Mystery Reach, War Creek Reach and Little Bridge Creek Habitat Restoration Project

Basis of Design Report

SUBMITTED TO
Yakama Nation Fisheries

December 2021

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1. Preface

The Upper Twisp River and Little Bridge Creek Habitat Enhancement Project consists of three reaches. The first reach is on Little Bridge Creek, a tributary of the Twisp River near river mile (RM) 9.5 entering from the north. The Little Bridge reach starts at RM 0.7 and ends at RM 2.0. The second work reach is on the Upper Twisp between RM 16 and 18. This reach will be referred to as the War Creek reach. The third work reach is located on the Upper Twisp River between RM 20 and 22. This reach will be referred to as the Mystery reach. The two Upper Twisp reaches are broken out separately by name because there are significant differences in construction methods and there is a two-mile gap between the two. All three work reaches are northwest of Twisp, WA (Figure 1**Error! Reference source not found.**) on land owned by the United States Forest Service. The goal of the proposed project is to enhance adult spawning and juvenile rearing habitat for ESA-listed endangered Upper Columbia spring Chinook Salmon (*Oncorhynchus tshawytscha*) and threatened summer steelhead (*Oncorhynchus mykiss*) in accordance with the 2017 Biological Strategy (UCRTT 2017). Bull trout (*Salvelinus confluentus*) and west slope cutthroat trout will also benefit from the project.

1.1 Name and titles of sponsor, firms and individuals responsible for design

The project is sponsored by Yakama Nation Fisheries (YN). Inter-Fluve is the engineering design firm. Mike McAllister (PE) is the licensed engineer of record for this project and Mike Brunfelt (LG) is the project manager.

1.2 List of project elements that have been designed by a licensed professional engineer

Mike McAllister (PE) is the licensed engineer of record for this project. Project elements include the following, with BPA HIP III activity and risk category included:

Table 1. Activity categories and risk included in the project.

Description of Proposed Enhancement	Work Element	HIP IV Category	HIP IV Risk Level
Large wood placement using helicopters and ground-based equipment to improve main channel habitat.	Install habitat-forming natural material instream structures	2d	Low

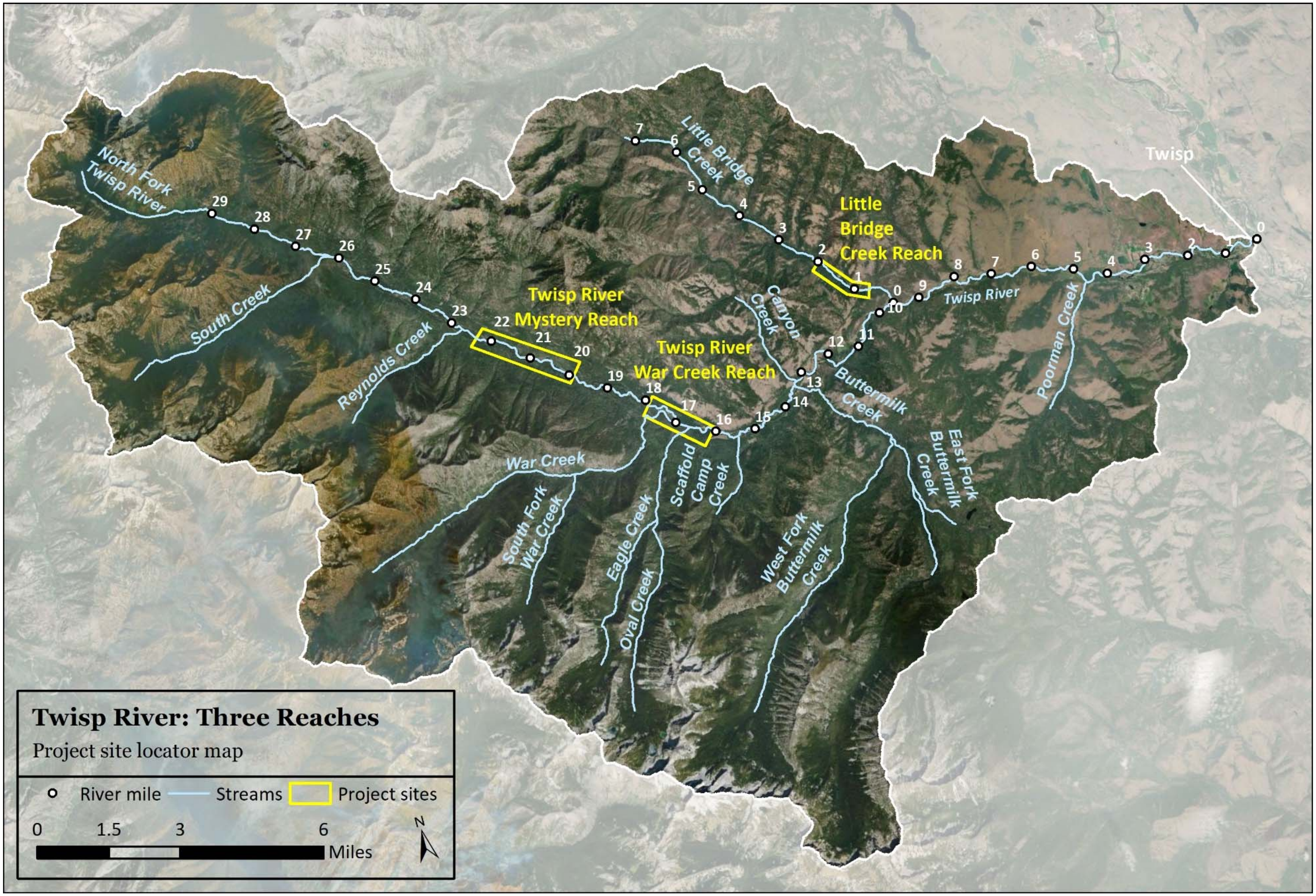
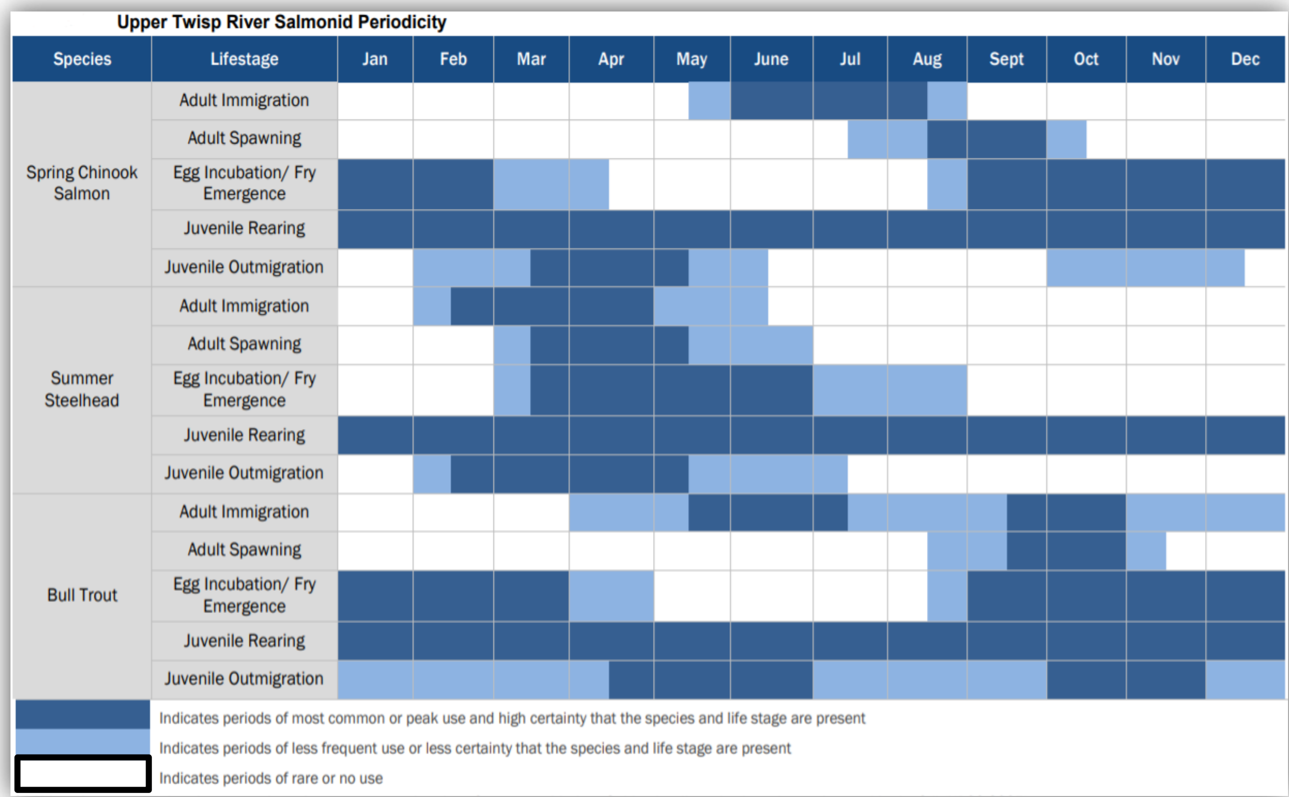


Figure 1. Project reach location map.

1.3 Explanation and background on fisheries use (by life stage period) and limiting factors addressed by the project

Fish species known to utilize the project areas include ESA-listed (endangered) spring Chinook Salmon, ESA-listed (threatened) summer steelhead and Bull Trout, and unlisted Westslope Cutthroat Trout, Pacific Lamprey, Mountain Whitefish, and non-native Brook Trout (Figure 2). Chinook Salmon, steelhead, and Bull Trout are focal species for this habitat enhancement project, while the work is also expected to benefit all species present.

Figure 2. Life history timing of fish species within the Upper Twisp River and Little Bridge Creek.



1.3.1 *Summer steelhead*

Adult summer steelhead destined for the Twisp River and Little Bridge Creek pass Wells Dam from July through May, with peak migration in September. Most adults overwinter in the Wells pool, while some hold in large pools in the mainstem Methow River. Adult summer steelhead enter the Twisp River and then Little Bridge Creek from February through May, holding in deep pools with overhead cover (NWPCC 2004). Spawning begins in late March, peaks in late April, and lasts through May. Egg survival is highly sensitive to intra-gravel flow, temperature and is particularly sensitive to siltation earlier in the incubation period (Healy 1991). Fry emerge from the redds 6-10 weeks after spawning (Peven 2003).

Age-0 juveniles spend their first year primarily in shallow riffle habitats, feeding on invertebrates and utilizing overhanging riparian vegetation and undercut banks for cover (Moyle et al. 2002, US Fish and Wildlife Service 1995). Age-0 steelhead use slower, shallower water small boulder and large cobble substrate (Hillman et al. 1989). Older juveniles prefer faster moving water including deep pools and runs over cobble and boulder substrate (US Fish and Wildlife Service 1995). Juveniles out-migrate between ages one and four, though some hold over and display a resident life history form. Smolts begin migrating downstream from natal areas from April through mid-May (NWPCC 2004).

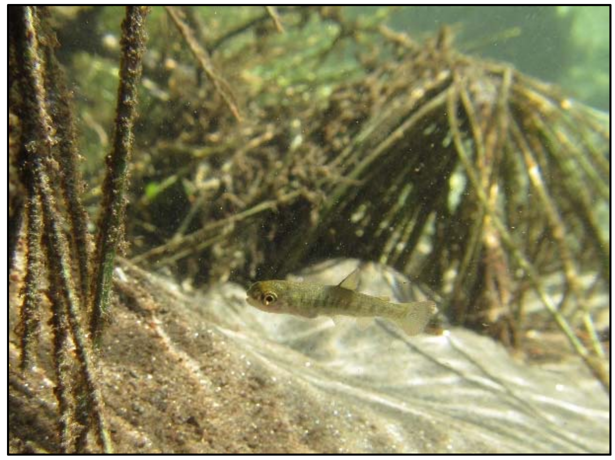


Figure 3. Sub yearling steelhead resting behind a constructed log structure (Entiat basin, WA).

1.3.2 *Spring Chinook*

Spring Chinook enter the Twisp River from late May through early September, with peak spawning occurring in late August and early September (Inter-Fluve 2016). Spawning in the Twisp River is concentrated between RM 10 and 27, and Little Bridge Creek is not a primary spring Chinook spawning area (Inter-Fluve 2016).

Fry emerge in the spring and seek out backwater or margin areas with lower velocities, dense cover, and abundant food (Quinn 2005). Near-shore areas with eddies, large woody debris, undercut tree roots, and other cover are very important for post-emergent fry (Hillman et al. 1989, Healy 1991). Age-1 parr move into deeper pools with resting cover in natal streams and migrate to smaller tributaries for extended periods of rearing. On the Twisp River, juvenile rearing occurs downstream of RM 27 (Inter-Fluve 2016). Spring Chinook express a stream-type life history where they rear for 1 year in freshwater before out-migrating as yearlings from late February through early May.

Figure 4. Yearling spring Chinook feeding in the Entiat River, WA.

1.3.3 *Bull Trout*

The Twisp River and Little Bridge Creek support a population of resident, fluvial, and adfluvial bull trout (NWPCC 2004). Bull Trout from the Columbia River migrate into the Methow subbasin from May through June (BioAnalysts 2002, 2003). Spawning occurs in Little Bridge Creek, the Twisp River from RM 22 to 29, and other tributaries from mid- September through October. Bull trout juveniles rear in headwater streams for at least two years before migrating downstream as adults or sub-adults to express fluvial, adfluvial, or resident life histories in downstream reaches (McPhail and Baxter 1996).

1.3.4 *Limiting factors for resident and anadromous fish*

Ecological concerns for the Twisp River and tributaries such as Little Bridge Creek have been summarized in the document *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region* (UCRTT 2017). The Regional Technical Team (RTT) identified several ecological concerns or limiting factors affecting habitat conditions in the Twisp River and Little Bridge Creek. They are:

1. Peripheral and transitional habitats (side channel and wetland habitat conditions).
2. Channel structure and form (instream structural complexity).
3. Channel structure and form (bed and channel form).
4. Riparian condition (riparian condition and large wood recruitment).
5. Food (altered primary productivity or prey species competition and diversity).
6. Sediment (increased sediment quantity).
7. Species interactions (introduced competitors and predators).

The RTT also noted the need to better understand the interaction of other native species with Bull trout found in the Twisp River and Little Bridge Creek.

1.4 Little Bridge Creek Reach: List of primary project features including constructed or natural elements

1.4.1 *Large Wood*

The project reach will import logs with root wads to a nearby staging area, and place them in the channel and adjacent floodplain using a heavy lift helicopter. The project will enhance habitat and address ecological concerns 1, 2, 3 and 4 listed above. The wood structures will be “constructed” by directing the helicopter pilot to the placement and orientation of each large wood piece. The individual wood pieces will be concentrated in groups to enhance channel complexity, floodplain inundation, side channel development, gravel sorting and pool scour.

1.5 Upper Twisp War creek Reach: List of primary project features constructed or natural elements

1.5.1 *Large Wood*

The project reach will use imported logs with root wads from outside the valley and locally sourced whole trees to construct apex log jams and bank buried log jams to effect lateral migration, improve deep pool habitat, gravel sorting and juvenile rearing habitat at all discharges. Construction will be completed using ground-based equipment. In some locations a heavy lift helicopter will be used to both place and stage large wood for ground-based equipment. The project will enhance habitat and address ecological concerns 1, 2, 3 and 4 listed above.

1.6 Upper Twisp Mystery reach: List of primary Project features constructed or Natural Elements

1.6.1 *Large Wood*

Ground based equipment will be used to bring trees to accessible areas of the river and construct large wood habitat to enhance lateral migration, pool habitat formation, gravel sorting for spawning and complex cover habitat for juvenile rearing at all discharges. Where no ground-based equipment access is feasible, a heavy lift helicopter will be used to place large wood in areas suitable to develop complex habitat. The wood placements will be concentrated to enhance high flow stability, channel complexity, floodplain inundation, gravel sorting and pool scour. The project will enhance habitat and address ecological concerns 1, 2, 3 and 4 listed above.

Figure 5. Heavy lift helicopter large wood delivery and channel habitat construction. Photo credit: Yakima-Klickitat Fisheries Project.

1.7 Little Bridge Creek: 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

1.7.1 *Infrastructure and flood risk*

There is no flood risk associated with the project. The work area is on USFS land. Imported logs specified for the project would be self-stable. The bankfull channel width in Little Bridge Creek is 25-35 feet. Hydraulic modeling indicates that even during the 100-yr flood, water depths are only 2-4 feet. Although each log could be expected to shift during a large flood, it would not move a significant distance from its original placement due to its length, weight, and root wad. The introduced wood is expected to increase overbank flow, bank scour, side channel inundation, and floodplain complexity over time. There are no structures near the project that would be at risk.

Figure 6. Ground crew removing chokers from helicopter placed logs similar to that proposed for the Upper Twisp.

1.7.2 *Design criteria*

Design criteria for large wood and secondary channel habitat associated with the project are as follows:

- Wood used in this project will be naturally stable and will move but remain in the project reach during the 100-year return peak flow.
- Large wood will be placed and oriented using a helicopter to provide habitat during all flows, sort bedload to improve spawning opportunities, and collect smaller wood material to further increase habitat complexity.

1.7.3 *Risk of failure to perform*

The channel is well suited to intense wood treatments that will capture smaller woody debris, induce lateral scour, overflow side channel development, sort gravel, scour pools and enhance channel and riparian complexity at low and high flows. There is very low risk that importing large wood will fail to improve channel and floodplain habitat.

1.8 Upper Twisp War Creek: 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

1.8.1 *Infrastructure and flood risk*

There is no flood risk associated with the project. The work area is on USFS land.

1.8.2 *Design criteria*

Ground-based heavy equipment will be used to construct the project. The log structures are designed to remain in place and are ballasted through burial and pile installation. Lateral migration that will occur as a result of the large wood structures is intended to enhance gravel sorting, pool development, improve natural large wood deposits (through lateral migration), and natural habitat development. The large wood structure designs are intended to remain stable during the 25-year flood.

1.8.3 *Risk of failure to perform*

The channel is well suited to intense wood treatments. Several natural analog examples within the upper Twisp River show that large tree obstructions force pool scour and create complex habitat beneficial to salmonids that would otherwise not exist. The wood structure designs are large. This design choice is consistent with what is observed and needed to effectively capture small woody debris, induce lateral scour, enhance overflow side channel development, gravel sorting, pool scour and associated channel and riparian complexity at low and high flows. There is low risk that importing large wood will fail to improve channel and floodplain habitats for salmonids.

1.9 Upper Twisp Mystery reach: 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

1.9.1 *Infrastructure and flood risk*

There is no infrastructure flood risk related to the project. The work area is on USFS land. Any wood that may transport downstream that is associated with the project will accumulate in a large natural wood deposit upstream of a narrow bedrock canyon.

1.9.2 *Design criteria*

Ground-based heavy equipment and a heavy lift helicopter will be used to construct the project. The ground-based equipment (excavators) will tip or winch over adjacent whole trees and move them to the channel to construct large wood jams. In areas where equipment access is limited, trees will be felled into the channel. Wood movement is expected but will remain in the project reach due to a downstream bedrock constriction. The large wood is intended to sort gravel to enhance spawning and create complex pool and cover habitat.

A heavy lift helicopter will be used to fly imported and pre-staged large wood to natural wood deposition zones. The wood will be heavily concentrated and stacked vertically to resist movement, improve lateral scour, induce pool scour, sort gravel and accumulate native smaller pieces of wood. The wood concentrations constructed by helicopter will be allowed to adjust and move also. No ballasting methods will be used.

1.9.3 *Risk of failure to perform*

The channel is well suited to intense wood treatments that will capture small woody debris, and induce lateral scour, gravel sorting, pool scour and associated channel and riparian complexity at low and high flows. There is very low risk that importing large wood will fail to improve channel and floodplain habitat. Helicopter-placed large wood is not expected to leave the project reach due to the same downstream bedrock constriction.

1.10 Description of disturbance including timing and areal extent and potential impacts associated with implementation of each element

1.10.1 *Little Bridge Creek*

Helicopter large wood placements are not expected to create any stream impacts. Project timing is July to August.

1.10.2 *Upper Twisp River War Creek*

Impacts from ground-based equipment construction will be limited to access paths to construction sites and clearing limits required to build each log jam. These impacts are temporary. To access some work areas, live stream crossings will be necessary but limited. Disturbed ground surfaces will be re-graded, seeded and planted as part of the project. Project timing is July to August.

1.10.3 *Upper Twisp River Mystery reach*

Helicopter wood placements are not expected to cause any significant impacts. Impacts from ground-based equipment will be limited to access paths to each construction site. These impacts are temporary and limited. Disturbed ground surfaces will be re-graded, seeded and planted as part of the project. Project timing is July to August.

2. Resource inventory and evaluation

2.1 Description of past and present impacts on channel, riparian and floodplain conditions

2.1.1 *Little Bridge Creek*

Historical aerial photos show no significant impacts to the riparian zone across the floodplain. Poor photo resolution, however, limits the effectiveness of this type of analysis. Recent drone footage shown in the concept drawings clearly illustrates a healthy riparian area and floodplain along most of the channel. Where the channel has migrated against the valley wall, natural hillside slope failures and sediment delivery has occurred.

Segments of the project reach were selectively logged decades ago (prior to earliest available aerial image). Large diameter stumps can be found along the valley bottom in areas that are now dominated by spruce trees. Evidence suggest that logging of large tree was selective and not in significant numbers.

Riparian vegetation is robust. The channel is well shaded during the summer and where in-channel native large wood exists habitat complexity is good. The floodplain is dominated by dense thickets of dogwood and willow, with red alder and cottonwood overstory. There is abundant small wood in the channel. However, large wood loading is relatively low and there are relatively few sources of large standing trees that would provide significant loading of stable, enduring large wood over time (**Error! Reference source not found.**).

Figure 7. Riparian area with willow, dogwood, red alder. Numerous small wood pieces.

2.1.2 *Upper Twisp War Creek and Mystery reach*

Impacts to the upper Twisp have mostly occurred in the distant past leaving the Mystery and War Creek reach in a partially impaired but recovering condition. Valley bottom roads, timber harvest, mining, fires, bridges and campgrounds have altered the reach and the watershed upstream of the project. Acute levels of disturbance such as forest fires, roads and timber harvest have been most impactful and have depleted the valley bottom and large wood (trees) that may eventually find their way into the river channel and create natural salmonid habitat (cover and pools). Although the valley bottom has patches of large trees, a significant percentage are in a young seral stage that will take decades to mature enough to create significant habitat as they enter (fall into) the active stream channel.

2.2 Instream flow management and constraints in the project reach

2.2.1 *Little Bridge Creek*

Near the upstream end of the project reach, Aspen Meadows Irrigation Ditch diverts water from Little Bridge Creek for agricultural and domestic use. The water is diverted from the channel by a fish passable weir. The diversion enters a pipeline installed approximately 15 years ago to improve irrigation efficiency and instream flows.

2.2.2 *Upper Twisp War and Mystery reach*

There are no known instream flow management constraints.

2.3 Description of existing geomorphic conditions and constraints on physical processes

2.3.1 *Little Bridge Creek*

Washington State geologic maps show the watershed is composed of sedimentary and volcanic rocks. During field work, shale and conglomerate bedrock exposures were found in small segments of valley toe eroded by Little Bridge Creek. Harder intrusive bedrock exists in the adjacent watersheds north of the Little Bridge Creek watershed. Glacial till carried over the watershed divide during alpine and continental glacial advance exists within Little Bridge Creek. During field work glacially transported intrusive granitic and metamorphic boulder lag deposits were observed in the channel. The same crystalline rocks were also observed within the smaller mobile bedload fraction in Little Bridge Creek. The majority of bedload observed in the channel is composed of sedimentary and volcanic rock origin composing bedrock within the watershed boundaries.

Figure 8. A) Lag boulders in Little Bridge Creek. B) Boulders in steep segment of Little Bridge Creek.

The project reach runs within a narrow valley that is 110-220 feet wide. Reach average grade is 2.9%. Local near surface bedrock, boulders, and old slope failures cause an alternating profile of localized steep areas interspersed by mild gradient areas. Steeper segments exhibit low width to depth ratio, bed armoring, lateral stability and steeper near vertical streambanks due to large cobble/boulder bank substrate.

In flatter channel segments, mobile cobble and gravel predominate and floodplain zones within the valley bottom are more frequently active. In some low gradient areas, beaver dam activity has been successful due to the reduction in stream power. There are frequent wood deposits formed from single trees or groupings of small and medium sized wood, and a few jams supported by large wood. The creek reacts to wood loading by storing and sorting gravels suitable for salmonid spawning, improving overhead cover, and developing habitat through deposition, scour, and planform adjustments caused by the large wood. Deep scour pools are associated with wood except in areas where depth is refused by boulders or bedrock.

Figure 9. A) Wood jam and bar formation in Little Bridge Creek. B) Fallen tree and bar formation in Little Bridge Creek.

The channel is capable of laterally migrating and avulsing within wider flatter segments of the project reach within zones not controlled by near surface bedrock or boulder deposits. The wood causes direct lateral migration through flow redirection, as well as locally aggrading the channel to facilitate overbank flow, channel avulsion and side channel development. Flatter channel segments are highly responsive to large wood loading.

2.3.2 *Upper Twisp War and Mystery reach*

The Upper Twisp War and Mystery reach fall within similar geologic and geomorphic contexts. Existing geomorphic conditions in the Upper Twisp are those left behind following alpine glacial advance and retreat. Bedrock geology in the upper Twisp headwaters is composed of intrusive ingenious rocks. Further down valley, the northeast (left) side of the valley is composed of sedimentary and volcanic rocks and the southwest (right) side of the valley composed of metamorphic rocks. Alpine glacial advances moved down the Twisp River valley following the NW to SE trending structural fault zone that divides the sedimentary and volcanic rocks on the northeast side of the valley from the metamorphic rocks on the southwest side of the valley. Glacial retreat and outwash filled the valley with alluvium. During glacial melt and retreat, tributaries formed perpendicular confluences to the valley depositing alluvium eroded from their watersheds onto the valley floor, forming alluvial fans.

As glacial retreat proceeded, melt water and sediment supply that filled the valley lessened. The reduction in sediment supply enabled the Twisp to slowly cut down through deposited glacial alluvium and today is primarily controlled vertically by bedrock contacts and alluvial fan deposits. Bed, bank, landslides and tributaries continue to feed the project reach with new and reworked alluvium that form the channel boundaries much of the Twisp River runs within.

Along steeper segments of channel, bedrock, alluvial fan and glacial terraces form one or both channel boundaries preventing lateral migration. Immobile boulder deposits exist within these steeper channel segments and are commonly sourced from high glacial terraces, hillslope failures and debris torrent runouts (alluvial fans) from tributary drainages. In the wider, flatter channel valley segments generally upstream of bedrock controls and alluvial fan deposits, bed and banks are composed of alluvium commonly moved during annual runoff. In these locations large wood material plays a more dynamic role in developing complex pools, split flows, gravel sorting and cover habitat essential to both adult spawning and rearing salmon.

There are minor constraints from bridges and roads that have bisected or impinged upon the valley and river. The War Creek campground bridge and road approach bisects the valley but is not significantly altering geomorphic river processes. The bridge and its approach fit within existing planform condition. Although this condition could change, it would require several decades or a large magnitude flood and upstream avulsion event. Therefore, it is possible future changes in river alignment could put the road and bridge in conflict with river processes, but currently, this is not the case. There is another bridge located downstream of Mystery Campground. It spans a relatively steep bedrock-controlled sediment transport reach and does not significantly alter existing geomorphic processes. These conditions are unlikely to change during the lifespan of the bridge.

2.4 Description of existing riparian condition and historical riparian impacts

2.4.1 *Little Bridge Creek*

There is little evidence of recent historical riparian impacts. Riparian conditions are excellent with extensive and dense thickets of willow and red osier dogwood on the floodplain, providing ample beaver food and dam construction material. Larger trees within the floodplain consist of mostly of early to mid-seral cottonwood and alder. Fir and spruce trees intersperse the floodplain but predominantly occur on the adjacent hillslopes.

Beaver activity appears to occur where stream lope is flatter, floodplain connection is greater and stream power is lower (Figure 11). Observation of dam washouts and repair indicate presence of a local beaver population. Increased instream wood complexity will likely improve habitat suitability for beavers by attenuating stream energy and increasing floodplain inundation.

Figure 10. Partially washed-out beaver dam and recent repair efforts in Little Bridge Creek.

2.4.2 *Upper Twisp War Creek*

The riparian area immediately adjacent to the channel is in good condition. However, the floodplain riparian area east of the channel is in poorer condition as it recovers from the abandonment of an old channel alignment east of the current main channel. Large areas of immature and sparse cottonwood vegetation exist on exposed former gravel bars and channel. It will take decades for this area to fully revegetate. Other areas throughout the valley have good riparian valley bottom vegetation.

2.4.3 *Upper Twisp Mystery reach*

Riparian vegetation adjacent to the channel is in good condition. Valley bottom vegetation has well established mature trees but also significant areas where previous logging activity has resulted in a young seral age class of trees. Most of the logging activity has taken place above the 100-year flood stage.,

2.5 Description of lateral connectivity to floodplain and historical floodplain impacts

2.5.1 *Little Bridge Creek*

Aside from evidence of historical selective logging, there are no known historical floodplain impacts within the project reach. As explained in previous sections, floodplain connectivity is strongly dependent on local slope and valley bottom width. In flatter wider sections of the valley, woody debris jams and beaver activity enhance floodplain connectivity by creating hydraulic roughness and sediment deposition. These areas demonstrate that the system is very reactive to wood inputs. There is abundant small- to medium-sized wood, but many of the fallen trees and wood structures appear to be short lived (subject to decay and breakage) and transient. Larger trees grow near the toe of the valley bottom, and where the stream runs along the valley edge, fallen trees contribute to stream and floodplain complexity. However, the stream corridor has relatively few large trees capable of providing enduring large wood structures to impose long-term and significant channel response on the reach scale. Additional large wood structures would increase the frequency and duration of overbank flows, expand the extents of floodplain inundation, and increase habitat complexity across the valley bottom.

2.5.2 *Upper Twisp War Creek and Mystery reach*

In the past, road and bridge floodplain impacts have occurred at the War Creek reach. However, the current road and bridge alignment, bridge capacity and adjacent valley bottom surface are not significantly impacted. Lateral floodplain connectivity is within the natural range of variability through the upper Twisp. There is no reach-based incision within either project reach. Rather, floodplain inundation and complexity are highly dependent on large trees in the channel and the associated increase in lateral migration and channel length.

2.6 Tidal influence in project reach and influence of structural controls (dikes or gates)

Not applicable to this project.

3. Technical data

3.1 Incorporation of HIP IV specific activity conservation measures for all included project elements

HIP IV conservation measures have been included within the project designs and drawings.

3.2 Little Bridge Creek: Summary of reach information and measurements (survey, bed material, etc.) used to support assessment and design

3.2.1 *Elevation data*

Project survey was completed in November, 2018. The project area was walked to identify and survey treatment sites and survey cross-sections for hydraulic modeling. Survey was completed using total station survey equipment and relative datum. Temporary control points were established.

3.2.2 *Fish use*

Fish presence and life-stage timing data were taken from the 2017 Biological Strategy (UCRTT 2017), Methow Subbasin Plan (NWPCC 2004), Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (UCSRB 2007), Middle Twisp Reach Assessment, and empirical PIT tag and screw trap data from Columbia River Data Access in Real Time (DART 2018). Habitat preference information was taken from the primary literature.

3.2.3 *Aerial images*

Aerial images used in the drawings were taken November, 2018.

3.2.4 *Wood Loading*

Wood treatment opportunity was compared with research on natural wood loading conducted by Fox and Bolton in 2007. Fox and Bolton (2007) examined undisturbed streams 0-30 meters wide within the Douglas fir-ponderosa pine (DF-PP) forest zone similar to the forest zone of Little Bridge Creek. Their research showed that for streams in DF-PP zones (n=14), wood volume ranged from 0 to 23 cubic meters per 100 meters of stream length. For comparison purposes a 40-foot long 18-inch diameter log provides approximately 2.2 cubic meters of wood volume.

The Upper Twisp River and Tributaries Habitat Assessment (Tetra Tech 2017) inventoried wood numbers and sizes in Little Bridge Creek. The assessment survey found that Little Bridge Creek Reach 2, where the project is proposed, contained 130 small, 50 medium, and 26 large wood pieces. For comparison to Fox and Bolton, the assessment survey results are converted to metric units. The volume of wood in Reach 2 was roughly 359 cubic meters over 3,700 meters of stream. This scales as 282 cubic meters of wood in the project length of 2,900 meters, or approximately 10 cubic meters per 100 meters of stream. To approach the maximum volume of 23 cubic meters per 100 meters found by

Fox and Bolton, the project could hold a total of 667 cubic meters of wood. With 282 cubic meters of existing wood in reach, adding 385 cubic meters, or 175 logs (2.2 cubic meters each) would comport with the maximum loading reported in DF-PP streams by Fox and Bolton.

3.3 Upper Twisp War Creek: Summary of reach information and measurements (survey, bed material, etc.) used to support assessment and design

3.3.1 *Elevation data*

A Survey was completed within the project area by Rio ASE in 2016. Additionally, 2018 LiDAR was used. Inter-Fluve completed additional field survey to confirm previous survey data for design plans and drawings in October 2020.

3.3.2 *Aerial images*

Aerial images for base maps are dated October 2019. Historical aerial photos were also examined during the design process.

3.3.3 *Sediment Sampling*

Wolman pebble counts were collected by Rio ASE in 2016 at four representative locations. Grain sizes on gravel bars had a D50 (50^{th} percentile) of 83 mm and D84 (84^{th} percentile) of 152 mm. In their riffle samples, D50 was 108 mm and D84 197mm (Rio ASE, 2016).

3.3.4 *Wood Loading*

The Upper Twisp River and Tributaries Habitat Assessment (Tetra Tech 2017) inventoried wood numbers and sizes in the Upper Twisp. The study reaches falling within the War Creek and Mystery Reach project areas contained on average 40 pieces of large wood per mile in the Mystery Reach and 16 pieces per mile in the War Creek Reach.

Fox and Bolton (2007) examined undisturbed streams 0-30 meters wide within the Douglas fir-ponderosa pine (DF-PP) forest zone similar to the forest zone of the Twisp River. Their research showed that for streams in DF-PP zones (n=14), wood volume ranged from 0 to 23 cubic meters per 100 meters of stream length. Imported wood with the specified dimensions of 18” diameter and 40 feet long provides approximately 2.2 cubic meters of wood volume each. This would equate to approximately 10 imported pieces of large wood per 100 meters of stream to meet the upper end of the Fox and Bolten research. The War Creek and Mystery Reach combined are approximately 12,800 meters long. Natural loading volume estimates for the combined reach distance would equate to approximately 1,280 pieces of large wood assuming the upper range found by Fox and Bolten. The total existing estimate determined by the 2017 Tetra Tech assessment data for the combined Mystery and War Creek Reach is 112 pieces.

3.4 Upper Twisp Mystery reach: Summary of reach information and measurements (survey, bed material, etc.) used to support assessment and design

3.4.1 *Elevation data*

A Survey was completed within the project area by Tetra Tech in 2018. Additionally, 2018 LiDAR is available for the entire valley bottom.

3.4.2 *Aerial images*

Aerial images for base maps are dated October 2019. Historical aerial photos were also examined during the design process.

3.4.3 *Sediment Sampling*

In 2018 Tetra Tech completed six Wolman pebble counts. Tetra Tech Wolman bed samples in alluvial river segments greater than 90% gravel, cobble and sand were characterized by D50 (50th percentile) grain sizes between 62 and 78 millimeters and D84 (84th percentile) grain sizes between 150 and 200 millimeters (Tetra Tech, 2018). These size classes are consistent within that observed and measured by Rio ASE in Upper Twisp War Creek, are transported frequently (1.5-2-year return discharge) and compose the alluvial self-formed channel segments observed in the field.

3.4.4 *Wood Loading*

See War Creek (3.3.4).

3.5 Little Bridge Creek: 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

Little Bridge Creek has no stream gage. However, peak flow estimates were calculated for two previous reports. The first report, The Upper Twisp and Tributaries Habitat Assessment (Tetra Tech 2017) summarized the predicted peak flows from USGS regional regression equations (Mastin et al. 2016). In the second report, the USBR Methow Subbasin Geomorphic Assessment hydrologic analysis (USBR 2008) used a combination of gage data and regression analysis. Both peak discharge estimates are reported for the confluence with the Twisp River. The project reach is a short distance upstream (RM 0.7 to RM 2). Peak flow estimates from both reports are summarized in Table 2. The greater magnitude discharges from the USBR study were used in the hydraulic model to provide a conservative evaluation of the hydraulic forces and water depths at modelled flood flows.

Table 2. Peak Discharge Estimates for the Little Bridge Creek Project Reach (cfs).

Flow Event	USGS	USBR
2-year	90	188
10-year	241	349
25-year	346	439
50-year	442	508
100-year	544	580

3.6 Upper Twisp War Creek: 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

Rio ASE conducted a hydrologic analysis sufficient to complete a project design within the Upper Twisp War Creek work area (Rio ASE, 2016). Two major tributaries enter the work area that needed to be accounted for during hydraulic analysis. To accomplish the task, Rio ASE applied the Twisp USGS gage 12448998 data (29 years continuous daily flow) to the USGS PeakFQ program by using the methodology described within the JSGS Bulletin 17B (USFS, 1981).

The most upstream tributary is War Creek entering from the south approximately 2,600 feet downstream of the National Forest Road 4420 bridge crossing. Watershed area upstream of War Creek is 78 square miles and downstream of War Creek it is 105 square miles. Approximately 3,300 feet downstream of War Creek, Eagle Creek enters from the south. Watershed area downstream of Eagle Creek is 120 square miles. Rio ASE bracketed the peak flow hydraulic analysis upstream and between the two tributaries. Tables 3,4 and 5 summarize peak flow return discharge results from the 2016 analysis.

Recurrence flow	Upstream War of Creek	2-YR	5 -YR	10-YR	25-YR	50-YR	100-YR
Discharge (cfs)		655	962	1,178	1,463	1,685	1,914

Table 3. Peak Discharge Estimates for the Upper Twisp upstream of War Creek in cubic feet per second (cfs).

Recurrence flow	Downstream of War Creek to Eagle Creek	2-YR	5 -YR	10-YR	25-YR	50-YR	100-YR
Discharge (cfs)		885	1,299	1,590	1,976	2,276	2,585

Table 4. Peak Discharge Estimates for the Upper Twisp downstream of War Creek and upstream of Eagle Creek in cubic feet per second (cfs).

Recurrence flow	Downstream of Eagle Creek	2-YR	5 -YR	10-YR	25-YR	50-YR	100-YR
Discharge (cfs)		1,007	1,478	1,810	2,249	2,591	2,943

Table 5. Peak Discharge Estimates for the Upper Twisp downstream of Eagle Creek in cubic feet per second (cfs).

3.7 Upper Twisp Mystery reach: 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

Tetra Tech completed a hydrologic analysis sufficient to complete final designs (Tetra Tech, 2018). There are no major tributaries that enter the project area. Tetra Tech applied the 12448998 USGS gage in Twisp to an area analysis using the U.S. Army Corp of Engineers Hydraulic Engineering Center Statistical Software Package (HEC-SSP) and Log-Pearson III adjusted by watershed area. Tetra Tech also used the regional regression equations developed by Mastin et al. in 2016 to compare with the USGS gage-based result. The following two tables show the results of this 2018 analysis.

Recurrence flow	USGS Twisp River Gage Area Adjusted	2-YR	5 -YR	10-YR	25-YR	50-YR	100-YR
Discharge (cfs)		750	1,104	1,358	1,703	1,971	2,253

Table 6. Peak Discharge Estimates for the Upper Twisp Mystery Reach using USGS Twisp River Gage area adjusted in cubic feet per second (cfs).

Recurrence flow	WA Regional Regression (Mastin et al.)	2-YR	5 -YR	10-YR	25-YR	50-YR	100-YR
Discharge (cfs)	29	894	1,390	1,770	2,280	2,730	3,170

Table 7. Peak Discharge Estimates for the Upper Twisp Mystery Reach using WA Regional Regression Equations in cubic feet per second (cfs).

3.8 Summary of sediment supply and transport analyses conducted, including data sources including sediment size gradation used in streambed design

General observations of sediment supply, type and transport are noted in previous report sections. Upper Twisp Mystery reach bed characteristics were sampled by Tetra Tech with Wolman pebble counts at six locations between RM 20.1 and RM 22.2 (Tetra Tech, 2018). Their data confirms there is a continuum between erodible channel segments that are alluvial formed and unerodable channel segments that are not. Bedrock, glacial and/or debris torrent boulder deposits act to steepen local slopes and create both bed and bank boundaries that are immobile or mobile only during large flood events. Large whole trees that enter the channel enhance bed and bank erosion, storage and sorting within alluvial formed channel segments, creating complex rearing and spawning habitats. The project design seeks to emulate this large wood process and will not have any effect on average sediment supply, transport or channel profiles.

3.9 Little Bridge Creek hydraulic modeling or analyses conducted and outcomes – implications relative to proposed design

A one-dimensional (1D) hydraulic model was developed for existing conditions to determine flood stage and large wood transport potential. Creek stage and velocity results during modelled flood flows were compared with field observations, floodplain resilience, and specified large wood sizes to determine wood mobility risk.

3.9.1 *Hydraulic Model*

The U.S. Army Corps of Engineers' Hydraulic Engineering Center River Analysis System (HEC-RAS 5.0.3; USACE 2016) was used to run the steady-state, one-dimensional (1D) model for hydraulic computations to predict stage and velocity of floods in the project area. The existing conditions HEC-RAS model was developed using the 2018 survey data, which was collected along a representative reach of the stream and floodplain.

The upstream and downstream model boundary conditions were set to normal depth since they are located on riffles. Manning's 'n' or roughness values correspond with various types of land cover and channel characteristics. A roughness value of 0.04 was applied to the main channel, and 0.12 was applied to the overbank/floodplain regions. These values are consistent with field observations as well as published guidelines for channel types and vegetation conditions (Arcement & Schneider 1989).

3.9.2 *Model Results*

The model predicts that in-channel flow depths vary 2-4 ft and velocities vary 5-13 ft/s, with the greatest depth and velocity occurring during the 100-yr flood. The velocity on the floodplain is much lower, varying 0.9-2.6 ft/s (Figure 12).

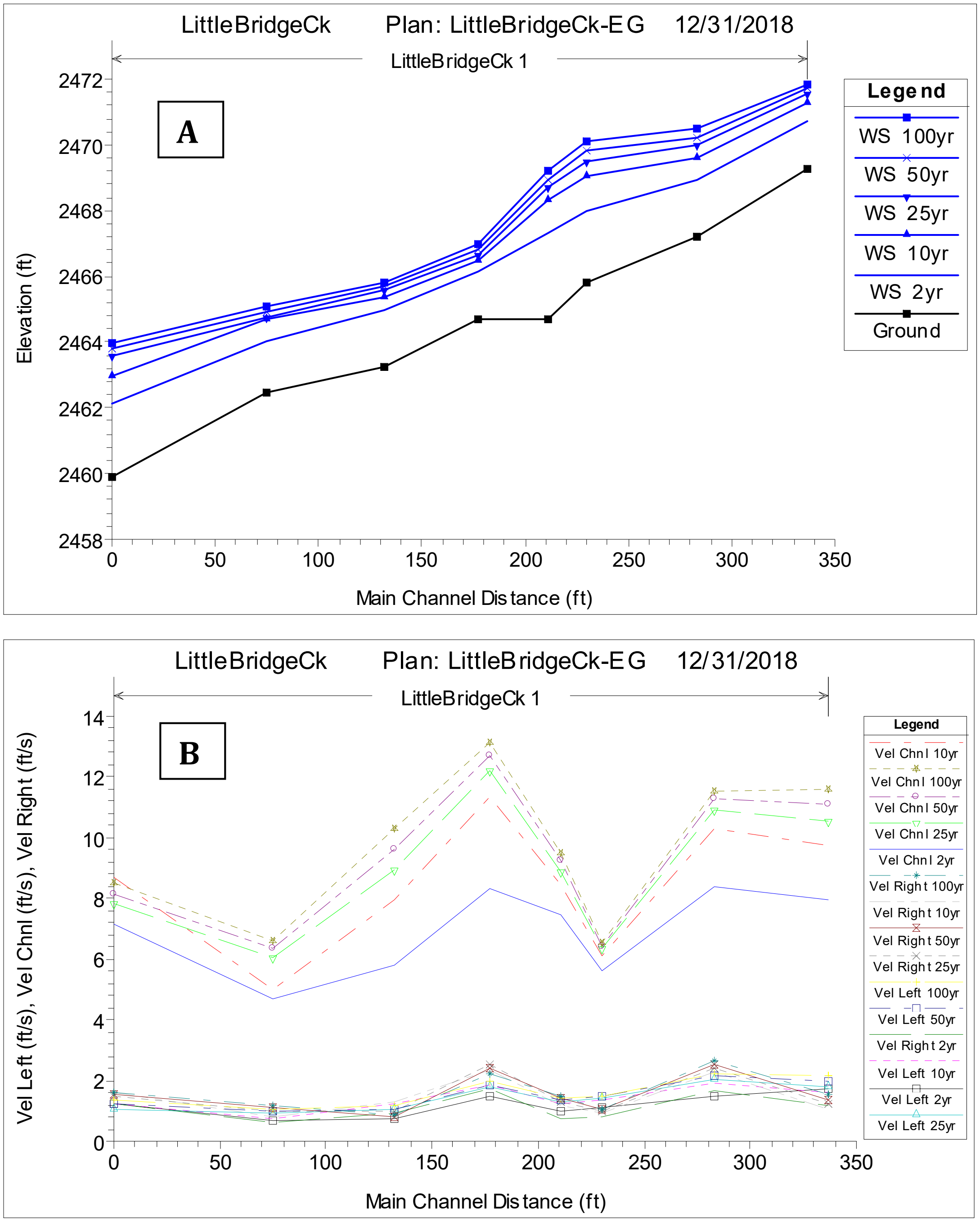


Figure 11. Long profile (A) and velocity plot (B) from HEC-RAS

3.10 Upper Twisp at War Creek - hydraulic modeling or analyses conducted and outcomes – implications relative to proposed design

A one-dimensional (1D) hydraulic model was developed for existing conditions to determine flood stage and large wood transport potential. Creek stage and velocity results during modelled flood flows were compared with field observations, floodplain resilience, and specified large wood sizes to determine wood mobility risk.

3.10.1 *Hydraulic Model*

The U.S. Army Corps of Engineers' Hydraulic Engineering Center River Analysis System (HEC-RAS 5.0.3; USACE 2016) was used to run the steady-state, one-dimensional (1D) model for hydraulic computations to predict stage and velocity of floods in the project area. The existing conditions HEC-RAS model was developed using the 2020 survey data.

The upstream and downstream model boundary conditions were set to normal depth since they are located on riffles. Manning's 'n' or roughness values correspond with various types of land cover and channel characteristics. A roughness value of 0.04 was applied to the main channel, and 0.12 was applied to the overbank/floodplain regions. These values are consistent with field observations as well as published guidelines for channel types and vegetation conditions (Arcement & Schneider 1989).

3.10.2 *Model Results*

Three reaches were modeled to demonstrate flood hydraulics at a range of channel/floodplain conditions. Velocities for the 25-yr flood varied 4-10 ft/s, and the highest velocity is 11.4 ft/s occurring during the 100-yr flood (Figure 13).

Proposed conditions were modeled by adding blocked obstructions where log structures are proposed. The model predicts that log structures raise water surface roughly 2 feet, and increase velocity up to 1.5 ft/s. These are considered short term impacts as the river banks and bed are expected to readily respond by local scour and lateral erosion. Model results were utilized to support field observations of natural debris and logjam heights to inform helicopter log placements. Velocity and depth results informed stability design for buried and pile ballasted log structures.

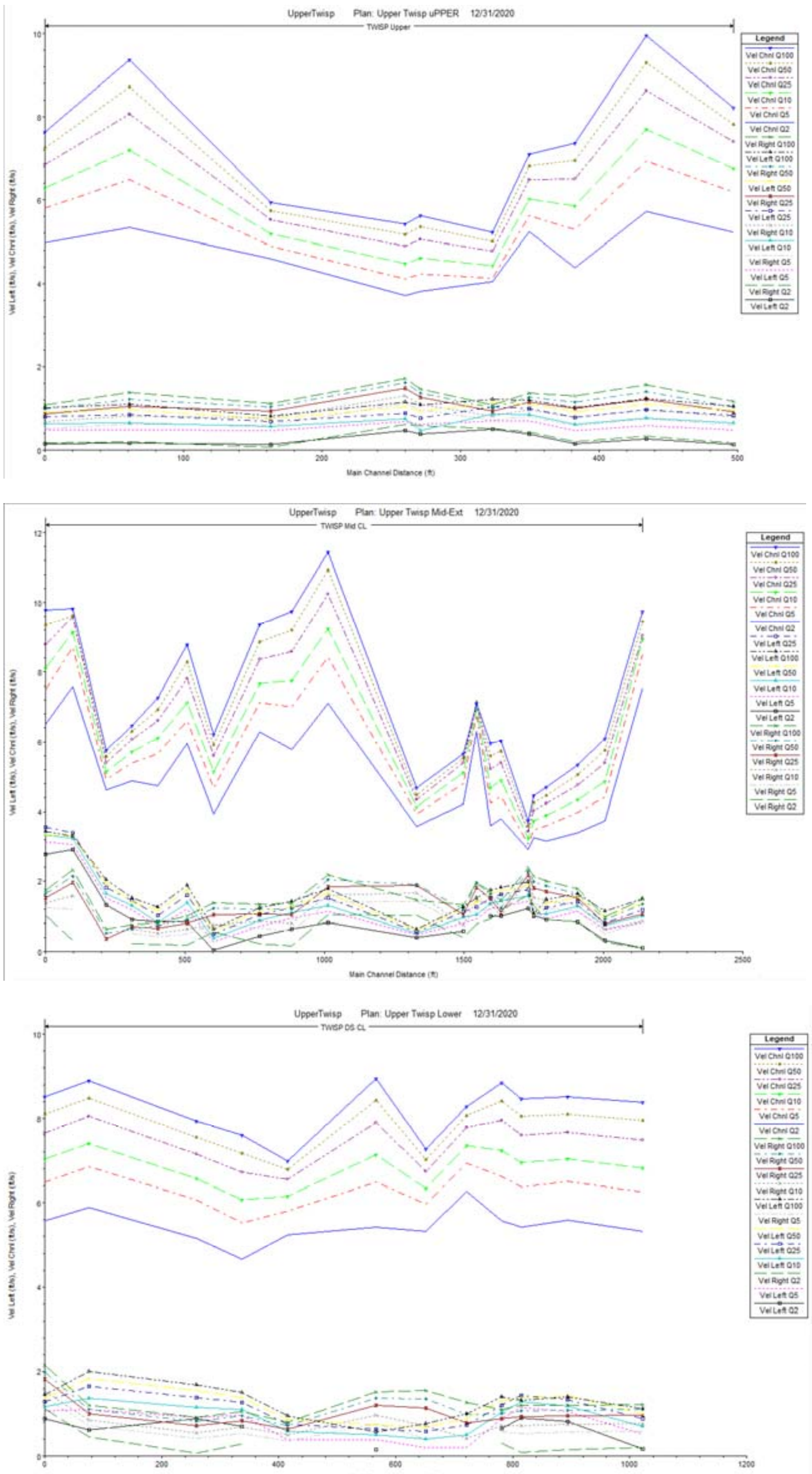


Figure 13. Velocity profiles for three modeled reaches in Upper Twisp River

3.11 Upper Twisp Mystery reach hydraulic modeling or analyses conducted and outcomes – implications relative to proposed design

A one-dimensional (1D) conservative analog hydraulic model was developed for application within the Mystery reach. Analog modelled flood flows were compared with field observations, floodplain resilience, and specified large wood sizes to determine wood mobility risk.

3.11.1 *Hydraulic Model*

The U.S. Army Corps of Engineers' Hydraulic Engineering Center River Analysis System (HEC-RAS 5.0.3; USACE 2016) was used to run the steady-state, one-dimensional (1D) model for hydraulic computations to predict stage and velocity of floods in the project area. The existing conditions HEC-RAS model was developed using the 2020 survey data, which was collected along a relatively narrow analog segment of the Twisp within War Creek to represent maximum wood mobility possible in the both project reaches. Peak flow versus stage in this model enables a conservative template of wood mobility to help guide placement and stacking heights for all helicopter placements and ground based whole tree placements.

The upstream and downstream model boundary conditions were set to normal depth since they are located on riffles. Manning's 'n' or roughness values correspond with various types of land cover and channel characteristics. A roughness value of 0.04 was applied to the main channel, and 0.12 was applied to the overbank/floodplain regions. These values are consistent with field observations as well as published guidelines for channel types and vegetation conditions (Arcement & Schneider 1989).

3.11.2 *Model Results*

War Creek/Mystery narrow analog stage discharge relationship was modelled to apply within the Mystery reach. The stream power and velocity in this lower valley segment is similar or greater than that of the Mystery Reach and can be applied as a conservative estimate of wood mobility. Knowledge and understanding of these results along with visual observations of stage at each wood placement site will be relied upon when constructing and adjusting project designs using both ground based and helicopter wood placement.

3.12 Stability analyses and computations for project elements, and comprehensive project plan

3.12.1 *Little Bridge Creek*

Based on the conceptual design shown in the Appendix A, the model results predict that large wood will remain relatively stable during floods. It is possible that a 40-foot log with roots could move by partial buoyancy, rotation, or translation. However, due to bankfull channel width of 25-35 feet, moderate flood depth, and dense riparian vegetation, a matrix of intermingled and stacked logs is not expected to move more than minor adjustments. In the event that a log does become dislodged from a jam, it would not be transported significant distances in the channel without encountering other stabilizing resistance from vegetation, debris, sediment, boulders, and changes in stream form.

Stability analysis and computations for project elements have followed professional practice guidelines for large wood design (Knutson and Fealko 2014 and USBR and ERDC 2016), stream habitat restoration (Cramer 2012), Stability of Ballasted Woody Debris Habitat Structures (D'Aoust and Millar 2000), and institutional knowledge combined with professional judgment for the design of specific project elements.

3.12.2 *Upper Twisp War Creek*

Ballast using both burial and vertical piles will be used for the project work in the War Creek Reach. Stability analysis and computations for project elements have followed professional practice guidelines for large wood design (Knutson and Fealko 2014 and USBR and ERDC 2016), stream habitat restoration (Cramer 2012), Stability of Ballasted Woody Debris Habitat Structures (D'Aoust and Millar 2000), and institutional knowledge combined with professional judgment for the design of specific project elements.

3.12.3 *Upper Twisp Mystery reach*

The Mystery reach treatment method and designs using whole tree and imported wood, whether placed by equipment or helicopter, is likely to adjust and move over time. In the Mystery Reach, movement within the reach is likely, but beyond the project reach is highly unlikely due to both a bedrock construction and natural depositional zone at the downstream most end of the project reach.

Both excavator placement and helicopter-based placement will be guided by a conservative analog hydraulic model stage discharge relationship and associated wood mobility. Both types of placement will be variable and rely heavily on fit in the field placement and application of visual and analog hydraulic model results likely to act on various sizes and configurations of wood placements. Whole tree placement using trees harvested from the adjacent valley will require field adjustment based on direction of tree felling, movement of the whole tree to the river, orientation of the root wad and associated tree length and mass. Similarly, during helicopter wood placement, field adjustment will be required continually. Field placement of large wood will be completed under the supervision of the project designers.

Stability analysis and computations for project elements have followed professional practice guidelines for large wood design (Knutson and Fealko 2014 and USBR and ERDC 2016), stream habitat restoration (Cramer 2012), Stability of Ballasted Woody Debris Habitat Structures (D'Aoust and Millar 2000), and institutional knowledge combined with professional judgment for the design of specific project elements.

3.13 Description of how preceding technical analysis has been incorporated into and integrated with the construction – contract documentation

The preceding analysis is the basis for evaluating large wood stability at project locations where stabilization measures, such as partial burial or timber piles, will be implemented per the specifications described in the design drawings. The drawings are engineering stamped construction drawing set with sufficient detail to allow contractors to bid and build the project. Material quantities and specifications are included in the drawings.

3.14 For projects that address profile discontinuities (grade stabilization, small dam and structure removals): A longitudinal profile of the stream channel thalweg for 20 channel width upstream and downstream of the structure shall be used to determine the potential for channel degradation

Not applicable to this project.

3.15 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

Not applicable to this project.

4. Construction – contract documentation

4.1 Incorporation of HIPIV general and construction conservation measures

Standard conservation measures for projects completed in the Twisp River are included in the drawings.

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

Construction drawings details can be viewed in the drawing set.

4.3 List of all proposed project materials and quantities

Large wood volumes are included in the construction drawings. Imported and placed large wood/trees are the only proposed material for the project. Threaded rod will be used in the War Creek reach only.

4.4 Description of best management practices that will be implemented and implementation resource plans including:

- Reach access staging and sequencing plan
- Work area isolation and dewatering plan
- Erosion and pollution control plan
- Reach reclamation and restoration plan
- List of proposed equipment and fuels management plan

4.5 Calendar schedule for construction/implementation procedures

A construction timeframe has not been finalized but likely to occur within the in-water work window of 2022.

4.6 Reach or project specific monitoring to support pollution prevention and/or abatement

Standard erosion and pollution control measures are shown in the drawing set.

5. Monitoring and adaptive management plan

Monitoring and adaptive management plans will be determined at the discretion of the Yakama Nation. It is anticipated that following project construction a monitoring plan will be completed at a scale and level of effort similar to previous Yakama Nation projects constructed within the Methow Basin.

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7. Appendices

A - Project plan sheets

B – Hydraulic Model

C - Large Wood Stability Calculations