nhc
northwest hydraulic consultants

NHC Ref. No. 2006082

Lewis County Public Works
2025 NE Kresky Avenue
Chehalis, WA 98532

Attention: Ann Weckback
Environmental Planner

Copy to: **Tim Fife, PE**

Via email: Ann.Weckback@lewiscountywa.gov

Re: **Crumb Road Culvert Replacement**
Hydraulic Memo

Dear Ms. Weckback:

1 INTRODUCTION

Lewis County (County) is replacing the Crumb Road crossing of Highland Creek. The culvert is failing as material below the culvert and a portion of the headwall washed out during January and February 2020 flood events. The crossing is listed as a partial barrier to fish passage. Northwest Hydraulic Consultants, Inc. (NHC) performed survey, hydrologic, hydraulic, and geomorphic analyses and concept design to support the County with a crossing design as described below.

1.1 Project Site Description

The project site is located west of Morton in Lewis County, WA (Section 2, Township 12, Range 4E) where Highland Creek crosses Crumb Road. The crossing is located 2,200 feet upstream of the confluence with the Tilton River. The existing crossing is a single arch pipe, 11.42 feet (ft) in span and 7.25 ft in rise.

2 WATERSHED ASSESSMENT

2.1 Stream Assessment

NHC visited the project location on September 15, 2020 to collect pertinent information to support the crossing assessment. The field survey extended 500 feet downstream and 600 feet upstream of the Crumb Road crossing. NHC measured an average bankfull width (BFW) of approximately 22 feet (upstream average of 23 feet and downstream average of 22 feet). In the reach extending 600 feet upstream of Crumb Road, Highland Creek is not confined and maintains connectivity with a wooded riparian zone and floodplain, which supplies large woody debris (LWD) to the stream. The sinuosity of the stream, measured as the ratio of the channel length to valley distance, is 1.1. While technically designated as a straight channel according to Leopold and Wolman (1957) classification (s<1.3), the planform exhibits alternating channel bends coinciding with riffle-pool morphology. The cut-banks are steep and often undercut into the exposed mudstone bedrock, carving deep pools into the weak rock along the bends. Bank strength is reinforced by the roots of mature alder and some cedar. Coarse lateral gravel bars line the banks adjacent to the cut-banks and along the banks of the straight riffles and glides, reaching up to two feet in height (Figure 1). The presence of these gravel deposits is largely influenced by large wood either in the channel or exposed in channel banks. Wood therefore contributes to channel complexity upstream by initiating riffle-pool morphology, while also providing stability in the absence of large grains.

Figure 1 Wood-forced pools and lateral gravel bars upstream of Crumb Road

The channel bends sharply just upstream of the culvert inlet, undercutting the steep right bank. Mudstone is exposed on the channel bed along the bend. On the opposite bank there is both a large gravel deposit and a LWD jam formed by a mature alder tree growing from the left bank racking up wood and pieces of mudstone. Large angular rock from the roadway fill was in the channel in the immediate vicinity of the culvert inlet and outlet. The water surface drop at the outlet was 7 inches during the time of the survey (Figure 2). A large outfall pool has formed downstream in the widened reach before the stream transitions to confined channel conditions 50 feet downstream of the outlet. Bankfull width decreases to an average of nine feet as the channel bends sharply into the confined reach, with bank heights between four and five feet tall. The scour along the left bank has exposed mudstone bedrock and undercut mudstone banks.

Figure 2 Existing conditions at the Crumb Road culvert outlet

Overall, Highland Creek downstream of Crumb Road exhibits less channel complexity and sediment storage than the observed upstream reach. Channel confinement between steep mudstone banks persists until about 300 feet downstream of the outlet as the valley walls open and bankfull width increases from 20 to 30 feet. Large (2- to 3-foot DBH) alder protect the blocky mudstone banks from failure. Gravel deposits are less frequent downstream of the culvert outlet, coinciding with sparce in-channel LWD. Instead of the consistent riffle-glide morphology observed upstream, the downstream reach contains mostly pools and low velocity glides (Figure 3). Pool depths increase from one foot upstream of Crumb Road to two or three feet downstream.

Figure 3 Mature trees reinforce vertical mudstone banks downstream in a long deep pool

2.2 Bankfull Width Measurements

Bankfull width (BFW) was measured at three locations upstream and three locations downstream of the crossing to capture the varying channel geometry across the surveyed extent of Highland Creek. Measurements ranged from 19 feet within the confined reach downstream of Crumb Road to 28 feet wide about 300 feet downstream of the road crossing (Figure 4). Bankfull width and overall channel geometry and morphology are more consistent upstream, between 22 and 24 feet wide, shallow banks, and the ability to accommodate higher sediment loads in lateral bar formations. WDFW measured a toe width of 15 feet but did not list an average width or ordinary high-water width. The average measured BFW from the upstream and downstream locations is approximately 22 feet.

Lewis County	Relative Elevation (Feet)		SCALE - 1:1,632	*Highland Creek Crumb Road Crossing*
nhc northwest hydraulic consultants	106 – 0		0 50 100 150 200 Feet N	*Bankfull Width Locations*
			Coordinate System: NAD 1983 STATEPLANE WASHINGTON SOUTH FIPS 4602 FEET	
			Job: 20006082 *DATE: 19-OCT-2020*	*FIGURE 4*

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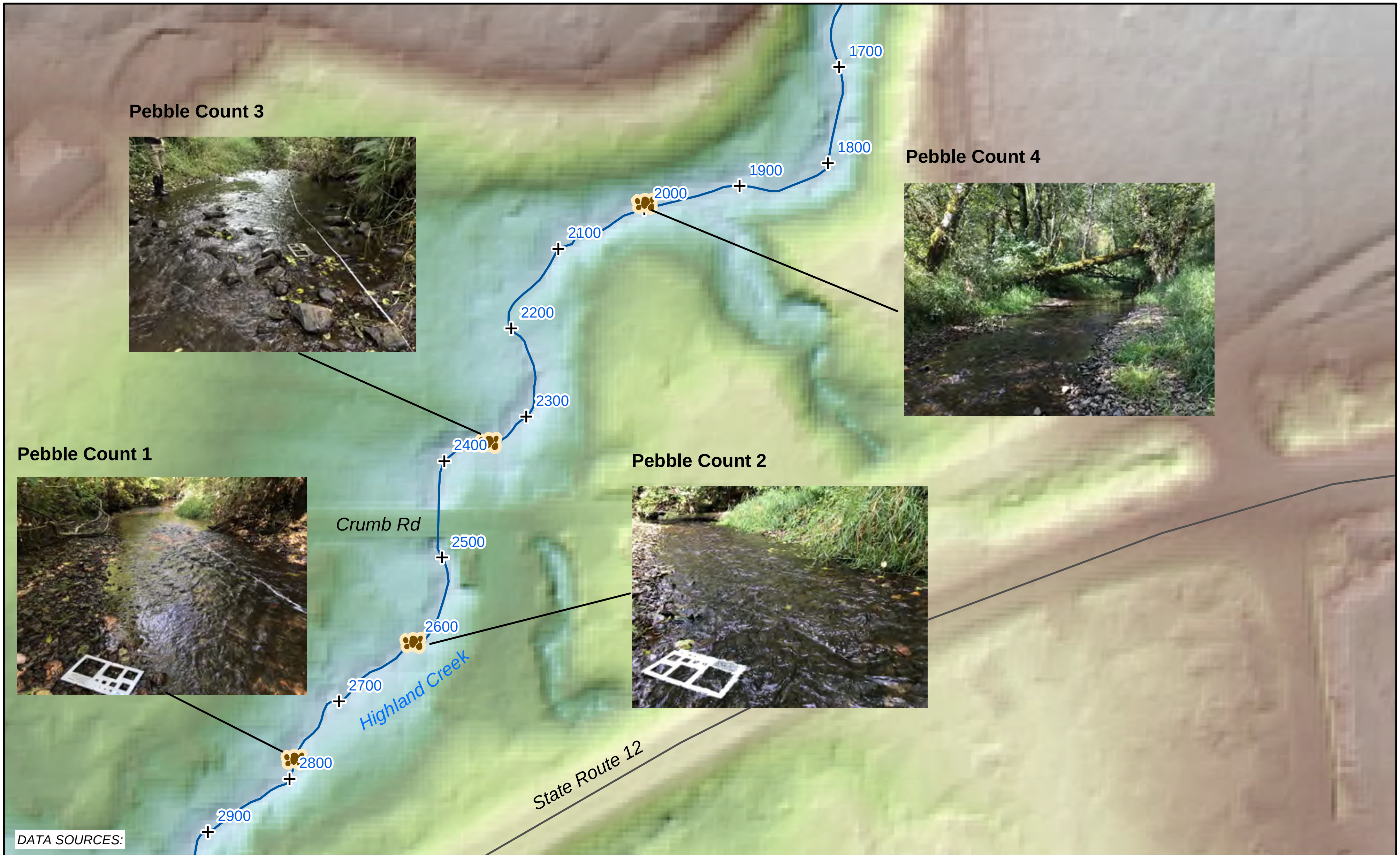
2.3 Grainsize Analysis

NHC collected pebble counts at four locations upstream and downstream of the Crumb Road crossing. Figure 5 shows the locations of the pebble counts. Characteristic grain sizes from the four pebble counts are summarized in Table 1 and Figure 6 shows the grainsize distributions. Overall, the observed substrate is relatively consistent through the observed reach. Large stabilizing grains (> 3.5 inches) are extremely rare in the existing system. Stabilizing bed features observed upstream include large wood and blocks of mudstone that have been eroded from the banks. Fewer stabilizing features were observed downstream, resulting in thinned gravel deposits, deeper pools, and more exposed mudstone on the channel bed. Without stabilizing large grains, the channel bed likely experiences full mobilization upstream and downstream of the crossing, with less deposition occurring downstream due to decreased LWM hydraulic influences and increased channel confinement. Larger angular large grains appear downstream of Crumb Road in several locations, more notably after the channel widens 300 feet downstream of the crossing. These grains are likely eroded fill from the Crumb Road crossing prism, supported by evidence of their relative angularity compared to the rest of the streambed and their absence upstream.

Pebble Count 1 was taken 300 feet upstream of the crossing in a riffle. The bed is not widely graded and lacks clast sizes larger than 3.5 inches. Pebble Count 2 was taken at the riffle located just upstream of the notable channel bend above the culvert inlet. The sharp bend and large wood jam likely initiate backwater conditions at high flows, as seen by the large lateral gravel deposit on the left bank. The channel bed was very similar in appearance, imbrication, and distribution as Pebble Count 1.

Downstream of the crossing, the channel corridor narrows, and bank heights increase. There is a very short and steep riffle approximately 120 feet downstream of the culvert crossing that marks the transition from glides and transverse bars to a deep pool. This riffle, with small boulder and large cobble stabilizing grains, is not representative of the observed stream, but does represent a stable bed at high flows. The large grains were mostly angular, likely eroded fill material transported from the Crumb Road crossing. Pebble Count 4 was taken in a riffle reach 320 feet downstream of the culvert to compare riffle beds upstream and downstream of the crossing. The relative grainsize distributions are similar, but the downstream riffle is slightly finer.



Lewis County	Relative Elevation (Feet)	
northwest hydraulic consultants	Value	
	106	
	0	

SCALE - 1:1,632

0 50 100 150 200 Feet

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Coordinate System: NAD 1983 STATEPLANE WASHINGTON SOUTH FIPS 4602 FEET

Job: 20006082 | DATE: 19-OCT-2020

Highland Creek Crumb Road Crossing

Pebble Count Locations

FIGURE 5

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Table 1 Highland Creek Characteristic Grainsizes

Particle Size Distribution	PC 1 Sta 27+80 Upstream (in)	PC 2 Sta 26+10 Upstream (in)	PC 3 Sta 24+50 Downstream (in)	PC 4 Sta 20+10 Downstream (in)
D_{16}	1.0	1.1	1.1	1.1
D_{50}	1.6	1.7	1.7	1.5
D_{84}	2.3	2.4	5.7	2.2
D_{95}	2.8	3.1	7.7	2.6
D_{max}	3.5	3.5	14.1	3.5

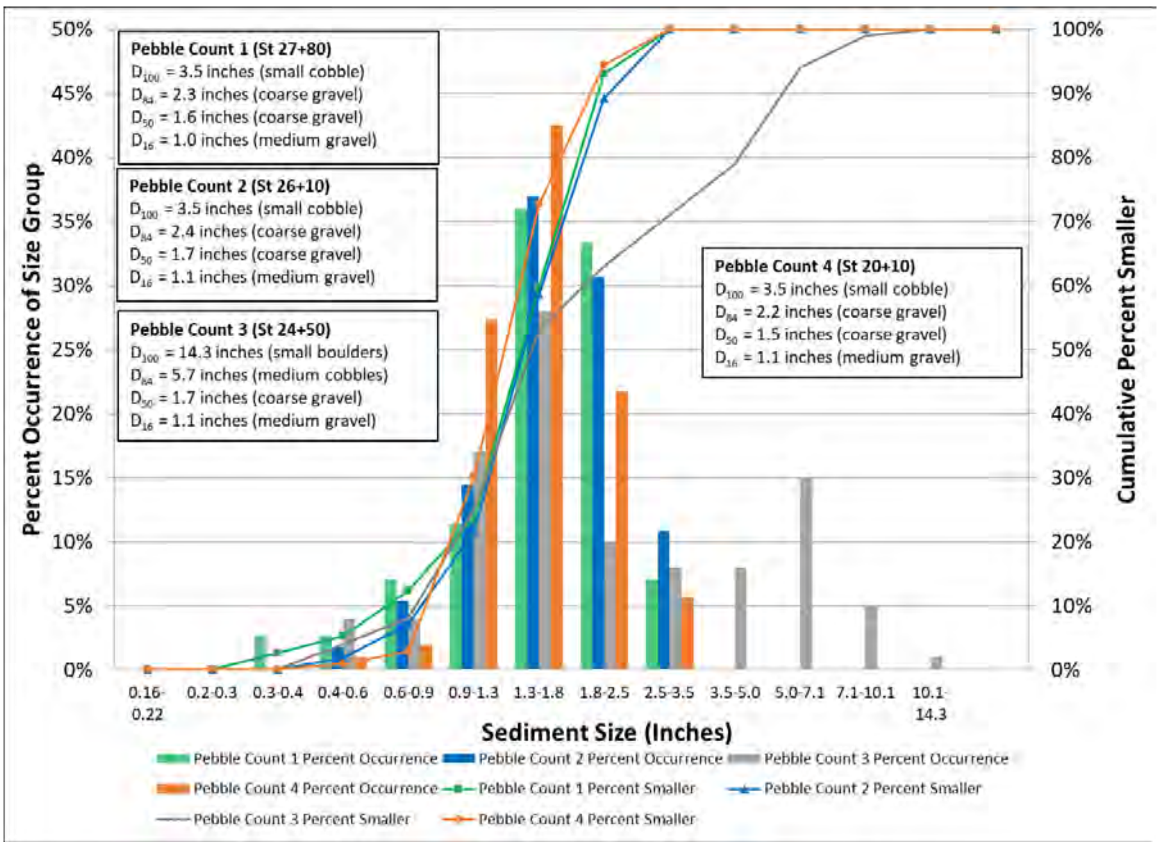


Figure 6 Grain size distribution of Highland Creek pebble counts

2.3.1 Vertical Channel Stability

An assessment of long-term channel stability in the reach was conducted using topographic survey data, the best-available LiDAR, and evidence of aggradation and erosion observed in the field. Crumb Road culvert is currently acting as grade control across Highland Creek. At the time of the survey, the perched culvert had a water surface drop of 7 inches at the outlet. The culvert accommodates a one-foot profile discontinuity between the upstream channel bed and the downstream incised bed. Based on the 2009

LiDAR profile, the upstream and downstream water surface slopes are approximately 0.8%, with locally steeper slopes along riffles (Figure 7). A two-foot-deep scour pool has formed immediately downstream of the over-steepened 4% grade culvert.

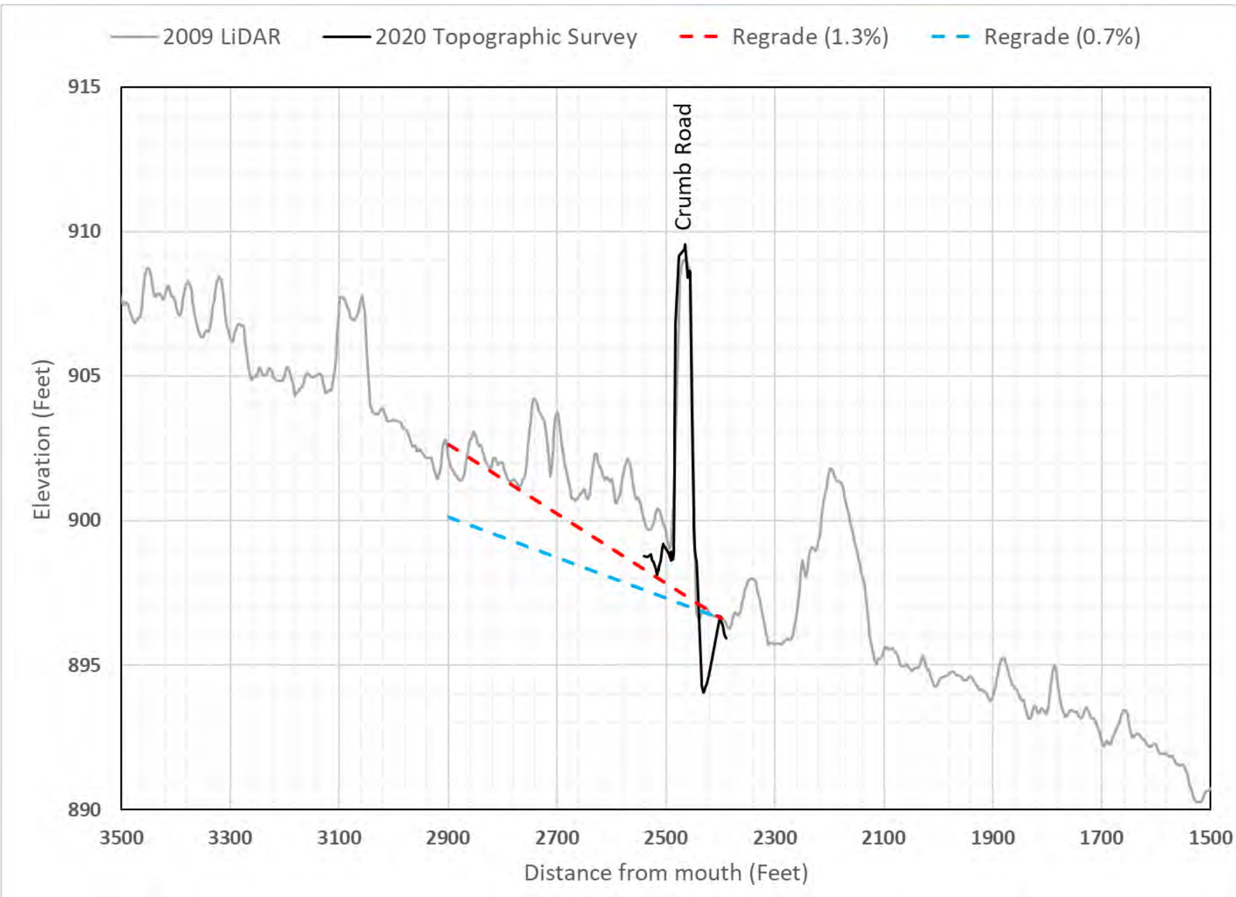


Figure 7 Longitudinal profile of Highland Creek

Grade controlling features are not evenly distributed across the observed stream reach. Large wood provides the primary grade control of the channel bed upstream of Crumb Road. Extensive lateral bars up to 2 feet in height store gravel in areas of LWD influence. Pool scour rarely exceeds 1 foot, with an average tail-out depth of 6 inches. In contrast large wood is mostly absent downstream of Crumb Road until about 400 feet downstream of the culvert where the channel widens and is reconnected with the surrounding floodplain. As a result, the channel bed contains exposed mudstone in most reaches, with deep scour pools and minimal gravel bars. The primary grade controlling features are therefore the culvert, which currently prevents upstream knickpoint propagation, and a coarsely armored riffle at the location of Pebble Count 3. The rifle consists of small boulder and large cobble stone lines, jamming structures which stabilize the bed upstream.

Highland Creek downstream of Crumb Road is entrenched 3.5 to 5 feet below the surrounding floodplain, where it is incising into the blocky mudstone (Figure 8). High bank strength downstream limits channel widening, and is a function of both erosion-resistant mudstone bedrock (the same material as the channel bed) and root reinforcement from mature trees (Figure 3). This is evident in the BFW measurements which are two to five feet narrower than measured upstream. While bank undercutting occurs downstream, the channel adjusts mainly by channel bed scour. NHC measured scour pools 2 to 3 feet deep downstream of Crumb Road, typically located along cut bank margins. Although the mudstone is exposed on the channel bed on both sides of the roadway crossing, the upstream channel reach maintains an alluvial gravel-cobble bed in all channel sections except for the bend at the culvert inlet.

Figure 8 Down-cut banks downstream of Crumb Road expose mudstone and roots

Removal of the Crumb Road culvert is expected to trigger a regrade of the channel upstream. The existing culvert is currently acting as grade control, limiting the upstream propagation of the bedrock knickpoint. The rate of channel regrade, and upstream propagation of this knickpoint, is dependent on multiple factors, most importantly the relative strength of the streambed and stream banks. In the immediate vicinity of the culvert, the channel banks are composed of mudstone bedrock, making them equally or exceedingly stronger than the channel bed. As shear stress is greatest on the channel bed, the channel will continue to erode until either critical bank height is exceeded and mass failure results in channel widening, a control point in the bed is reached such as erosion resistant bedrock, or coarse sediment armors the channel bed. The mudstone layer is not smooth and compact, but instead blocky in structure. Propagation of the knickpoint will slow once the channel reaches the bedrock layer, the rate of which will be dependent on the channel's ability to either erode blocks of mudstone or slowly erode the bedrock from tooling scour of transported material.

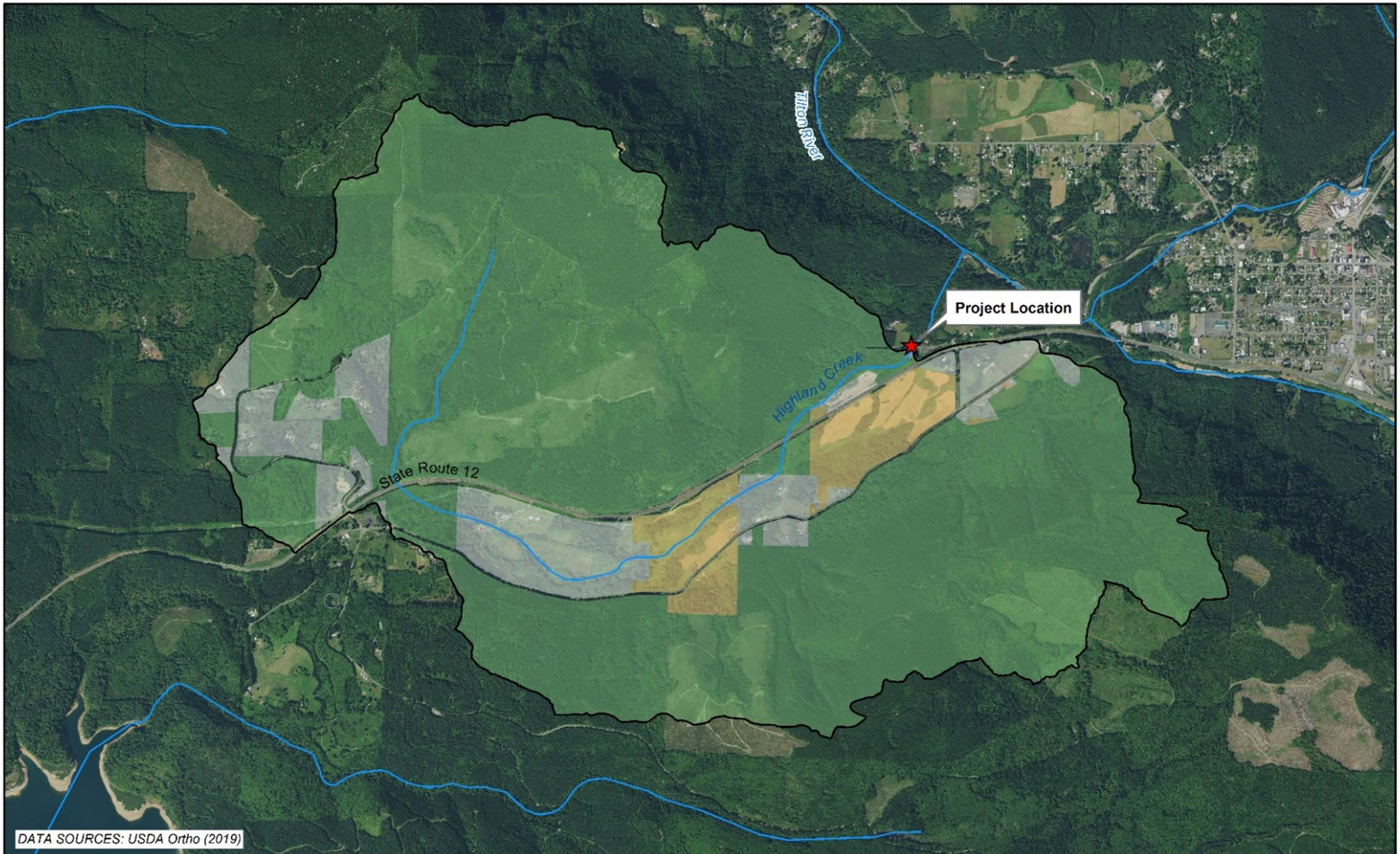
Given the observed scour downstream of Crumb Road, the existing knickpoint in the channel profile, and the observed sediment accumulation upstream, the channel may adjust vertically from up to two feet of degradation to up to two feet of aggradation. Sediment deposition on the order of 1 to 2 feet depends on grade controlling features such as large wood or engineered large grains supplying stable storage and accumulation. In the event of upstream knickpoint propagation, the channel is expected to regrade at a slope between 0.7 percent (the 2009 LiDAR average water surface slope) and 1.3 percent. According to Church (2006), the stable slope for the existing transported bed material is between 0.7 and 1.3 percent using the modified Lane (1955) alluvial channel equilibrium relationship. About two feet of vertical degradation is expected at the existing location of the culvert inlet if bedrock erosion propagates upstream at a regrade of 0.7 percent, the upper bound of potential degradation. The extent of upstream vertical degradation decreases under steeper regrade slope projections. The best available LiDAR data from 2009 contains anomalous topographic features that were not observed in the site visit. A combination of grade control, modified bed material, and modified channel profile, may reduce the risk for vertical channel adjustment and structure embedment requirements.

Two design components are recommended to provide channel profile stability, reduce periodic maintenance at the crossing, and reduce major risk to upstream bank stability and infrastructure. Both components are compatible with bridges or culverts as the replacement structure. First, downstream grade control at the outlet, buried approximately 3 feet deep to elevation 894 ft (NAVD88), will reduce the risk of a headcut propagating through the crossing. Buried boulders or boulder ballasted LWD are the recommended forms of downstream buried grade control as they would enable groundwater movement and provide flexibility for some settling and long-term adjustment. Second, a roughened bed, comprising a mix of 6-inch cobbles and streambed sediment per WSDOT (2020) materials specification 9-03.11, is recommended for the channel material. Some larger grains are recommended to be interspersed through the crossing. This bed mix will provide a stable bed with hydraulic diversity for fish habitat.

2.4 HYDROLOGY

2.4.1 Hydrologic Model

The Crumb Road crossing is in an ungaged reach of Highland Creek. NHC developed a range of peak flow estimates for Highland Creek using the Washington Department of Ecology's Western Washington Hydrology Model (WWHM) (2016). This model generates flows based on inputs including a continuous rainfall record and basin characteristics including area, land cover and soil types, and effective impervious area. The Highland Creek watershed at the project site was delineated to be 3,024 acres using available LiDAR data (PSLC, 2010). Basin-wide land use was defined and delineated using the NLCD dataset (Figure 9). The basin consists of approximately 80% forested areas with agriculture and low-density residential development making up approximately 20%. The total effective basin imperviousness is 10%. Lewis County's surface geology data was mapped to determine soil types. Table 2 depicts the basin property inputs used in the WWHM model.



Lewis County

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Land Use

- Agricultural Land
- Low Density Residential
- Forest

SCALE - 1:400,000

0 0.5 Miles

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Coordinate System: NAD 1983 STATEPLANE WASHINGTON SOUTH FIPS 4602 FEET

Job: 2006082

DATE: 01-OCT-2020

Highland Creek
Crumb Road Crossing

Basin Land Use

FIGURE 9

Table 2. Highland Creek Basin Properties

Soil Type	Cover	Area (acre)
C	Forest	1,847
C	Lawn	226
C	Pasture	661
C	Impervious	290

The WWHM model references the Longview gage record (1955-2009) for this site. Precipitation factors ranged from 1.46 to 1.57 across the basin. There is a sharp precipitation gradient from Chehalis (precipitation factor of 1.0) to the Cascade foothills of the project location (precipitation factor of 1.57). Flow routing was determined on the basin's surface and channel interflow. Model sensitivity was tested by varying precipitation factor from 1.0 to 1.57, and by varying the precipitation input timestep from 15-minute to an hourly moving average. A moving average reduces the bias that the precipitation factor introduces to peak flow events in the 15-minute data. The final precipitation factor chosen for the basin is 1.28 using an hourly timestep. The WWHM model results were compared to flows predicted by the USGS StreamStats flood frequency regression equations. Due to the similarity between StreamStats and WWHM model results, as shown in Table 3, reasonably conservative peak flow values were chosen for further analysis and are shown in Table 4.

Table 3. Highland Creek Hydrology Comparison – Peak Flows

Return Interval	WWHM Model Output (cfs)	Stream Stats (cfs)
2 Year	320	229
10 Year	510	452
100 Year	653	773
500 Year	702	1,010

Table 4. Highland Creek Hydrology – Peak Flows

Return Interval	2-yr	10-yr	100-yr	500-yr
Peak Flow (cfs)	320	510	773	1,010

2.5 Fish Resources and Barrier Assessment

Washington Department of Fish and Wildlife (WDFW) assessed the Highland Creek culvert for fish passage ability on May 8th, 2001. WDFW listed the culvert as a barrier due to water surface drop, measured at 0.3 meters. According to the WDFW report, the culvert settled near the outlet, thereby increasing the slope and likely contributing to the downstream scour. The average toe width measured was approximated as 15 feet and no bankfull width was provided. Coho, Steelhead and Resident Trout are suspected species present within the creek. The existing culvert is only 33% passable to fish.

3 HYDRAULIC ANALYSES

3.1 Hydraulic Model

Hydraulic analysis of existing and proposed conditions was performed using the U.S. Army Corps of Engineers' one-dimensional HEC-RAS modeling software (v5.0.7, 2019). The model reach extends approximately 250 feet upstream and downstream of the crossing. The geometry was constructed using data collected by NHC (2020) integrated with 2009 LiDAR data (PSLC, 2010). The hydraulic model includes 16 surveyed cross sections, roadway embankments, and culvert geometry. The model's Manning's roughness values (n) were estimated based on field observations and engineering judgement. Roughness values of 0.04 and 0.05 were selected for the channel and overbanks, respectively. Downstream water surface elevations were computed assuming a normal depth for a slope of 0.012.

3.2 Model Results

Hydraulic modeling demonstrates that the existing culvert reduces conveyance upstream of the crossing. Figure 10 shows computed flood profiles for existing conditions on Highland Creek; at the 2-year return interval, backwater conditions extend approximately 40 feet upstream of the crossing. The overflow and backwater conditions created by the existing culvert at Highland Creek have important implications regarding possible crossing replacement. An incipient motion analysis following Shield's methodology (USACE, 1994) suggests that under existing conditions, sediment transport upstream of Crumb Road is muted at the 2-year event as a result backwater and conditions created by the culvert. By replacing the culvert with an alternative crossing there is opportunity to improve conveyance through the crossing to reduce risk of overtopping at the crossing as well as improve sediment transport through the crossing.

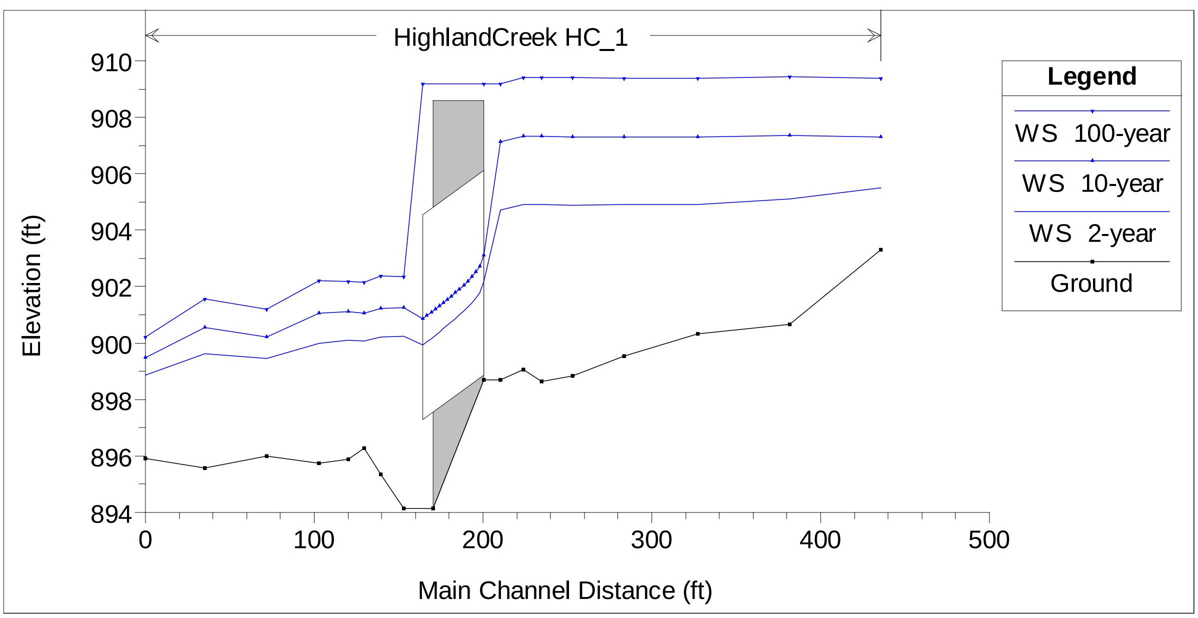

Figure 10. Computed event profiles for existing conditions

3.3 Concept Alternatives

NHC developed three alternative concept options for the crossing. Each alternative was designed with a minimum hydraulic opening of 29 feet consistent with the WCDG to improve hydraulic continuity through the reach and then modeled in HEC-RAS to assess impacts on hydraulics and potential channel responses. Comparison of these results provide an assessment of the suitability of each design within the context of the existing terrain and existing problems at the culvert crossing. Selection of a preferred concept may need to consider structural and geotechnical assessments that are outside the scope of this report. Each alternative is briefly described below, and concepts are illustrated in Appendix D.

3.3.1 Alternative 1: 29-Foot Box Culvert

A 29-foot box culvert was considered as an alternative that would reduce backwater effects that the current crossing experiences during flood events. The increased span of the culvert provides more conveyance than that of the existing crossing, increasing velocities which would be expected to restore sediment transport through the crossing.

3.3.2 Alternative 2: 29-Foot Open Bottom (3-Sided) Culvert

This alternative is identical to the box culvert for hydraulic assessment purposes. It is included as a structural alternative for cost comparison. Conveyance improves at all events with no backwater conditions present.

3.3.3 Alternative 3: 67-Foot Bridge

An approximately 67-foot wide bridge crossing was evaluated to replace the existing crossing. The low-chord of the bridge is set a minimum of 3 feet above the 100-year water surface, allowing for approximately 2.5 to 3 feet of structure thickness at existing roadway grades. Conveyance improves at all events with no backwater conditions present.

3.3.4 Alternatives Comparison

Figure 11 shows computed flood profiles for the culvert and bridge options (note, one profile is shown for the culvert options as the box and open bottom culverts are assumed to perform very similarly). Table 5 compares hydraulic results for each design alternative. Average channel velocities increase upstream and downstream relative to existing conditions to 5-6 feet per second in the 2-year event and 6-8 feet per second in the 100-year event. The hydraulic radius decreased in each alternative due to increased velocities through the crossing. Sediment transport is expected to increase through the crossing due to greater conveyance and reduced backwater effects. The existing crossing has a relatively steep slope of 4% which resulted in hydraulic conditions that produced a scour hole directly below the crossing. The slope of the existing crossing was modified in each alternative to be 1.2% to tie into the stream profile upstream and downstream; this gradient is consistent with reach slopes.

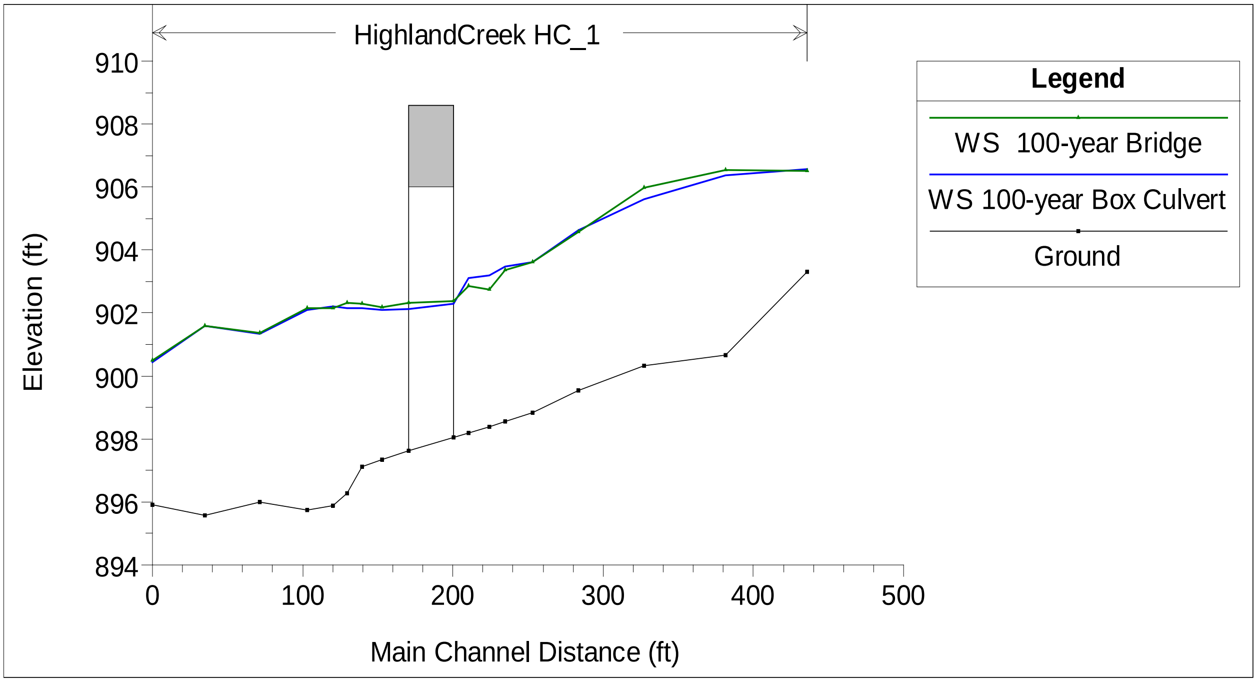

Figure 11. Computed 100-year profiles for alternatives

Table 5. Computed Hydraulic Parameters for Existing and Alternatives Designs

Model	[1]Crossing Velocities (ft/s) (Inlet | Outlet)			[2]Avg. Channel Velocities (ft/s) (Upstream | Downstream)			[3]Avg. Hydraulic Radius (ft) (Upstream | Downstream)		
	2-year	10-year	100-year	2-year	10-year	100-year	2-year	10-year	100-year
Existing	9.7 | 12	12 | 14	14 | 16	3.5 | 4.2	2.8 | 5.0	2.7 |5.7	2.4 |2.4	3.2 | 2.7	3.8 | 3.1
Alternatives 1 & 2	7.0 | 6.9	7.2 | 6.6	7.5 | 7.0	6.4 | 5.0	7.1 | 5.6	7.7 | 6.2	1.7 | 2.2	2.2 | 2.5	2.6 | 2.5
Alternative 3	6.0 | 6.4	6.5 | 6.8	7.5 | 7.1	6.2 | 5.0	7.0 | 5.6	8.0 | 6.1	1.7 | 2.2	2.2| 2.5	2.6 | 2.7

Notes:

1. Crossing velocities are taken at the culvert inlet and outlet for Existing Conditions.

2. Average channel velocities for cross-sections within approximately 100 feet upstream of crossing inlet or 100 feet downstream of crossing outlet.

3. Average hydraulic radius (flow area divided by flow top width) approximates average flow depth. Values are averages of cross-sections within approximately 100 feet upstream of crossing inlet or 100 feet downstream of crossing outlet.

3.4 Crossing Structure Type and Costs

Table 6 below compares concept level construction costs developed based on the layouts described above and shown in Appendix D. Additional costs may need to be considered and included for geotechnical analyses and structural design for the selected alternative.

Table 6. Planning level cost comparison

Box Culvert	3-Sided Culvert	Bridge
$1,318,000	$1,362,000	$1,970,000

4 CROSSING DESIGN

4.1 Structure Design

The proposed crossing design is based on the observed bankfull width sections upstream and downstream of the existing culvert. Based on WDFW criteria, a minimum 29-foot-wide crossing would be required. A 29-foot wide by 12.5-foot-high structure is proposed with the design channel section graded in the bed material; the culvert will be countersunk approximately 33% with 4 feet of streambed material depth within the culvert. For a bankfull width of over 15 feet, WCDG recommends a minimum freeboard of 3 feet above the 100-year water surface elevation. The culvert provides at least 3 feet of headroom for the 100-year storm. The headroom provided reduces risk of debris accumulation and flooding potential along Crumb Road.

4.2 Scour Analysis

Utilizing the results of the hydraulic analysis, scour calculations were performed based on the proposed conditions hydraulic model results following the procedures outlined in Evaluating Scour at Bridges Hydraulic Engineering Circular No. 18 5th Edition (HEC-18) (Arneson et al. 2012). Scour components considered in the analysis include:

- Long- and short-term aggradation/degradation
- General scour (i.e., contraction scour)
- Local scour

4.2.1 Lateral Migration

Highland Creek channel does not exhibit signs of lateral instability. Thus, it is anticipated that the proposed culvert and its foundation have a low risk of being impacted by lateral migration.

4.2.2 Long-Term Degradation

The channel could regrade through the crossing at approximately 0.7%, leading to approximately 0.6 feet of long-term degradation.

4.2.3 General Scour at the Culvert

Both live-bed and clear-water contraction scour equations were considered for the proposed crossing based on application of the Laursen method presented in the FHWA HEC-18 publication. Site observations and geomorphic factors indicate the bed is likely to be mobile during the 100-year peak flow, and thus live-bed contraction scour is reasonable for the site. Contraction scour was calculated to be 0.0 feet for the 100- and 500-year peak flow event due to the minimal contraction from the upstream sections into the crossing.

4.2.4 Local Scour

Local scour considers the greater of abutment scour and bend scour, assuming that the two factors would not be coincident during a flood event. The scour depth calculated with the NCHRP 24-20 method is the total scour depth rather than the abutment scour component that is then added to contraction scour. The calculated total abutment scour depth is 1.9 and 1.0 feet, for the 100- and 500-yr events, respectively.

Bend scour measures the scour at the toe of the outer bank in a meander pool that results due to high boundary velocities and boundary shear stresses. Bend scour was calculated following the methodology outlined in HEC-23 (Lagasse et al. 2009). Average bend scour is 3.0 feet for both the 100- and 500-yr events.

4.2.5 Total Scour

Total scour includes the three components previously discussed: long-term degradation, contraction scour, and local scour (maximum of abutment or bend scour). These three components are added to obtain the total scour. It is assumed that each component can occur independent of the others, and thus adding them together includes a factor of safety into the design. Total scour at the structure is 3.6 feet, for the 100- and 500-yr events, respectively, which is less than the depth of bed material in the crossing.

4.3 Channel Section

The WCDG recommends that a reconstructed stream channel should have a cross section and a general configuration similar to the existing channel upstream and downstream of the proposed crossing (Barnard et al., 2013). The existing conditions in the project reaches upstream and downstream of the crossing were evaluated, as detailed in Section 2.0. A similar section may consist of a compound channel with bankfull width of 22 feet, set inside the minimum 29-foot hydraulic opening. Figure 12 shows the proposed typical bankfull width section.

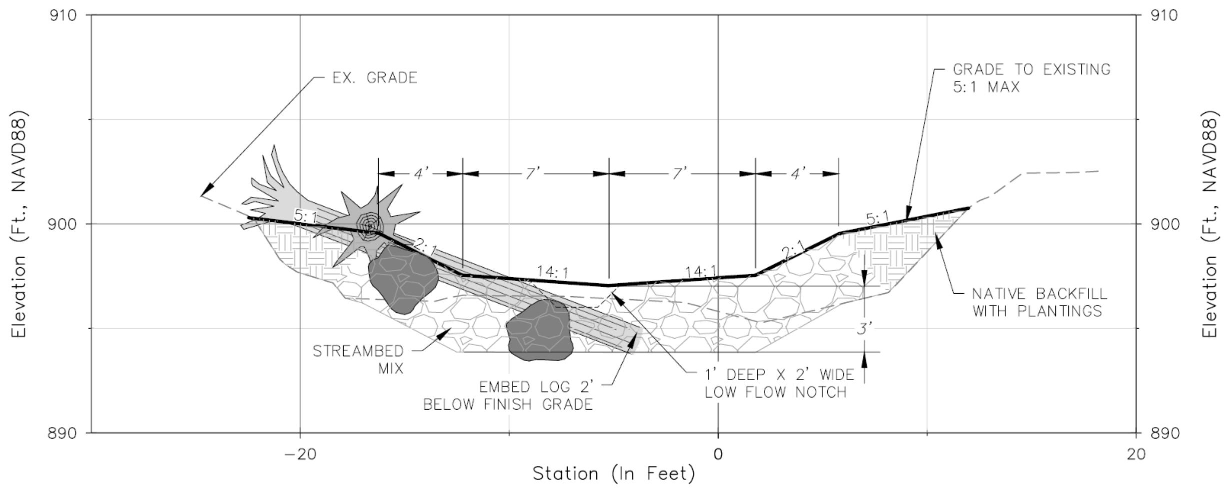

Figure 12. Proposed typical bankfull width section

4.4 Channel Profile

A riffle-glide and plane-bed at constant 0.7 to 1.5% slope through the crossing is consistent with reach morphology and compatible with observed streambed material size. The scour hole at the existing culvert outlet eroded because of an over-steepened 4% culvert slope, which is inconsistent with both reach-scale morphology and streambed size. The proposed channel will begin downstream of the scour hole and be graded in at 1.2% to fill the scour hole and tie into existing grade upstream.

4.5 Streambed Mix

The existing streambed material, D_{50} of 1.6 inches, fully mobilizes at a 2-yr event, a statement supported by both visual field evidence of the streambed and bars, and the hydraulic model results. The proposed streambed mix is slightly coarser than the observed bed material to provide bed roughness and stability to promote prolonged alluvial cover in the regraded crossing and reduce the risk of headcut erosion. A composite channel bed material, comprising a mix of 4- to 8-inch cobbles and streambed sediment per WSDOT (2020) materials specification 9-03.11, would be necessary to sustain channel hydraulics with constant 0.8 to 1.5% grades. A mix of 20% streambed sediment, 40% 4-inch cobbles and 40% 8-inch cobbles is recommended to provide a well graded mix in the regraded section of channel and in the proposed crossing. Figure 13 illustrates the proposed average streambed gradation compared to observed. Based on observed scour downstream of Crumb Road, the minimum bed material thickness is 3 feet.

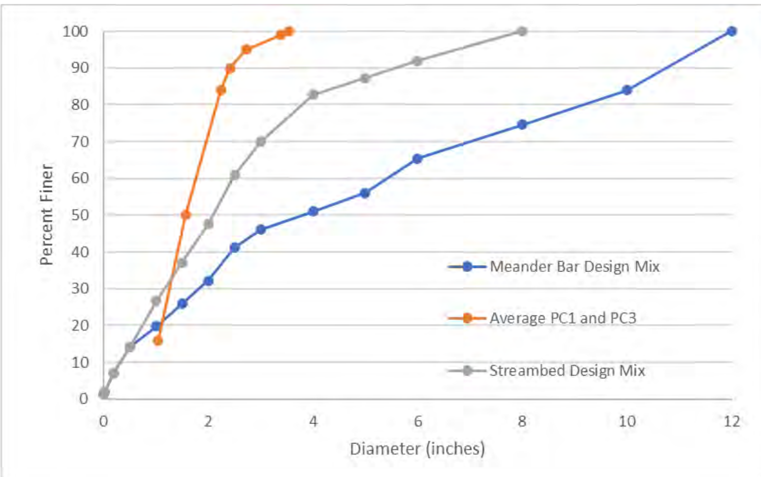

Figure 13. Proposed streambed gradation

4.6 Channel Complexity

Several channel complexity features are included to improve hydraulic diversity and provide channel stability at higher flows. Downstream of the crossing, large woody debris is proposed to provide flow redirection away from the outer left bank. Individual coarse grains, 12- to 18-inch Streambed Boulders, are included within the bankfull channel to support channel formation of a low flow meander within the crossing and prevent plane bed formation. Within the crossing, two meander bars are proposed within the crossing to prevent channel entrainment along the structure and maintain cross-sectional geometry. The first bar should be constructed along the left bank of the structure to account for the existing scour along this bank. Spacing between the two bars is approximately 35 feet. The meander bars will project 7.5 feet from the structure walls and should be constructed to a scour depth of 4-feet, with a mix of 20% WSDOT streambed sediment with 80% 12” cobbles.

4.7 Floodplain Impacts

The project site is located within a FEMA Zone A floodplain without 100-year Base Flood Elevations. Therefore, impacts from the proposed structure may allow for water surface elevation rise of up to one foot per Lewis County Code. In existing conditions, the crossing is undersized, and flow is supercritical and a small hydraulic jump forms at the outlet. When hydraulic continuity is restored through the proposed crossing, a minor rise occurs at the structure outlet. Comparison of existing and proposed conditions modeling shows the structure causes a maximum rise of 0.1-feet during a 100-year event on Highland Creek. Computed proposed water surface elevations are lower than existing conditions upstream of the crossing. As the simulated rise is less than 1 foot, the project complies with FEMA and Lewis County requirements.

5 REFERENCES

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6 CLOSURE

DISCLAIMER

This document has been prepared by Northwest Hydraulic Consultants Inc. in accordance with generally accepted engineering practices and is intended for the exclusive use and benefit of Lewis County and their authorized representatives for specific application to the Crumb Road Culvert Replacement in Lewis County, WA. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Northwest Hydraulic Consultants Inc. No other warranty, expressed or implied, is made. Northwest Hydraulic Consultants Inc. and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any parties other than Lewis County.

Sincerely,

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6-9-22

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06/09/22

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APPENDIX A – SITE VISIT PHOTOS

Figure 14: Conditions at the culvert inlet, including eroded roadway fill and a lack of alluvial cover on the culvert bottom (Station 25+00, white arrow indicates flow direction)

Figure 15: View of the channel bend upstream of the culvert inlet, with exposed mudstone bed, bank scour, and a debris jam forming on a large tree spanning much of the channel (Station 25+70, white arrow indicates flow direction)

Figure 16: View of the channel bend from downstream, including the extensive gravel bar that has formed on the left bank (Station 26+10, white arrow indicates flow direction)

Figure 17: Exposed bank upstream of the stream crossing, showing mudstone bedrock at the base overlain with alluvium and forest soil (Station 28+20)

Figure 18 View of the eroding roadway crossing above the culvert outlet (Station 25+50, white arrow indicates flow direction)

Figure 19: Channel conditions immediately downstream of the culvert outlet as seen from the roadway, with the deep scour pool transitioning into a transverse bar near at the channel bend (Station 25+50, white arrow indicates flow direction)

Figure 20 Existing conditions at the culvert outlet, showing a water surface drop and exposed bedrock in the nearby banks and below the culvert itself (Station 26+00, white arrow indicates flow direction)

Figure 21 Channel conditions at the transition from the culvert outfall area to the confined reach just downstream of a sharp channel bend (Station 26+70, white arrow indicates flow direction)

APPENDIX B – HYDROLOGIC ANALYSIS

StreamStats Report - Crumb Road

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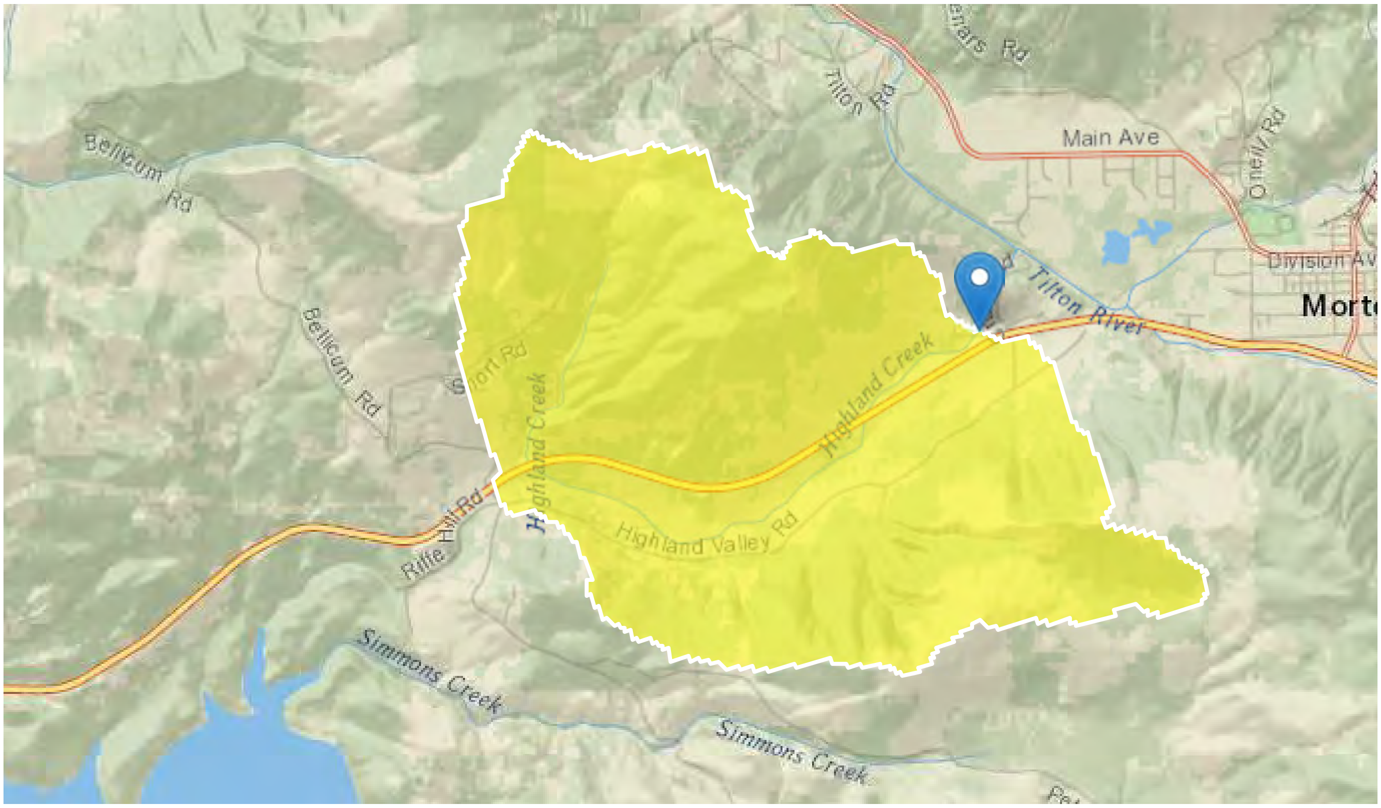
Time: 2022-06-07 20:50:57 -0700



Crumb Road Area modified to reflect LiDAR watershed delineation (4.7 sq mi)

Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	4.7	square miles
PRECPRIS10	Basin average mean annual precipitation for 1981 to 2010 from PRISM	77	inches

General Disclaimers

Parameter values have been edited, computed flows may not apply.

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Peak Region 4 2016 5118]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.7	square miles	0.18	2230
PRECPRIS10	Mean Annual Precip PRISM 1981 2010	77	inches	11.9	187

Peak-Flow Statistics Flow Report [Peak Region 4 2016 5118]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	ASEp
50-percent AEP flood	229	ft^3/s	43.1	1220	52.5
20-percent AEP flood	355	ft^3/s	68.4	1840	50.6
10-percent AEP flood	452	ft^3/s	85.2	2400	50.5
4-percent AEP flood	573	ft^3/s	101	3260	51.7
2-percent AEP flood	669	ft^3/s	111	4040	52.9
1-percent AEP flood	773	ft^3/s	121	4950	54.2
0.5-percent AEP flood	860	ft^3/s	127	5820	55.5
0.2-percent AEP flood	1010	ft^3/s	136	7500	58

Peak-Flow Statistics Citations

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E.,2016, Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver 1.1, October 2016): U.S. Geological Survey Scientific Investigations Report 2016–5118, 70 p. (http://dx.doi.org/10.3133/sir20165118)

Application Version: 4.9.0
StreamStats Services Version: 1.2.22
NSS Services Version: 2.2.0

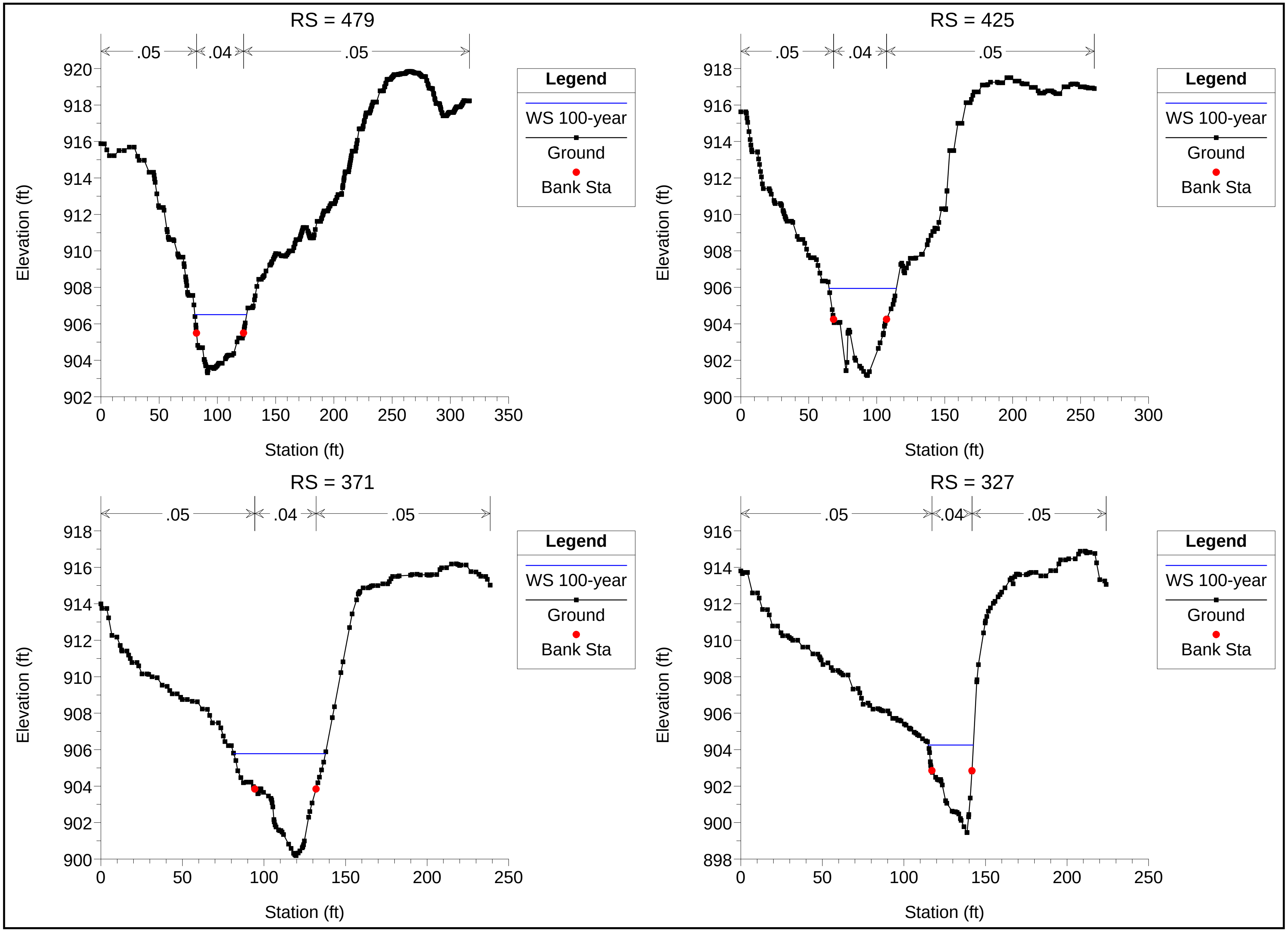
APPENDIX C – HYDRAULIC ANALYSIS

HEC-RAS Plan: Existing River: HighlandCreek Reach: HC_1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
HC_1	479	2-year	320.00	903.32	905.49	905.49	906.16	0.020094	6.60	50.21	40.35	0.98
HC_1	479	10-year	510.00	903.32	907.30		907.57	0.002889	4.33	131.77	52.40	0.42
HC_1	479	100-year	773.00	903.32	909.39		909.56	0.001035	3.61	264.83	75.64	0.28
HC_1	425	2-year	320.00	901.17	905.08		905.23	0.002738	3.19	100.46	45.47	0.38
HC_1	425	10-year	510.00	901.17	907.37		907.46	0.000627	2.44	223.58	67.36	0.20
HC_1	425	100-year	773.00	901.17	909.43		909.50	0.000337	2.30	409.92	106.47	0.16
HC_1	371	2-year	320.00	900.19	904.99		905.12	0.001414	3.01	119.72	51.95	0.29
HC_1	371	10-year	510.00	900.19	907.35		907.42	0.000443	2.41	260.78	68.27	0.18
HC_1	371	100-year	773.00	900.19	909.41		909.49	0.000304	2.46	436.28	104.39	0.16
HC_1	327	2-year	320.00	899.45	904.88		905.05	0.001838	3.29	98.83	35.36	0.32
HC_1	327	10-year	510.00	899.45	907.30		907.40	0.000565	2.65	234.72	72.30	0.20
HC_1	327	100-year	773.00	899.45	909.39		909.47	0.000339	2.54	417.32	103.99	0.16
HC_1	296	2-year	320.00	898.78	904.89		904.99	0.000743	2.65	144.17	61.44	0.22
HC_1	296	10-year	510.00	898.78	907.32		907.38	0.000277	2.17	332.77	92.74	0.15
HC_1	296	100-year	773.00	898.78	909.41		909.46	0.000184	2.11	554.08	118.41	0.12
HC_1	278	2-year	320.00	898.62	904.91		904.97	0.000441	1.99	174.01	60.14	0.17
HC_1	278	10-year	510.00	898.62	907.33		907.37	0.000193	1.76	368.22	96.51	0.12
HC_1	278	100-year	773.00	898.62	909.41		909.45	0.000135	1.75	590.36	115.89	0.10
HC_1	268	2-year	320.00	899.05	904.89		904.97	0.000528	2.22	167.72	69.96	0.18
HC_1	268	10-year	510.00	899.05	907.32		907.37	0.000208	1.86	362.55	95.67	0.12
HC_1	268	100-year	773.00	899.05	909.41		909.45	0.000144	1.85	590.12	119.61	0.11
HC_1	254	2-year	320.00	898.70	904.74	902.12	904.94	0.001665	3.59	90.72	24.84	0.31
HC_1	254	10-year	510.00	898.70	907.16	903.10	907.35	0.000850	3.49	159.34	84.25	0.24
HC_1	254	100-year	773.00	898.70	909.21	904.04	909.43	0.000729	3.87	267.76	117.87	0.23
HC_1	250		Culvert									
HC_1	196	2-year	320.00	894.13	899.98	897.12	900.10	0.001138	2.81	114.03	39.43	0.26
HC_1	196	10-year	510.00	894.13	900.86	897.91	901.06	0.001403	3.60	143.96	47.35	0.30
HC_1	196	100-year	773.00	894.13	901.92	898.77	902.21	0.001564	4.37	185.05	63.32	0.33
HC_1	183	2-year	320.00	895.35	899.96	897.74	900.08	0.001203	2.78	115.60	49.29	0.26
HC_1	183	10-year	510.00	895.35	900.85	898.34	901.04	0.001442	3.50	147.95	57.18	0.30
HC_1	183	100-year	773.00	895.35	901.91	899.03	902.18	0.001543	4.20	192.96	73.27	0.32
HC_1	173	2-year	320.00	896.05	899.71	898.57	900.04	0.004657	4.62	69.19	41.29	0.49
HC_1	173	10-year	510.00	896.05	900.46	899.24	900.98	0.005791	5.79	88.09	46.35	0.55
HC_1	173	100-year	773.00	896.05	901.40	900.05	902.11	0.007419	6.77	114.14	57.92	0.63
HC_1	163	2-year	320.00	895.85	899.64	898.51	899.99	0.004856	4.75	67.32	42.37	0.50
HC_1	163	10-year	510.00	895.85	900.36	899.22	900.92	0.006230	5.98	85.34	47.16	0.58
HC_1	163	100-year	773.00	895.85	901.27	900.06	902.03	0.007213	7.01	110.27	54.55	0.64
HC_1	146	2-year	320.00	895.73	899.43		899.88	0.008539	5.68	62.87	30.59	0.66
HC_1	146	10-year	510.00	895.73	900.23		900.80	0.008352	6.46	89.04	35.78	0.67
HC_1	146	100-year	773.00	895.73	901.27		901.86	0.007276	6.71	133.25	53.29	0.65
HC_1	115	2-year	320.00	896.13	899.13		899.61	0.008288	5.92	64.99	38.45	0.67
HC_1	115	10-year	510.00	896.13	900.07		900.55	0.005703	6.11	102.26	40.85	0.59
HC_1	115	100-year	773.00	896.13	901.13		901.66	0.004515	6.52	147.02	43.55	0.55
HC_1	79	2-year	320.00	895.69	898.47		899.20	0.013747	6.84	46.78	22.54	0.84
HC_1	79	10-year	510.00	895.69	899.28		900.20	0.013057	7.70	66.20	25.41	0.84
HC_1	79	100-year	773.00	895.69	900.32		901.36	0.011129	8.18	94.46	29.06	0.80
HC_1	43	2-year	320.00	894.65	898.06	897.69	898.73	0.012015	6.55	48.82	22.05	0.78
HC_1	43	10-year	510.00	894.65	898.85	898.40	899.76	0.012006	7.63	66.81	23.42	0.80
HC_1	43	100-year	773.00	894.65	899.76	899.26	900.94	0.011998	8.72	88.69	24.93	0.81

HEC-RAS Plan: Proposed_90pct River: HighlandCreek Reach: HC_1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
HC_1	479	2-year	320.00	903.32	905.49	905.49	906.13	0.022584	6.38	50.14	40.35	1.01
HC_1	479	10-year	510.00	903.32	905.95	905.95	906.81	0.020113	7.42	69.04	42.20	1.00
HC_1	479	100-year	773.00	903.32	906.51	906.51	907.61	0.017827	8.44	93.12	44.49	0.99
HC_1	425	2-year	320.00	901.17	904.33		904.67	0.008068	4.66	68.76	39.63	0.62
HC_1	425	10-year	510.00	901.17	905.03		905.46	0.006679	5.29	98.22	45.07	0.59
HC_1	425	100-year	773.00	901.17	905.94		906.44	0.005111	5.72	141.79	49.49	0.55
HC_1	371	2-year	320.00	900.19	903.95		904.26	0.006622	4.51	70.96	38.60	0.58
HC_1	371	10-year	510.00	900.19	904.75		905.13	0.004965	4.95	107.65	50.43	0.53
HC_1	371	100-year	773.00	900.19	905.78		906.18	0.003557	5.20	162.58	56.26	0.48
HC_1	327	2-year	320.00	899.45	902.83	902.83	903.72	0.022116	7.56	42.32	24.49	1.01
HC_1	327	10-year	510.00	899.45	903.48	903.48	904.67	0.019411	8.75	58.76	26.06	1.00
HC_1	327	100-year	773.00	899.45	904.25	904.25	905.78	0.017204	9.94	79.45	27.69	0.99
HC_1	296	2-year	320.00	898.78	901.98	901.98	902.91	0.020986	7.73	41.41	22.86	1.01
HC_1	296	10-year	510.00	898.78	902.69	902.69	903.87	0.019508	8.72	58.48	25.17	1.01
HC_1	296	100-year	773.00	898.78	903.46	903.46	904.97	0.017443	9.87	78.90	28.18	1.00
HC_1	278	2-year	320.00	898.25	902.05		902.43	0.006239	4.96	64.99	30.11	0.58
HC_1	278	10-year	510.00	898.25	902.91		903.41	0.005382	5.70	92.04	32.83	0.57
HC_1	278	100-year	773.00	898.25	903.91		904.54	0.004774	6.45	126.70	37.17	0.56
HC_1	267	2-year	320.00	898.13	901.33	901.33	902.26	0.019161	7.77	41.95	24.59	0.99
HC_1	267	10-year	510.00	898.13	902.03	902.03	903.24	0.016696	8.92	60.06	27.01	0.97
HC_1	267	100-year	773.00	898.13	902.78	902.78	904.36	0.016000	10.31	81.19	30.19	0.99
HC_1	233		Bridge									
HC_1	196	2-year	320.00	897.28	900.36	899.86	900.88	0.015693	5.78	55.61	39.08	0.72
HC_1	196	10-year	510.00	897.28	901.32	900.60	901.87	0.010064	6.02	89.17	53.33	0.62
HC_1	196	100-year	773.00	897.28	902.49	901.33	903.04	0.006728	6.14	135.25	84.43	0.53
HC_1	183	2-year	320.00	897.10	900.18	899.61	900.69	0.012207	5.75	57.67	45.81	0.65
HC_1	183	10-year	510.00	897.10	901.23	900.38	901.73	0.007888	5.88	96.67	61.39	0.56
HC_1	183	100-year	773.00	897.10	902.45	901.17	902.92	0.005402	5.96	155.44	83.33	0.49
HC_1	173	2-year	320.00	896.97	900.01		900.55	0.014356	5.93	54.54	44.33	0.70
HC_1	173	10-year	510.00	896.97	900.99		901.62	0.010369	6.43	82.14	51.69	0.63
HC_1	173	100-year	773.00	896.97	902.10		902.83	0.008336	7.02	118.36	65.28	0.60
HC_1	163	2-year	320.00	897.00	899.81		900.40	0.016121	6.19	51.70	42.16	0.73
HC_1	163	10-year	510.00	897.00	900.77		901.50	0.012668	6.87	74.98	48.75	0.68
HC_1	163	100-year	773.00	897.00	901.83		902.72	0.010691	7.65	106.17	60.97	0.65
HC_1	146	2-year	320.00	895.73	899.39		900.14	0.012568	6.97	46.01	30.34	0.80
HC_1	146	10-year	510.00	895.73	899.81	899.81	901.18	0.018242	9.38	54.86	32.63	1.00
HC_1	146	100-year	773.00	895.73	900.82	900.82	902.43	0.014424	10.26	79.36	43.66	0.93
HC_1	115	2-year	320.00	896.13	899.00	898.83	899.71	0.014284	6.79	47.97	38.11	0.85
HC_1	115	10-year	510.00	896.13	900.12	899.30	900.55	0.005431	5.65	104.02	40.96	0.57
HC_1	115	100-year	773.00	896.13	901.20	899.89	901.68	0.004164	6.05	149.91	43.72	0.52
HC_1	79	2-year	320.00	895.69	898.47		899.20	0.013738	6.84	46.79	22.54	0.84
HC_1	79	10-year	510.00	895.69	899.18	898.91	900.20	0.013114	8.12	63.53	25.03	0.86
HC_1	79	100-year	773.00	895.69	900.04	899.76	901.36	0.011915	9.27	86.53	28.06	0.86
HC_1	43	2-year	320.00	894.65	898.06	897.68	898.73	0.012013	6.55	48.82	22.05	0.78
HC_1	43	10-year	510.00	894.65	898.78	898.39	899.74	0.012009	7.89	64.98	23.28	0.81
HC_1	43	100-year	773.00	894.65	899.60	899.22	900.93	0.012003	9.30	84.65	24.68	0.85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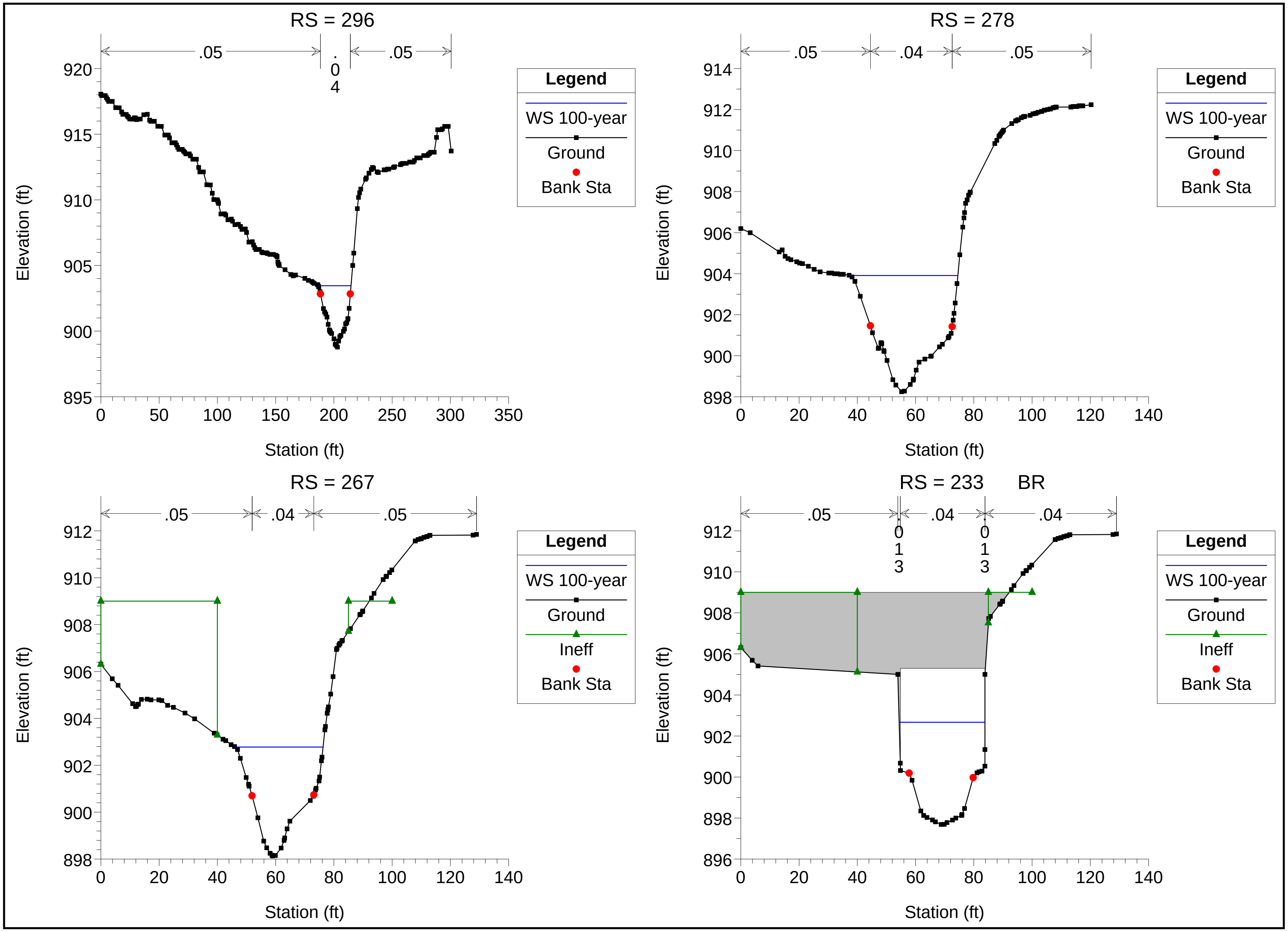

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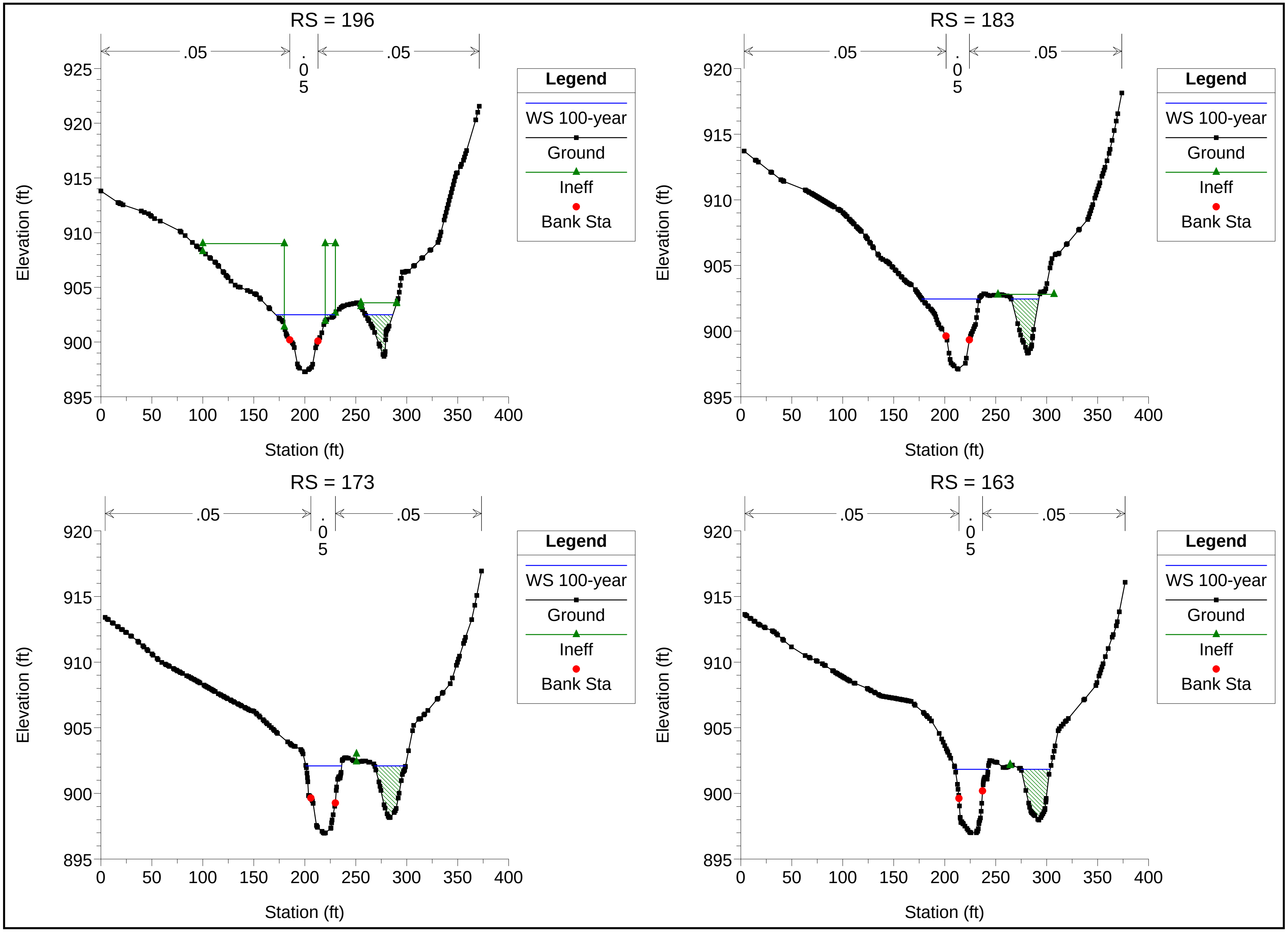
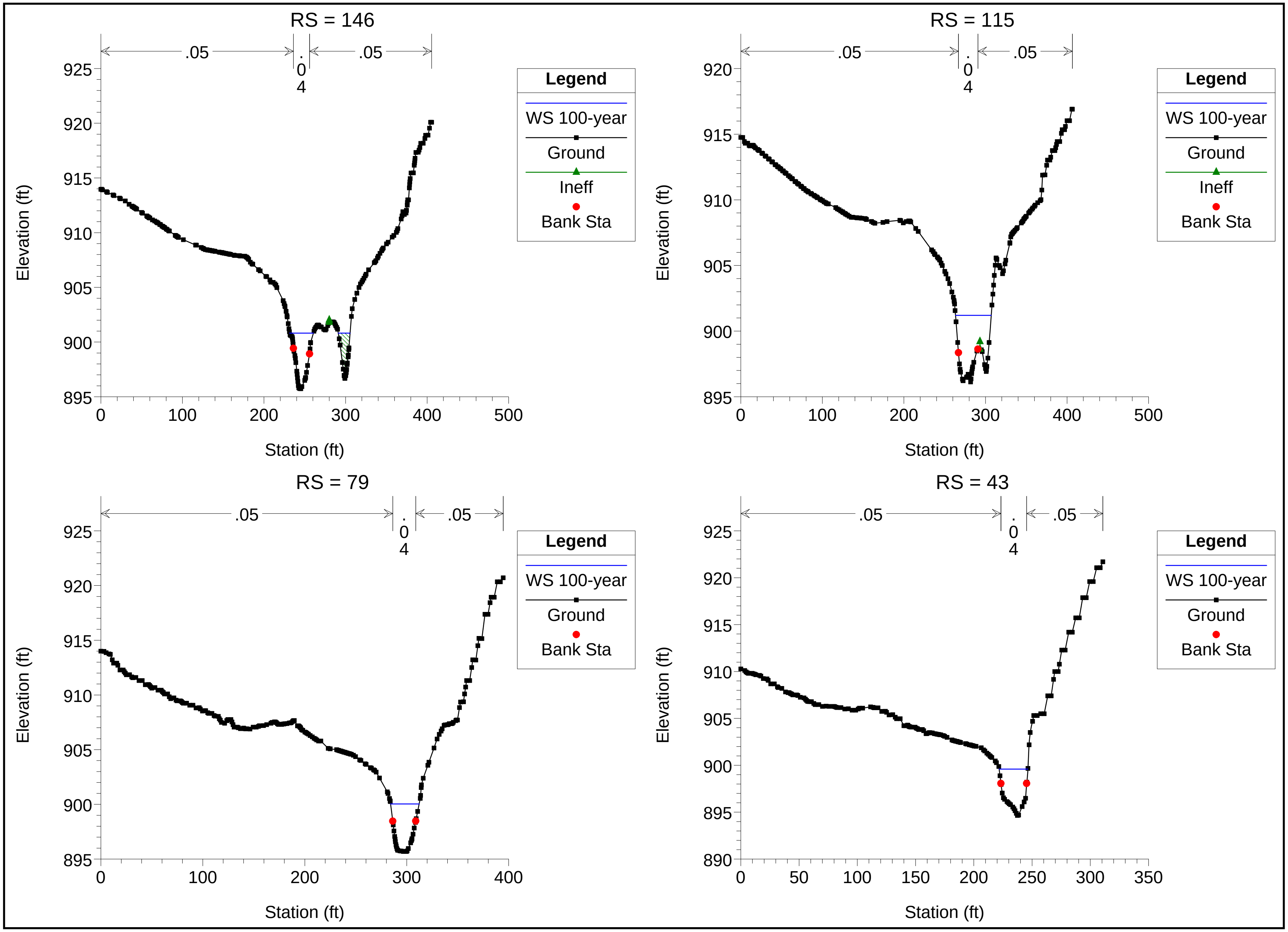
Ineff
Bank Sta
Elevation (ft)
Station (ft)
RS = 233 BR
.05
.013
.04
.013
.04
Legend
WS 100-year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)



RS = 196
.05
.
0
5
.05
Legend
WS 100-year
Ground
Ineff
Bank Sta
Elevation (ft)
925
920
915
910
905
900
895
0
50
100
150
200
250
300
350
400
Station (ft)
RS = 183
.05
.
0
5
.05
Legend
WS 100-year
Ground
Ineff
Bank Sta
Elevation (ft)
920
915
910
905
900
895
0
50
100
150
200
250
300
350
400
Station (ft)
RS = 173
.05
.
0
5
.05
Legend
WS 100-year
Ground
Ineff
Bank Sta
Elevation (ft)
920
915
910
905
900
895
0
50
100
150
200
250
300
350
400
Station (ft)
RS = 163
.05
.
0
5
.05
Legend
WS 100-year
Ground
Ineff
Bank Sta
Elevation (ft)
920
915
910
905
900
895
0
50
100
150
200
250
300
350
400
Station (ft)


RS = 146
.05
.
0
4
.05
Legend
WS 100-year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
RS = 115
.05
.
0
4
.05
Legend
WS 100-year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)
RS = 79
.05
.
0
4
.05
Legend
WS 100-year
Ground
Bank Sta
Elevation (ft)
Station (ft)
RS = 43
.05
.
0
4
.05
Legend
WS 100-year
Ground
Bank Sta
Elevation (ft)
Station (ft)

Summary - Incipient Motion - Bathurst

Project:	Crumb Road
Location:	Morton, WA
Stream:	Highland Creek
Engineer:	A. Lunde
Geomorphologist:	A. Duffy
Date Collected:	9/22/2020
Date Analyzed:	10/26/2020
Reviewed By:	

For channels steeper than 1 percent (S = 0.01) where the flow depth is shallow with respect to the channel bed particle sizes ($R/D_{50} < 10$), water depth can be quite variable because large rocks or **wood** pieces on or near the surface influence depth (Bathurst 1987). For such channels, Bathurst et al. (1987) used flume data to construct the following equation, which predicts the critical unit discharge for entraining the D_{50} particle size in well-sorted sediments:

Riffle Bathurst Critical Discharge Method

Stream Simulation and Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings Appenix E (USDA 2008)

$$q_{c-D50} = \frac{0.15 g^{0.5} D_{50}{}^{1.5}}{S^{1.12}} \quad D_{50} = \left(\frac{S^{1.12} q_{c-D50}}{0.15 g^{0.5}}\right)^{\frac{2}{3}} \quad D_{16} = \frac{D_{84}}{8} \quad D_{50} = \frac{D_{84}}{2.5} \quad D_{100} = \frac{D_{84}}{0.4} \quad D_{84} = 3.45 * S^{0.747} * \frac{(1.25 * q_c)^{\frac{2}{3}}}{g^{\frac{1}{3}}}$$

Cross Section:	Through Structure

Event	Q [cfs]	Energy Slope [ft/ft] (S)	Stream Width [ft] (W)	Specific Discharge [cfs] (Qc)	D16 [ft]	D50 [ft]	D84 [ft]	D100 [ft]
100-year	773.0	0.012	22.0	35.1	0.06	0.20	0.50	1.24
10-year	510.0	0.012	22.0	23.2	0.05	0.15	0.38	0.94
2-year	320.0	0.012	22.0	14.5	0.03	0.11	0.28	0.69

Rock Size		Stable D84 (in)					
		2-year	10-year	100-year			
[in]	[mm]	3.31	4.51	5.95			
36.0	914	No Motion	No Motion	No Motion			
32.0	813	No Motion	No Motion	No Motion			
28.0	711	No Motion	No Motion	No Motion			
23.0	584	No Motion	No Motion	No Motion			
18.0	457	No Motion	No Motion	No Motion			
15.0	381	No Motion	No Motion	No Motion			
12.0	305	No Motion	No Motion	No Motion			
10.0	254	No Motion	No Motion	No Motion			
8.0	203	No Motion	No Motion	No Motion			
6.0	152	No Motion	No Motion	No Motion			
5.0	127	No Motion	No Motion	Motion			
4.0	102	No Motion	Motion	Motion			
3.0	76.2	Motion	Motion	Motion			
2.5	63.5	Motion	Motion	Motion			
2.0	50.8	Motion	Motion	Motion			
1.5	38.1	Motion	Motion	Motion			
1.0	25.4	Motion	Motion	Motion			
0.50	12.7	Motion	Motion	Motion			
0.19	4.75	Motion	Motion	Motion			
0.02	0.425	Motion	Motion	Motion			
0.003	0.0750	Motion	Motion	Motion			

APPENDIX D – CONCEPT ALTERNATIVES

PLANNING LEVEL CONSTRUCTION COSTS						
PROJECT:	Crumb Road Crossing Replacement	CHECKED BY:		ERR		
BY:	Jessica Lammers (NHC)	DATE:		12/17/2020		

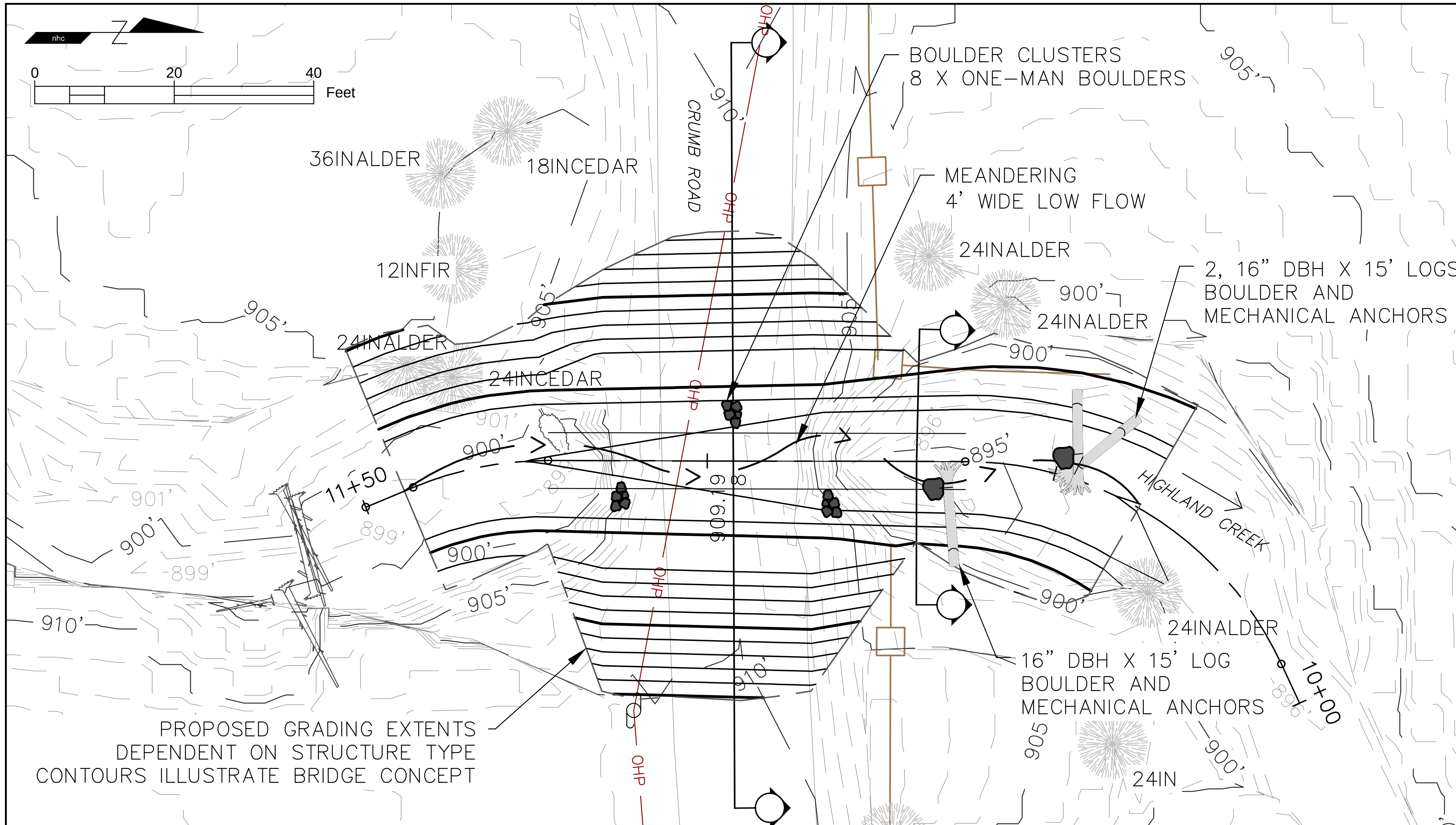
Item No.	Bid Item	Unit	Unit Price	Box Culvert Amount	3-Sided Culvert Amount	Bridge Amount
1	Site Preparation & Clearing and Grubbing	AC	$ 20,000	$ 1,286	$ 1,286	$ 1,286
2	Removing Drainage Structure	LS	$ 10,000	$ 10,000	$ 10,000	$ 10,000
3	Excavation and Haul	CY	$ 30	$ 52,400	$ 65,600	$ 40,000
4	Bedding	CY	$ 50	$ 1,800	$ 2,650	$ -
5	Select Borrow Incl. Haul	TON	$ 25	$ 21,375	$ 32,500	$ -
6	Precast Reinforced Concrete Box Culvert	SF	$ 110	$ 208,413	$ -	$ -
7	Precast Reinforced Concrete Three Sided Structure	SF	$ 120	$ -	$ 195,910	$ -
8	Prestressed Concrete Girders — Span 50 - 175 FT	SF	$ 350	$ -	$ -	$ 656,250
9	Crane	LS	$ 40,000	$ 40,000	$ 40,000	$ -
10	Surfacing, Guardrail, Traffic	LF	$ 500	$ 67,500	$ 75,000	$ 60,000
11	Streambed Sediment and Cobbles	TON	$ 75	$ 52,875	$ 55,125	$ 41,250
12	Streambed Boulders	EA	$ 110	$ 2,640	$ 2,640	$ 2,640
13	Rock for Erosion and Scour Protection, Class A	TON	$ 75	$ -	$ -	$ 10,875
14	Individual Habitat Log	EA	$ 2,000	$ 6,000	$ 6,000	$ 6,000
15	3-Man Boulders	EA	$ 500	$ 1,000	$ 1,000	$ 1,000
16	Plantings	LS	$ 20,000	$ 20,000	$ 20,000	$ 20,000
17	Temporary Bypass Road	LS	$ 100,000	$ 100,000	$ 100,000	$ 100,000
18	Temporary Traffic Control	LS	$ 40,000	$ 40,000	$ 40,000	$ 40,000
19	Temporary Stream Diversion	LS	$ 40,000	$ 40,000	$ 40,000	$ 40,000
	Subtotal			$ 665,289	$ 687,711	$ 1,029,301
	DEWATERING	Varies		$ 66,529	$ 68,771	$ 102,930
	EROSION & SEDIMENTATION CONTROL	Varies	(See Note 3)	$ 66,529	$ 68,771	$ 51,465
	CONTINGENCY	30%		$ 199,587	$ 206,313	$ 308,790
	Subtotal			$ 997,933	$ 1,031,566	$ 1,492,486
	MOBILIZATION	10%		$ 99,793	$ 103,157	$ 149,249
	Subtotal			$ 1,098,000	$ 1,135,000	$ 1,642,000
	STATE SALES TAX	10%		$ 109,800	$ 113,500	$ 164,200
	CONSTRUCTION MANAGEMENT	10%		$ 109,800	$ 113,500	$ 164,200
	PERMITTING	County		$ -	$ -	$ -
	Total Estimated Project Cost (Rounded)			**$ 1,318,000**	**$ 1,362,000**	**$ 1,970,000**

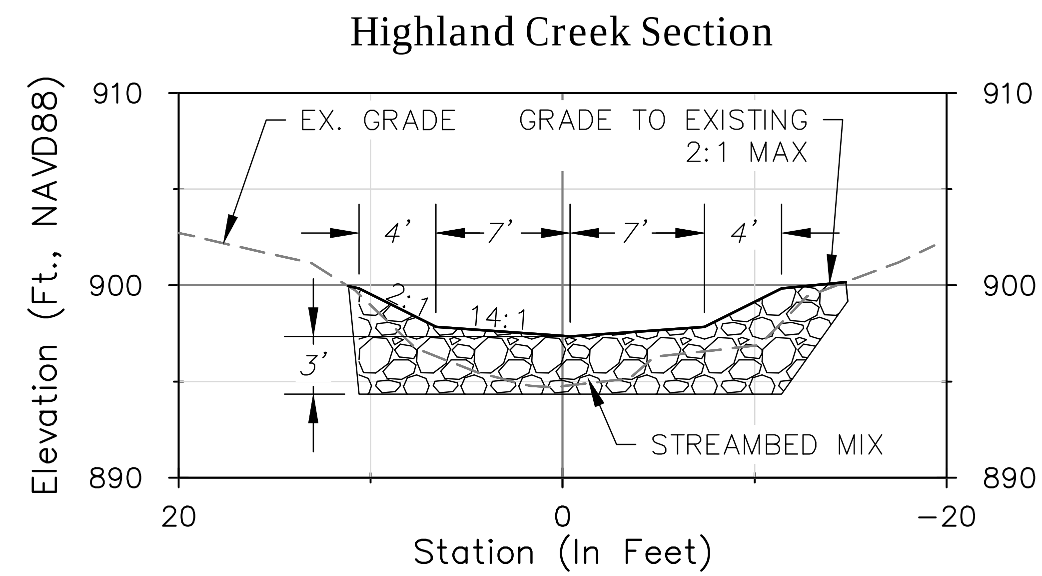
Notes:

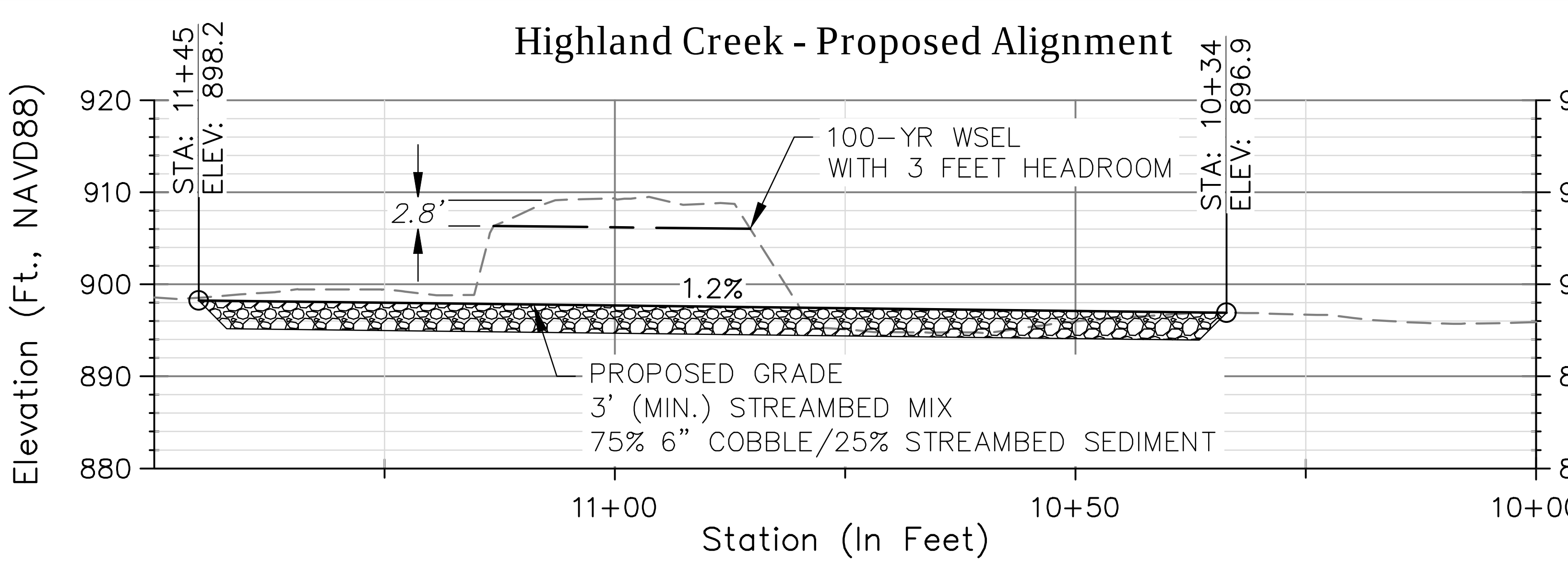
1. The above cost opinion is in 2020 dollars and does not include future escalation, financing, or O&M costs.

2. The order-of-magnitude cost opinion has been prepared for guidance in project evaluation from the information available at the time of preparation and for the assumptions stated. The final costs of the project will depend on actual labor and material costs, actual site conditions, productivity, competitive market conditions, final project scope and schedule, and other variable factors. As a result, the final project costs will vary from those presented above. Because of these factors, funding needs for individual projects must be scrutinized prior to establishing the final project budgets.

3. Increase percentage markup if work is in or immediately adjacent to flowing or standing water, steep slope, and/or other erosion-prone conditions.







Lewis County
Department of Public Works

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nhc
northwest hydraulic consultants
12787 gateway drive south
tukwila, washington 98168-3308
phone: (206) 241-6000
fax: (206) 439-2420

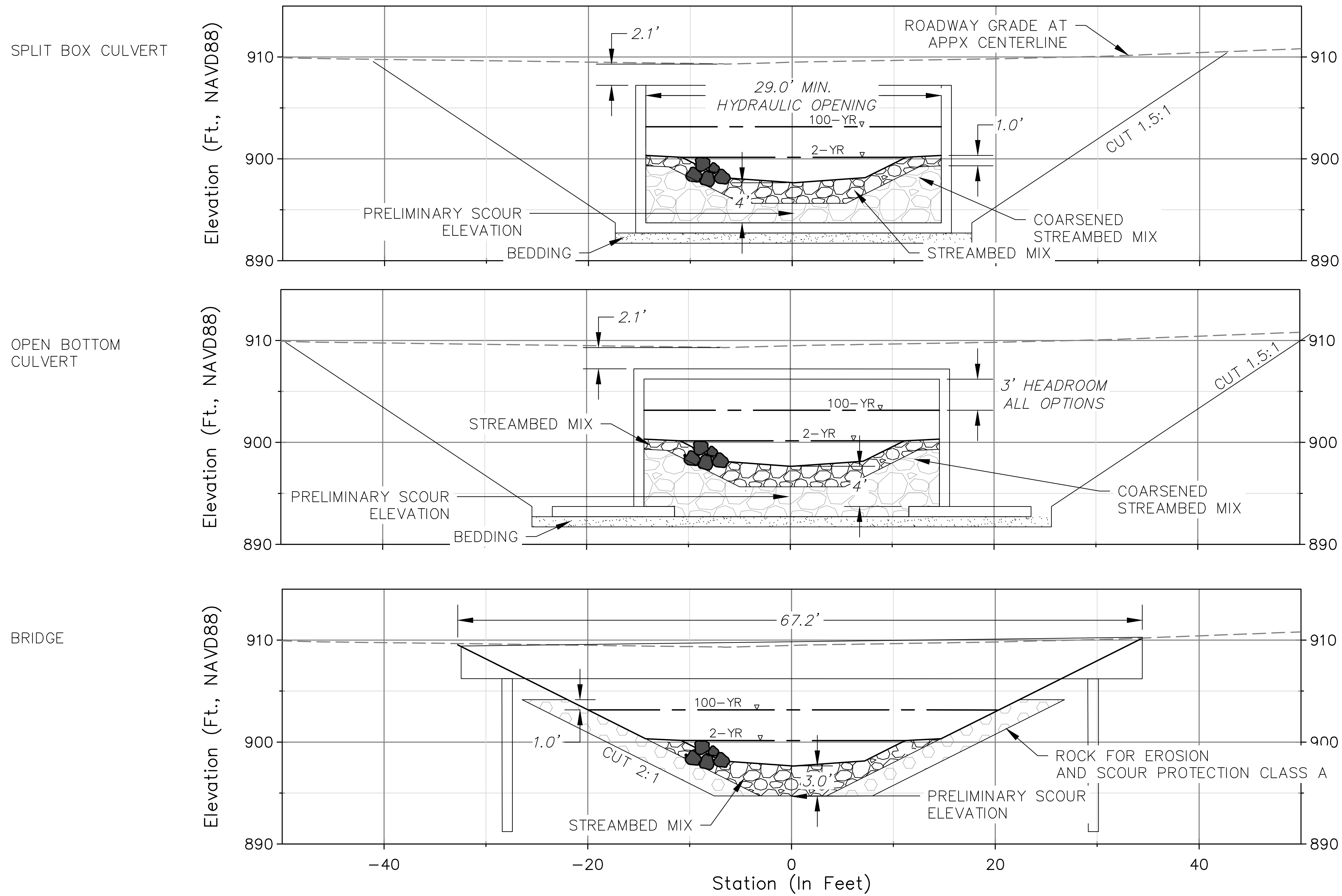
Job: 2005617	
Rev: 0	
Drft: MAO	
Chkd: JML	
Date:16Dec20	

NOT FOR CONSTRUCTION

CRUMB ROAD CROSSING REPLACEMENT

30% CONCEPT DESIGN

FIGURE 1



NOTES:

1. SEE FIGURE 1 FOR TYPICAL CROSS SECTION SLOPES AND DIMENSIONS.
2. STRUCTURE DIMENSIONS AND COMPONENTS ARE APPROXIMATE FOR CONCEPT LAYOUT PURPOSES AND WILL BE DESIGNED BY OTHERS.

0 10 20 Feet

Lewis County
Department of Public Works

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NOT FOR CONSTRUCTION

CRUMB ROAD CROSSING REPLACEMENT

ROADWAY PROFILE AND STRUCTURE OPTIONS

FIGURE 2