Mill Creek Fish Passage Project

Final Basis of Design Report

April 2020

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1 INTRODUCTION

The Chelan Country Natural Resource Department (CCNRD) is leading the design efforts to restore habitats associated with Endangered Species Act (ESA) listed salmonids within the Wenatchee River basin, Chelan County, WA through multiple efforts including the project described herein. In 2018 the CCNRD was awarded an RCO Salmon Recovery grant and a Brian Abbot Fish Barrier Removal Board grant for design and construction of a documented fish barrier on Mill Creek, a tributary to Peshastin Creek. The existing culvert is located on Mountain Home Ranch Road, a county road maintained by Chelan County Public Works (CCPW), just upstream of the confluence of Mill Creek and Peshastin Creek (Figure 1). The proposed project actions are centered around improving fish passage in Mill Creek by replacing the existing undersized culvert with an appropriately sized structure which accommodates a natural streambed through the crossing utilizing WDFW stream simulation design guidelines (Barnard et al., 2013).

This report presents the basis of design for design of project elements associated with the Mill Creek Fish Passage project. The report includes a discussion of preliminary design (60%) and includes a discussion of revisions made to the design to advance designs to draft final (90%). The current iteration of design plans (90%) are presented in Appendix A, and the associated construction cost estimate is provided in Appendix B.

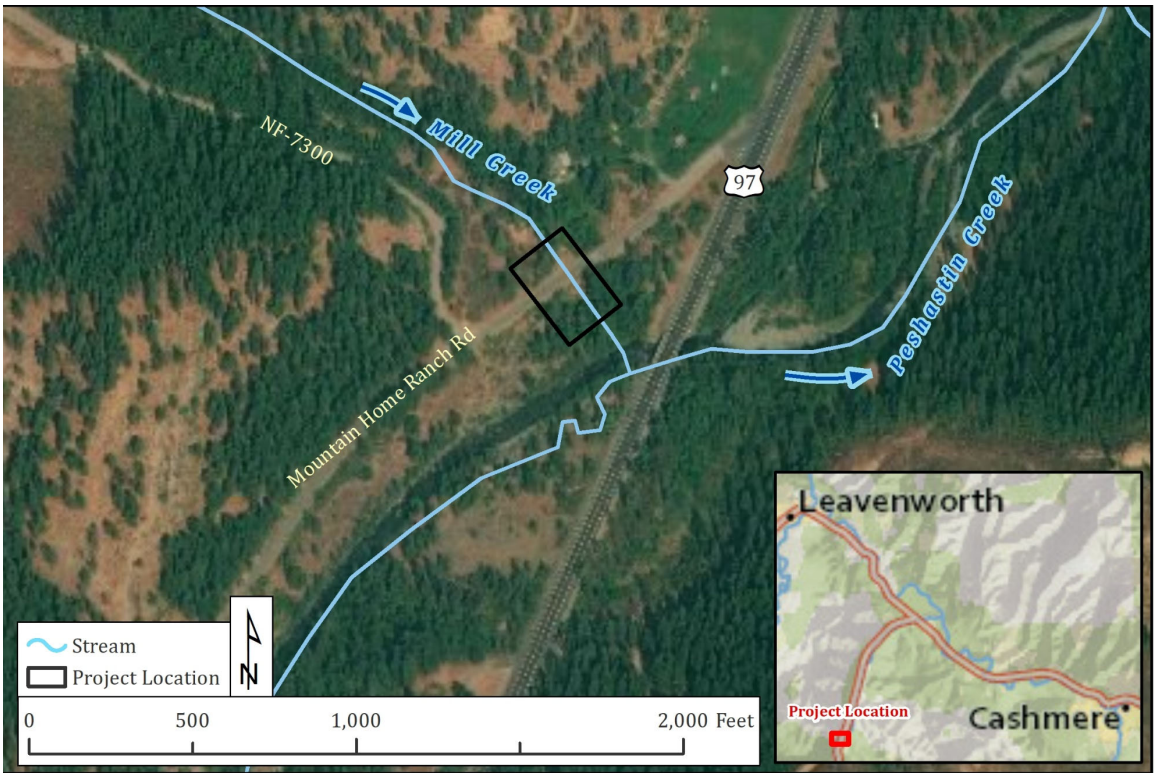

Figure 1. Mill Creek Fish Passage Project Location

2 EXISTING CONDITIONS

Existing conditions at the project site were characterized and analyzed using a combination of available data, and field data which were collected in support of project development. Site visits were conducted on February 26th and March 13th of 2018 to characterize general site conditions and to help with initial phases of project development; a more detailed site visit including topographic survey, a geomorphic characterization of site conditions, multiple bankfull measurements, a pebble count, and identification of relevant planimetric features

was conducted on May 2, 2019. Additionally, Chelan County Public Works (CCPW) provided ROW and parcel boundary documentation. A utility locate was initiated by CCNRD staff prior to the ROW survey conducted by CCPW and relevant utility locations were included in the survey. Lastly, subsurface conditions were characterized utilizing geotechnical data gathered through a single bore hole near the existing culvert; subsurface conditions and design recommendations are included in Appendix C.

Geomorphic Conditions

The project site is located on the alluvial fan of Mill Creek, approximately 180-ft upstream of the confluence with Peshastin Creek. The watershed drains the eastern flank of the Stuart Range at Wedge Mountain, and the area south of Boundary Butte. The watershed is characteristically steep with a narrow valley bottom with little to no floodplain. The geology of the watershed is typified by earlier Cenozoic deposits to the east of the Leavenworth Fault (trending along NF 7300 north of the creek), with older uplifted Mesozoic rocks to the west (Figure 2). The Leavenworth Fault is part of a series of NW-SE trending normal faults defining the southwestern margin of the Chiwaukum Graben (Campbell, 1988). The Eocene Chumstick Formation (Clark Canyon Member) underlies the watershed from the mouth of the creek to east of the Leavenworth Fault. The Chumstick Formation is composed of folded sedimentary rocks, locally contributing to slope instability where folded bedding planes can separate. A large old landslide deposit is mapped just to the east of the Leavenworth Fault and south of the creek, indicating potential contribution of colluvium to the alluvial fan of Mill Creek. West of the fault are rocks of the older Jurassic Ingalls ophiolite complex, and Cretaceous tonalite of the Mount Stuart batholith (Tabor et al., 1980). An additional old large landslide deposit is mapped down-slope of the ophiolite/tonalite contact, along the margins of the intrusion.

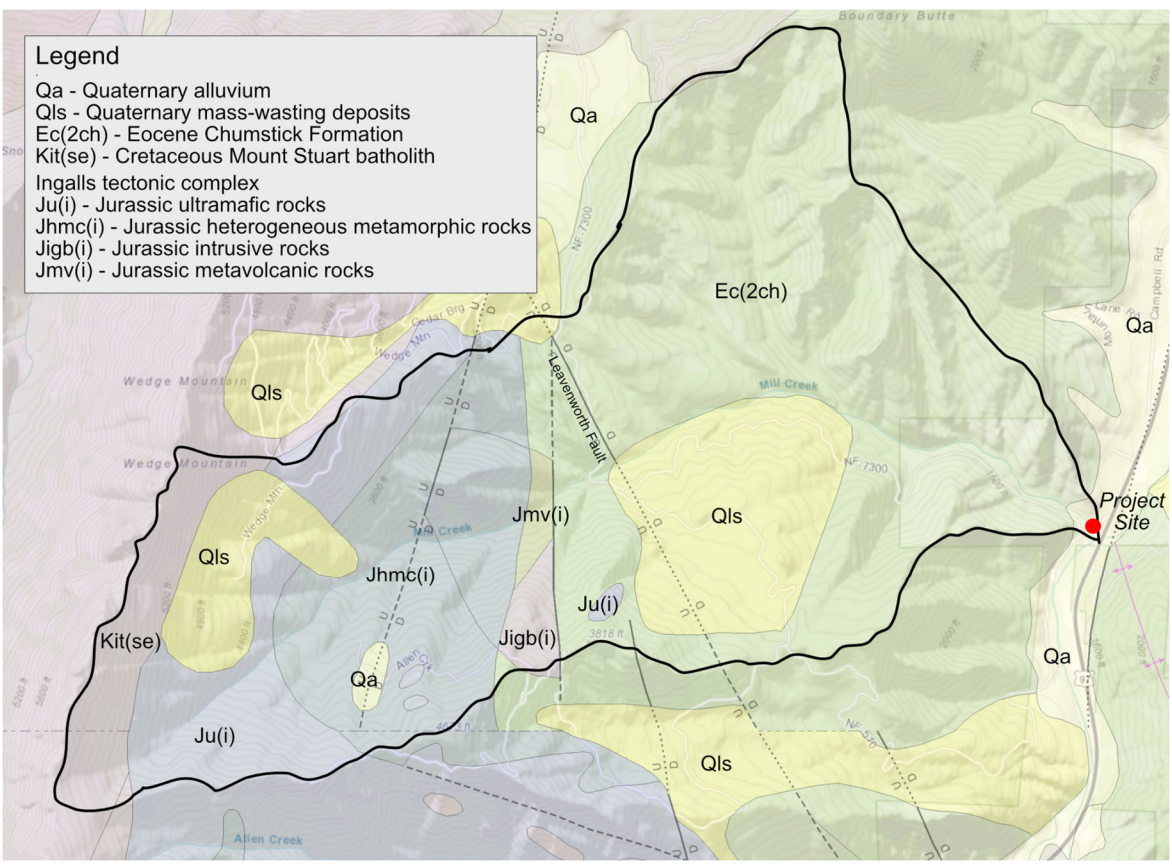

Figure 2. Geologic Map (1:100,00) of the Mill Creek Watershed (Campbell, 1988)

Mountain Home Ranch Road traverses the alluvial fan, crossing the channel with a 5 ft wide by 4 ft tall concrete box culvert, and intercepting overland flow headed down the fan. The road is visible on the earliest available air photo from 1957 (Figure 3) and is likely much older as logging and grazing occurred in the watershed around the turn of the 20th century (Interfluve, 2010). It appears that much of the watershed above the project site has been logged over time, with historic logging roads traversing much of the western and southern watershed over time. More direct channel confinement occurs primarily at the downstream end of the creek, at Mountain Home Ranch Road.

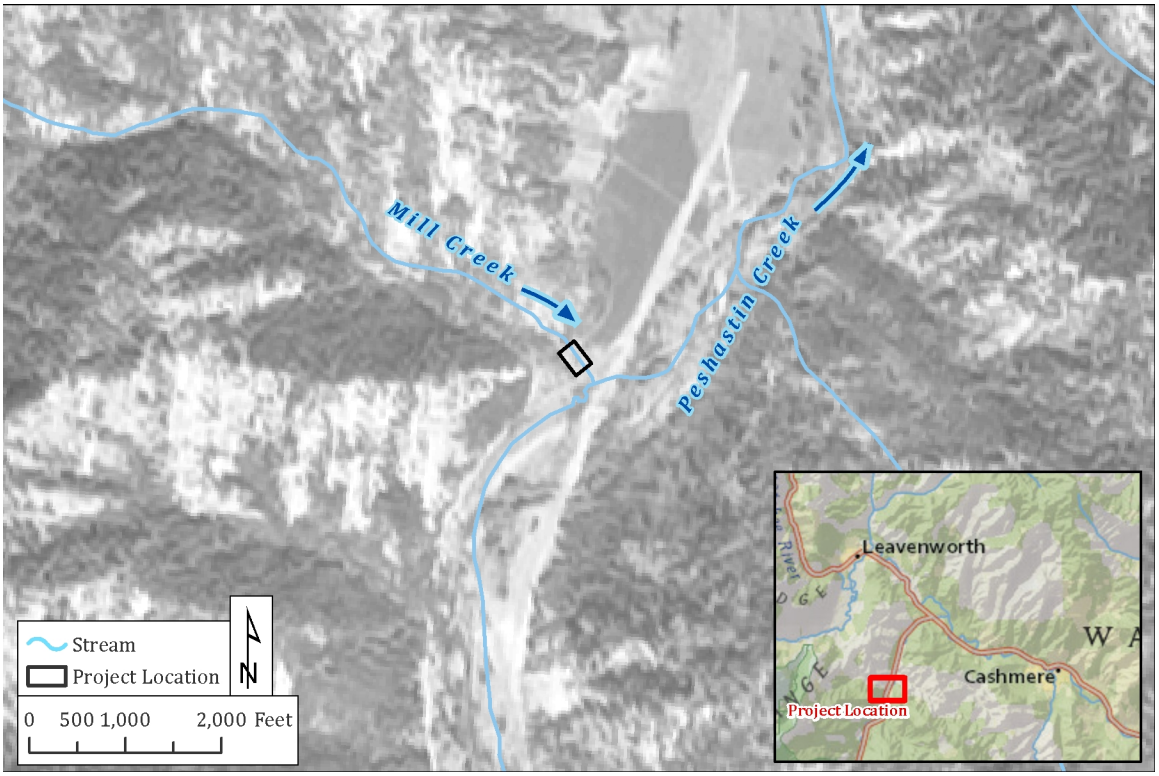

Figure 3. Annotated Version of 1957 Aerial Photo

As Mill Creek enters the much larger Peshastin Creek valley, an alluvial fan has formed that the channel would have historically migrated across. Evidence of this is clear on the LiDAR as abandoned channels and flow paths are visible across the fan. Deposits within the fan are likely a mix of alluvial and colluvial deposits as the underlying geology of the area is naturally unstable and susceptible to mass wasting. The creek is a single thread, entrenched channel through the alluvial fan and project reach (Figure 4). Upstream of the culvert through Mountain Home Ranch Road, the channel is typically 9 - 10-ft wide, with steep to undercut 3 - 4-ft high banks with dense root structure (Figure 5). The channel is very straight, with rock steps averaging 3-ft high and spaced approximately 25-ft apart up to 100-ft (Figure 4). The rock composing each step is typically 3-ft in diameter and angular to sub-rounded. Flow is typically concentrated to either side of each step, creating a low-flow channel and forming a 1 - 2-ft deep pool immediately downstream (Figure 5). The channel bed is composed of a range of particle sizes, predominately coarse gavels (D_{50} = 29mm, Figure 6) with finer material found in the lee of obstructions in the channel. Some small wood pieces are present in the channel, racking up on larger clusters of alder along the channel banks (STA 25, 115) and large rocks in the channel (STA 35) (Figure 4).

Based on the history of disturbance at the site, and observations during the field assessment, it appears that the channel upstream of the culvert has been constructed to improve conveyance and stability. The presence of the angular large rock, spanning the channel every 25-ft appears to have been placed to dissipate stream energy

immediately upstream of the road crossing. Based on the distribution of large angular rock in the channel, it appears that a rock step near STA 125' failed in the past, with the largest rock (5-ft dia) of the failed step now sitting in the channel near STA 90 (Figure 4). Smaller angular rock observed in-between the rock steps on the channel bed appear to be failed pieces of upstream rock steps (STA 80, 70, 60).

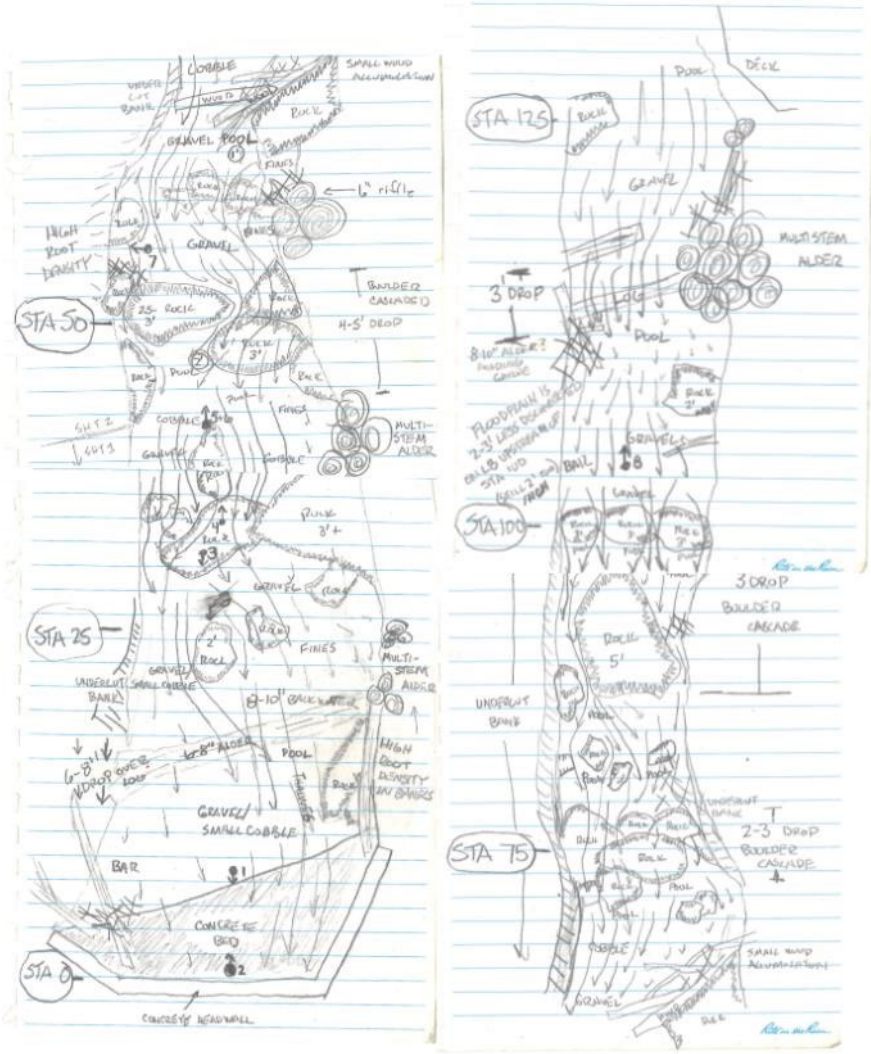

Figure 4. Field Sketch of Mill Creek Upstream of Mountain Home Ranch Road Culvert

Figure 5. Dense root mass along channel banks (left), and rock step forcing two-foot deep pool in Mill Creek (right)

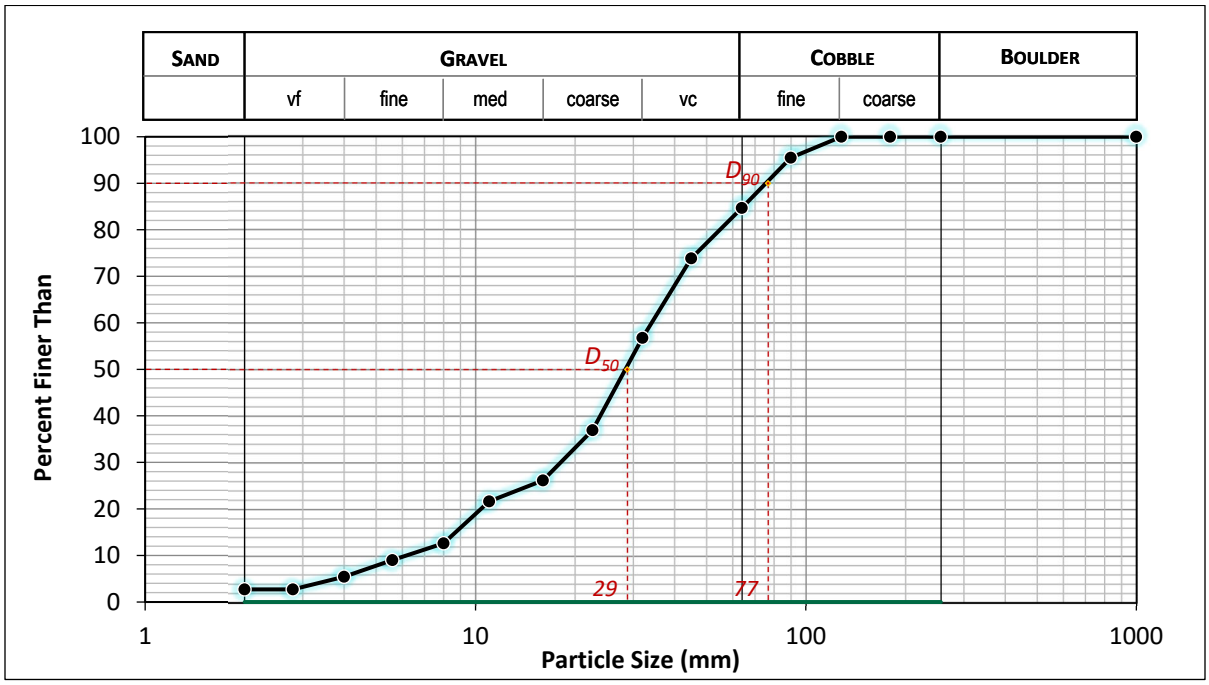

Figure 6. Particle Size Distribution for Pebble Count Conducted in Lee of Boulder Step

Fish Use and Passage Status

Mill Creek is a tributary to Peshastin Creek which supports populations of spring Chinook, steelhead, and bull trout as well as redband and cutthroat trout. Recent studies indicate that Peshastin Creek is somewhat unique in the Wenatchee River basin as it consistently produces high numbers of steelhead spawners compared to other tributaries and also boasts the highest ratio of wild-to-hatchery spawners (Truscott et al., 2018). Mill Creek has apparently not been the focus of spawning surveys (likely due to short distance between the confluence with Peshastin Creek and the known fish passage barrier) so no documentation of adult presence downstream of the culvert has been located to date; however, previous surveys of Mill Creek indicate that replacing the culvert at Mountain Home Ranch Road will provide access to an additional 2.2 miles of perennial stream.

The existing culvert which conveys Mill Creek under Mountain Home Ranch Road has been inventoried at least twice in the last decade to assess fish passage, once by the US Bureau of Reclamation (USBR) in 2011, and again in 2016 by the Cascade Columbia Fisheries Enhancement Group (2016). Both assessments identified the existing culvert as a fish passage barrier with rating of 33% passability (Appendix D). Average gradient in lower Mill Creek ranges from approximately 5-7% but the existing culvert only has an approximate slope of 2.8% (Figure); as a result of this lower slope in the existing culvert and flow constriction into the undersized culvert, a large drop has formed at the outlet of the culvert. Concrete aprons and wingwalls are included on both the upstream and downstream ends of the existing culvert. Setting the culvert at a flatter slope than the natural gradient and inclusion of concrete aprons has led to slight deposition upstream of the culvert as well as the scour (and associated drop in water surface elevation) at the culvert outlet.

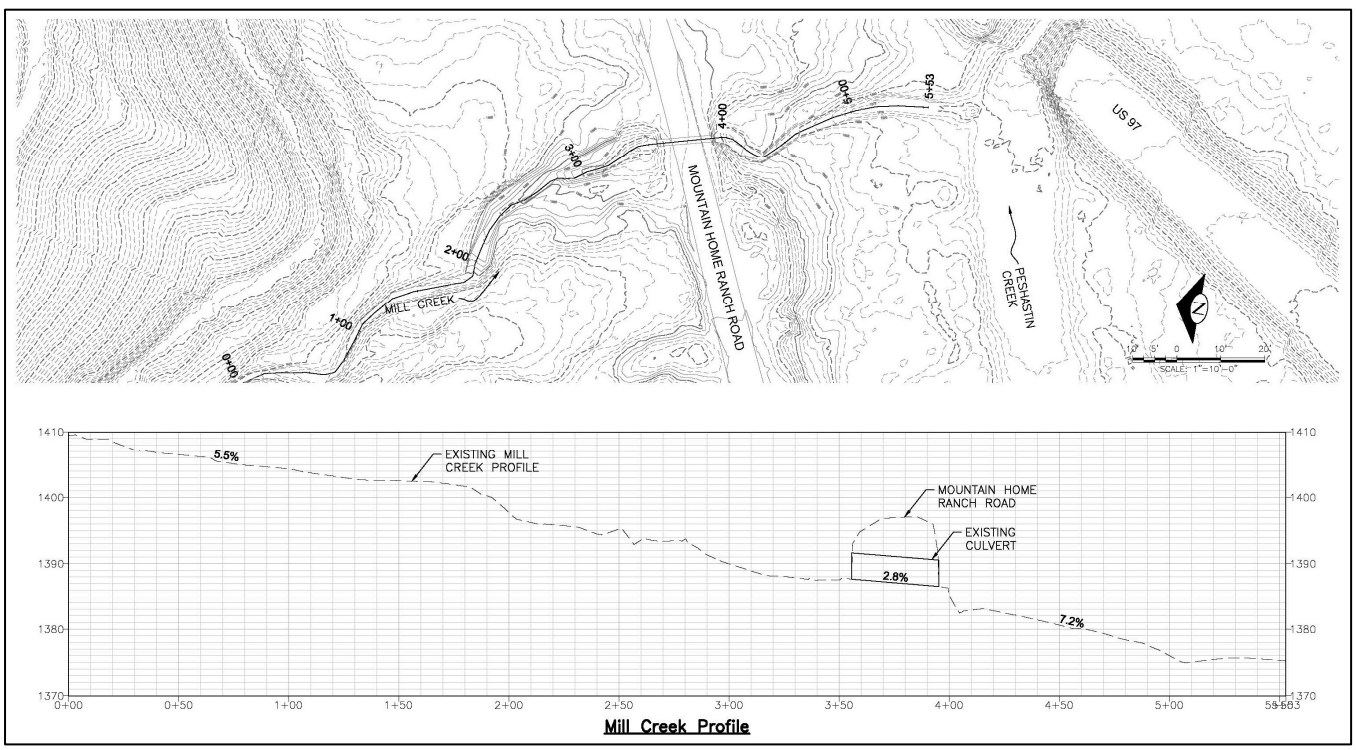

Figure 7. Plan and Profile View of Existing Conditions in Lower Mill Creek

Past Design Efforts

Twice in the past decade, CCNRD has championed efforts to implement a design which restores full fish passage at the existing Mill Creek culvert on Mountain Home Ranch Road. The first effort was in collaboration with the Natural Resources Conservation Service (NRCS) and took place in 2013. The design featured a 42-foot span bridge set on shallow abutments, and ultimately failed to be implemented due to a disagreement between the design engineer and CCPW over applicable design criteria for the abutments. A follow-up effort was undertaken a year later when Sargent Engineers, Inc. developed a design which addressed CCPW's concerns. The design developed in the second effort featured a 45-foot span bridge set on deep foundations. The construction cost estimate for this design was $1.13M in 2014; it was not advanced past preliminary design due to the low likelihood of securing construction funding.

3 PROJECT GOALS AND OBJECTIVES

The main purpose of this project is to restore full fish passage in lower Mill Creek at the Mountain Home Ranch Road crossing. Implementation of this project would address the #5 ranked ecological concern from the Biological Strategy for the Peshastin Creek basin (UCRTT, 2017). The following goals and objectives were developed to help ensure successful project implementation.

- Goal 1: Restore full fish passage in Mill Creek by establishing a stable channel through a replacement culvert crossing with a design life of at least 50-years.
  - Objective 1a: Utilize applicable WDFW design guidelines to develop a design which will remain stable while conveying the flows up to the 100-year event.
  - Objective 1b: Consider recent WDFW publications regarding climate change and incorporating climate change considerations into culvert design.
- Goal 2: Provide a design which satisfies all applicable CCPW design criteria for project implementation in 2020.
  - Objective 2a: Incorporate appropriate project elements to satisfy CCPW criteria for Rural Local Access Class 1 roads for the section of road required to be removed and replaced as part of the project.
  - Objective 2b: Ensure public safety throughout construction.
  - Objective 2c: Incorporate geotechnical recommendations in to design.
- Goal 3: Provide a design which is cost-effective, balances concerns of fish passage, climate change, debris flow potential, and allows for implementation in 2020.
  - Objective 3a: Develop a design within practical funding limits that strikes a balance of somewhat contradictory design requirements (maximize culvert size while minimizing construction cost).

4 PRELIMINARY DESIGN ALTERNATIVES

Several design alternatives were considered when efforts to improve fish passage in Mill Creek were renewed for a third time in 2018. Given that this project's primary purpose is to improve fish passage, the alternatives considered varied only in the structure type which would replace the existing culvert as all other design elements (channel design, road design, etc.) would essentially remain unchanged across various alternatives.

The initial design produced by NRCS was ruled out as a possible alternative due to the fact that the issue of agreeing on appropriate abutment design was never resolved. Therefore, all alternatives considered featured foundations which are at or below the anticipated scour depth. The first alternative considered was a bridge

with deep footings and abutments similar to the design produced by Sargent Engineers, Inc. This alternative would provide excellent flood conveyance and easily accommodate a stream simulation channel.

A second alternative which was evaluated was a precast reinforced concrete split box culvert (PRCSBC) sized appropriately to accommodate a stream simulation channel per WDFW passage guidelines (Barnard et al., 2013). Initial estimates of bankfull width were conservative at 13 feet resulting in a minimum span of 18 feet per WDFW guidelines (1.2 times bankfull width plus additional 2 feet, rounded up to the nearest whole number). This alternative would also accommodate a stream simulation channel though with less conveyance than the bridge alternative.

The third alternative pursued was a structural plate pipe arch culvert. This alternative has a unique benefit of being able to choose from several industry standard culvert shapes and sizes to tailor the structure to project specific needs. This alternative easily accommodates a stream simulation channel and allows for greater conveyance than the PRCSBC in alternative two, but is lower than the conveyance of the bridge in Alternative 1.

5 PREFERRED ALTERNATIVE

CCNRD and NSD reviewed alternatives internally and sought input from project stakeholders (CCPW) and geotechnical engineers (PanGEO, Inc.) who had collected geotechnical data as part of the design effort by Sargent Engineers, Inc. Alternatives were refined based on preliminary discussions with staff from PanGEO; the preliminary recommendation was to make sure that the structure footings for each alternative were set at approximately 15 feet below the existing road surface to ensure adequate bearing capacity. This input resulted in selecting structures for alternatives 2 and 3 which were larger than initially anticipated. For alternative 2, the PRCSBC was an 18 foot span and 11 foot rise. The structural pipe culvert shape selected was a high radius arch; in order to accommodate the recommendation for footing depth the most logical standard shape and size was a 20 foot, 8 inch span and a 12 foot, 1 inch rise.

The ability of each alternative to satisfy project goals and objectives was evaluated. All alternatives evaluated met the minimum design standards for conveying the 100-year flood and accommodating a stream simulation channel. Alternative 1 provided the greatest assurance that extreme events beyond the 100-year flood could be accommodated (increased flows due to climate change, potential debris flow events), however, the anticipated construction cost makes this alternative nearly impossible to pursue under current funding limitations. For this reason, alternative 1 was ruled out.

Alternatives 2 and 3 are fairly similar, though there are key differences. The PRCSBC in alternative 2 is approximately 3-4 times more expensive than the structural pipe arch culvert in alternative 3. The pipe arch culvert selected also features a larger conveyance area than the PRCSBC allowing for more assurance that extreme events and potential debris flows would not result in structure failure. The size of the PRCSBC could of course be increased to match conveyance ability of the structural pipe arch culvert, but this would further increase construction costs, bringing the ability to fund the project into question. For these reasons, alternative 3 was selected as the preferred alternative. This alternative provides a reasonable middle ground between meeting the absolute minimum in terms of structure size, provides the lowest construction cost of all three alternatives considered, and still allows for all other pertinent design criteria to be met. The preferred alternative was presented in preliminary plans which were used to secure grant funding for this design and implementation effort.

6 DESIGN CONSIDERATIONS AND PRELIMINARY ANALYSES

Early design development efforts focused on identifying a design for a stable channel which can accommodate the natural range of flows and sediment transport which naturally occur within Mill Creek without

compromising fish passage through the culvert crossing. In order to accomplish this, WDFW's stream simulation design guidelines provided in the 2013 Water Crossing Design Guidelines (Barnard et al., 2013) were utilized. Conditions in lower Mill Creek satisfy the criteria for application of the stream simulation approach per WDFW, namely:

- Moderately confined channel
- Bankfull width less than 15 feet
- Length-to-width ratio (for the replacement culvert) of less than 10
- Culvert bed slope not greater than 1.25 times the upstream channel slope

The stream simulation design approach is a geomorphic approach to designing stream crossings. The focus of the design is to base channel design on nearby reference conditions based on the assumption that if fish and other aquatic organisms can successfully navigate through the adjacent channel then if those same conditions are carried through the culvert the culvert should not present a barrier to fish movement. In general, a channel is first designed based on geomorphic conditions nearby, but outside the influence of the culvert, and then the design is verified using analytical tools.

With slopes over 4% (scenario 2 for stream simulation culverts), WDFW recommends a cascade or step-pool morphology within the culvert. Given the apparent relatively high degree of stability of boulder steps likely constructed during previous culvert installation, a similar approach was applied to this effort. First, an appropriate general cross-section shape was identified using measured bankfull widths and by querying topographic data. A bankfull width of 11 feet was chosen based on bankfull measurements (see Appendix E). This cross-sectional shape was then applied to an equilibrium slope which ties in at points upstream and downstream of the existing culvert to transition smoothly from the upstream channel, through the culvert, and into the channel downstream of the replacement culvert. Channel alignment was also modified slightly to better align with natural conditions; as it currently sits, Mill Creek flows out of the culvert into a plunge pool and bends to the right before entering a sharp meander back to the left before flowing nearly straight to the confluence with Peshastin Creek. The proposed modified alignment of the creek dampens the severe meanders experienced downstream of the culvert while still allowing an appropriate slope to be used through the culvert (Figure 8). Locations for step-pools were identified based on guidance from WDFW which states that "spacing of steps is somewhat variable, but one to four channel widths with a maximum 0.8-foot drop between successive crests is recommended" (Heiner, 1991 as cited in Barnard et al., 2013). To accommodate this recommendation, boulder steps were placed approximately every 14 feet within the proposed channel to limit drop between steps to 0.8 feet (Figure 8).

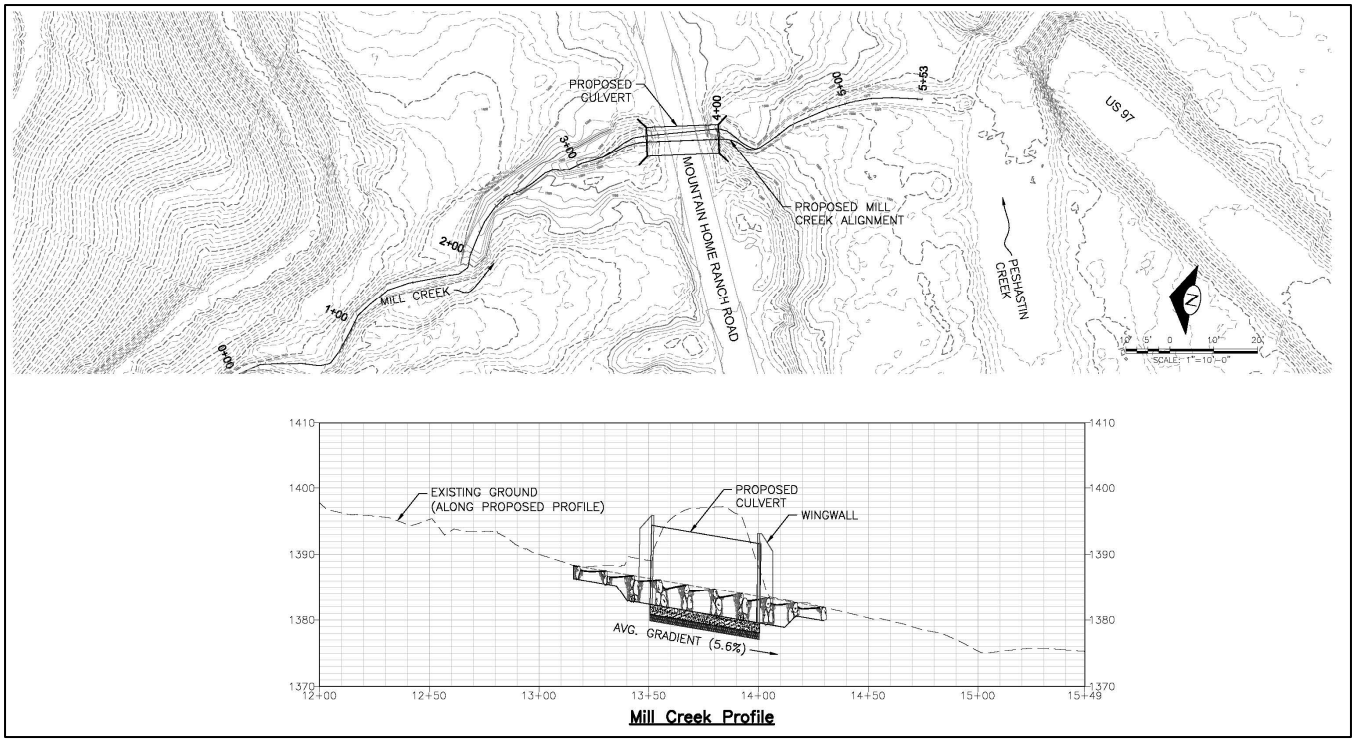

Figure 8. Proposed Mill Creek Alignment and Profile

Hydrologic and Hydraulic Assessment

Once a proposed channel design had been identified in terms of its dimensions, pattern, and profile, a topographic representation of the proposed channel was generated in AutoCAD Civil 3D for further assessment. A hydraulic model was developed to assess stability of the channel, estimate potential scour under extreme conditions, and to verify that extreme flow events can be conveyed through the culvert while maintaining freeboard. This section summarizes the hydrologic and hydraulic analyses conducted in support of this design effort.

Hydrology Assessment

Very little site-specific streamflow data are available at Mill Creek, however, CCNRD did monitor streamflow to document spring runoff during several high flow seasons from 2011 to 2014, providing a short, 4-year period of record. The peak instantaneous discharge value measured during this time was a flow of 56.5 cfs on March 29, 2012. During low flow periods (typically July – September), discharge in Mill Creek commonly drops to approximately 1-2 cfs based on the available flow data.

When verifying a stream simulation channel design there are several flows of interest, but perhaps the two most important flows to consider are a typical “bankfull” flow and the estimate 100-year flood. The WAC for water crossing structures (WAC 220-110-070) specifies that the 100-year flow shall be used as the design flow for bridges and culverts, and as such a reasonable estimate of the magnitude of this event is important. Once identified, these flows can be run through a hydraulic model representing proposed conditions to see how flow changes, if at all, when routed through the proposed channel. In order to estimate discharges for these events, several sets of regression equations were utilized and compared to the short period of record available for validation when reasonable. When estimating design flow magnitude, WDFW recommends the following methods in order of preference:

- Gauge data with a period of record of at least 10 years
- A continuous flow simulation model calibrated to existing conditions
- Local regression model closely matched to gauged stream(s) with at least 10 years of record, and
- Regression model to which one standard error has been applied to the estimate to compensate for the inherent uncertainty

Given the relative lack of data available for Mill Creek, the fourth option was pursued. Several regression models are available for use in generating estimates of peak streamflow at ungauged locations. The Washington State Department of Transportation (WSDOT) published a regression model in 2002 (Orsborn and Orsborn, 2002) specific to East Cascade and Blue Mountain streams. The USGS published a regression model in 1998 (Sumioka et al., 1998) which was in effect at the time the 2013 WDFW guidelines were published, but has since been updated with a more recent publication (Mastin et al., 2016). The regression models were each utilized to estimate several flows which were common among all models and then compared with each other. When compared, the early regression models by WSDOT and USGS agreed well with each other and with peak flows from the relatively short period of record. The updated USGS regression model predicts much higher values, particularly for the less common flood events, but still agrees fairly well with observed data. For this project, the approach taken was to average the value of the estimated peak flow plus one standard error across all three regression models utilized. The results of this approach are summarized in Table 1 and Figure 9.

Table 1. Predicted Flow Magnitudes from Three Regression Models and Design Values Utilized

RETURN INTERVAL (YRS)	WSDOT (2002)		USGS (1998)		USGS (2016)		DESIGN VALUE
	Predicted Q (cfs)	Predicted Q + 1 S.E. (cfs)	Predicted Q (cfs)	Predicted Q + 1 S.E. (cfs)	Predicted Q (cfs)	Predicted Q + 1 S.E. (cfs)	Predicted Q + 1 S.E. (cfs)
2	34.6	36.3	29.8	54.2	24.7	43.7	**44.7**
25	94.7	107.0	90.7	169.6	83.1	205.1	**160.6**
100	138.3	160.4	128.4	246.5	186.0	373.3	**260.1**

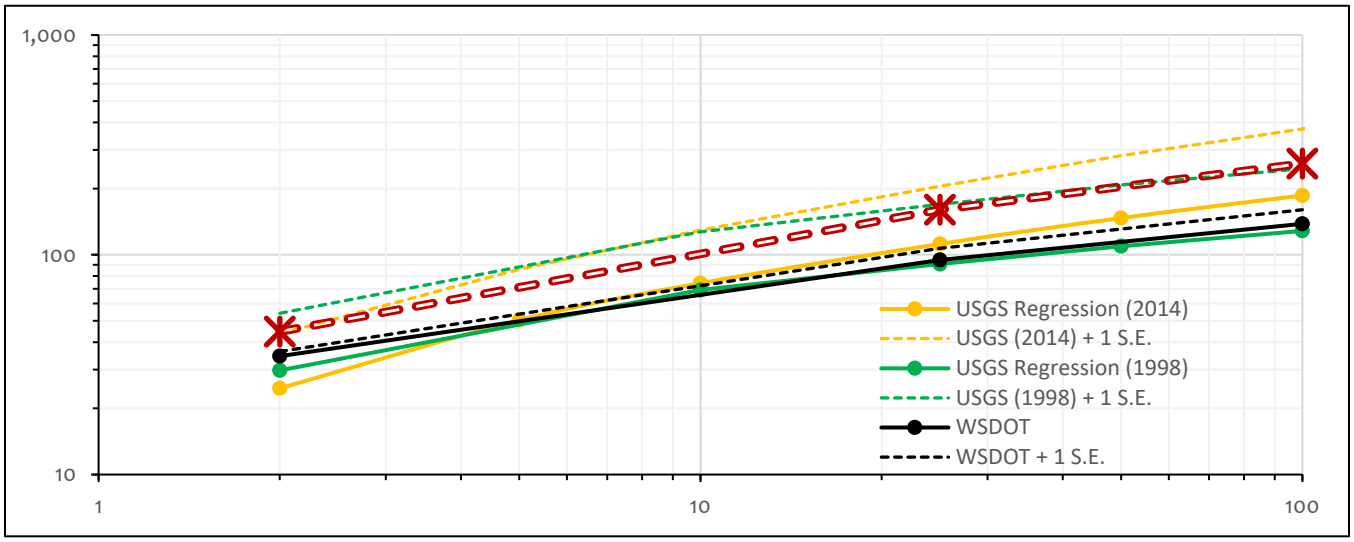

Figure 9. Predicted Flow Magnitudes from Three Regression Models and Design Values Utilized

Hydraulic Assessment

A hydraulic model of Mill Creek was developed to analyze effects of proposed conditions on reach hydraulics. The model was developed using Hydronia's RiverFlow2D Plus GPU version and Aquaveo SMS v12.3 software interface for pre- and pos-processing of model inputs and results. RiverFlow2D is a two-dimensional finite volume computer model that provides depth-averaged hydraulic parameters at centroids within a triangular mesh model domain. The model domain covered approximately 530 feet of lower Mill Creek with the downstream end of the domain approximately 50 feet upstream from the confluence with Peshastin Creek. The model contains a representation of physical conditions immediately following construction.

In order to accurately capture the topography and yield results with fine enough detail in areas of interest, the model mesh was created using finer spacing in the channel than outside the channel in adjacent terrace and road areas. The mesh spacing utilized in the model is summarized in Table 2.

Table 2. Mesh Spacing Used in Hydraulic Model Development

SURFACE TYPE	MESH SPACING (FT)
Mill Creek Channel	1
Mill Creek Terraces and Floodplain (approximate)	3
Roads and Outer Boundary	5

Each model element within the model domain was assigned to a roughness value with an associated roughness value which is used to simulate hydraulic resistance in the hydraulic model. Roughness values selected were based on published recommendations for roughness values in one-dimensional hydraulic models (USACOE, 2016) and adjusted slightly to account for the fact that two-dimensional models account for more energy dissipation within the solution routine that one-dimensional models do; this adjustment was made based on professional experience with two-dimensional hydraulic models. Roughness values used within the model domain are summarized in Table 3.

Table 3. Hydraulic Roughness Values Used in Hydraulic Model Development

ROUGHNESS CATEGORY	MANNING'S n VALUE
Channel	0.042
Floodplain	0.070
Boulders (boulder steps)	0.060

RiverFlow2D is capable of incorporating one-dimensional culvert hydraulic calculations within a two-dimensional computational mesh (Hydronia, 2018). RiverFlow2D does this by utilizing simulated hydraulic values within the model domain as inputs in equations published by FHWA to determine conveyance through the culvert. This approach does not allow for simulation of hydraulics within the culvert. Given the complex nature of the channel bed as it travels through the culvert, the decision was made to model two-dimensional flow throughout the entire model domain; this approach is valid provided the walls of the culvert are not inundated at any time during the hydraulic simulation. Culvert walls were approximated in the hydraulic model using near vertical slopes which originate at the point where the constructed bed meets the walls of the proposed culvert (Figure 10).

Several flows were run through the hydraulic model to aid in assessment of the proposed channel design. Peak flows calculated in the hydrologic analysis, as well as two low flows were simulated to assess hydraulic conditions of the proposed design (Table 4). The flows in Table 4 were used as upstream boundary conditions for the hydraulic model; the downstream boundary condition was set as "free outflow", meaning that velocities

and water surface elevations at the downstream boundary were calculated by the model with flow only allowed to exit the model domain.

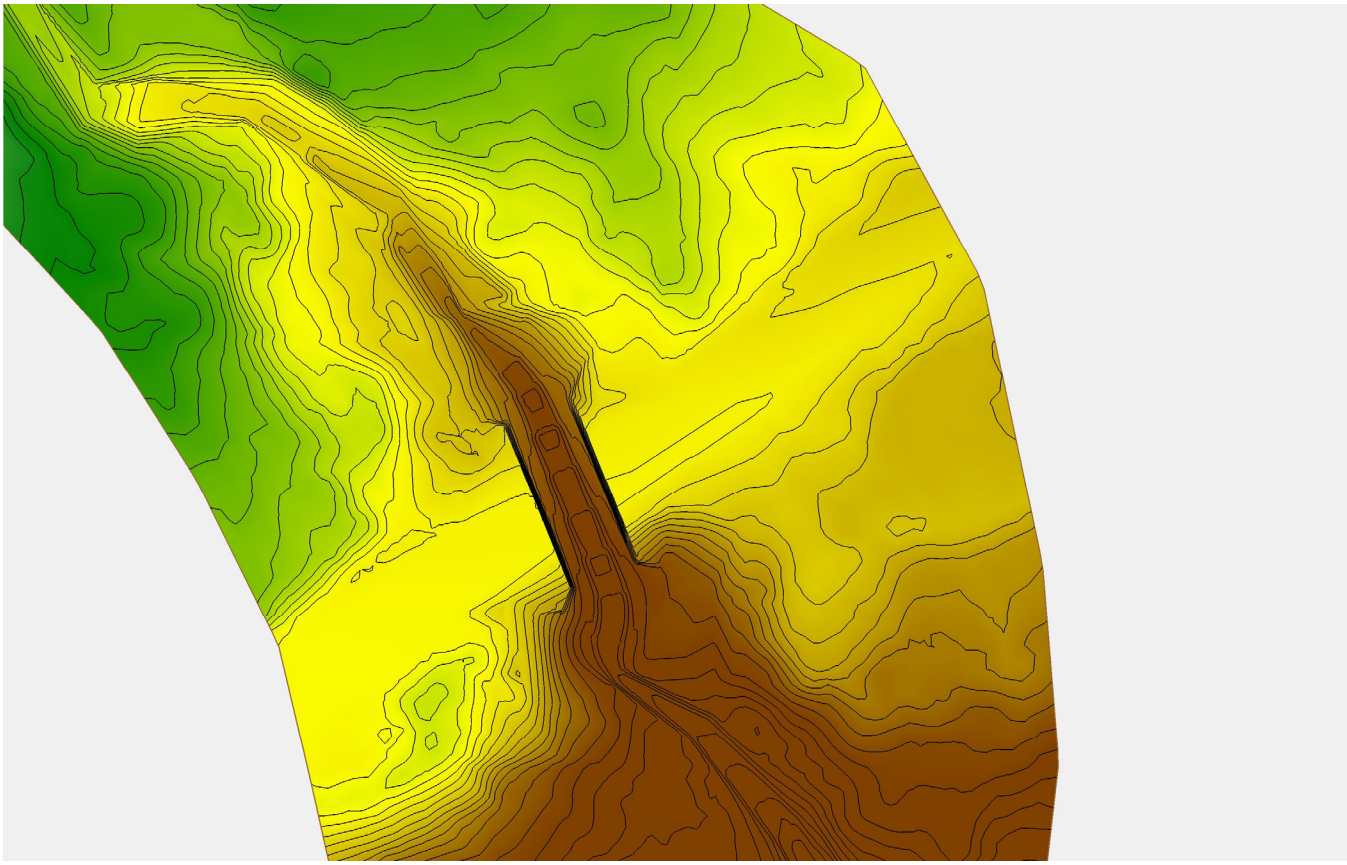

Figure 10. Topographical Representation of Proposed Conditions in Hydraulic Model Domain

Table 4. Modeled Discharge Values at Inflow to Mill Creek Hydraulic Model

EVENT	MODEL INFLOW (CFS)
Seasonal Low Flow	4
Seasonal High Flow	10
2-yr Flood	45
25-yr Flood	160
100-yr Flood	260

Results of hydraulic simulations of proposed conditions were examined to verify that the proposed channel design does not adversely affect hydraulics, sediment transport, or fish passage. Simulated depths and velocities within the proposed culvert crossing are consistent with the range of values experienced outside the culvert in the channel upstream and downstream of the culvert. Select hydraulic results are presented in Figure 11 through Figure 15. Average velocities within the culvert appear to be slightly lower than outside the culvert, likely due to the large amount of energy dissipated by the boulder steps included in the channel profile. Depths within the culvert are similar to those outside the culvert at both a typical bankfull (estimated as the 2-year event for this project) and the 100-year event. These results suggest that the proposed channel design will provide fish passage and accommodate the full range of expected discharges and sediment transport likely to occur at Mill Creek. Lastly, the approach of simulating hydraulics within the culvert by essentially removing it

from the model and allowing two-dimensional hydraulic simulations to take place within the "culvert" is considered valid in this case as flows just begin lapping at the walls of the structure during the 100-year event under proposed conditions. Had flows significantly inundated the vertical walls representing the horizontal limits of the proposed culvert, the hydraulic approach utilized for this effort would have required modification and would have utilized more traditional one-dimensional modeling techniques. We feel that being able to simulate and subsequently visualize results from a two-dimensional model throughout the proposed culvert bed is a worthwhile endeavor when applicable.

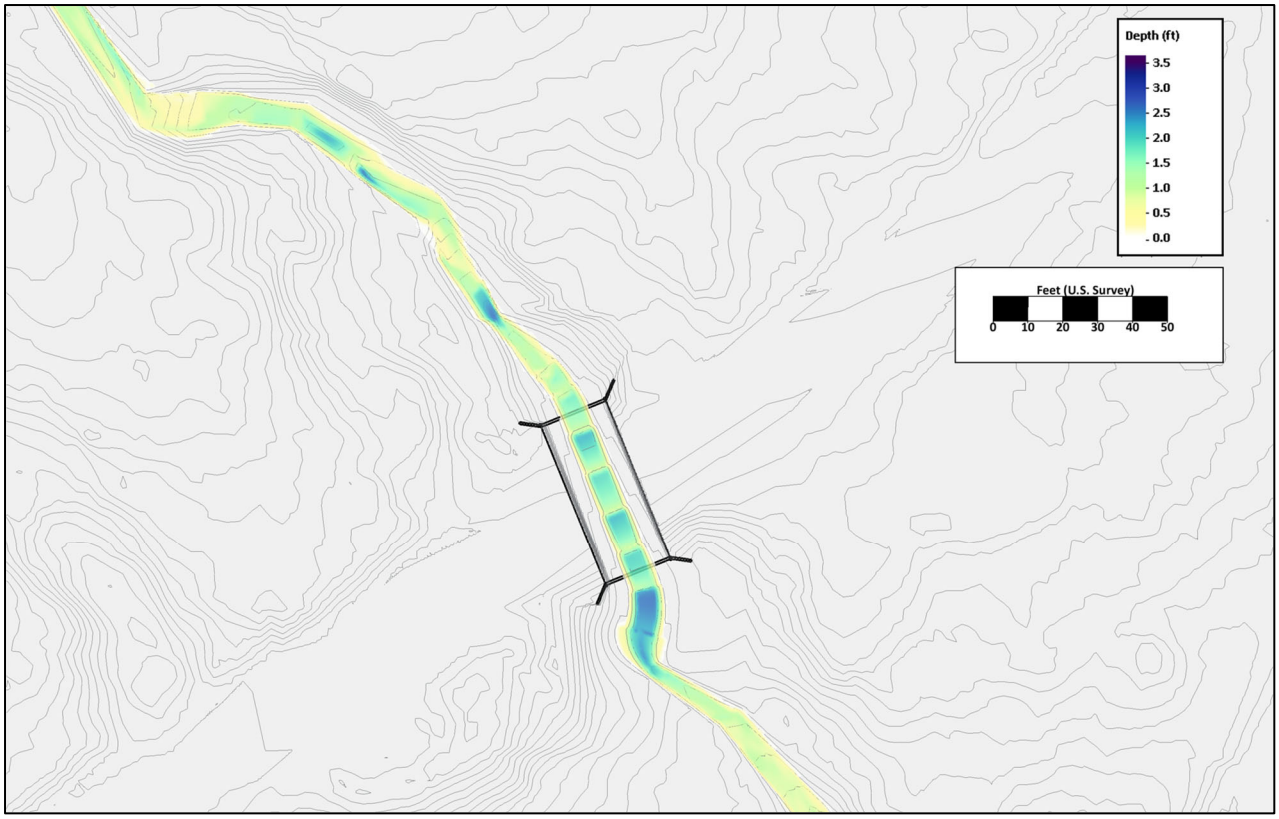

Figure 11. Simulated Depths under Proposed Conditions for the 2-year Event

Figure 12. Simulated Velocities under Proposed Conditions for the 2-year Event

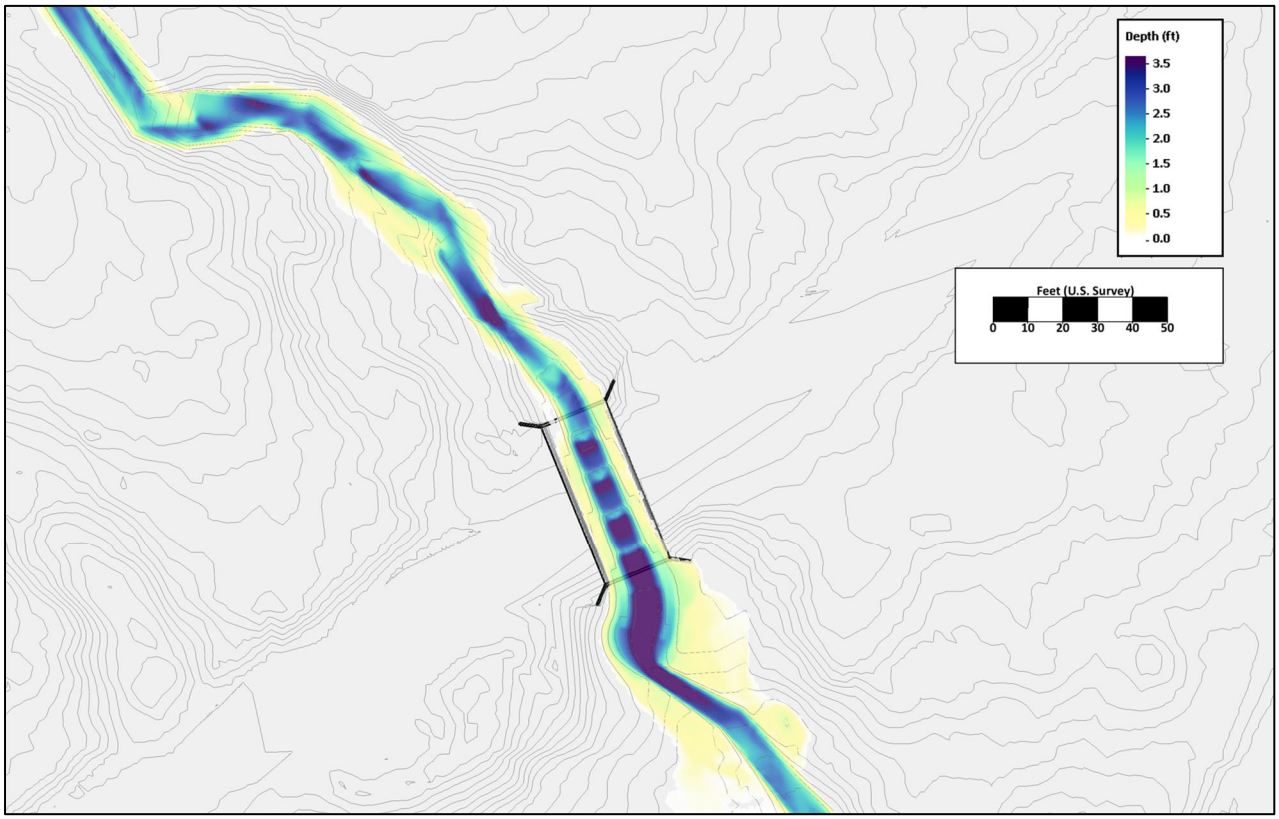

Figure 13. Simulated Depths under Proposed Conditions for the 100-year Event

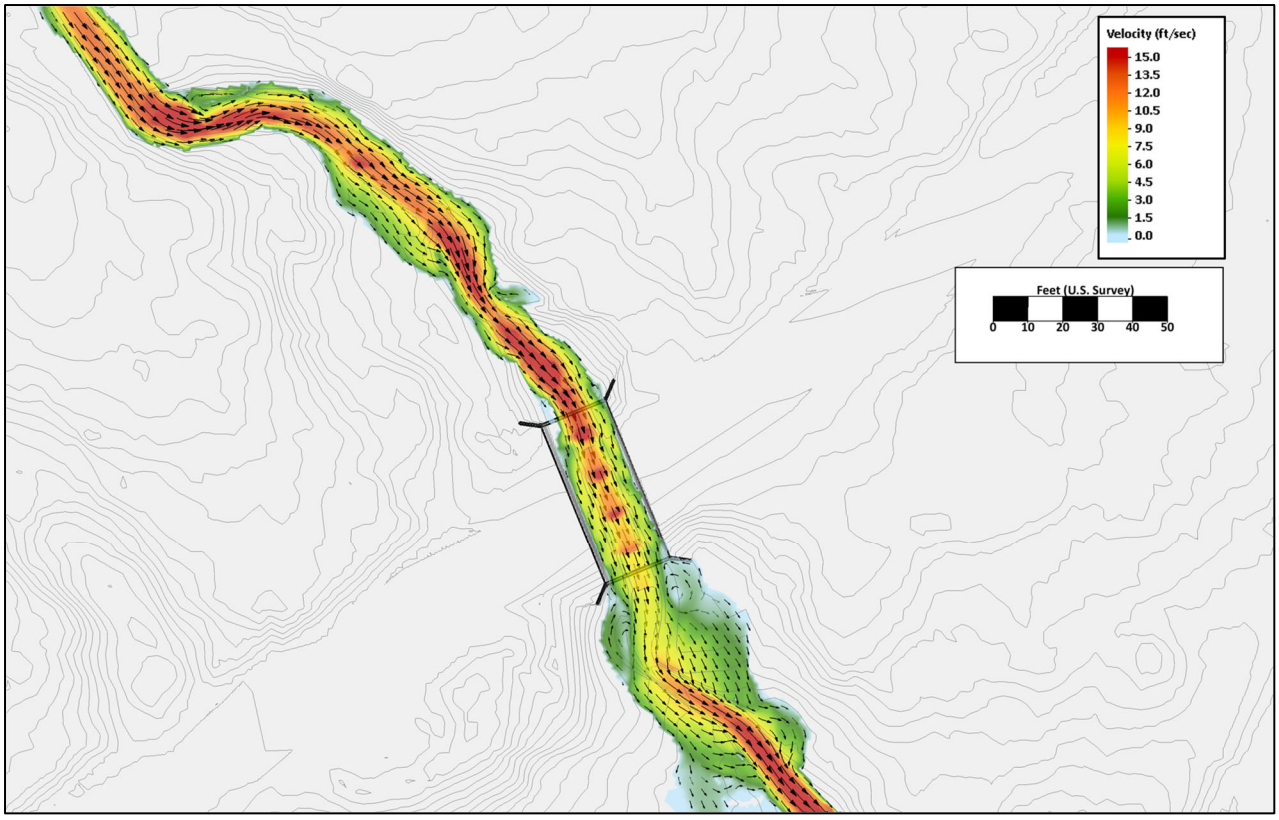

Figure 14. Simulated Velocities under Proposed Conditions for the 100-year Event

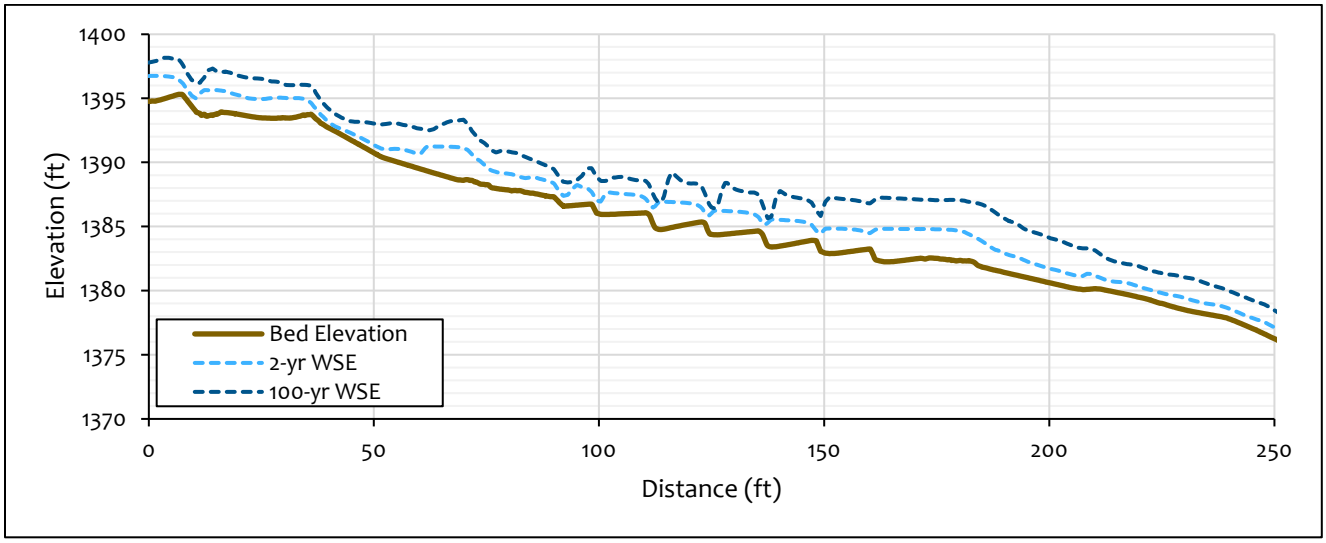

Figure 15. Simulated Water Surface Elevation Profiles for the 2- and 100-year Events

Channel Bed Design

The hydrologic and hydraulic analyses described earlier suggest that the proposed design will provide full fish passage while accommodating the full range of expected conditions in Mill Creek, provided that the channel is constructed as shown in the design and that the channel bed itself does not experience significant deformation or failure over time and that the proposed culvert remains structurally sound. Two additional analyses were performed in order to ensure that the channel bed is resilient to changes over time due to sediment transport,

and that the proposed culvert is protected from potential scour during high flow events. These analyses are briefly summarized in this section.

Sediment Sizing

General guidance provided by WDFW design guidelines (2013) was utilized to develop a streambed gradation. For scenario 2 stream simulation culverts (slope greater than 4%), WDFW provides several key design concepts which were applied to this project:

- The shape of the channel is defined during construction; steps are formed by larger pieces in the mix with pools and hollows below the average grade line (see Figure 8).
- Steps should be composed of material that is immobile at any but the highest expected flows.
- The bed has a "monolithic" structure where the largest particles contact each other and form a continuous support network.
- In general, the larger particles in a natural step-pool channel are roughly similar in size to the depth of flow at its bankfull condition.
- For culverts where the slope of the bed matches the adjacent reach, sediment gradation upstream of the culvert can be used to help characterize a suitable design gradation.
- The Bathurst equation can be utilized to estimate the size of the D84 particle which would be on the threshold of motion for a given discharge.
- General guidelines for sediment gradation are provided
  - D84/D100 ~ 0.4
  - D84/D50 ~ 2.5
  - D84/D16 ~ 8.0

These concepts, combined with actual pebble count data and general site observations were utilized to develop a streambed mix. Given that large particles have apparently been successful at supporting a stable channel, the decision was made to break the streambed mix into two portions, the coarse fraction (or portion that will be used to construct boulder steps and to randomly intermix larger particles) and the fine fraction (which will comprise the balance of the streambed between steps).

Particle sizes for the coarse fraction were based on site specific observations of stable particles (approximately 2-3 feet in diameter at previously constructed boulder steps) and the fact that larger particles in a natural step-pool are similar in size to bankfull depth. Simulated depths during bankfull conditions are typically on the order of 1.5-2.5 feet though there is considerable variation within the modeled reach. Given these observations, the WSDOT specification for two-man and three-man streambed boulders will be utilized to specify the size of boulders in the coarse fraction. Each boulder step will be required to be constructed of at least 30% three-man streambed boulders with the remainder coming from two-man streambed boulders.

The fine fraction will make up the remainder of the bed material and will be composed of a well-graded mix of particle sizes. The Bathurst equation as summarized in WDFW guidelines was used as a starting point to estimate D84 particle size which results in a predicted D84 of 10 inches for proposed conditions within the culvert. General guidelines for ratios of particle sizes from WDFW result in 25-inch, 4-inch, and 1.25-inch sizes for the D100, D50, and D16, respectively. These values were then compared to the actual pebble count which was conducted in an area where the fine fraction is anticipated to reside (in the lee of a boulder step). Across the board, the pebble count produced smaller particles than the WDFW mix suggested (Table 5); a recommended design gradation for the fine fraction was developed based on an approximate middle-ground between both sets of values. The design gradation will be specified as a mix of WSDOT specifications for 12-inch

cobbles, streambed sediment, and one-man streambed boulders mixed in a 3:2:1 ratio to approximate the design mix shown in Table 6. The fine fraction shall be mixed at the specified ratio and placed in successive lifts which are "washed in" by spraying the constructed lift with water pumped from a pump, preferably capable of high pressure. Washing in the constructed bed helps seal the streambed and ensures that no surface flow will be lost to interstitial spaces within the channel bed.

Table 5. Particle Size Distributions Used to Generate Design Streambed Mix for Fine Fraction

PARTICLE PERCENTILE	WDFW GUIDELINES (INCHES)	PEBBLE COUNT (INCHES)
D100	25	5
D84	10	2.5
D50	4	1.1
D16	1.5	0.4

Table 6. Preferred Design Streambed Mix for Fine Fraction

PERCENT PASSING	PARTICLE SIZE (INCHES)
100	18
84	9-12
50	3-5
16	0.25 – 0.75
10	No. 40 Sieve
5 Min.	No. 200 Sieve

Scour Calculations

An assessment of potential scour at the replacement culver was conducted to verify that footing depths are not susceptible to failure should scour occur. When analyzing scour at culverts there are typically three major scour mechanisms which can contribute to scour: long-term degradation, contraction scour, and local scour at to piers or abutments (typically reserved for bridges). The total scour depth is then estimated as the sum of the three individual scour components (Arneson, et al., 2012).

Long-term degradation can be thought of as a lowering or scouring of the streambed due to natural or anthropogenic causes. The channel upstream of the existing culvert appears to be relatively stable with little to no change over the past several decades, likely due in part to the boulder steps which were apparently installed during a previous construction effort. For these reasons, long-term degradation is not anticipated to occur at the site and will not contribute to total scour.

Contraction scour is a lowering of the streambed at the crossing structure which results from contraction of the flow to a smaller area and causes the streambed to become mobile. Contraction scour could possibly occur at the project site if flow is indeed constricted during the design event (100-year flood). For this reason, contraction scour could possibly contribute to total scour and was estimated using procedures identified in HEC-18 (Arneson, et al., 2012). First, an estimate of critical velocity for the design bed material was made to determine if clear-water or live-bed conditions are present. The fine fraction portion of the design streambed mix was used for this determination. With a D_{50} of 4 inches and an average depth of 3 feet, the critical velocity was determined to be 9.0 ft/sec. Average velocity during the design event just upstream of the culvert is approximately 13 ft/sec indicating that live-bed scour conditions are present. Live bed contraction scour for HEC-18 Case 2 (flow confined to the main channel, no overbank flow) was then estimated using HEC-18 equation 6.2 and 6.3. Inputs to equation 6.2 were selected from sampling existing topography, and querying hydraulic

model results. The calculated contraction scour under proposed conditions is 0.90 ft which represents a small scour depth relative to the thickness of the constructed bed. The small calculated scour depth is likely due to the fact that with the proposed design, very little actual flow contraction occurs. Nevertheless, the estimate of 0.90 feet was considered to contribute to total scour for purposes of this analysis.

Local scour occurs when vortices form around piers, abutments, embankments, and other infrastructure obstruct flow. Model results indicate that flow just begins to reach the outer edge of the culvert at the design event and therefore local scour is not anticipated to occur and is not considered to contribute to total scour.

The total predicted scour at the project site under proposed conditions is less than a foot, and footing depths are set more than four times the estimated total scour depth of 0.90 feet. As such, the proposed structure is well protected against potential scour during the design event.

Geotechnical Assessment and Design Recommendations

A geotechnical analysis utilizing geotechnical boring data collected during a previous design effort as part of the current effort. General subgrade conditions and design recommendations specific to this effort were provided in a geotechnical report (see Appendix C). Recommendations provided in the report were incorporated in the plans. Specific values and characteristics of subgrade materials are being made available to all possible bidders for use in developing site-specific designs for culvert footings, headwalls, and wingwalls. Specific design values provided by PanGEO are included in the special provisions for the project.

Temporary Detour Design

During initial project scoping discussions with CCPW the impacts of temporary full road closure were discussed. Several residences and private parcels sit to the west of the project site which are primarily accessed via Mountain Home Ranch Road. A secondary access is provided via USFS Road 7300, but this requires a lengthy detour to Leavenworth and several miles of travel on forest roads. With construction anticipated to require approximately 2-3 weeks of road closure, special accommodations will be required to address access to the private parcels as well as access for emergency vehicles should they be required to access said private parcels at any point during road closure. There are two main strategies for maintaining access to the private parcels for both residents and emergency vehicles. The first approach is to fully close the road, reach an agreement with landowners during the construction period that allows for walk-in access and provides full-time emergency vehicle presence by parking an emergency vehicle past the road closure point. The second approach is to maintain at least one-way traffic throughout construction. Given site constraints, this approach will require installation of a temporary bridge, and full-time traffic control during construction. The second approach provides more assurance that in the event of an emergency, residences can quickly evacuate, and emergency vehicles can quickly access all areas in the project vicinity; ultimately CCPW decided to require that one-way traffic be maintained throughout construction. CCPW also provided some general guidance for the temporary detour and bridge:

- Temporary detour should accommodate turning radii of emergency vehicles
- Temporary bridge shall be designed to withstand HS-20-44 loading
- Temporary bridge shall include guardrail or similar traffic barrier

A temporary detour route satisfying these requirements was developed and approved by the private landowners affected by this detour. The detour alignment was routed such that it avoids large trees and private infrastructure on the private parcel. To ensure that emergency vehicles will be able to navigate the temporary detour, a vehicle sweep analysis was performed using a WB-40 design vehicle to represent typical emergency vehicles; a similar approach was recently used for road design in Portland, OR (City of Portland, 2008). Special

provisions will be included which require a temporary bridge with traffic barrier to be provided by the contractor with shop drawings stamped by a structural engineer certifying that the temporary bridge is designed to withstand HS-20-44 loading. As part of this effort we verified that these bridges are available for rent or purchase, however we recommend that the project go out to bid as soon as possible to accommodate a possibly long lead-time to acquire such a bridge.

Road Design Considerations

Chelan County road design standards for Rural Local Access Class I Roads (Chelan County Code Section 15.30.240) were applied to the section of road required for removal and replacement as part of this project. In particular, the following design standards were applied per Chelan County Code:

- Nominal pavement width of 28 feet
- Hot mix asphalt – 3 inches compacted depth
- Crushed surfacing top course – 3 inches compacted depth
- Crushed surfacing base course – 6 inches compacted depth

Beam guardrail Type 31 was also included in the design. Guardrail placement, length of need, and terminal locations were based on guidance found in the WSDOT Design Manual (2019).

Other Design Considerations

Additional design recommendations and considerations included in this design effort focused primarily on the potential for catastrophic events due to some combination of environmental conditions such as climate change, significant watershed disturbance (fire within watershed), and debris flows. Designing for the potential of these events is difficult as very little prescriptive design guidance is available in the literature. WDFW and the University of Washington have recently published findings related to climate change and predicted long-term trends of precipitation, runoff, and modifications in bankfull width which is a key driver when sizing culverts using the stream simulation design approach (Wilhere et al., 2016 and Mauger et al., 2018). In general, most climate change models suggest that both the magnitude and frequency of extreme events will increase in the future; corresponding to this change, bankfull widths of streams are generally anticipated to increase in the future. The Climate Impacts Group (CIG) at the University of Washington developed a tool based on their research which provides a probabilistic estimate of culvert failure during the design lifespan by integrating anticipated climate change with predicted changes in bankfull width to the design width of a culvert. The predicted probability of failure of the proposed culvert using this tool is 0% for design lifespans of 50 to 79 years (the maximum allowed in the tool) suggesting a design capable of accommodating a wide range of future climate conditions.

In the event of extensive fire or deforestation within the watershed followed by heavy rainfall, there is at least a possibility that a debris flow could occur somewhere within the watershed. Debris flows such as the 1996 Ruby Slide have occurred nearby in the Peshastin watershed (Interfluve, 2010) and a small debris flow scar is visible within the Peshastin Creek drainage just a few miles from the project site. Most research focused on predicting debris flows is related to predicting debris flows under post fire conditions. No prescriptive design guidelines related to debris flow potential could be located; WDFW commentary on the topic is general and states that culverts are typically “not designed to pass catastrophic events like debris flows or mud slides” and that “when working in watersheds known for a high frequency of such events the designer may want to consider a vented ford or an elevated bridge.” It is unclear what constitutes a “high frequency” of debris flows; regardless, neither a vented ford nor an elevated bridge is feasible under current site conditions and funding mechanisms. As such,

the most reasonable path forward is to design a culvert which maximizes conveyance while maintaining an acceptable construction cost. Design development to date has attempted to strike this delicate balance.

7 CONSTRUCTION METHODS AND COST ESTIMATE

Construction of project elements is anticipated to be completed with traditional, ground-based equipment including both wheeled and tracked machines. Construction of the temporary detour will be among the first actions completed. The temporary detour is located upstream of the anticipated excavation limits for culvert installation. Some clearing, grading, and temporary relocation of a fence will be required to construct the temporary detour as shown. A temporary bridge rated for HS-20-44 loading will be required to transport traffic on the temporary detour across Mill Creek during construction. Mill Creek will be rerouted around the work area to allow dewatering throughout construction. Temporary cofferdams will be installed upstream and downstream of the work area and Mill Creek will be rerouted through a pipe and/or pump to just downstream of the work area. Groundwater will be pumped out of the work area to an upland area and allow to infiltrate. Construction is anticipated to take 3-4 weeks from initiation to completion. Temporary impacts from construction are anticipated to include:

- Clearing associated with temporary detour establishment and excavation for culvert and headwall installation.
- Temporary impacts to aquatic life associated with work area isolation and dewatering. This will require removal of fish and other aquatic life within the isolated area. Removal will be performed according to standard practices with every effort made to minimize impacts to aquatic life.
- Throughout construction traffic on Mountain Home Ranch Road will be disrupted and controlled via flagger and/or a temporary traffic signal through and/or around the work area during construction.

A construction cost estimate was prepared in support of this project (Appendix B). The cost estimate is largely based on our professional judgment, the most recent cost data available, consultation with construction contractors and recent experience with similar projects.

Construction costs were calculated in a single Microsoft Excel workbook, using consistent unit costs for each bid item. Construction quantities for each element were multiplied by their respective unit costs, and the resulting products totaled into a construction sub-total Additional costs for taxes, contingencies, and incidentals were accounted for as a percentage of the construction sub-total. The construction sub-total was then increased by the percentages of the additional fees to estimate the total construction cost.

8 PERMITTING AND STAKEHOLDER CONSULTATION

CCNRD staff have been proactive in consulting with landowners and project stakeholders potentially affected by project actions. Considerations and concerns which have been documented to date include:

- Chelan County Public Works (CCPW)
  - CCPW has helped identify applicable design standards for road design and temporary detour design.
  - CCPW has also provided input on the level of plan, specification, and calculation review that will need to take place prior to project initiation.
  - CCPW has been supportive of the project to date, and has provided ROW and utility surveys to help inform the design process.
- John and Debin Smith (private landowners)

    - Mr. and Mrs. Smith own the private parcel which will be directly affected by project actions, mainly the construction of the temporary detour. They are amenable to the project and are aware of the temporary and permanent impacts anticipated as a result of project actions.
- Washington Department of Fish and Wildlife (WDFW)
    - WDFW has been made aware of the project and are planning on conducting a site visit following submittal of this (60%) design package.
- National Marine Fisheries Service (NMFS)
    - NMFS has also been made aware of the project. More involved discussions are planned following submittal of this design package.

CCNRD will continue to consult with private landowners and project stakeholders as the design progresses. Discussions related to permits are anticipated to initiate in the late summer or early fall of 2019 with the goal of securing permits well before the anticipated construction window in the summer of 2020.

9 DRAFT FINAL DESIGN UPDATE

As part of the design process, NSD performed an internal review of project elements before advancing designs to draft final (90%). This review focused primarily on hydraulics, channel bed design elements, and further vetting of the preferred structure type.

Additionally, preliminary designs (60%) were distributed to project stakeholders including the project sponsor (CCNRD), landowners, WDFW, SRFB reviewers, and CCPW to allow for review of the preliminary design. Comments on design of project elements were documented in a comment matrix and responses to all comments were generated by NSD. Between the comments received from project stakeholders and the internal review performed by NSD, several design modifications were incorporated into the draft final designs; a summary list of the most important design modifications is included below. For a list of all design comments and responses, refer to Appendix F.

- Channel Design Modifications
    - The shape of the channel bottom was modified to include a thalweg. Two separate WDFW reviewers requested similar modifications to the design of the proposed channel. NSD discussed this change in detail. A low-flow thalweg was added, replacing the flat bottom channel that was included in the 60% design.
    - Boulder steps within the culvert will now extend to the culvert walls. There was a concern that not extending the steps to the culvert wall could possibly allow flanking of the boulder steps; the design was modified accordingly.
    - The spacing and drop across each boulder step was also modified based on detailed discussions with WDFW reviewers. The boulder steps included in the 60% design averaged 0.8 ft of drop per step; right at the limit of being considered a fish passage barrier. Given the irregularities of the materials which will be used to construct the boulder steps, and the desire to provide additional assurance that the project will provide fish passage the spacing of boulder steps was modified to reduce the drop across each boulder step. The revised design includes two additional boulder steps and results in an average drop across each step of 0.7 ft.
- Culvert Design Modifications
    - As part of NSD's design review process, it was discovered that the cost for furnishing the culvert itself have increased approximately 33% since the initial cost estimate was acquired nearly two years ago. This discovery resulted in revisiting alternatives for viable structure shapes and

weighing the costs and benefits for several structure types. In particular, ease of construction and durability of the structure were primary concerns. As a result of this review and input from CCNRD, the culvert structure was modified to a thicker gauge and deeper corrugation. This change allows for a culvert that does not require concrete thrust blocks and results in faster, easier construction. Similarly, the thicker steel plate provides additional protection against corrosion and extends the design life of the culvert.

- Traffic Control Plan Modifications
  - CCPW was instrumental in providing additional guidance and feedback on the design of the traffic control plans included in the 90% design. The project site is limited in space for signage and as such does not allow for application of accepted traffic control plan examples from WSDOT or the MUTCD without some modification. NSD and CCPW iteratively refined the traffic control plans to reach the version included in the 90% plans. Changes to the 60% design included additional signage, inclusion of additional channelizing devices, and the addition of signage to USFS Rd 7300.

10 FINAL DESIGN UPDATE

Draft final design deliverables were provided to project stakeholders for review. Comments from project stakeholders were documented and considered for inclusion in the project. Minor modifications to the plans made as a result of review of the draft final design deliverables include the following:

- Boulder Steps
  - The design of the boulder steps themselves did not change, rather the display and notes describing construction of the boulder steps were updated to clarify design intent. Namely, the boulder steps in plan view were extended the full length of the step across the channel and notes describing construction were revised to make clear the difference between two-foot-thick and four-foot-thick boulder steps.
- Headwalls and Wingwalls
  - CCPW suggested that a separate bid item be added to cover the work associated with design and construction of the structural earth walls for the headwalls and wingwalls shown on the plans. CCPW also suggested that WSDOT GSPs be included in the specs to better clarify what type of structural earth wall is to be used, and the design parameters to be used in designing said walls.
- Traffic Control Plan Modifications
  - CCPW requested that an additional traffic control plan be incorporated into the plans. The CCPW supplied plan was added to the plans.
- Minor Edits
  - Several minor edits were made to the plans to improve clarity and intent. These included modifications to notes and callouts in several locations throughout the plans.

11 LIMITATIONS

We have prepared this report for CCNRD, their authorized agents, and regulatory agencies responsible for the Mill Creek Fish Passage Project. Within the limitations of scope, schedule, and budget, our services have been executed in accordance with generally accepted practices for fish passage and culvert design at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment, and experience. No warranty or other conditions, expressed or implied, should be understood.

The construction cost estimate provided for this project was prepared using the most recent cost data available and was vetted based on our professional experience. Construction of fish passage projects is performed by relatively few contractors and costs for materials (culverts, streambed material, hardware, etc.) required for projects can vary widely depending on geographic location, material availability, timing of contracting, and overall status of the construction industry. The estimate we have provided should be viewed in this light.

We appreciate this opportunity to be of service to the CCNRD for this project and look forward to continuing to work on this project as it moves toward implementation. Please contact us if you have any questions regarding this report, or if you need additional information.

Sincerely,

Natural Systems Design, Inc.

Nic Truscott, PE, CFM

Project Engineer

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