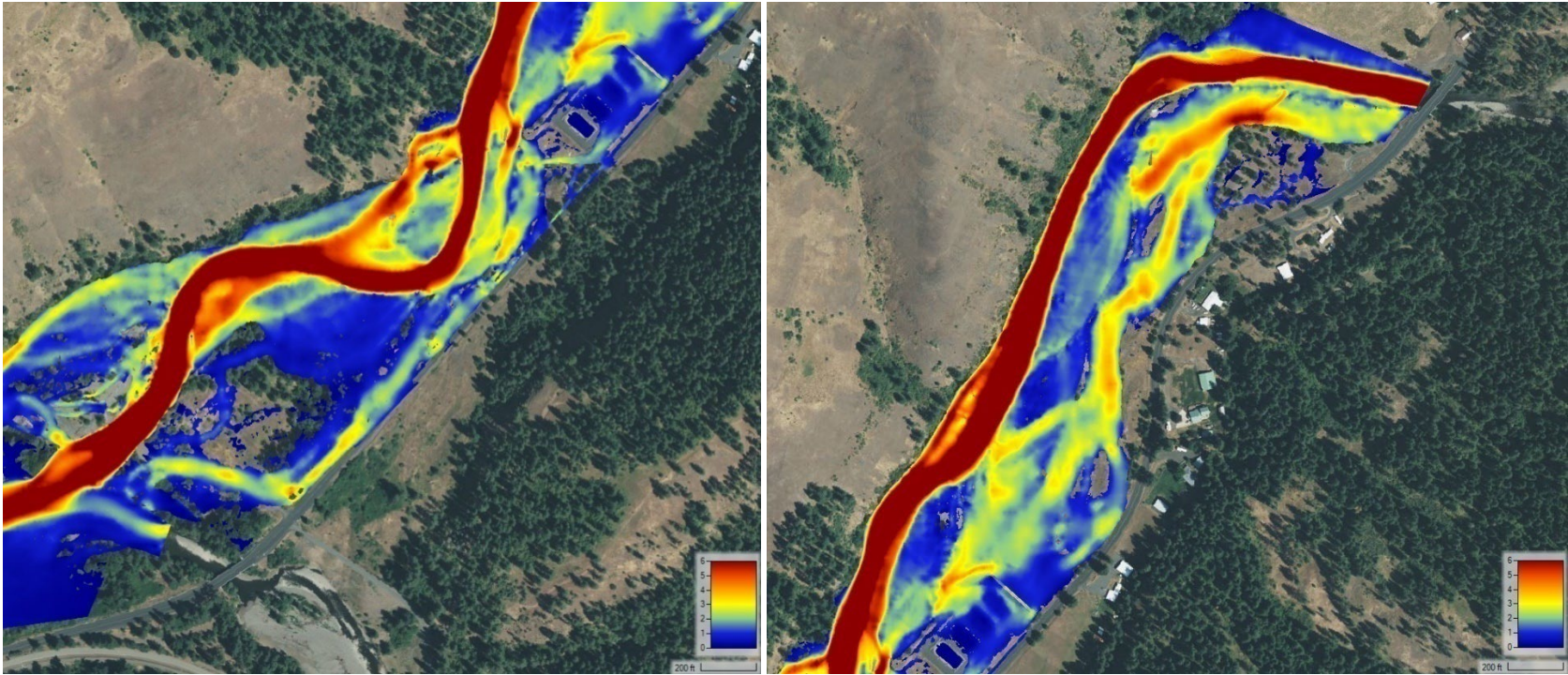


Figure 21. Simulated 100-year flood peak velocities in downstream (left) and upstream (right) portions of the project reach under proposed conditions. Velocity legend truncated at 6 ft/s to show greater resolution on the floodplain. Hydraulics will change with subsequent deposition around floodplain large wood placements and reforestation.

3.6 STABILITY ANALYSES AND COMPUTATIONS FOR PROJECT ELEMENTS, AND COMPREHENSIVE PROJECT PLAN

Based on the resulting comprehensive project plan depicted conceptually in Figure 17, the 2D model was then used for design of specific elements. Water surface elevations predicted at different flood levels were compared against floodplain swale inlet elevations and bank elevations at locations where larger fixed structures were considered. Velocity predictions were assessed at various potential structure locations to design for stability and function, and the highest velocity value used for a conservative stability design.

For the two bankfull indicator cross-sections depicted in Figure 22, the stable D_{50} particle size on top of the gravel bars was estimated to be approximately 17-18 mm at the 2-year flood (where dimensionless critical Shields stress $\tau^*_{cr} = 0.035$ for initiation of bedload motion; Wilcock et al. 1996; Buffington and Montgomery 1997). This value is comparable to that of the nearby PC-1 grain size distribution depicted in Figure 12, which is characteristic of more commonly transported bedload material. Given the predicted 2-year flood WSE is a little above the approximate bankfull level, and the incipient motion calculations of stable particle size on the top of the gravel bars are consistent with the pebble counts, the HEC-RAS model accordingly appears to be calibrated sufficiently for use in design.

Stability analyses for the design of each project element are described in greater detail below for specific types of LWM designs. It should be noted that constructed LWM structures can be expected to have a fixed functional lifespan before they fail or break down, typically on the order of 5-10 years.

3.6.1 EMBEDDED HABITAT LOGS

This project element is proposed for implementation in primarily the upper reach where channel migration is limited, and in the small side channel below the outfall. The structures are inexpensive to build and thus can be implemented in large numbers throughout the reach to distribute rearing habitat. Logs were laid out at locations in a relatively low density such that they would be expected to have minimal effect on flood water levels and avoid significantly increasing flood risk to the Imeques facility. The density of wood placed can affect the future stability of the channel and floodplain by increasing roughness and flow obstruction, which can promote sediment deposition and overbank flow frequency and duration. Both of these processes are associated with increased risk of channel and floodplain instability if the density of wood placement is too high. Moreover, locations where the channel is relatively straight and streambanks are low minimizes their potential to cause bank erosion and loss of log.

The logs can be distributed throughout the reach to provide more widespread instream habitat and gravel sorting functions. Logs can be set along just one bank to create scour pockets and habitat cover for juvenile salmonids, or on opposing banks to confine the thalweg and scour out a deeper slot that provides both depth and instream cover for adult and juvenile salmonids. In either case, embedding logs results in a low profile near the bank during floods, thus concerns with overflow directed at the bank and causing near term local erosion and scouring not associated with channel meandering are reduced compared with larger profile installations.

There is no hardware involved that would remain in the river. Large (diameter at breast height (DBH) ~12"-24") logs with rootwads would be anchored by embedding their ends into the riverbank and bed, with the rootwad typically sticking out more than 6' into the low flow channel (Figure 23). This application has worked successfully on CTUIR projects constructed in the South and North Touchet River, Tucannon River, and elsewhere. The rootwads rack up small debris and larger logs, focus low flows within a narrower, deeper thalweg, and create pocket habitat for juvenile and adult steelhead. The logs are embedded sufficiently deep that the backfill provides ballast countering buoyancy- and drag-induced instability. The rootwad is embedded within the streambed so that the log trunk is lying on top of the streambed and the rootwad provides habitat

at low summer flows. Boulders can be placed on top of the log and partially to fully countersunk in the ground with the log to provide additional stability. The logs can be placed singly or in pairs and protrude at variable distances from the bank to emulate random arrangements. A range of diameters is specified to also make the installations more random in appearance. The plans include dimensions for alternative sized logs pending supply availability accordingly.

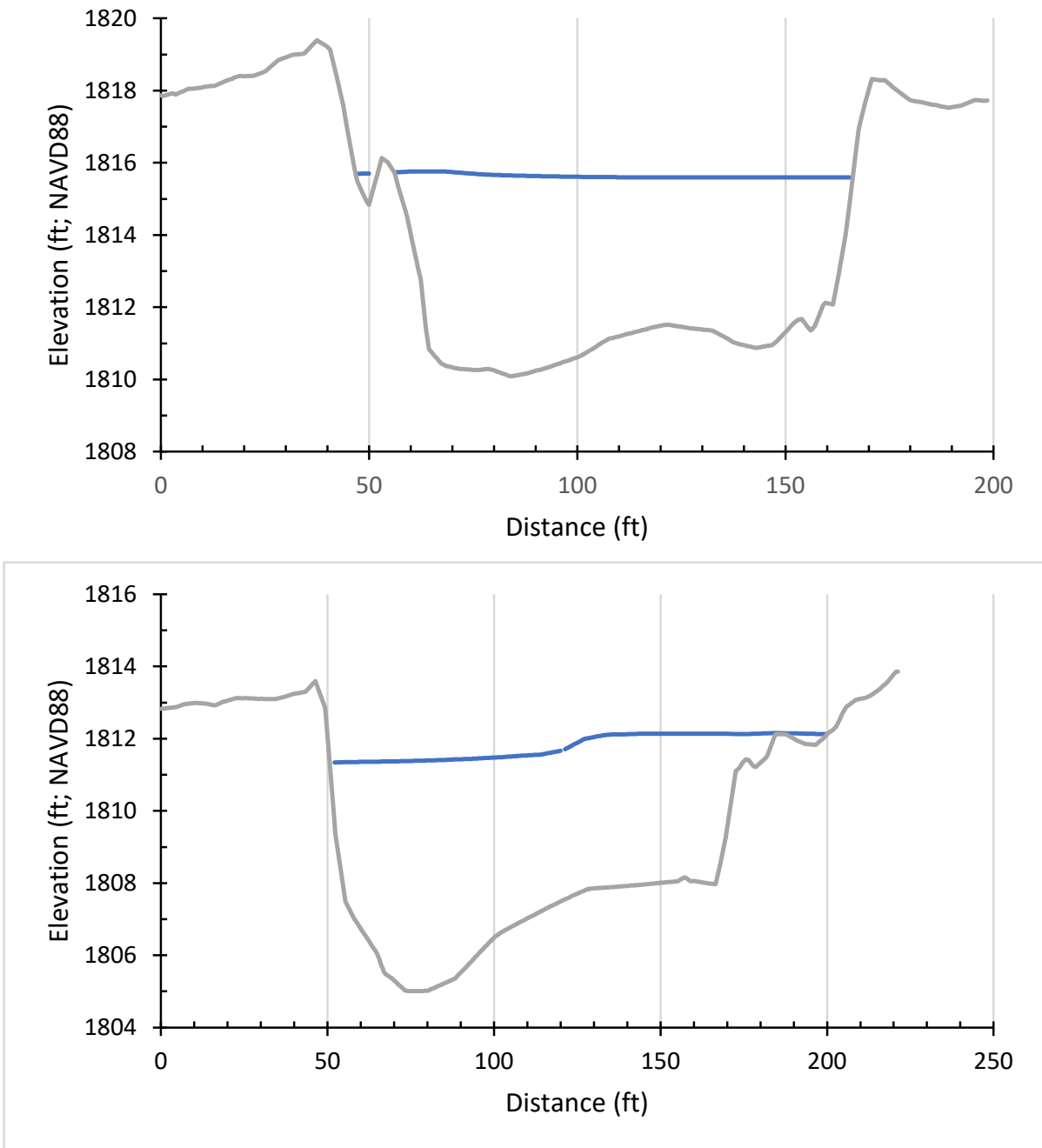


Figure 22. Examples of HEC-RAS model bankfull indicator cross-sections with 2-year flood WSE predictions for current condition. Cross-sections are located between the diversion intake and the bridge. The flood level is a little higher than bankfull.



Figure 23. Example of embedded habitat logs racking up debris.

Key design considerations are orientation, projection, and stability. The logs are specified to be oriented (i) horizontally with the rootwad extending upstream and downstream over a range of angles between $\pm 20^\circ$ from perpendicular to the bank, with most oriented upstream (i.e., where drag pressure pushes log into bank; e.g., NRCS [2001]), and (ii) vertically with the rootwad collar bottom at streambed grade and the butt end buried a minimum depth below the ground that varies with trunk diameter. Most logs are installed as individual projections into the flow, but some logs are grouped together for a less 'engineered' appearance. Monitoring work we have performed has indicated that the logs should project at least 6 feet from the wetted bank toe into the channel to create scour pocket water habitat used by juvenile salmonids. Spacing between log placements ideally should be twice the projection length into the channel to reduce flow interference effects at the rootwad and allow wake zone reattachment with the bank downstream of each log to maximize scour potential. A minimum spacing of about 12 feet tends to work in most cases where local scour is desired.

Stability is factored into the design by evaluating the forces acting to pull out embedded logs laterally by streamwise drag force and vertically by buoyancy force. The method of Broms (1964; in Murthy 2003) is used first to evaluate lateral resistance of partially embedded horizontal logs to movement in the streamwise and vertical directions. The necessary input for calculating the streamwise loading force is the maximum predicted mean column velocity at the 100-year flood, a drag coefficient (conservative $CD = 1.2$), and the projected area of the structure, following the standard form drag force equation (e.g., D'Aoust and Millar 2000).

The destabilizing vertical force caused by buoyancy is countered by calculating the submerged weight of the fill on top of the embedded logs and balancing moments of force about the tip of the log. Consideration of overturning moment forces typically requires a deeper installation of the tip than considering static vertical force balance. A buoyant specific gravity $SG = 0.5$ is used for Douglas fir (USFS 2010); with time, this value should increase as parts of the log become waterlogged. A minimum embedment depth is calculated for different log diameters and lengths to provide sufficient ballast weight of soil against uplift and pull-out. Ignoring the stabilizing effect of soil shear resistance provides an additional factor of safety (SF). The depth of

installation of the butt end of the log in the soil is calculated assuming the logs are installed at an angle below horizontal, and is set so that the moment of soil weight equals ($SF=1$) or exceeds ($SF>1$) the moment buoyant force of the log.

3.6.2 POST ASSISTED LOG JAM STRUCTURES (PALS)

Modular post-assisted log structures (PALS) consisting of a crisscross array of multiple logs with rootwads are specified to provide local scour pools as holding and cover habitat for adult Chinook prior to and during spawning, and for splitting high flows onto the floodplain. These small modular structures scale well with the size of the Umatilla River within the project reach and are simpler and relatively cost effective to construct compared with larger, deeper installed structures. They can be installed alone, or in groupings (Figure 24). Vertical logs with rootwads partially emulate the geomorphic effect of mature riparian trees, and must be installed deep enough to help hold the structure together during floods. The structure consists of an array of crisscrossed horizontal logs with rootwads protruding out into the channel, and the array held in place by vertical anchor logs with buried rootwads and hemp rope lashing. Hemp rope is proposed to temporarily help hold the structure together while it seasons, while yet allowing it to fail safely and then biodegrade if necessary. Gravel and boulder ballast fill on top helps hold the structure in place. The vertical posts serve another function where they can rack up floating logs during high water, thereby building on the structure and helping reduce the potential for more general adverse impacts to private property and infrastructure downstream. This design was applied to provide instream habitat cover throughout the project reach, and to promote maintenance of multiple channels in the more geomorphically active downstream reach. The design can also help split high flows onto the floodplain as part of a floodplain connectivity design.

Fourteen PALS were placed at various locations in the reach to provide a range of functions depending on location. Some were sited to create scour pool habitat at the structure, some were sited as bar apex structures to maintain side channels, and others were sited along the bank edge to split overbank flows for increased floodplain connectivity via pilot or existing swales.

Depending on the function, a minimal number of four or five horizontal logs was specified to be laid out at the surface of the riverbed to reduce construction cost and conserve logs. In the case of structures providing instream habitat, five logs are used with one longer log protruding far out into the channel and being held in place by the structure overall. In both cases, two shorter logs are aligned streamwise and the other two logs are longer and oriented perpendicular to the channel. There is no need to bury additional logs for anchoring because that function is provided by six vertical boles with rootwads. Logs buried below the river bottom elevation do not appear to have a natural analog in the Umatilla River and would not provide much if any additional habitat function over that provided by the five logs specified. The vertical boles block lateral movement, and hemp rope used to tie the horizontal logs to the boles effects resistance to buoyancy forces.

The structures were designed so that vertical boles provide lateral (drag forces) and pull-out (buoyancy forces) support to the structure, and the crisscrossed horizontal logs interlock with the vertical boles. Drag and scour were evaluated conservatively by assuming a debris buildup with a projected obstruction dimension of 6 feet high by 15 feet long. A drag coefficient $CD=2.0$ was used to represent a massive obstruction (Alonso 2004). Scour depth was estimated using the HEC-18 method (Arneson et al. 2012) to be approximately 8.5 feet at 10 feet/s (approximately the peak velocity predicted by HEC-RAS during the 100-year flood). Practically, this depth is a difficult target for excavation in local rivers based on previous project experience working in the wet, due to caving-in of excavation side walls. Also, the HEC-18 result is probably an over-estimate for the size of channel (it is more likely that the scour depth will scale with the obstruction height, or around 6 feet).



Figure 24. Example of two small modular PALS intended to trap wood, create instream habitat cover, and spit high flows towards floodplain flow paths.

Inferring that the anticipated scour depth during the 100-year flood is around 6 feet or more, and it may not be practical to excavate to ~8.5 feet depth at a location adjacent to the wetted channel, several aspects of the design were conceived to counter the potential destabilizing effect of scour at the base of the structure and allow for shallower excavation for the vertical boles:

- The horizontal logs perpendicular to the channel were designed to be buried a sufficient distance back in the riverbank, and tied together with the interlocking horizontal and vertical logs using hemp rope so that the entire structure would hold its shape during the time of maximum scouring. The scour hole that develops will be around the outside edge of the structure, and as long as the back end of the structure holds in place, the structure should remain in place.
- The vertical boles were designed to be installed complete with rootwads to provide anchoring while reducing the excavation depth required to counter the combined potential for scour and pull-out by buoyancy and drag (logs without rootwads would need to be installed deeper to achieve the same resistance to pull-out). The combined force resisting pullout was taken as the submerged weight of the substrate plus the internal friction force resisting shearing of the substrate upwards. The number of vertical boles was balanced with the excavation depth, where more boles with rootwads result in requiring less excavation depth for anchoring vs. resulting in a more massive structure with potentially greater scour depth and more complicated construction with more materials. It was determined that 6 vertical boles with rootwads would require a minimum 3.0 feet thick layer of gravel on top to resist pull-out. The boles are laid out so that three are situated near the back end of the crisscrossed horizontal logs, away from the scour hole, and have more than 8 feet of gravel fill holding them in place; this location is also back from the river edge, and thus less susceptible to caving in of the excavation side walls so that the hole can be dug deeper there. There is one bole up front closest to the scour hole location, and that one is installed the shallowest, around 5 feet below the bed. The remaining two boles are located more downstream and between the front one and back three boles, where the scour hole will be unlikely to expose them.

In the case of PALS that are installed mid-channel in the vicinity of the diversion intake and outfall structures, embedded debris logs and streambed boulders are also installed to slow down velocities in the vicinity of the

structure, thereby reducing scouring potential. The wood installations should work collectively to slow down flood velocities locally and promote deposition instead.

The PALS were designed partly to fail safely in the event of significant erosion or avulsion around the structure during extreme, closer to flood of record level events, by specifying hemp rope to bind the logs and vertical boles together for near term stability. In the event of excessive scouring associated with unanticipated shifting of the channel, the hemp rope should break under stress in the event the structure stays as one as it is entrained downriver and wraps itself around a bridge pier. Friction (associated with the wrap around the vertical boles) and tension forces in the rope (for point of breakage) were analyzed in previous designs for larger structures, and determined to be adequate; this was later borne out by persistence after severe flooding in other applications. By extension, the specified rope diameter will be sufficient for this application.

3.6.3 EXPOSED DEBRIS LOGS

Exposed debris logs are a variation of flood fencing, which consists of close arrays of vertical posts that are implemented to trap wood and promote sediment deposition. Pseudo-random arrays are constructed using single logs with rootwads embedded at an angle into the substrate, with the rootwads oriented facing upstream within roughly $\pm 45^\circ$ of flood flow velocity vector direction, and a vertical post to help hold the log in place against drag forces. The array pieces act in concert to trap floating debris and create a lee zone for sediment deposition and vegetative colonization of cottonwood and other species' seedlings and rhizomes (Figure 25). Arrays are situated at select locations on low profile gravel bars to promote deposition, which in turns steers flow concentration along the thalweg. Arrays are also sited to split high flows over low elevation floodplain areas where future connectivity might be possible, on higher elevation mid-channel gravel deposits to trap loose LWD logs and promote island evolution for habitat complexity, and on the floodplain to train overbank flows away from the acclimation pond facility. In addition, arrays are proposed to help maintain a meandering thalweg in front of the existing diversion intake.

The proposed design involves single logs with rootwads embedded at an angle into the substrate with the rootwads oriented facing upstream within $\pm 45^\circ$ of flood flow velocity vector direction. The logs are designed to be held in place passively by the weight of the overlying substrate, ignoring resistance to shearing within the surrounding substrate during pull-out to provide a safety factor. A similar design analysis as that used for sizing installation depth of embedded habitat logs was applied. 1 foot additional depth was added to accommodate degradation of the bar surface.

Each log is also laid out with a vertical bole installed on the downstream side, which provided redundant, back-up resistance against drag forces in case of excessive scouring around the log leads to exposing more of the log than anticipated. The boles were specified to have a height extending up to the 50-year flood so that they can trap debris logs at higher flood levels. The design procedure for bole installation dimensions was iterative, reflecting a balance between maximizing flow obstruction, minimizing local scour depth, and resisting buoyancy pullout, breakage, and ploughing. Depth of bole installation was the sum of design scour depth around bole and minimum depth to prevent buoyancy pull-out. Ploughing was evaluated using piling design principles, but was neglected because the phenomenon has not been observed to occur frequently, and when it has, has not resulted in a noted loss of a bole. Scour depth was estimated using, alternatively, standard single pier and bridge piling scour equations from HEC-18 (Arneson et al. 2012) and from experimental studies of Dey et al. (2008). Pull-out depths were determined by considering substrate-wood friction coefficient, and assuming the upper 5 times diameter depth does not provide substantive resistance, following general piling design guidelines (e.g., Peck et al. 1974; FEMA Prestandard 356).



Figure 25. Example of a debris catching log array placed on a gravel bar to trap wood and promote sediment deposition and vegetative colonization.

3.6.4 CRIB JAM

Consistent with designs constructed for the CTUIR at the Thornhollow facility and elsewhere, log crib structures provide lateral scour pool habitat as well as reduce potential for bank erosion. For this project, the log crib structure would be designed to be small in vertical profile and held in place by a combination of gravel and boulder ballast, lateral embedment of key pieces, log-log interlocking, and vertical posts. This structure when placed on the outside of a bend can promote development and persistence of a bend scour pool that provides low flow habitat for adult Chinook, including in streams smaller than the Umatilla River (Figure 26). Streamwise-oriented logs with rootwads are held in place by logs above. Anchoring of the structure overall is to be provided by (i) horizontal logs embedded in the bank that pin down streamwise logs with rootwads, (ii) vertical posts that are set back from the edge, and (iii) boulder and gravel ballast backfill. The horizontal pinning logs are themselves also held in place by boulders situated on top of them that are partially embedded in the floodplain and are sized to counter the logs' buoyancy force if submerged. The posts are considered critical to stability of the structure, but do not need to protrude substantially higher than the structure itself. The structure is expected to last roughly 5-10 years while planted softwood and willow and dogwood stakes take hold, after which it can either remain in place or rot and break up during flooding.

This design is to be implemented along the right bank at the sharp bend below the current diversion intake location. Debris logs installed in the opposing bank point bar may enhance scouring at the base of the structure by promoting additional deposition that forces the thalweg toward the structure. The crib jam is designed essentially the same way as embedded logs, except that there is also a horizontal log running along the toe of the streambank providing an additional upwards buoyancy force. The horizontal logs are held in place underneath multiple embedded logs placed adjacent to each other. The design of embedment

dimensions reflects the additional buoyancy of the horizontal log. In addition, vertical stabilizing posts were added to the design to provide additional lateral stability, with the force required to overturn the post evaluated using the method of Broms (1964; in Murthy 2003).



Figure 26. Example scour pool formation in front of a crib jam.

3.6.5 STREAMBED BOULDER CLUSTERS

Instream boulders will be placed in small self-stabilizing clusters to assist with promoting deposition around PALS and debris logs that are proposed to be placed in the vicinity of the diversion intake and outfall to promote development and maintenance of opposing gravel-cobble bars that maintain a low flow channel thalweg in front of the facility structures. The approach is a natural analog to self-stabilizing cobble clusters observed in gravel bed streams (Church et al. 1998). Clusters are also proposed for placement on a low-profile mid-channel bar below the bridge to promote a more meandering thalweg in an otherwise essentially plane bed morphology. The placement coincides with the potential location for a new diversion intake on the other side of the channel, and thus may benefit that design in the future if implemented.

The clusters may also provide hydraulic habitat complexity at higher flow levels, and are an established approach to increasing instream habitat diversity for steelhead and other salmonid species (e.g., > 2 feet wide boulders, Ward and Slaney 1979). Steelhead adults and juveniles (and potentially migrating Chinook adults depending on accessibility as a function of flow level) are known to use larger boulders for velocity cover for conserving energy overall, and/or as bioenergetically efficient feeding stations. Boulders providing this type of habitat are generally found in streams with gradients between about 1 percent to 3 percent (Mooney et al. 2007) and thus appear appropriate for placement in the project reach.

The highest velocity predicted by the HEC-RAS model at the 100-year flood is less than 10 ft/s between the diversion intake and the bridge. A drag force balance analysis following D'Aoust and Millar (2000) predicts that a boulder stable at 10 feet/s would have a minimum average diameter of around 3.1 feet. The corresponding dry weight is approximately 2,600 pounds for a specific gravity =2.65. Design charts presented

in USACE (1994) for stone size in turbulent stilling basins based on Isbash's relation indicate that a D_{50} of approximately 1.25 feet is stable at 10 feet/s. A D_{100} equal to twice the D_{50} (which is a little larger than would be specified for stable riprap design) would be approximately 2.5 feet. Thus boulders placed in self-stabilizing clusters should have an average diameter of around 2.5 feet and larger to reduce the risk of physical displacement and loss of cluster integrity by high flows.

Boulder cluster cross-stream spacing involved professional judgment combined with general criteria for boulder placements where submerged area of boulders should not exceed 20% and 10% respectively of total flow area across the channel (Fischenisch and Seal 2000; Saldi-Caromile et al. 2004; Mooney et al. 2007). This criterion is associated with reducing risks of increasing roughness significantly during flooding. Design criteria for streamwise spacing of clusters vary, but in general the idea is to space clusters so that their downstream wake zones do not overlap; Mooney et al. (2007) present criteria from which a minimum spacing of 3 feet between clusters is inferred. A spacing criterion double that was selected initially based on professional judgment. It was reasoned that boulders should not be placed so close that they substantially increase overall channel roughness during overbank flows. Roughness relations developed by Pagliara and Chiavaccini (2006) for a range of boulder concentrations suggest that more than 100 boulders with a diameter around 2 feet would be needed in a 110 feet wide by 200 feet long reach to measurably increase the total streambed Manning's n roughness coefficient. The total number of boulders was kept below this in the vicinity of the diversion intake to minimize their effect on overall channel roughness.

3.7 DESCRIPTION OF HOW PRECEDING TECHNICAL ANALYSIS HAS BEEN INCORPORATED INTO AND INTEGRATED WITH THE CONSTRUCTION – CONTRACT DOCUMENTATION

Design specifications are given directly on the plans. Where appropriate, standard specifications are identified. There are no special provisions anticipated for this project in addition to the plans.

3.8 FOR PROJECTS THAT ADDRESS PROFILE DISCONTINUITIES (GRADE STABILIZATION, SMALL DAM AND STRUCTURE REMOVALS): A LONGITUDINAL PROFILE OF THE STREAM CHANNEL THALWEG FOR 20 CHANNEL WIDTHS UPSTREAM AND DOWNSTREAM OF THE STRUCTURE SHALL BE USED TO DETERMINE THE POTENTIAL FOR CHANNEL DEGRADATION

See Figure 3 which depicts a distinct concave slope break in the vicinity of the confluence with Meacham Creek. The longitudinal elevation profile above and below the slope break is roughly linear. The presence of this slope break is consistent with the deposition and active channel migration observed downstream of the Imeques acclimation facility outfall. Overall, the longitudinal elevation profile indicates the absence of any significant discontinuity that could be associated with potential for degradation or head-cutting. Instead, mainstem channel aggradation could be expected over the long term in the vicinity of the slope break, and where floodplain connectivity is increased.

3.9 FOR PROJECTS THAT ADDRESS PROFILE DISCONTINUITIES (GRADE STABILIZATION, SMALL DAM AND STRUCTURE REMOVALS): A MINIMUM OF THREE CROSS-SECTIONS – ONE DOWNSTREAM OF THE STRUCTURE, ONE THROUGH THE RESERVOIR AREA UPSTREAM OF THE STRUCTURE, AND ONE UPSTREAM OF THE RESERVOIR AREA OUTSIDE OF THE INFLUENCE OF THE STRUCTURE) TO CHARACTERIZE THE CHANNEL MORPHOLOGY AND QUANTIFY THE STORED SEDIMENT

N/A

4.0 CONSTRUCTION – CONTRACT DOCUMENTATION

4.1 INCORPORATION OF HIP IV GENERAL AND CONSTRUCTION CONSERVATION MEASURES

Sheets 3-5 of the plans specify all HIP IV general and construction conservation measures.

4.2 DESIGN – CONSTRUCTION PLAN SET INCLUDING BUT NOT LIMITED TO PLAN, PROFILE, SECTION AND DETAIL SHEETS THAT IDENTIFY ALL PROJECT ELEMENTS AND CONSTRUCTION ACTIVITIES OF SUFFICIENT DETAIL TO GOVERN COMPETENT EXECUTION OF PROJECT BIDDING AND IMPLEMENTATION

See design plans. As part of construction activities, the project will involve specifically:

- Using an excavator to embed individual LWD logs with rootwads and a crib jam at various locations throughout the reach to provide widely distributed instream habitat and gravel sorting functions;
- Using an excavator to install PALS to create a hard point that results in local scour pool creation around protruding wood pieces, and/or promote a split channel morphology; vertical boles installed as part of the jam for stability are also intended for catching and racking loose logs during high water to create a larger jam;
- Using an excavator to place supplemental streambed boulders on the streambed as part of measures to promote bar formation and maintenance that directs the thalweg in front of the diversion intake;
- Using an excavator to install logs with rootwads and boles on low elevation gravel bars to increase gravel deposition, and on higher elevation gravel deposits to trap loose LWD jam logs floating downstream during floods;
- Increasing floodplain connectivity between the river mainstem and selected relic floodplain swales by excavating small pilot channels that will connect the river with floodplain forest vegetation more frequently during high flow events; and
- Planting native vegetation to increase and enhance riparian, floodplain, and older floodplain terrace forest vegetation diversity and density, and provide a future source of LWD to the stream channel.

4.3 LIST OF ALL PROPOSED PROJECT MATERIALS AND QUANTITIES

Table 4 lists estimates of quantities. Planting quantities will be provided on the site restoration and revegetation sheets.

Table 4: Estimated quantities.

PURPOSE	ITEM	SPEC/DIM	AMOUNT	UNIT
PERMIT VOLUMES/AREAS	FLOODPLAIN EARTH BALANCED CUT & FILL VOLUME	-	208	CY
	FLOODPLAIN EARTH CUT, CLEARING/GRUBBING AREA	-	0.24	ACRES
	IN-CHANNEL BALANCED GRAVEL REDISTRIBUTION VOLUME		1240	CY
	IN-CHANNEL BALANCED GRAVEL REDISTRIBUTION AREA OF DISTURBANCE		0.55	ACRES
	FLOODPLAIN RIPRAP REMOVAL	-	127	CY
	FLOODPLAIN FILL AREA	-	0.17	ACRES
	LOG WORK CUT & FILL AREA	-	0.86	ACRES
	IMPORTED ROCK VOLUME (BOULDERS, ROAD FORD SURFACING)	-	241	CY
	IMPORTED LOG VOLUME	-	962	CY
	VEGETATION CLEARING AREA (INCLUDES ACCESS, WORK AREAS)	-	0.60	ACRES
	TEMPORARY STAGING AREAS (DISTURBED)	-	0.05	ACRES
	TEMPORARY ACCESS ROAD AREA (NEW, NON-COMPACTED)	-	0.11	ACRES
	TOTAL AREA OF DISTURBANCE	-	2.46	ACRES
ROCK	STREAMBED BOULDERS - ARRAYS	4000 LB	54	EA
	STREAMBED BOULDERS - CLUSTERS	3000 LB	108	EA
	AGGREGATE FOR ACCESS ROAD COVER	ANGULAR 6"-MINUS	26	CY
EMBEDDED LOGS	LOGS W/ ROOTWADS	(14"-24") DBH X (30'-35')L	57	EA
	BALLAST BOULDERS	VARIES, SEE TABLE 2	VARIES	EA
POST ASSISTED LOG STRUCTURES	LOG W/ ROOTWAD	(14"-18") DBH X 35'L	24	EA
	LOG W/ ROOTWAD	(12"-14") DBH X (35'-40')L	8	EA
	LOG W/ ROOTWAD	(14"-18") DBH X 20'L	24	EA
	LOG W/ ROOTWAD	MIN 12" DBH X 20'L	72	EA
	MANILA HEMP ROPE	1" DIA	1848	LF
CRIB JAM	LOG W/ ROOTWAD (BUCKED)	(12"-16") DBH X 30'L	8	EA
	LOG W/ ROOTWAD (BUCKED)	(10"-12") X 30'L	2	EA
	LOG W/ ROOTWAD, BRANCHES	(12"-14") DBH X 30'L	7	EA
	VERTICAL BOLES	MIN 12" X 12'L	7	EA
	BALLAST BOULDERS	2000 LB MIN	15	EA
EXPOSED DEBRIS LOGS	LOGS W/ ROOTWADS	(14"-20") DBH X (30'-35')L	166	EA
	VERTICAL BOLES	(10"-12") X 12'L	166	EA
TESC	SILT FENCE	SEE SHEET 7	AS NEEDED	LS
WATER MANAGEMENT	SUPERSACKS/SANDBAGS FOR COFFER DAMS	SEE SHEET 8	AS NEEDED	LS
	PUMP FOR IN-CHANNEL WORK	SEE SHEET 8	AS NEEDED	LS
	PLASTIC SHEETING	SEE SHEET 8	AS NEEDED	SY

4.4 DESCRIPTION OF BEST MANAGEMENT PRACTICES THAT WILL BE IMPLEMENTED AND IMPLEMENTATION RESOURCE PLANS INCLUDING:

4.4.1 SITE ACCESS STAGING AND SEQUENCING PLAN

The following general sequence of activities is planned, assuming construction begins in mid- to late June:

1. Clear/grub as needed and develop access routes and staging areas. Save larger slash/woody debris to add to top of log jams and debris log arrays.
2. Prepare staging area and sensitive access route surfaces. Truck-haul logs and streambed boulders to site, sort and stage logs and boulders. No hazardous material staging is permitted within 150 feet of ordinary high water.
3. Install temporary erosion control at locations indicated on plans, and any other locations deemed necessary depending on conditions encountered.
4. Pilot channel excavation and riprap removal above water may occur prior to the in-water work window, with appropriate temporary erosion and sediment control measures (TESC) measures implemented.
5. Starting on or after July 1, begin instream work, install logs and streambed boulders where indicated in plans, following TESC, water management, and fish salvage plans. Where indicated on the plan sheet detailing access, place channel crossing logs on channel bottom prior to crossing channel as needed. Work progressively in upstream or downstream direction per contractor's choice.
6. In-water work is estimated to occur over the full duration of the standard six-week window (July 1-August 15).

7. Measures will be implemented to temporarily protect potential spawning habitat areas of the streambed at designated shallow-water stream crossing locations, such as placement of steel plates or a construction bridge.
8. Final clean up and abandon access routes as necessary.
9. Prepare site for re-vegetation and permanent erosion control.
10. In following spring, complete planting plan.

4.4.2 WORK AREA ISOLATION AND DEWATERING PLAN

General and specific HIP IV measures are provided as standalone sheets in the plan set. TESC and water management plan specifics are also presented as standalone sheets in the plan set.

ODFW requires a project specific approved in-water work window for the Umatilla River

(<https://www.dfw.state.or.us/lands/inwater/Oregon%20In-water%20Work%20Guidelines%20January%202022.pdf?msclkid=6c7719e8a6c511eca3ff1bf4749751a8>). The standard approved in-water work window for this project is July 1-August 15. Work elements involving ground disturbance within the current wetted channel footprint shall follow this plan. All in-water work areas shall be isolated using sandbags, supersacks, and/or other approved measures following the Design Plans with the goal of avoiding or minimizing turbidity and other water quality impacts, and for avoiding impacts to fish in the work area.

The general procedure to isolate an area where logs are to be placed in-water or where an excavation footprint may project onto wetted riverbed areas is as follows:

1. Work area isolation and fish capture activities will occur during periods of the coolest air and water temperatures possible, normally early in the morning versus late in the day, and during conditions appropriate to minimize mortality for the species present.
2. Where a trench is to be excavated for placing individual embedded habitat logs:
 - a. Excavate trench to target grade, peeling back to avoid dropping sediments into the stream channel, and leaving small undisturbed plug at water's edge.
 - b. Sweep in downstream direction with beach seines to chase fish away from work area; any fish remaining in the seine shall be collected with a hand dip net, transported in a bucket with suitable aeration if needed, and released at a safe location downstream.
 - c. Scoop plug, quickly place log in trench as water flows into trench, place fill to stop inflow to trench, complete backfill.
3. At other, larger log installations:
 - a. Sweep in downstream direction with beach seines to chase fish away from work area; any fish remaining in the seine shall be collected with a hand dip net, transported in a bucket with suitable aeration if needed, and released at a safe location downstream.
 - b. Place sandbags in an arc, starting upstream of the work area, extending out into the channel and downstream approximately 2/3 of the way needed.
 - c. Using electrofishing gear, clear the partially enclosed area of any fish that have not been chased out by sandbag placement activity.
 - d. Fish should be released upstream of the next riffle above the activity location.
 - e. Complete the enclosure.
 - f. Check for fish again using electrofishing equipment.
 - g. If a pump is necessary once the isolated area is cleared of fish, discharge to a confined swale in the floodplain to avoid sedimentation issues. If necessary, use staked straw bales to assist with water containment and infiltration.
4. Work in different isolation areas should proceed in the downstream direction.
5. Dewatering will not be conducted in areas occupied by lamprey, unless lampreys are salvaged using guidance set forth in "USFWS Best Management Practices to Minimize Adverse Effects to Pacific Lamprey."

6. The design was developed in such a way that it is expected construction actions within each isolation area can be completed in 1 day. Sites requiring more than one day shall be checked for fish each morning prior to resuming construction.
7. Sandbags shall be removed as soon as construction is complete within the isolated area. Sandbags should be removed starting at the downstream end and working back upstream so that the isolated area stays as quiescent as practicable during removal. This should allow for gradual dispersion of residual disturbed fine sediments.

Where logs are to be placed in the dry, such as on gravel bars, build a small push-up berm as needed first to isolate the excavation area from the stream flow.

Isolate the channel fill area opposite the diversion intake with supersack cofferdams and ply sheeting in the wetted right channel at (i) its upstream end to shunt all flow to the left channel in front of the intake and (ii) its downstream end to isolate the right channel area to be filled, and construct a gravel berm or use silt fencing along the perimeter of the fill area between the two cofferdams.

General procedures for herding fish in areas where the excavator will be working within the wetted channel involve use of seining and electrofishing capture and relocation methods (described above and in HIP IV conservation measures sheet of the Design Plans) in that order, working in the downstream direction.

All electrofishing activities will be performed by CTUIR staff, and will follow the following NMFS guidelines that are also part of BPA's HIP IV conservation measures.

STEP 1 – ISOLATE

As directed above, temporary sandbag or supersack cofferdams will be installed to isolate work areas and prevent fish from entering the project area. Workers shall wade in the vicinity of bag placement prior to placement to ensure fish are chased away. If an isolation area remains in place more than one day, the area will be monitored at the beginning of the next day to ensure fish have not entered the area somehow.

STEP 2 – SALVAGE

As described below, fish trapped within the isolated work area will be captured to minimize the risk of injury, then released at a safe site upstream, following these general procedures:

1. To the extent practicable, fish will first be collected by hand or dip nets.
2. If the water is sufficiently deep and the bed sufficiently regular/smooth, seines with a mesh size to ensure entrapment of the residing ESA-listed fish will be used.
3. A backpack electrofisher shall be used to capture any fish hiding within the substrate, following these NMFS guidelines:
 - a. Only direct current (dc) or pulsed direct current (pdc) will be used.
 - i. If conductivity is less than 100 μ s, voltage ranges from 900 to 1,100 v. will be used.
 - ii. For conductivity ranges between 100 to 300 μ s, voltage ranges will be 500 to 800 v.
 - iii. For conductivity greater than 300 μ s, voltage will be less than 400 v.
 - b. Electrofishing will begin with a minimum pulse width and recommended voltage and then gradually increase to the point where fish are immobilized.
 - c. The anode will not intentionally contact fish while the current is being emitted.
 - d. If mortality or obvious injury (defined as dark bands on the body, spinal deformations, de-scaling of 25% or more of body, and torpidity or inability to maintain upright attitude after sufficient recovery time) occurs during electrofishing, operations will be immediately discontinued, machine settings, water temperature and conductivity checked, and procedures adjusted or postponed to reduce mortality.
4. Buckets will be used to transport captured fish, where the time fish are in a transport bucket will be limited, and will be released as quickly as possible; the number of fish within a bucket will be limited based on size, and fish will be of relatively comparable size to minimize predation; aerators for

buckets will be used or the bucket water will be frequently changed with cold clear water at 15 minute or more frequent intervals; buckets will be kept in shaded areas or will be covered by a canopy in exposed areas; dead fish will not be stored in transport buckets, but will be left on the stream bank to avoid mortality counting errors.

5. Fish will be released as rapidly as possible (especially for temperature-sensitive bull trout) in an area that provides adequate cover and flow refuge, at a suitable location upstream.
6. Salvage will be supervised by a qualified fisheries biologist experienced with work area isolation and competent to ensure the safe handling of all fish.

If fish salvage is not effective, the pump used in the isolation area will then be required to have fish screens to avoid juvenile fish entrainment, and the screens will meet current NMFS fish screen criteria.

STEP 3 – SALVAGE NOTICE

Once salvage operations are completed, a salvage report will document procedures used, any fish injury or mortality (including numbers of fish affected), and a description of the causes for mortality, as required on the reporting form.

4.4.3 EROSION AND POLLUTION CONTROL PLAN

General and specific HIP IV measures are provided as standalone sheets in the plan set. All refueling areas are to be located more than 150 feet away from the channel, per HIP IV conservation measures listed on the Design Plans. The contractor will be required to prepare and adhere to a Spill Control and Pollution Prevention Plan.

TESC and pollution control BMP details are identified on the Design Plans. The following specific BMPs are to be implemented by the contractor:

1. All work shall be performed during the summer low flow period to minimize disturbance extent within the wetted channel. The relevant standard approved instream work window is from July 1-August 15.
2. Contractor shall have sufficient materials on hand for temporary erosion and sediment control, including silt fencing, straw, and geotextile fabric.
3. Silt fencing will be used to prevent sediments from entering the channel as a result of excavation activities associated with construction of bridge footings and widening of the floodplain upstream and downstream of the new bridge. This work will not require entering the channel with heavy equipment. Silt fencing shall follow specifications on the Design Plans.
4. Silt fencing will also be placed on the downslope side of any temporary riverbed spoils stockpile areas and fill areas.
5. Sandbags and/or supersacks shall be used to form a temporary coffer dam that isolates sections of bank where excavation or grading is required within the wetted channel. The temporary cofferdam shall be a minimum of 18" above the WSE to prevent wash-over induced by the excavator bucket. In the interest of reducing the time working in the water, an option exists per the Design Plans where the contractor may construct a cofferdam that isolates the excavation and then moves selected sandbags and reseals the work area during log placement. Examples are given on the Design Plans. Any area that is isolated shall be cleared of fish prior to beginning excavation or grading, following specifications above.
6. Creation of temporary berms using native streambed gravel is permitted on dry gravel bars, but shall not be permitted in the wetted channel unless a variance is proposed by the contractor, and the appropriate BMP plan is approved by ODFW.
7. Any pumping that is required to keep excavation workable will discharge to contained areas on the floodplain or other such areas as will allow infiltration of dirty water. No dirty water shall be allowed to runoff to stream. Areas may be contained naturally by topography, and/or closed off by straw

bales that are fixed in place with fence posts or rebar driven into the bales and ground. All pumps will be screened to avoid entraining fish, and screens will be inspected and cleaned regularly to avoid creation of high velocity spots on the screen surface.

8. Channel bank-to-bank crossings shall be accomplished by shortest distance across the wetted channel. If necessary, temporary logs shall be placed side by side with long axis oriented streamwise across the wetted portion of the channel at the locations indicated on the Design Plans and such that throughflow of low summer flows is possible.
9. All construction disturbed surfaces shall be restored by scraping compacted soils and seeding using native grass seed mix and/or live stakes as specified in Design Plans. Seeds shall be raked into the soil.
10. All excess spoils not used in constructing the setback berm shall be spread onsite over an area designated by the CTUIR that is at or above the established 100-year WSE.

4.4.4 SITE RECLAMATION AND RESTORATION PLAN

The Design Plans include site reclamation and restoration details, involving planting riparian shrub stakes in backfill at log placements involving excavation, reseeding of disturbed areas, and species-appropriate reforestation of existing riparian and open areas. Details are provided in Section 7.2.

4.4.5 LIST PROPOSED EQUIPMENT AND FUELS MANAGEMENT PLAN

The following equipment are anticipated:

- Tracked excavator(s) with thumb and bucket for general excavation, hauling, and placing logs and boulders, and for spreading spoils;
- Dump truck for hauling and dumping excavated material;
- A smaller tracked backhoe may be used for excavating trenches for log structures;
- Portable winches/come-alongs for moving logs manually;
- Primary and backup dewatering pumps with fish screens.

Contractor shall observe NMFS and HIP IV recommendations for use of hydraulic fluids in environmentally sensitive areas and applications. Environmentally friendly hydraulic fluids must be non-toxic and biodegradable if released accidentally into the environment.

Contractor shall follow all Spill Prevention, Control and Countermeasures (SPCC) identified as part of HIP IV conservation measures on the Design Plans. All fuels and refueling facilities must be stored more than 150 feet away from the channel ordinary high water extent.

4.5 CALENDAR SCHEDULE FOR CONSTRUCTION/IMPLEMENTATION PROCEDURES

Contractor will adhere to the following approximate schedule to the extent practicable:

- | | |
|---|-----------------------------|
| • Mobilization, site preparation (access, staging areas): | June 1-14 |
| • Haul logs, boulders to staging sites: | June 1-14 |
| • TESC implementation | June 14-20 |
| • Pilot channel excavation, riprap removal: | June 21-30 |
| • In-water work: | July 1-August 15 |
| • Site restoration, seeding, demobilization: | September 3-6 |
| • Plantings, Remaining site restoration: | March-April, following year |

A more detailed, daily schedule broken down by specific project elements will be provided by the Contractor prior to starting work, and shall be approved by the CTUIR project manager.

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

CTUIR's construction supervisor will be onsite to ensure: (i) staging and refueling occur at designated areas that meet HIP III requirements for distance from channel; (ii) heavy equipment hydraulics use appropriate biodegradable fluids; (iii) water management and TESC measures are implemented per plans to avoid turbidity exceedances, and temporarily shut down excavation activity in cases when excessive turbidity conditions are created. Visual monitoring shall occur every 10 minutes immediately downstream of work areas adjacent to or isolated from the stream water to ensure that there is negligible increase in turbidity in the channel, and during log placement. If significant leakage is detected resulting in an increase of >20 Nephelometric Turbidity Units (NTU) over background in the fully mixed zone, the holes shall be covered with additional sandbags.

5.0 MONITORING AND ADAPTIVE MANAGEMENT PLAN

5.1 INTRODUCTION

Effectiveness monitoring will be performed by the CTUIR with the objective of answering the basic question: Are project elements functioning as intended? If not, then the CTUIR's Adaptive Management Plan for this project is to assess the reason(s) why, and to the extent practicable, identify feasible replacement or mitigation measures.

5.2 EXISTING MONITORING PROTOCOLS

The CTUIR developed its Physical Habitat Monitoring Strategy (PHAMS; Jones et al. 2015) for monitoring the effectiveness of its restoration projects and program. Implementation of PHAMS involves practical methods that can be used to describe reach-scale changes in the five River Vision touchstones at restoration projects, encompassing surface and groundwater hydrology, geomorphology, hydrologic connectivity, and riparian vegetation. The suite of methods and metrics involved in implementing PHAMS are relatively simple, intuitive, and cost effective, and present a palette of metrics to choose from as appropriate to the project and setting that can be measured. The intent of monitoring for this project will be to measure selected simple metrics at the reach scale that can be used to describe changes in physical attributes comprising fish habitat, and whether those changes are associated with improved conditions.

5.3 PROJECT EFFECTIVENESS MONITORING PLAN

The monitoring plan will be focused on measures that indicate the effectiveness of individual and collective project elements. Validation monitoring (i.e., of population response, health, or survival) is not part of the proposed plan. The following five simplified objectives and associated monitoring questions are defined for the plan.

5.3.1 OBJECTIVE 1: MONITOR HABITAT COMPLEXITY

Describe qualitative and quantitative changes in instream habitat complexity associated with project elements. The following relevant questions will be monitored:

- Is pool habitat created/maintained, and what is the pool forming mechanism?
- Does the project element trap/retain woody debris in the channel?
- Is the project element associated with increased gravel sorting, and in what form?

5.3.2 OBJECTIVE 2: MONITOR FISH USE

Fish use of project elements intended to provide instream habitat will be monitored through visual observation with species/lifestage noted.

5.3.3 OBJECTIVE 3: MONITOR FLOODPLAIN CONNECTIVITY

Describe changes in floodplain connectivity frequency and duration. The following relevant questions will be monitored:

- What flows are pilot channels engaged at?
- Are pilot channel inlets and floodplain flow paths enlarging/static/filling?

- What is the duration and timing of inundation along target floodplain flow paths relative to floodplain vegetation needs?
- What are the minimum flows for which side channels remain connected and passable for fish?
- Is trapping and/or stranding of fish occurring on the floodplain?

5.3.4 OBJECTIVE 4: MONITOR NATURAL PROCESSES

Describe changes in channel form in vicinity of project elements that confirm whether each measure performed its desired function. The following questions will be monitored:

- Is the project element associated with conversion of channel type from simpler to more complex?
- Is accelerated sediment erosion/deposition occurring in association with project elements?
- Is channel planform length/slope changing?

5.3.5 OBJECTIVE 5: MONITOR REVEGETATION

Describe survival and growth of floodplain and riparian plantings. The following questions will be monitored:

- What is percent survival by species?
- Are invasive species colonizing restored areas?

5.3.6 OBJECTIVE 6: MONITOR RISK

Describe changes in channel form in vicinity of private land at upstream end of reach, and in the vicinity of previous recent deposition on the floodplain in the direction of the acclimation ponds, to identify potential future erosion and flooding risks, for informing adaptive management response.

- Has channel migration or avulsion occurred or is at increased risk of occurring, and if so, in what form, where, and how extensively?
- Have there been notable changes in flood elevations?

5.4 PROJECT REVIEW TEAM TRIGGERS

The following possible triggers in Table 5 are relevant to adaptive management only if a project element is found through monitoring to not achieve its intended habitat objective, or results in an unanticipated risk, so that an appropriate adaptive management decision can be made where feasible. An adaptive management response may not be feasible if specific project elements are rendered ineffective by an extreme flood event or other unanticipated phenomenon, but even in that instance the resulting knowledge can be used to inform the selection and design of future project. At the highest level, the monitoring plan results will inform the CTUIR as to what project element types work best in the Umatilla River, and what types do not work well, to guide future planning and design.

Table 5: Proposed adaptive management triggers and corresponding responses.

Project Element	Monitoring Objective	Trigger/Event/Risk	Adaptive Management Response
Embedded Habitat Logs	Habitat Complexity	No scour pool around rootwad	Assess if sediment loading from upstream is at a temporary or persistently high level, inform future planning and design

Project Element	Monitoring Objective	Trigger/Event/Risk	Adaptive Management Response
Embedded Habitat Logs	Habitat Complexity	No fish use	Consider shifting to alternative installations, inform future planning and design
Embedded Habitat Logs	Habitat Complexity	Avulsion abandons channel	Consider placing wood in new channel, too
Embedded Habitat Logs	Habitat Complexity	Loss of log	Evaluate whether contractor followed design plans or loss was due to unanticipated event, inform future planning and design
PALS	Habitat Complexity	No scour pool around structure	Assess reason, inform future planning and design
PALS	Habitat Complexity	No fish use	Consider shifting to alternative installations, inform future planning and design
PALS	Floodplain Connectivity	No/diminished split flow around structure	Evaluate if additional actions that increase mainstem channel roughness would help
PALS	Risk	Partial or full channel logjam forms that promotes avulsion that could affect private lands or infrastructure	Engage State regulatory staff, remove or alter structure and/or logjam
PALS	Risk	Loss of structure during extreme flood	Evaluate cause and fate of structure pieces, inform future planning and design
Debris Logs	Natural Processes	No deposition/riparian vegetation colonization	Evaluate cause, inform future planning and design
Streambed Boulder Clusters	Diversion Intake Reliability	No local aggradation	Evaluate if additional actions that increase mainstem channel roughness would help
Pilot Channel	Floodplain Connectivity	Inlet fills in with woody debris, sediments	Evaluate if additional actions that increase mainstem channel roughness would help
Pilot Channel/Floodplain Flow Paths	Floodplain Connectivity	Excessive channel erosion and/or head cut formation leading to increased potential for premature avulsion	Evaluate avulsion potential and effects to existing habitat, consider adding large wood to new channel near inlet to regulate flow/reverse erosion
Pilot Channel/Floodplain Flow Paths	Risk	Increased floodplain flows associated with flooding or erosion risks to Imeqes acclimation facility	Consider adding large wood to new channel near inlet to regulate flow/reverse erosion
Plantings	Revegetation	Survival targets not met after Year 1 post-planting	Assess cause, protect from browse/replace mortalities in kind if cause not hydrology-related
Plantings	Invasive species	Colonization begins before native species become established	Apply treatment(s) to remove/kill invasives

5.5. MONITORING FREQUENCY, TIMING, AND DURATION

5.5.1. BASELINE SURVEY

A pre-project baseline habitat survey will not be performed prior to construction, implementing the monitoring protocols described below.

5.5.2. AS-BUILT SURVEY

An as-built survey will be performed following construction during base flow in the late summer to early fall, following completion of construction. The survey will record the locations of each log placement, and verify grading of pilot channels. This survey amount to completing implementation monitoring, not effectiveness.

5.5.3. MONITORING SITE LAYOUT

Effectiveness monitoring will occur over the length of the project reach. Locations for monitoring specific project elements will correspond to the as-built survey locations.

5.5.4. POST-BANKFULL EVENT SURVEY

The first effectiveness monitoring survey will occur the summer after the first bankfull flood event, implementing the monitoring protocols described below.

5.5.5. FUTURE SURVEY (RELATED TO FLOW EVENT)

A subsequent survey will occur five (5) years thereafter, implementing the monitoring protocols described below. In addition, CTUIR facility staff are frequently onsite and can visually assess project functioning and potential future problems at an early stage both during and following freshets and flood flows.

5.6 MONITORING TECHNIQUE PROTOCOLS

The CTUIR plans on a simplified monitoring approach evaluating project implementation and effectiveness.

5.6.1 PHOTO DOCUMENTATION AND VISUAL INSPECTION

Photo documentation will occur using both ground-based georeferenced photo points and opportunistic future aerial photographic imagery. Project elements will be inspected periodically as part of ongoing site visits performed by CTUIR staff, and any placed wood pieces that were lost in floods will be identified and the reason for instability evaluated.

5.6.2 LONGITUDINAL PROFILE

Longitudinal profile and changes in the profile will be extracted from analysis and modeling products produced from LiDAR survey data.

5.6.3 HABITAT SURVEY

Monitoring will involve mapping locations, approximate areas and residual depths of pools that have formed in association with placed large wood the year after construction, after spring runoff.

5.6.4 SURVIVAL PLOTS

Tree and stake plantings will be surveyed the first year for survival, using randomized plots. Percent survival below 75 percent will trigger adaptive management evaluation and response.

5.6.5 CHANNEL AND FLOODPLAIN CROSS-SECTIONS

The project reach is geomorphically dynamic, and unstable in terms of lateral and vertical morphology such that it may be difficult to elucidate changes due to the project vs. those that would occur naturally. Nonetheless, future LiDAR data will be used when available to evaluate channel morphology changes in bankfull depths and widths at hydraulic control locations, channel migration rates, and floodplain flow path development. Pre-project conditions will be derived from a green LiDAR survey performed in 2017.

5.6.6 FISH PASSAGE

Fish passage of smolts departing the acclimation ponds via the outfall into the river will be evaluated visually during winter base flow by determining if the flow split measures have maintained a channel in front of the outfall.

Floodplain flow paths will be walked in the field after selected extreme events for evidence of trapping and stranding potential.

5.7 DATA STORAGE AND ANALYSIS

Data will be stored in the CTUIR's online data base.

5.8 MONITORING QUALITY ASSURANCE PLAN

Data collection will be automated using a GIS supported Field collection guide template to minimized missed data fields or mis-assigned data. In the office prior to exporting data to storage, field personnel export data sets to spreadsheet to identify data points that may be out of range or erroneous.

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7.0 APPENDICES

7.1 PROJECT PLAN SHEETS

Provided separately.

7.2 CONCEPT PLANTING PLAN

A variety of reforestation strategies are proposed that involve planting native conifers, hardwoods, and shrubs to increase riparian, floodplain, and older floodplain terrace vegetation diversity and density, restore disturbed areas, and provide a future source of LWD to the stream channel. Currently the valley bottom floodplain forests include a limited natural coniferous component due to past logging without replanting. Accordingly, the goal of our proposed design is to restore the riparian forest dominant tree species composition and structure, with species targeted to specific zones. An intact riparian gallery forest will provide: local climatic ameliorization by increasing shade and humidity; future sources of in-channel and floodplain large wood supporting channel and fish habitat structure and processes; thermal cover for wildlife; allochthonous carbon input to the stream ecosystem and food web; and roosting and nesting habitat for riparian bird populations.

The strategy for conifer reforestation focuses on planting the following three species known to be native to the area (Hanberry et al. 2020) in environmentally appropriate areas: ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*) and understory grand fir (*Abies grandis*) (Figure 27). Exclusively Ponderosa pine forest will be planted on open, higher elevation areas that would not be inundated at the 5-year flood after enhancing floodplain connectivity. The resulting forest buffer would provide wind dampening, local temperature ameliorization and more mesic conditions within the adjacent valley bottom. The forest buffer would also provide additional avian population habitat and wildlife thermal cover. On open floodplain areas where floodplain connectivity would be enhanced, a mix of ponderosa pine and Douglas fir would be planted, at similar overall density to the upland areas. Grand fir would be interplanted within existing wooded floodplain areas. Grand fir is a shade tolerant conifer and will develop into the overstory as current hardwood trees senesce over the next 25-75 years. As confirmation of the suitability of this strategy, several grand fir specimens were observed growing in the understory onsite. The objective of the grand fir plantings is to accelerate reestablishment of conifers in a deciduous-dominated floodplain and riparian forest. Tree planting densities were specified based on estimates of historical conditions in eastern Oregon and Washington reflecting natural fire regimes (Stine et al. 2014).

To enhance the riparian zone and promote local stability, live stakes of native willows (*Salix* sp.) and dogwood (*Cornus* Sp.) would be planted alongside/on top of installed large wood pieces within ordinary high water. As an option, stakes could be installed elsewhere to promote streambank stability.

A special planting strip is proposed outside of the east fence line to reduce velocities across the pond facility grounds during the 100-year flood peak, and at the same time also provide a local First Foods resource that reflects cultural history. Three plant species were selected that are commonly propagated by the CTUIR and that are suited to the site soil and hydrology conditions: serviceberry (*Amelanchier alnifolia*), mock orange (*Philadelphus Lewisia*), and chokecherry (*Prunus virginiana*). As an option, mock orange could also be planted among the ponderosa pine and Douglas fir plantings.

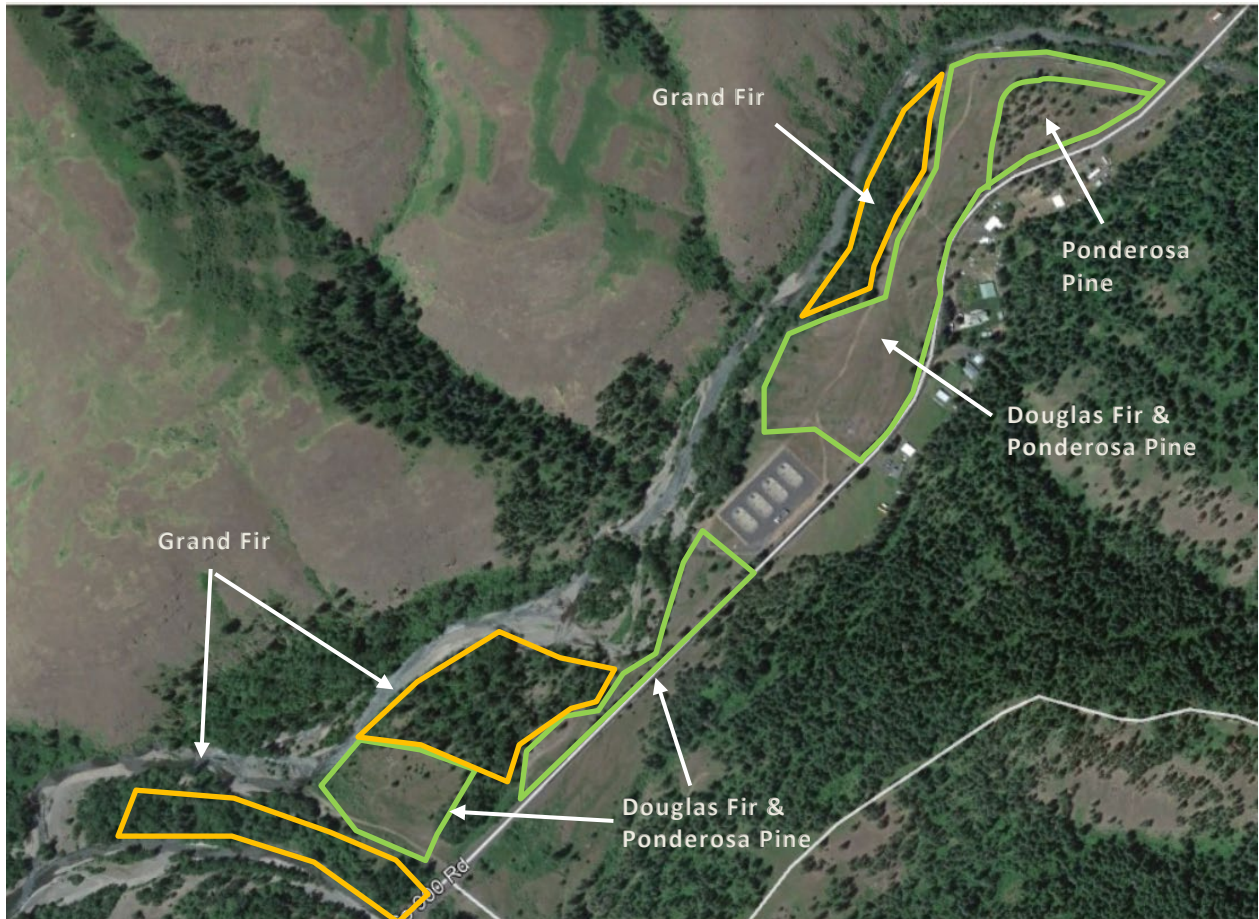


Figure 27. General conifer planting strategy layout.

7.3 OTHER SUPPORTING REPORTS

7.4 HIP REVIEW COMMENTS AND RESPONSES

TO BE INSERTED IN FINAL REPORT VERSION

Angle $\Theta = 0.095383$ radians

FloodplainLength= 14.90454 ft

Moment Component Calculations

Backfill Bank Above Toe, Floodplain

Volume= 59.6 ft³
Submerged Weight= 3696 lb
Moment Distance= 7.5 ft
Moment= 27672 lb-ft =0 if $L_2 < nH/\cos \Theta$

Backfill Bank Slope

Volume= 12 ft³
Submerged Weight= 744 lb
Moment Distance= 16.96 ft
Moment= 12619.46 lb-ft

Backfill Below Toe El

Volume= 27.9 ft³
Submerged Weight= 1728 lb
Moment Distance= 7.0 ft
Moment= 12085 lb-ft

Bank Log Bole

Volume= 48.9 ft³
Buoyancy Force= 1679 lb
Moment Distance= 17.5 ft
Moment= 29383 lb-ft

Toe Log (1/3)

Volume= 0.0 ft³
Buoyancy Force= 0 lb
Moment Distance= 35.0 ft
Moment= 0 lb-ft

Bank Log Rootwad

Volume= 16.1 ft³
Buoyancy Force= 554 lb
Moment Distance= 36.8 ft
Moment= 20385 lb-ft



Job No. 4949001

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Design By PDV

Date 12/29/22

Project IMEQUES

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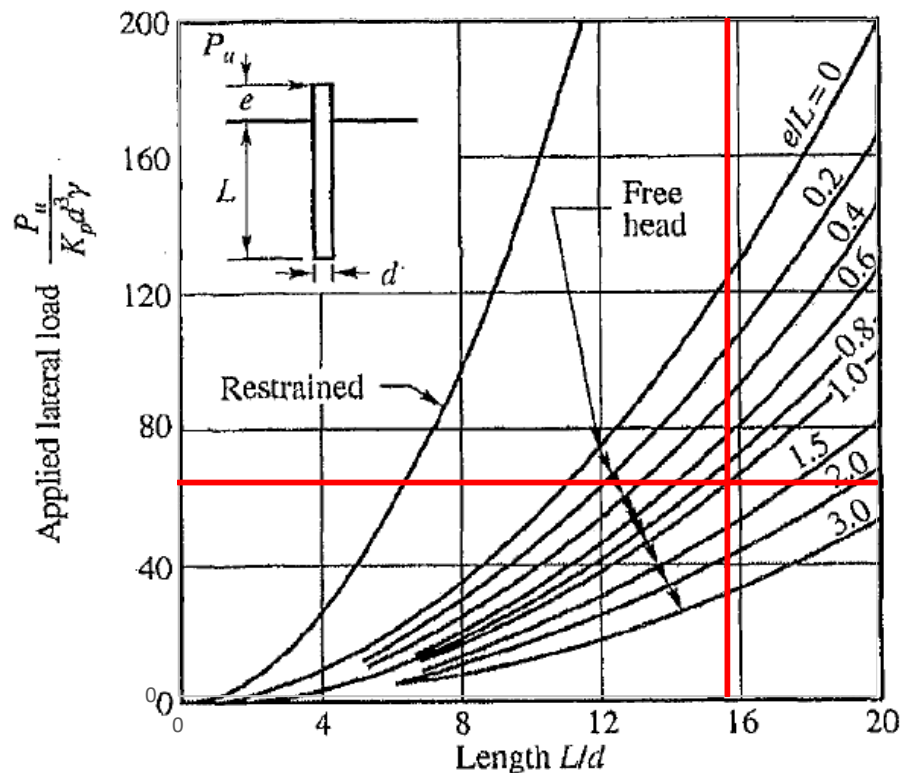
Date _____

Subject Habitat Log Anchoring: Lateral Stability

Log w/ Rootwad, Minimum Installation Depth Into Bank, Non-Cohesive Soil

Diameter d=	1.33 ft	14 inches
Total Length =	35 ft	
Exposed Length e =	14 ft	
Soil Friction Angle	30 degrees	0.52 radians
Effective Soil Unit Weight (wet)=	62 lbf/ft ³	SG=2.65, P=0.4
Velocity=	10 ft/s	
Drag Coefficient=	1.2	
Rootwad Area=	3.6 ft ²	

Drag Force P_u =	27845 lbf	L=	21.0 ft
Rankine Passive EP Coeff K_p =	3.0	L/d=	15.8
Applied Lateral Load=	63	e/L=	0.67 OK



estimate lateral resistance of a short pile in cohesionless
 embedded length (after Broms (1964b))

7.5.2 CRIB JAM

Crib Jam Design Spreadsheet		12/29/2022	
Input Design Parameters: Scour		Input Design Parameters: Buoyancy Pull-Out	
6.0	Approach Depth (ft) (y_1)	0.4	Horizontal Stress Factor, Upward Load, K_u (drilled/excavated)
11.0	Approach Velocity (ft/s) (V_1)	1.0	Horizontal Stress Factor, Upward Load, K_u (displacement)
20	Bedload/Substrate D_{50} (mm)	32	Angle of internal friction, Φ (gravel/glacial till; degrees)
40	Bedload/Substrate D_{95} (mm)	28	Angle of internal friction, Φ (sand; degrees)
1.05	K_1 (square nose = 1.1, angle of attack < 5 degrees)	2.55	Specific Gravity of Substrate, S_s
1.1	K_3	0.30	Porosity, λ (gravel/sand)
0	Flow Angle of Attack to ELJ (deg)	0.20	Porosity, λ (compacted glacial till)
5	ELJ Projected Width (ft)	100	% of Structure Submerged
55	ELJ Length (ft)	0.45	Green Wood Specific Gravity (Doug Fir=0.45, W Red Cedar=0.31)
4.0	Design Goal Maximum Scour Depth at ELJ Base (ft)	9000	Design Holding Capacity, Earth Anchor (lbf) Type: MR2
Input Design Parameters: Log Number/Dimensions		2.5	Specific Gravity of Boulder Ballast, S_{BL}
Size Class I: Key Members/Toe Logs		1874	Minimum Dry Weight per Boulder (lb)
1.166667	Bole Butt Diameter (ft)	7	Number of Anchoring Boles
1	Bole Tip Diameter (ft)	657	Fill Area Above Logs (ft ²)
40	Bole Length (ft)	Input Design Parameters: Drag Force/Anchoring	
2	Number of Logs	6.0	Structure Projected Height (ft)
2	Number With Rootwads	1.94	water density (slug/ft ³)
3	Rootwad Diameter (ft)	1.0	Drag Support Bole Diameter (ft)
Size Class II: 30 ft pieces		7	Number of Boles With Rootwads to Stabilize Against Drag
1.333333	Bole Butt Diameter (ft)	11.0	Maximum Approach Velocity (ft/s)
1.2	Bole Tip Diameter (ft)	6	Bole Height Above Bed (ft)
30	Bole Length (ft)	2.0	Drag Coefficient (C_d) for ELJ Mass, flat plate approximation
15	Number of Logs	1.15	Load Duration Coefficient C_D
15	Number With Rootwads	1.00	Temperature Effect Coefficient C_t
3	Rootwad Diameter (ft)	1.00	Untreated Factor C_u
Size Class III: Vertical Boles		0.80	Single Piling Factor C_{SP}
1	Bole Butt Diameter (ft)	115	Shear Design Value (lbf/in ²): Doug Fir
1	Bole Tip Diameter (ft)	115	Shear Design Value (lbf/in ²): Western Hemlock
10	Bole Length (ft)	95	Shear Design Value (lbf/in ²): Western Red Cedar
7	Number of Logs	66	Shear Design Value (lbf/in ²): Black Cottonwood
0	Number With Rootwads	61	Shear Design Value (lbf/in ²): Balsam Poplar
0	Rootwad Diameter (ft)	1850	Bending Moment Design Value (lbf/in ²): Doug Fir
Size Class IV		1650	Bending Moment Design Value (lbf/in ²): Western Hemlock
0	Bole Butt Diameter (ft)	1350	Bending Moment Design Value (lbf/in ²): Western Red Cedar
0	Bole Tip Diameter (ft)	1230	Bending Moment Design Value (lbf/in ²): Black Cottonwood
0	Bole Length (ft)	980	Bending Moment Design Value (lbf/in ²): Balsam Poplar
0	Number of Logs	1.1	Additional Safety Factor of Design
0	Number With Rootwads	Created by P. DeVries P.E., R2 Resource Consultants	
0	Rootwad Diameter (ft)		

Anchoring Design - Vertical Lift

Created By: P. DeVries P.E.

12/29/2022

Developed Following (i) Force Balance (ii) Foundation Engineering 2nd Ed (Peck et al.) and FEMA Prestandard 356

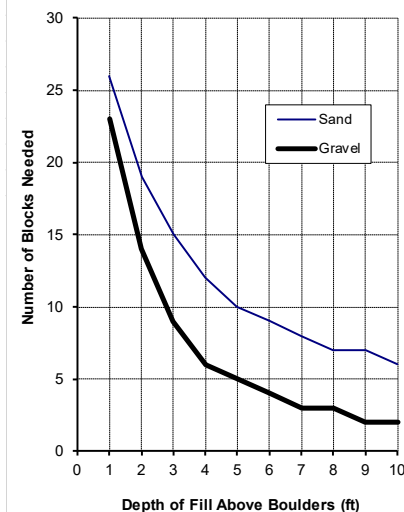
(i) Hard Anchoring Requirements (Redundant to Pilings)		Computed Parameters:	
3	Maximum Number of Earth Anchors Required, or	37	Single Bole Volume, Size Class I (ft ³)
23	Maximum Number of Exposed Boulders Required For Ballast	3	Single Rootwad Volume, Size Class I (ft ³)
		79	Total Log Volume, Size Class I (ft ³)
		38	Single Bole Volume, Size Class II (ft ³)
		3	Single Rootwad Volume, Size Class II (ft ³)
		614	Total Log Volume, Size Class II (ft ³)
		8	Single Bole Volume, Size Class III (ft ³)
		0	Single Rootwad Volume, Size Class III (ft ³)
		55	Total Log Volume, Size Class III (ft ³)
		0	Single Bole Volume, Size Class IV (ft ³)
		0	Single Rootwad Volume, Size Class IV (ft ³)
		0	Total Log Volume, Size Class IV (ft ³)
		748	Total Volume Submerged (ft ³)
		-25698	Buoyancy of Submerged Fraction (lbf)
		0	Weight of Exposed Fraction (lbf)
		-25698	Net Buoyancy Force (lbf)
		-25698	Maximum Possible Buoyancy (lbf)
		-49.0	Piling Buoyancy Force per Unit Length (lbf/ft)
		24	Friction Angle δ (timber:gravel/glacial till)
		21	Friction Angle δ (timber:sand)
		0.45	Friction coefficient $\tan(\delta)$ (gravel/glacial till)
		0.38	Friction coefficient $\tan(\delta)$ (sand)
		0.64	Drilled K_{gravel}
		0.55	Drilled K_{sand}
		0.73	Drilled $K_{\text{glacial till}}$
		0.6	Minimum Soil Backfill Thickness Above Logs (ft)
(ii) Minimum Piling Embedded Length L_e (ft) [Use Goal Seek Below]			
6.74	A1. Drilled/Excavated in Gravel (ft)		
	A2. Drilled/Excavated in Sand (ft)		
	A3. Drilled/Excavated in Glacial Till (ft)		
	B1. Pile Driven in Gravel (ft)		
	B2. Pile Driven in Sand (ft)		
	B3. Pile Driven in Glacial Till (ft)		
A1. Drilled/Excavated in Gravel			
-4371	Total Buoyant Force of Boles (lbf)		
4295.5	Resistance Force/Piling (lbf)		
30068	Total Resistance Force of Pilings (lbf)		
0.00085524	Goal Seek Target = 0, Changing A1. Embedded Length		
A2. Drilled/Excavated in Sand			
-2058	Total Buoyant Force of Boles (lbf)		
0	Resistance Force/Piling (lbf)		
0	Total Resistance Force of Pilings (lbf)		
-27756.01185110	Goal Seek Target = 0, Changing A2. Embedded Length		
A3. Drilled/Excavated in Glacial Till			
-2058	Total Buoyant Force of Boles (lbf)		
0	Resistance Force/Piling (lbf)		
0	Total Resistance Force of Pilings (lbf)		
-27756.01185110	Goal Seek Target = 0, Changing A3. Embedded Length		

Design Chart for Using Boulder Ballast as Anchors in Gravel/Sand Beds

Created By: P. DeVries P.E.

12/29/2022

Buoyancy Load (lbf): 25698		Friction Against Pull-Out (Gravel)	
Specific Gravity: 2.5		Average Vertical Coulomb Load/Unit Width (lbf/ft)	
		Pullout Resistance (lbf)	
Dimensions of Block		Wet Weight, Gravel/Sand (lbf)	
L (ft)	W (ft)	H (ft)	Volume (ft ³)
3	2	2	6.2816
		Wet Weight (lbf)	
		589	
Depth of Fill Above Boulder (ft)		No. of Boulders	
		Sand Gravel	
1		26 23	
2		19 14	
3		15 9	
4		12 6	
5		10 5	
6		9 4	
7		8 3	
8		7 3	
9		7 2	
10		6 2	
		407 995	
		813 1402	
		1220 1809	
		1627 2215	
		2033 2622	
		2440 3029	
		2847 3435	
		3253 3842	
		3660 4249	
		4067 4655	
		31 139	
		62 556	
		94 1252	
		125 2225	
		156 3477	
		187 5006	
		219 6814	
		250 8900	
		281 11264	
		312 13906	



Drag Force Shear, Bending Moment on Boles (Breaking Condition)		Created By: P. DeVries P.E.	
12/29/2022			
Developed Following AFPA Engineered Wood Design Manual & USDA Forest Products Laboratory Wood Handbook			
Structural Integrity Check: Shear - Continual Debris Load		Computed Parameters	
OK	Doug Fir	7042	Drag Force Resultant on ELJ (lbf)
OK	Western Hemlock	1006	Drag Force Resultant of Debris per bole (lbf)
OK	Western Red Cedar	21127	Max Drag Force Resultant Moment of Debris on one bole (lbf-ft)
OK	Black Cottonwood	3018	Max Drag Force Resultant Moment of Debris per bole (lbf-ft)
OK	Balsam Poplar	1.00	Size Factor C_F
		1018	Moment of inertia, I (in ⁴)
		6	distance from neutral axis to extreme fiber, c (in)
		170	Section modulus, S (in ³)
Structural Integrity Check: Bending - Continual Debris Load		11218	Shear Design Criterion (lbf): Doug Fir
OK	Doug Fir	11218	Shear Design Criterion (lbf): Western Hemlock
OK	Western Hemlock	9267	Shear Design Criterion (lbf): Western Red Cedar
OK	Western Red Cedar	6438	Shear Design Criterion (lbf): Black Cottonwood
OK	Black Cottonwood	5950	Shear Design Criterion (lbf): Balsam Poplar
OK	Balsam Poplar	24061	Bending Moment Design Criterion (lbf-ft): Doug Fir
7	Number of Boles to Stabilize Against Drag (Specified)	21460	Bending Moment Design Criterion (lbf-ft): Western Hemlock
		17558	Bending Moment Design Criterion (lbf-ft): Western Red Cedar
		15998	Bending Moment Design Criterion (lbf-ft): Black Cottonwood
		12746	Bending Moment Design Criterion (lbf-ft): Balsam Poplar



Job No. 4900001.01

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Design By PDV

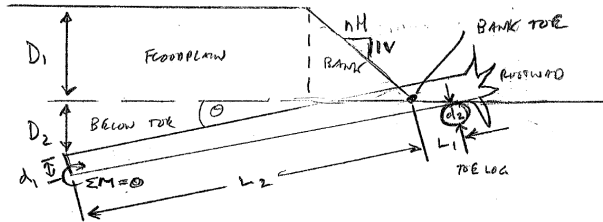
Date 12/29/22

Project IMEQUES

Check By

Date _____

Subject Crib Jam Log Buoyancy Ballast - Lower Layer



SG wood=	0.45
nH:1V Bank	2

Backfill Porosity (if gravel fill)	0
submerged bulk weight soil=	62 lb/ft3

Soil Weight Only; (Ignore shear resistance)

Bank Log Dimensions:

d1=	1.3 ft	diameter
L ₁ =	10 ft	exposed length to rootwad
L ₂ =	20 ft	buried length

Toe Log Dimensions:

d2=	1.0 ft	diameter
lt=	7.5 ft	Total Length

Bank Height:

$D_1 =$	5 ft	Height above bank toe
$D_2 =$	1 ft	depth below bank toe

For Vertical Force Balance:

FB_{logs} = 2061 lb buoyancy force
W_{Backfill} = 7015 lb -----> check: OK

For Moment Balance :

M _{logs} =	41225 lb-ft	buoyancy force	
M _{Backfill} =	53557 lb-ft	check:	OK

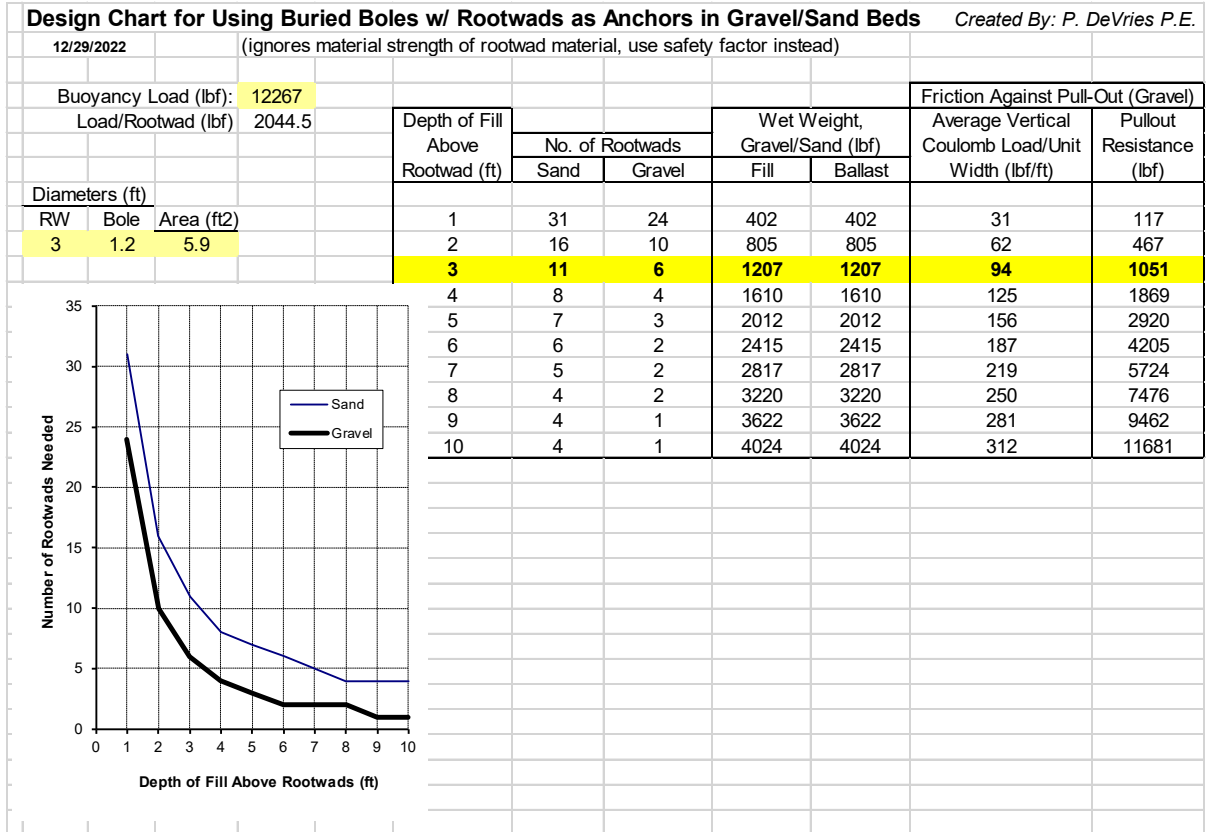
Ballast Deficit:	-1028 lb	(wet weight, min 40% from butt end)
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7.5.3 PALS STRUCTURES

ELJ Design		12/29/2022	
Input Design Parameters: Scour		Input Design Parameters: Buoyancy Pull-Out	
6.0	Approach Depth (ft) (y_1)	0.4	Horizontal Stress Factor, Upward Load, K_u (drilled/excavated)
10.0	Approach Velocity (ft/s) (V_1)	1.0	Horizontal Stress Factor, Upward Load, K_u (displacement)
20	Bedload/Substrate D_{50} (mm)	32	Angle of internal friction, Φ (gravel/glacial till; degrees)
40	Bedload/Substrate D_{95} (mm)	28	Angle of internal friction, Φ (sand; degrees)
1.05	K_1 (square nose = 1.1, angle of attack < 5 degrees)	2.55	Specific Gravity of Substrate, S_s
1.1	K_3	0.30	Porosity, λ (gravel/sand)
0	Flow Angle of Attack to ELJ (deg)	0.20	Porosity, λ (compacted glacial till)
15	ELJ Projected Width (ft)	100	% of Structure Submerged
20	ELJ Length (ft)	0.45	Green Wood Specific Gravity (Doug Fir=0.45, W Red Cedar=0.31)
4.0	Design Goal Maximum Scour Depth at ELJ Base (ft)	9000	Design Holding Capacity, Earth Anchor (lbf) Type: MR2
Input Design Parameters: Log Number/Dimensions		2.2	Specific Gravity of Boulder Ballast, S_{BL}
Size Class I: Key Members		1649	Minimum Dry Weight per Boulder (lb)
1.166667	Bole Butt Diameter (ft)	6	Number of Anchoring Boles
1	Bole Tip Diameter (ft)	Input Design Parameters: Drag Force/Anchoring	
40	Bole Length (ft)	6.0	ELJ Projected Height (ft)
1	Number of Logs	1.94	water density (slug/ft ³)
1	Number With Rootwads	1.0	Drag Support Bole Diameter (ft)
3	Rootwad Diameter (ft)	6	Number of Boles With Rootwads to Stabilize Against Drag
Size Class II: 30 ft pieces		11.0	Maximum Approach Velocity (ft/s)
1.5	Bole Butt Diameter (ft)	10	Bole Height Above Bed (ft)
1.2	Bole Tip Diameter (ft)	2.0	Drag Coefficient (C_d) for ELJ Mass, flat plate approximation
30	Bole Length (ft)	1.15	Load Duration Coefficient C_D
4	Number of Logs	1.00	Temperature Effect Coefficient C_t
4	Number With Rootwads	1.00	Untreated Factor C_U
3	Rootwad Diameter (ft)	0.80	Single Piling Factor C_{SP}
Size Class III: Vertical Boles		115	Shear Design Value (lbf/in ²): Doug Fir
1.2	Bole Butt Diameter (ft)	115	Shear Design Value (lbf/in ²): Western Hemlock
1	Bole Tip Diameter (ft)	95	Shear Design Value (lbf/in ²): Western Red Cedar
20	Bole Length (ft)	66	Shear Design Value (lbf/in ²): Black Cottonwood
6	Number of Logs	61	Shear Design Value (lbf/in ²): Balsam Poplar
6	Number With Rootwads	1850	Bending Moment Design Value (lbf/in ²): Doug Fir
3	Rootwad Diameter (ft)	1650	Bending Moment Design Value (lbf/in ²): Western Hemlock
Size Class IV		1350	Bending Moment Design Value (lbf/in ²): Western Red Cedar
0	Bole Butt Diameter (ft)	1230	Bending Moment Design Value (lbf/in ²): Black Cottonwood
0	Bole Tip Diameter (ft)	980	Bending Moment Design Value (lbf/in ²): Balsam Poplar
0	Bole Length (ft)	1.1	Additional Safety Factor of Design
0	Number of Logs	Created by P. DeVries P.E., R2 Resource Consultants	
0	Number With Rootwads		
0	Rootwad Diameter (ft)		

Scour Design Spreadsheet for ELJ		Created By: P. DeVries P.E.	
12/29/2022			
Developed Following HEC-18			
Predicted Design Scour Depth & Radius		Computed Parameters	
Around ELJ Structure on River Bed, Native Substrate:		0.72	Approach Flow Froude Number
8.5	Y _s (ft)	6.1	V _{CD50} (ft/s) (surrounding substrate)
17.0	Max Scour Hole Radius (ft)	7.7	V _{CD95} (ft/s) (surrounding substrate)
Counter-Measure Design Apron For Target Scour Depth		2.9	V _{ICD50} (ft/s) (surrounding substrate)
315	Apron Substrate D ₁₅ (mm)	3.8	V _{ICD95} (ft/s) (surrounding substrate)
463	Apron Substrate D ₅₀ (mm)	3.16	V _R (surrounding substrate)
788	Apron Substrate D ₉₅ (mm)	1.333333333	L/a
8.8	Minimum Apron Thickness (ft) (No Degradation)	1.0	K ₂ calculated eqn 6.4
12.4	Minimum Apron Radius From ELJ (ft) (No Degradation)	0.48	K ₄
Log Jam Dimensions (From Input Sheet):		0.4	flow depth:ELJ width y/a<0.8?
15	ELJ Projected Width (ft)	229	ELJ width:D ₅₀ >50?
20	ELJ Length (ft)	1.65	V ₁ /V _c
		0.82	K _{w use}
		0.82	K _w calculated
		0.224	K ₄ target (scour counter-measure)
		21.0702285	1000 x V _R (target scour counter-measure)
		21.07025312	1000 x V _R (calculated scour counter-measure)
		17.3	V _{CD50} (ft/s) (scour counter-measure)
		20.7	V _{CD95} (ft/s) (scour counter-measure)
		9.9	V _{ICD50} (ft/s) (scour counter-measure)
		12.1	V _{ICD95} (ft/s) (scour counter-measure)

Anchoring Design Spreadsheet for ELJ		Created By: P. DeVries P.E.	
12/29/2022			
Developed Following (i) Force Balance (ii) Foundation Engineering 2nd Ed (Peck et al.) and FEMA Prestandard 356			
(i) Hard Anchoring Requirements		Computed Parameters:	
2	Maximum Number of Earth Anchors Required, or	37	Single Bole Volume, Size Class I (ft ³)
14	Maximum Number of Exposed Ecology Blocks Required For Ballast	3	Single Rootwad Volume, Size Class I (ft ³)
(ii) Minimum Piling Embedded Length L _e (ft) [Use Goal Seek Below]		39	Total Log Volume, Size Class I (ft ³)
6.28	A1. Drilled/Excavated in Gravel (ft)	43	Single Bole Volume, Size Class II (ft ³)
	A2. Drilled/Excavated in Sand (ft)	4	Single Rootwad Volume, Size Class II (ft ³)
	A3. Drilled/Excavated in Glacial Till (ft)	187	Total Log Volume, Size Class II (ft ³)
	B1. Pile Driven in Gravel (ft)	19	Single Bole Volume, Size Class III (ft ³)
	B2. Pile Driven in Sand (ft)	3	Single Rootwad Volume, Size Class III (ft ³)
	B3. Pile Driven in Glacial Till (ft)	130	Total Log Volume, Size Class III (ft ³)
A1. Drilled/Excavated in Gravel		0	Single Bole Volume, Size Class IV (ft ³)
-4789	Total Buoyant Force of Boles (lbf)	0	Single Rootwad Volume, Size Class IV (ft ³)
2842.6	Resistance Force/Piling (lbf)	0	Total Log Volume, Size Class IV (ft ³)
17055	Total Resistance Force of Piling (lbf)	357	Total Volume Submerged (ft ³)
0.00000057	Goal Seek Target = 0, Changing A1. Embedded Length	-12267	Buoyancy of Submerged Fraction (lbf)
A2. Drilled/Excavated in Sand		0	Weight of Exposed Fraction (lbf)
-2941	Total Buoyant Force of Boles (lbf)	-12267	Net Buoyancy Force (lbf)
0	Resistance Force/Piling (lbf)	-12267	Maximum Possible Buoyancy (lbf)
0	Total Resistance Force of Piling (lbf)	-49.0	Piling Buoyancy Force per Unit Length (lbf/ft)
-15207.26608412	Goal Seek Target = 0, Changing A2. Embedded Length	24	Friction Angle δ (timber:gravel/glacial till)
A3. Drilled/Excavated in Glacial Till		21	Friction Angle δ (timber:sand)
-2941	Total Buoyant Force of Boles (lbf)	0.45	Friction coefficient tan(δ) (gravel/glacial till)
0	Resistance Force/Piling (lbf)	0.38	Friction coefficient tan(δ) (sand)
0	Total Resistance Force of Piling (lbf)	0.64	Drilled K _{gravel}
		0.55	Drilled K _{sand}
		0.73	Drilled K _{glacial till}



Drag Force Shear, Bending Moment on Boles (Breaking Condition)		Created By: P. DeVries P.E.	
12/29/2022			
Developed Following AFPA Engineered Wood Design Manual & USDA Forest Products Laboratory Wood Handbook			
Structural Integrity Check: Shear - Continual Debris Load		Computed Parameters	
OK	Doug Fir	21127	Drag Force Resultant on ELJ (lbf)
OK	Western Hemlock	3521	Drag Force Resultant of Debris per bole (lbf)
OK	Western Red Cedar	63380	Max Drag Force Resultant Moment of Debris on one bole (lbf-ft)
OK	Black Cottonwood	10563	Max Drag Force Resultant Moment of Debris per bole (lbf-ft)
OK	Balsam Poplar	1.00	Size Factor C_F
		1018	Moment of inertia, I (in ⁴)
		6	distance from neutral axis to extreme fiber, c (in)
		170	Section modulus, S (in ³)
OK	Doug Fir	11218	Shear Design Criterion (lbf): Doug Fir
OK	Western Hemlock	11218	Shear Design Criterion (lbf): Western Hemlock
OK	Western Red Cedar	9267	Shear Design Criterion (lbf): Western Red Cedar
OK	Black Cottonwood	6438	Shear Design Criterion (lbf): Black Cottonwood
OK	Balsam Poplar	5950	Shear Design Criterion (lbf): Balsam Poplar
		24061	Bending Moment Design Criterion (lbf-ft): Doug Fir
		21460	Bending Moment Design Criterion (lbf-ft): Western Hemlock
		17558	Bending Moment Design Criterion (lbf-ft): Western Red Cedar
		15998	Bending Moment Design Criterion (lbf-ft): Black Cottonwood
		12746	Bending Moment Design Criterion (lbf-ft): Balsam Poplar
6	Number of Boles to Stabilize Against Drag (Specified)		

7.5.4 STREAM BOULDERS

Boulder Stability Design		Method of D'Aoust & Millar (2000)			Created By: P. DeVries P.E.	
12/29/2022		Conversion Factor N->lbf: 0.22481				
		Per Boulder:			Wet Weight	WSDOT
		Dimensions of Boulder			Approx	
		L (ft)	W (ft)	H (ft)	(lbf)	Size (ft)
		4	3	3	1766	3.33
Debris Log w/ Rootwad?	N					
# Debris Logs =	0				Volume of debris=	0 ft3
Debris Log Length=	0	ft		Projected Perpendicular Log Area for Drag=	0	ft2
Debris Log Diameter=	0	ft		Projected Streamlined Log Area for Drag=	0.0	ft2
Log Specific Gravity=	0.45	Doug Fir				
Height of Debris Front=	0	ft		Buoyancy Force (debris)=	0	lbf
Approach Velocity =	10	ft/s		Drag Force (perpendicular logs) =	0	lbf
Drag Coeff. Debris =	0.3			Drag Force (streamlined logs) =	0	lbf
Boulder Specific Gravity:	2.5			Sum Volume of Boulders =	18.8	ft3
# Boulders =	1			Sum Submerged Weight of Boulders =	1765	lbf
Effective Boulder Diameter =	3	ft		Projected Boulder Area for Drag=	7.1	ft2
Friction Angle (Boulder-Gravel)=	33	degrees		Sum Drag Force on Boulders =	891	lbf
Drag Coeff. Boulder =	1.3			Lift Force on Boulders =	123	lbf
Lift Coeff. Boulder=	0.18			Tan (phi) =	0.65	
Flow:Debris Reynolds Number at 5 C =	0			Frictional Resistance Force =	1066.358	lbf
				Lenzi (2002) Boulder Shape Factor α =	0.523599	
Factor of Safety >1, log perpendicular to flow?		Factor of Safety >1, log streamlined w/ flow?				
FS (Lateral Movement) =		1.19637		FS (Lateral Movement) =		1.19637
FS (Buoyancy) =		14.3052		FS (Buoyancy) =		14.3052
Design Specifications:						
Number of Boulders =		1				
Minimum Dry Weight per Boulder =		2944 lb				