North Creede Stream Stability & Flood Mitigation

DRAFT Preliminary Basis of Design Report

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Project Overview

Headwaters Alliance (HWA) contracted with WaterVation, PLLC (WaterVation) for conceptual design services for the North Creede Stream Stability & Flood Mitigation Project (Project) on Willow Creek located in Creede, Colorado. This project begins at County Road 502 and extends downstream approximately 0.72 miles to the beginning of the concrete flume that runs through the City of Creede.

The long history of fires, floods, and mining activity within the Willow Creek Watershed has resulted in an excessive amount of sediment being delivered to the Project area. As a result, the entire length of Willow Creek, within the Project area, is actively aggrading (filling with sediment). This process has reduced the flood-carrying capacity of Willow Creek and increased the frequency by which adjacent infrastructure gets flooded. Additionally, the process of aggradation has resulted in lateral channel migration which is damaging adjacent roadway embankments, public recreation facilities, and existing flood control infrastructure. The following list represents the existing infrastructure currently being impacted by flooding:

- Approximately 0.61 Miles of County Road 503.
- The County Road 502 Bridge.
- The Creede Fire Department.
- The Underground Mining Museum.
- The Bachelor Loop Interpretive Site.
- Two Hockey Ponds.
- One Corrugated Metal Pipe Culvert.
- The Existing Concrete Flume.

Project Goals

The three primary goals, and corresponding objectives, for this Project are outlined below.

- **Goal #1: Reduce Sediment Loading Into the Downstream Flume.**
    - <u>Objective A:</u> Capture excess sediment load transported during bankfull flow conditions at the upstream end of the Project.
    - <u>Objective B:</u> Capture large sediments transported by flood flows at the downstream end of the project.
- **Goal #2: Restore Willow Creek Within the Project Area Using the Principles of Natural Channel Design.**
    - <u>Objective A:</u> Restore the bankfull channel dimension (cross section), pattern (planform), and profile (slope) to convey such that the restored channel conveys the incoming sediment load without creating excessive erosion or deposition.
    - <u>Objective B:</u> Reestablish and revegetate the floodplain to promote the establishment of a riparian corridor.
    - <u>Objective C:</u> Incorporate in-stream complexity (i.e. a variety of size and type of both riffles and pools) to support aquatic habitat needs. Incorporate floodplain vegetation and irregularity to support terrestrial habitat needs.
- **Goal #3: Provide Flood Protection For the City of Creede.**
    - <u>Objective A:</u> Restore the floodplain so that a direct connection exists between it and the bankfull channel. This ensures that the energy from flood flows is dissipated on the floodplain, thereby reducing the risk of flood-related damages.

WATERVATION

Watershed Assessments

Watershed Tour

A general watershed assessment was conducted on Tuesday, October 19th to gain an overall understanding of the stream and watershed conditions that could influence this Project. The following observations were made during this site visit:

West Willow Creek Subwatershed

The West Willow Creek subwatershed has a drainage area of approximately 13.2 square miles and can generally be characterized as a confined alluvial valley. The West Willow Creek watershed has a history of fires, flooding, and mining, all of which have influenced, and increased, the sediment supply into West Willow Creek.

In the headwaters, West Willow Creek exists as a sinuous stream with a large and well vegetated floodplain (Picture 1). At this location West Willow Creek is generally in a stable condition.

Picture 1. West Willow Creek Upstream of Equity Mine

Near the Equity Mine West Willow Creek becomes confined and is influenced by tailings produced by the Equity Mine (Picture 2).

Picture 2. West Willow Creek at Equity Mine

Downstream of the Equity Mine, West Willow Creek transitions into a stable wetland complex stream system with a broad, well-vegetated floodplain (Picture 3).

Picture 3. West Willow Creek Downstream of Equity Mine

The roadway crossing at the intersection of County Road 503 and 504 is causing localized erosion and significantly influencing the pattern of West Willow Creek. However, upstream of this location, West Willow Creek exists in a relatively stable form with a moderately wide, well-vegetated floodplain (Picture 4).

Picture 4. West Willow Creek Upstream of CR 503/504 Intersection

The stream and floodplain downstream of the intersection of County Road 503 and 504 are in relatively stable condition, but with a much narrow floodplain (Picture 5).

Picture 5. West Willow Creek Downstream of County Road 503/504 Intersection

Most of the stream stability issues begin near the Amethyst Mine ( ). Downstream of this point the stream becomes very incised and also coincides where most of the historic mining activity took place.

Picture 6. West Willow Creek Near Amethyst Mine

East Willow Creek Subwatershed

The East Willow Creek subwatershed has a drainage area of approximately 20.8 square miles and can generally be characterized as a confined alluvial valley. East Willow Creek shows evidence of flood damage; however, the stream corridor is showing signs of recovering in many (but not all) locations through natural processes. A dominant low flow and bankfull channel can be seen in many locations, the channel pattern is generally in a stable state as evidenced by well-vegetated overbanks, and the channel profile is beginning to show signs of bedform complexity (establishment of riffles, steps, and pools).

Picture 7. East Willow Creek

Large-scale landscape processes such as hillslope erosion, mass wasting, burn scars, mining, etc. are generally only present in the upstream headwaters and on the fringes of the subwatershed boundary. While these landscape processes are contributing to erosion and sediment loading, it is not at the level where it's causing channel instability within East Willow Creek or exacerbating sediment loading such as within West Willow Creek.

In summary, no in-stream or watershed-scale instabilities within East Willow Creek were identified that could be contributing to excessive sediment loading within the Project area.

Topographic Survey

The topographic survey was completed in November 2021 using photogrammetry collected by an Unmanned Aerial Vehicle (UAV). A local control point was established with Real-Time Kinematic (RTK) positioning using Global Navigation Satellite System (GNSS). Collected data was calibrated using the Online Positioning User Service (OPUS) developed by the National Geodetic Survey.

Geomorphic Assessment

The geomorphic assessment for the Project Reach was performed in October 2021 using protocols outlined in Watershed Assessment of River Stability and Sediment Supply (Wildland Hydrology, 2006) to quantify the degree of impairment for the existing stream. The data collected during the geomorphic assessment was supplemented with available current and historical aerial photography and topographic survey data collected for the Project Reach.

General project reach assessments included:

- Initial site assessment to document existing conditions with field notes and photographs.
- Identification of major geomorphic and sediment transport tendencies including transport and deposition zones along with potential sediment sources and sinks.
- A review of historical and existing aerial photography to evaluate changes in channel and floodplain conditions over time.
- Identification of vertical and lateral controls, such as roadways and utilities, in the vicinity of the project reach.

Detailed project reach assessments consisted of the following:

- Hydrologic – To evaluate flow regime and peak flow characteristics.
- Geomorphic – To evaluate existing channel dimension, pattern, and profile characteristics including sediment samples and classification of existing and potential stream type.
- Ecologic – To evaluate riparian and upland vegetation along with the identification of wetlands.
- Biologic – To evaluate quality of in-stream habitat, presence of fish species, and presence of macroinvertebrates.
- Stability – To evaluate vertical and lateral channel stability processes that are leading to erosion, deposition, and bank erosion.
- Sediment Competence – To evaluate aggradation and degradation tendencies within each reach. Calculations were performed using riffle pebble count information and point bar samples of maximum particle size.

The valley type was classified for the Project as a confined fluvial landscape formed from alluvial deposition (Rosgen 2018). The referenced valley classification table is provided in Figure 1. Stable stream types that exist within this valley type are Rosgen Stream Types B, C, and E. The existing stream was classified as a F4 using the Rosgen Classification of Natural Rivers as shown in Figure 2.

Figure 1 - Valley Classification (Rosgen 2015).

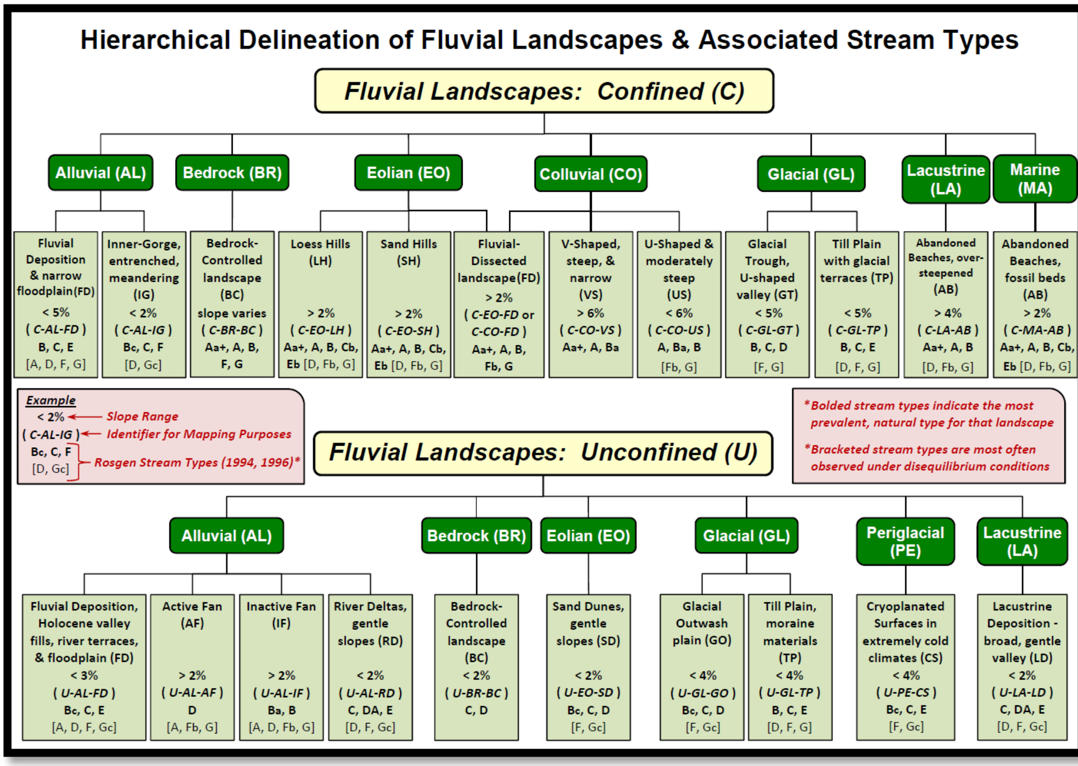
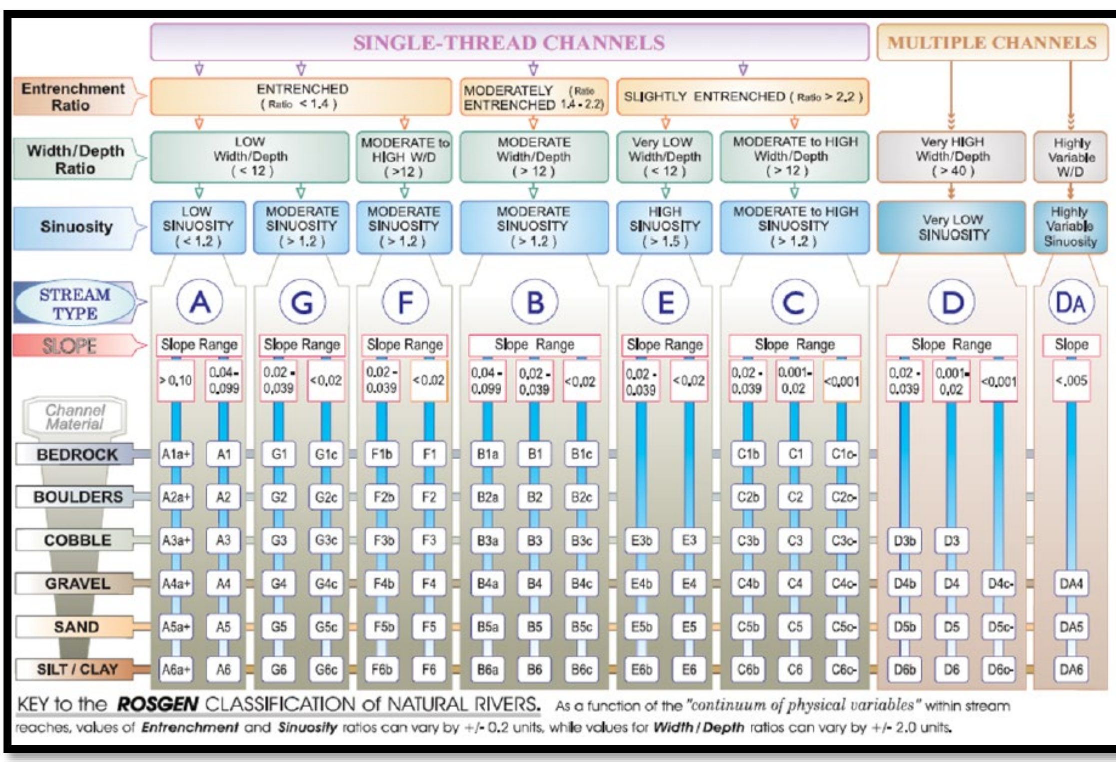


Figure 2 - Rosgen Classification of Natural Rivers



The geomorphic assessment of the Project Reach consisted of collecting:

- Longitudinal profile data for 3,300 feet of West Willow Creek, which included measurements of channel thalweg, water surface, bankfull elevation, and floodplain terraces.
- Cross section data for five cross sections. Riffle cross sections were also surveyed just upstream of the of the Project limits for use with comparing sediment transport characteristics.
- Active bed pebble counts at two riffle locations within the Project and two active-bed pebble for the surveyed riffles just outside of the upstream and downstream ends of the Project limits for use with comparing sediment transport characteristics.

A summary of the geomorphic survey data is provided in Table 1.

Table 1. Geomorphic Survey Data Summary for Project Reach

Parameter	**West Willow Creek**
Drainage Area (mi^2)	34.2
Stream Length (ft)	4093
Valley Length (ft)	4015
Valley Slope (ft/ft)	0.029
Sinuosity	1.02
Bankfull Discharge (cfs)	140
Stream Type (Rosgen)	F3b
Water Surface Slope (ft/ft)	0.025
Riffle Bankfull Width (ft)	29.4
Riffle Bankfull Cross Section Area (ft^2)	29.7
Riffle Mean Bankfull Depth (ft)	1.01
Riffle Maximum Bankfull Depth (ft)	2.33
Riffle Width/Mean Depth	29.1
Width of Flood Prone Area (ft)	37.1
Entrenchment Ratio	1.26
Pool Bankfull Cross Section Area (ft^2)	37
Bank Height Ratio	2.5
Pool Bankfull Width (ft)	39.6
Pool-Pool Spacing	56-273

Sediment & Substrate

Active-bed pebble counts were collected at two locations on West Willow Creek (upstream of the bridge and downstream of the confluence with East Willow Creek) and one location on East Willow Creek (just upstream of the confluence with West Willow Creek). Additionally, two channel bar samples were collected on West Willow Creek upstream of the bridge and downstream of the confluence with East Willow Creek. These data are used to estimate riffle bed velocity and calculate the competence of the channel at the riffle sections (Wildland Hydrology 2006). A summary of all collected sediment data is provided Figure 3 and Figure 4.

Figure 3. Sediment Gradations for Active Channel

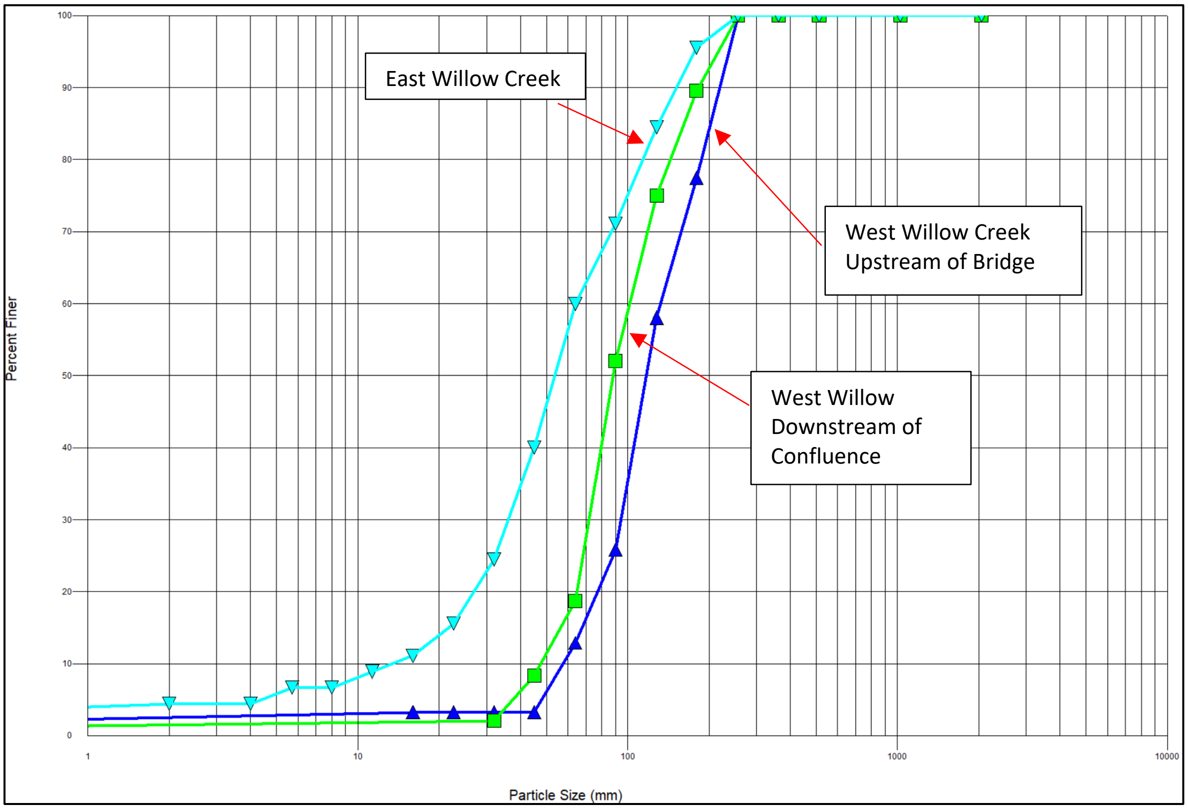
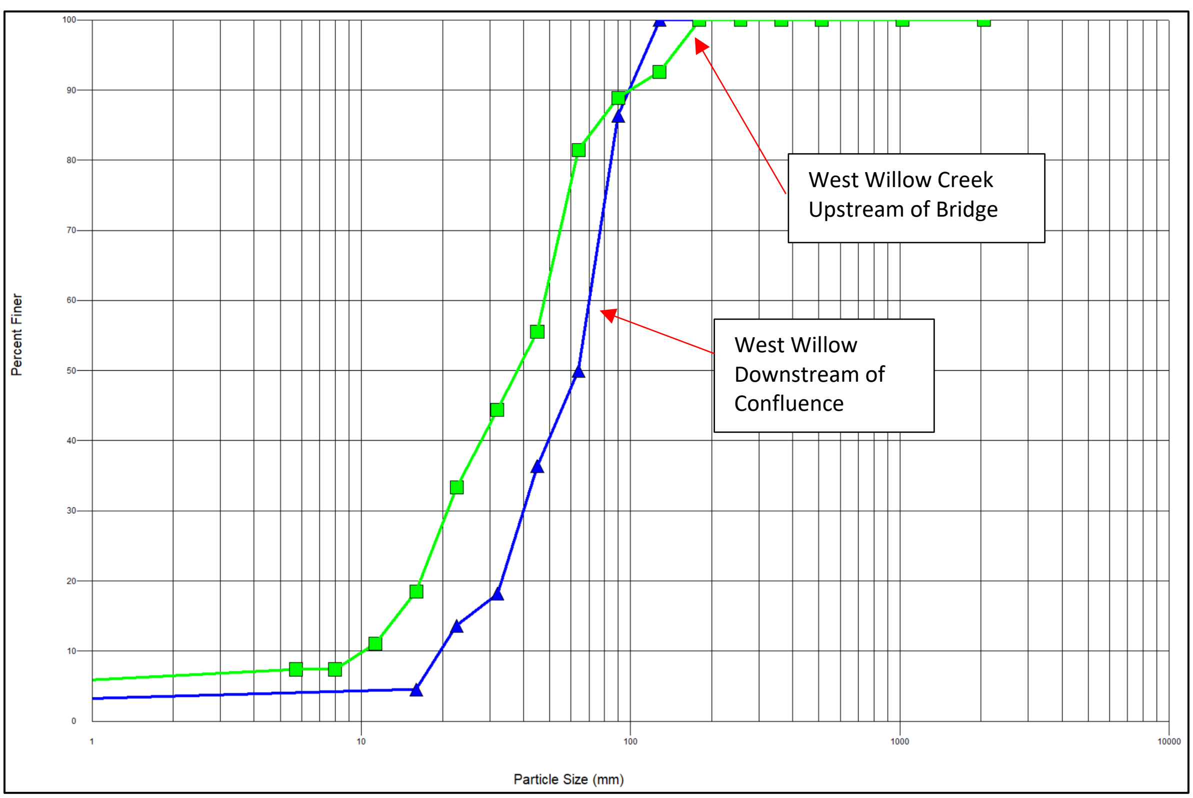


Figure 4. Sediment Gradations for Channel Bar Material



Sediment Transport Analysis

Two different types of sediment transport analyses were performed for the Project Reach: sediment competence analysis and sediment capacity analysis.

Sediment Competence

Sediment competence is the ability of a stream to move the largest particle made available from the immediate upstream supply (Wildland Hydrology 2006). A sediment sample collected on the lower one-third of a point bar can be used to infer the largest particle size made available to the reach being assessed. A reach must be competent and have the capacity to transport the sediment to remain stable (Wildland Hydrology 2006).

Sediment competence for the Project Reach was computed using the procedure outlined in the Natural Resources Conservation Service (NRCS) National Engineering Handbook Part 654. This procedure involves determining the required depth and slope necessary to move the largest particle made available to a reach from its upstream reach. If the depth or slope cannot move the largest particle, potential for aggradation exists. The required depth and slope are estimated using dimensionless and dimensional shear stress equations. The appropriate equation to use is based on the ratio of the median particle size of the riffle bed material to the median particle size of the point bar and the ratio of the largest particle from the point bar to the median particle size of the riffle bed material. If these ratios are within the specified range, the corresponding dimensionless equation is applied. If neither ratio is within the specified range, the dimensional method is used.

The competence for the Project Area was performed using data from the active-bed riffle pebble counts, bar samples, surveyed longitudinal profile, and surveyed cross sections. Competence calculations are performed with two sets of equations: one for dimensionless shear stress and one for dimensional shear stress. In order for the dimensionless shear stress equations to be used the ratio of the riffle d50 to bar d50 needs to be between 3 and 7 or the ratio of the riffle Dmax to riffle d50 needs to be between 1.3 to 3. Both sets of equations applied for the Project Reach. The results of the competence analysis are provided in Table 2. Results of this analysis show that the Project reach is competent, meaning that it is able to pass the largest particle made available from the immediate upstream supply.

Table 2 - Sediment Competence Analysis Results for Project Reach

Existing		Required		Largest Available Particle (mm)	Largest Predicted Particle (mm)	Competent?
Mean Depth (ft)	Slope (ft/ft)	Mean Depth (ft)	Slope (ft/ft)			
1.01	0.023	0.84	0.013	128	188	Yes

Sediment Capacity

A primary objective of stream restoration is creating a channel capable of transporting the quantity of sediment delivered by upstream erosion, entrainment, and transport processes. The sediment capacity analysis evaluates the ability of the creek to move the total volume of sediment coming into the system and reveals whether the system will have the tendency to aggrade or degrade. Total annual sediment yield is a useful property for evaluating sediment transport capacity, as it serves as a prediction of the total quantity of sediment transported through a particular cross section based on the annual flow and the quantity of sediment available for transport.

Sediment capacity for the Project Reach was computed using the procedure outlined in the NRCS National Engineering Handbook Part 654, which includes instructions for using the FLOWSED and POWERSED models embedded within the RiverMorph software package. FLOWSED and POWERSED are two models used in concert with one another for predicting annual sediment yield in rivers and evaluating changes in sediment transport capacity between two conditions for a particular segment of river (Wildland Hydrology 2006). FLOWSED computes a total annual sediment yield based on a Flow Duration Curve (FDC), which is a distribution of flows over a typical water year based on data from a stream gage, and a Sediment Rating Curve (SRC), which is a relationship between flow and transport rate normalized by measured sediment transport rates (bedload and suspended load) at bankfull. SRCs are derived from a Dimensionless Sediment Rating Curve (DSRC), which is derived from an extensive array of measured bankfull bedload and suspended load transport rates and made dimensionless, accordingly, using respective bankfull discharge and sediment transport rates. The resultant relationships are non-linear and stratified by Good/Fair or Poor stream conditions per the Pfankuch stability rating (Pfankuch 1975).

POWERSED integrates the dimensionless flow-duration curves in FLOWSED for a comparative (supply) reach by stream power, which is calculated for each stage based on hydraulic geometry. This relationship is then applied to the evaluation reach in a similar manner to predict the annual sediment yield. Using stream power accounts for changes in velocity, slope, hydraulic radius and/or roughness, providing a means for determining the effects of changes in hydraulic geometry and boundary conditions on transport capacity. Once complete, the output of the POWERSED model is a comparison of the annual yield of a supply reach to an evaluation reach. Multiple scenarios can be evaluated to ascertain the effects changes in slope, width/depth, and other hydraulic conditions have on transport capacity. The comparative (supply) reach represents the total annual sediment available to the system and the evaluation reach embodies the quantity of sediment the cross section of interest is capable of transporting. Agreement in the annual sediment yield between the comparative (supply) and evaluation reaches indicates stability of the evaluation reach (Rosgen 2006). If the supply is greater than the capacity of the evaluation reach, the channel is predicted to be in a state of aggradation; conversely. If the supply is less than the capacity of the evaluation reach, the channel is said to be in a state of degradation.

The flow duration curve for this Project was created using data from USGS Gage 08216500 and the procedures outlined in the NRCS NEH Part 654. Suspended sediment and bed load data are not available for the Project area. As a result, both suspended and bed load data were estimated from regional curves developed for north-central Colorado.

The results of the sediment capacity analysis are provided in Table 3. The results of the analysis show that the incoming sediment supply is nearly three times greater than the Project reach is able to convey. As a result, both Reach 1 and Reach 2 are aggrading.

Table 3 - Sediment Capacity Analysis for Project Reach

Reach	Sediment Transport Capacity (tons/year)			Result
	Upstream Supply	Project Reach	Difference	
West Willow Creek	4,130	1,822	-2,380	Aggrading

[1] The incoming sediment supply being delivered to the reach being evaluated. West Willow Creek upstream of the bridge.

[2] The sediment capacity of the reach being evaluated. West Willow Creek downstream of the confluence with East Willow Creek.

Preliminary Design

Hydrology

The drainage area for the Project ranges is approximately 34.2 square-miles at the downstream end of the Project. The annual average precipitation for the Willow Creek watershed is 31 inches and the average elevation of the contributing watershed is 11,474 feet (USGS Stream Stats). The bankfull channel was designed for a bankfull flow of 140 cubic-feet-per-second (cfs). All in-stream structures were designed for the 100-year flow of 834 cfs, which is the ratio of flow that is delivered to the Project area and that excludes Windy Gulch. The proposed floodplain can withstand up to the 10-year flood. Floods greater than the 10-year flood will likely cause some erosion, however, constraints within the Project corridor limit the extent to which larger floods can be protected against.

Flood Discharges

Flow data was obtained from the United States Geological Survey (USGS) Gage 08216500: WILLOW CREEK AT CREEDE, which has a drainage area of 34.2 square-miles. This gage was in operation between 1951 and 1982. While the gage is not currently operational, the historical dataset was used to gain an understanding of the magnitude of flood flows. The recent wildfire history in the Willow Creek watershed has altered the land use characteristics and has likely resulted in larger peak flows than reflected by historical gage data. Annual maximum peak flow data for USGS Gage 08216500 is provided in Table 4.

Table 4 – Major Flood Flows USGS Gage 08216500

Recurrence	Discharge (cfs)
5-Year	299
10-Year	384
25-Year	501
50-Year	594
100-Year	693

A recent study titled *CHAMP Phase III, Mineral County, Colorado Hydrologic Analyses Report (Wood 2019)* determined that a 100-year flood flow of 1,140 cubic-feet-per-second (cfs) be used for regulatory purposes.

Channel Forming Discharge

Channel forming flow is the flow most responsible for shaping the channel cross section over time. There are several methods for estimating the channel forming flow including effective discharge, known recurrence interval, and bankfull flow. The role of the channel forming discharge in shaping the morphology of all alluvial channels is the fundamental principle behind natural channel design (Wildland Hydrology 2006) and, therefore, needs to be estimated prior to beginning any design work.

Effective Discharge

Effective discharge is the mean discharge that moves the largest fraction of annual sediment load over time and is estimated by the integration of the flow duration curve and sediment transport rating curve. Calculating effective discharge requires a long history of gage data and sediment transport data. Sediment data is not available at USGS Gage 06206500 so effective discharge could not be calculated.

Recurrence Interval

The channel forming flow typically corresponds with a recurrence interval of 1- to 2-years. A statistical analysis of gage data was performed using the USGS PeakFQ Version 7.2 software to calculate peak flows for the flood recurrences typically associated with the channel forming flow. All peak flow estimations were made using the guidelines outlined in USGS Bulletin 17B. The results of this analysis are provided in Table 5.

Table 5 – Minor Flood Flows USGS Gage 08216500

Recurrence	Discharge (cfs)
1-Year	50
1.25-Year	115
1.5-Year	139
2-Year	186

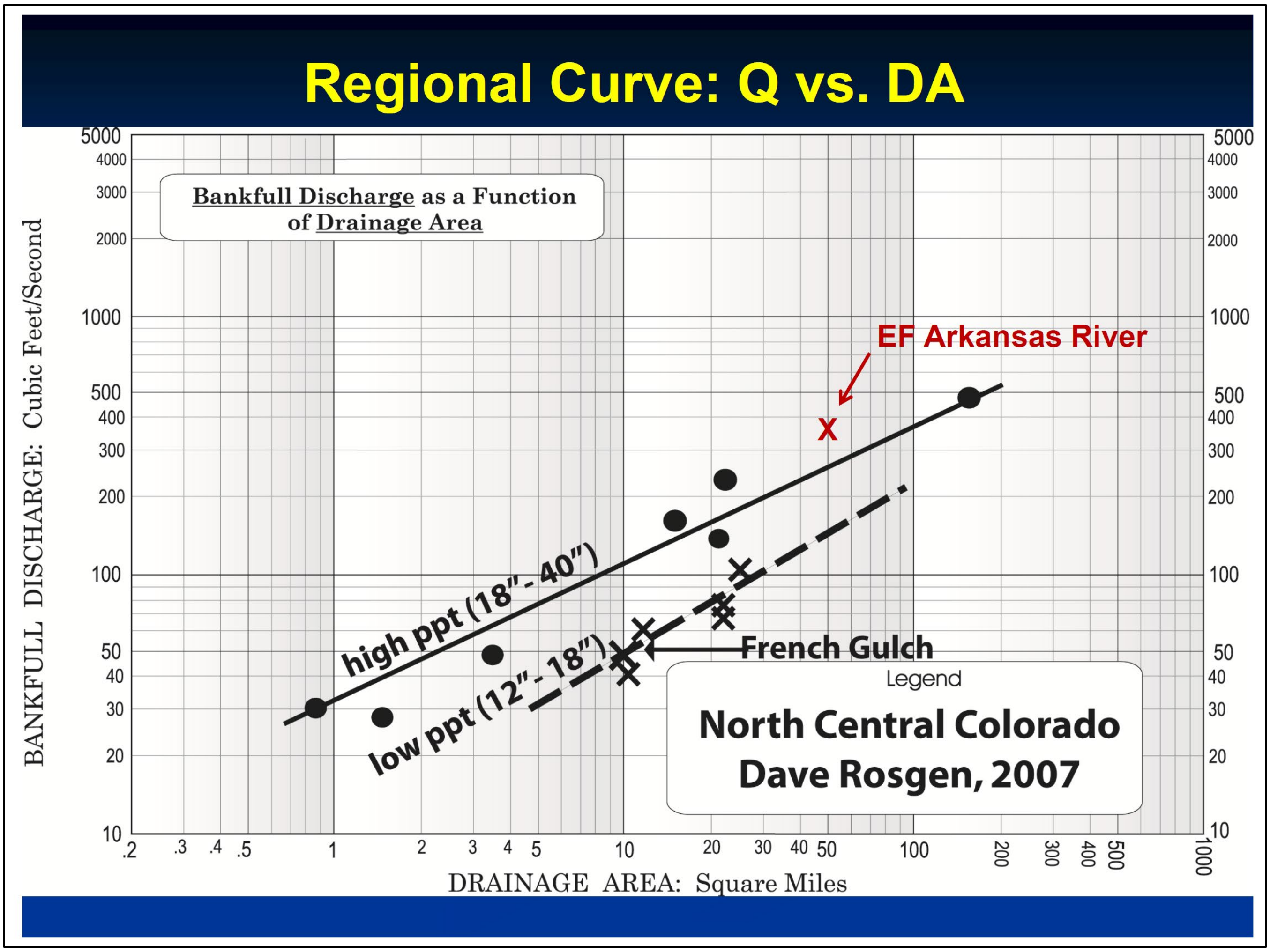
Bankfull Flow

Bankfull flow is a frequently occurring peak flow that occurs at a stage within the channel that corresponds to the incipient point of flooding. Estimations of bankfull flow, and bankfull cross section area, were made using the following methods:

1. Regional curves developed for Central Colorado (Rosgen 2007).
2. Field-based estimations that rely on bankfull indicators such as:
    a. The point of incipient flooding and/or highest depositional feature.
    b. Changes in vegetation.
    c. Changes in particle size distribution.
    d. Staining of rocks.

A bankfull flow of 200 cfs was estimated using the regional curves developed for Central Colorado (Figure 1, Rosgen 2007).

Figure 5. Regional Curve for Central Colorado



Field-based estimations of bankfull flow were made on West Willow Creek at a location where the stream cross section was in stable condition, and also appeared to have been stable for the past several years based on review of historical aerial imagery (Figure 5). The drainage area at this location is approximately 12.4 square-miles and the estimated bankfull cross section area is 11.9 square-feet. The bankfull cross section area was scaled based on drainage area in order to estimate bankfull flow at the Project site. The results of this analysis showed that the bankfull flow is approximately 140 cfs.

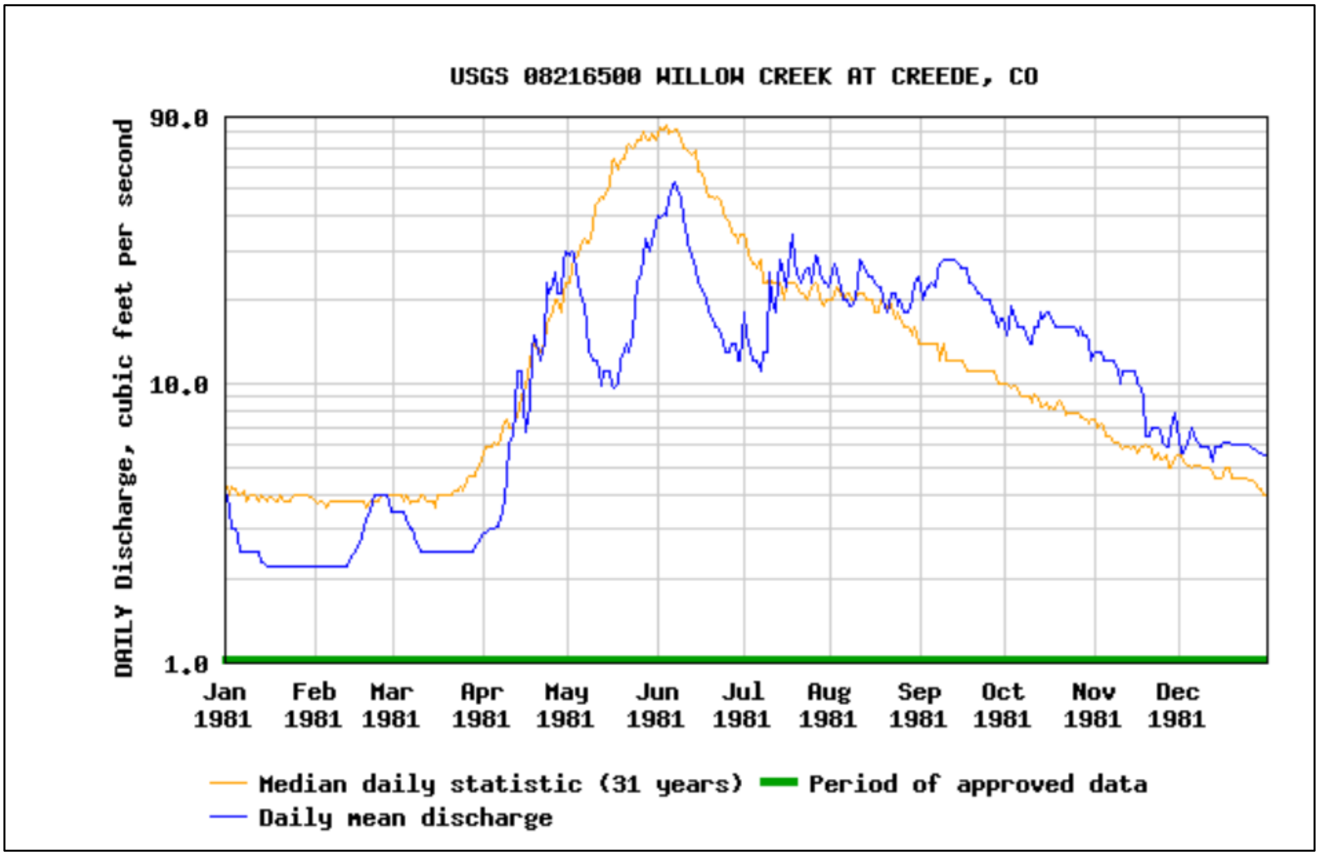
Figure 6. Reference Cross Section on West Willow Creek

A bankfull flow of 140 cfs is recommended for this Project based on a general agreeance of results between the regional curve, statistical analysis of USGS gage data, and field-based estimations of bankfull flow.

Low Flow Discharge

The low flow discharge generally represents baseflow conditions. The low flow channel, also known as the inner berm channel, is a smaller channel that is nested within the bankfull channel and has a cross section area that is generally 20% to 30% of the bankfull cross section area. The average mean daily flow for the Project is about 7 cfs (Figure 6) according to data recorded in 1981. However, based on measurements taken during field assessment work the low flow discharge was around 14 cfs. The inner berm cross section area for this project was sized using mean daily flow data, reference reach data, and further refined to meet sediment transport capacity goals.

Figure 7. Mean Daily Flow at USGS 08216500 (1981)



Geomorphic Channel Design

The geomorphic channel design for this Project was based on the design protocols outlined in NRCS NEH 654 (NRCS 2008). The natural channel design geometry was developed with information from the reference reach survey, industry-standard design criteria (referenced below), and validated with hydraulic and sediment transport modeling. A summary of geomorphic channel design parameters used for this Project are provided in Figure 7 and Figure 8. The proposed design parameters were developed with the following data sources and criteria:

- Existing conditions geomorphic survey.
- Reference reach data.
- U.S. Army Corps of Engineers, Hydraulic Design of Stream Restoration Projects (USACE 2001).
- Natural Resources Conservation Service, National Engineering Handbook Part 653 (NRCS 2010).
- A View of the River (Leopold 2006).
- River Morphology & Applications (Wildland Hydrology 2008).

The design parameters highlighted in red text fall outside of typical geomorphic channel design parameters and are caused by constraints throughout the Project corridor. In these areas, additional structure or stabilization measures were incorporated to provide additional protection.

Figure 8. Geomorphic Channel Design Parameters (Planform)

DIMENSIONLESS VALUES														
Parameter	NRCS NEH Part 654[1]		Applied River Morphology[2]		A View of the River[3]		River Restoration & NCD[4]		Reference Reach			Proposed Design		
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Average	Max	Min	Average	Max
Pool to Pool Spacing	4.0	10.0	4.0	5.0	N/A	N/A	5.0	7.0	3.2	4.6	6.6	3.0	4.4	7.6
Radius of Curvature	1.5	4.5	N/A	N/A	2.3		2.5	3.5	2.5	3.5	5.0	2.5	5.4	7.5
Meander Wavelength	11.3	12.5	10.0	14.0	10.0	14.0	10.0	14.0	7.3	9.2	11.0	6.4	8.8	13.9
Sinuosity	1.0	2.0	>1.2		N/A	N/A	1.6		1.1			1.1		
Belt Width	N/A	N/A	N/A	N/A	N/A	N/A	4.0	14.0	3.3	3.8	5.0	2.5	3.0	6.1
Riffle Length	N/A	N/A	N/A	N/A	N/A	N/A	2.0	3.0	1.3	2.8	3.5	1.0	2.7	4.2

DIMENSIONAL VALUES														
Parameter	NRCS NEH Part 654[1]		Applied River Morphology[2]		A View of the River[3]		River Restoration & NCD[4]		Reference Reach			Proposed Design		
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Average	Max	Min	Average	Max
Pool to Pool Spacing (ft)	80	200	80	100	N/A	N/A	100	140	64	93	133	61	88	153
Radius of Curvature (ft)	30	90	N/A	N/A	46		50	70	50	71	100	50	107	150
Meander Wavelength (ft)	225	249	200	280	200	280	200	280	146	184	221	128	176	277
Sinuosity	1.0	2.0	>1.2		N/A	N/A	1.6		1.1			1.1		
Belt Width (ft)	N/A	N/A	N/A	N/A	N/A	N/A	80	280	66	75	100	50	60	122
Riffle Length (ft)	N/A	N/A	N/A	N/A	N/A	N/A	40	60	26	56	70	21	53	85

Notes:

[1] Natural Resources Conservation Service, *National Engineering Handbook, Part 654, Chapter 12,* August 2017.

[2] Wildland Hydrology, *Applied River Morphology*, 1996.

[3] Leopold, Luna B., *A View of The River*, 2006.

[4] Wildland Hydrology, *River Restoration & Natural Channel Design Course & Manual*, October 2013. C4/B4 stream type.

Figure 9. Geomorphic Channel Design Parameters (Riffle Cross Section)

Parameter	Reference	Design
Abkf (ft2)	26.5	26.2
Wbkf (ft)	23	19.8
Dbkf (ft	1.15	1.32
W/D	20	15
Dmax (ft)	1.9	2.25
Entrenchment Ratio	2.3	2.6

Sediment Transport Modeling

Sediment transport analyses were performed for the proposed design to ensure that:

1. The design is competent, meaning that it has the stream power to move the largest particle being supplied from the upstream stream system.
2. The design has the capacity to move the total volume of sediment being supplied from the upstream stream system.

The competence for the proposed design was performed using data from the active-bed riffle pebble count, bar sample, surveyed longitudinal profile, and surveyed cross sections. Competence calculations are performed with two sets of equations: one for dimensionless shear stress and one for dimensional shear stress. In order for the dimensionless shear stress equations to be used the ratio of the riffle d50 to bar d50 needs to be between 3 and 7 or the ratio of the riffle Dmax to riffle d50 needs to be between 1.3 to 3. The results of the competence analysis are provided in Table 6.

Table 6 - Sediment Competence Analysis Results for Proposed Design

Proposed Design		Required		Largest Available Particle (mm)	Largest Predicted Particle (mm)	Competent?
Depth (ft)	Slope (ft/ft)	Depth (ft)	Slope (ft/ft)			
1.32	0.0227	0.84	0.0145	128	240	Yes

Sediment capacity for the Project Reach was computed using the procedure outlined in the NRCS National Engineering Handbook Part 654 along with the FLOWSED and POWERSED models embedded within the RiverMorph software package. Sediment transport capacity results for the proposed design are provided in Table 7.

Table 7 - Sediment Capacity Analysis for Proposed Design

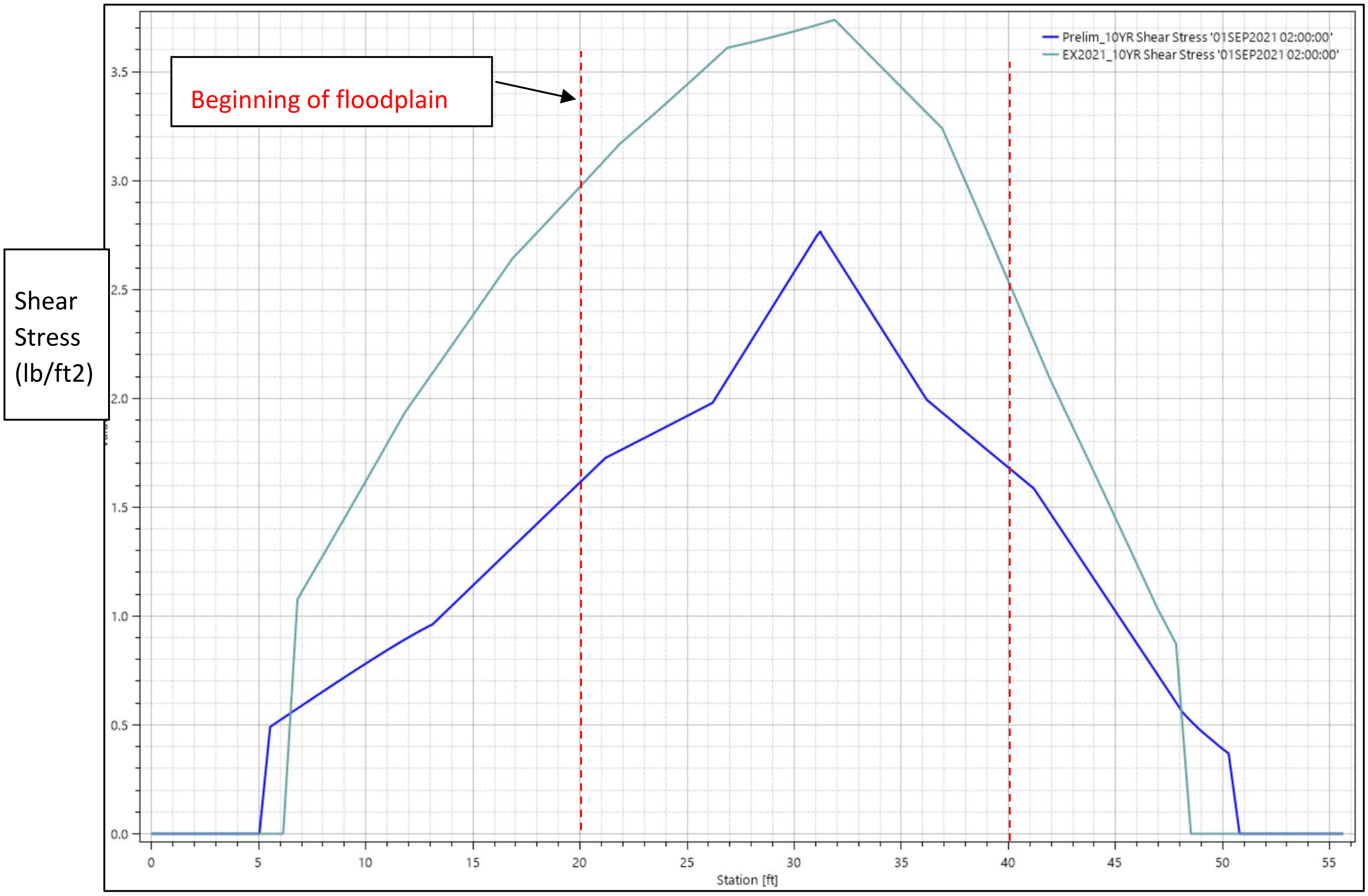
Sediment Transport Capacity (tons/year)			Result
Upstream Supply	Project Reach	Difference	
4,130	2,924	-1,206	Aggrading

As shown in Table 7, the proposed design does not have sufficient capacity to convey the incoming sediment load. As a result, it is recommended that the sediment basin upstream of the bridge be installed to capture excess sediment prior to constructing the West Willow Creek stream restoration work.

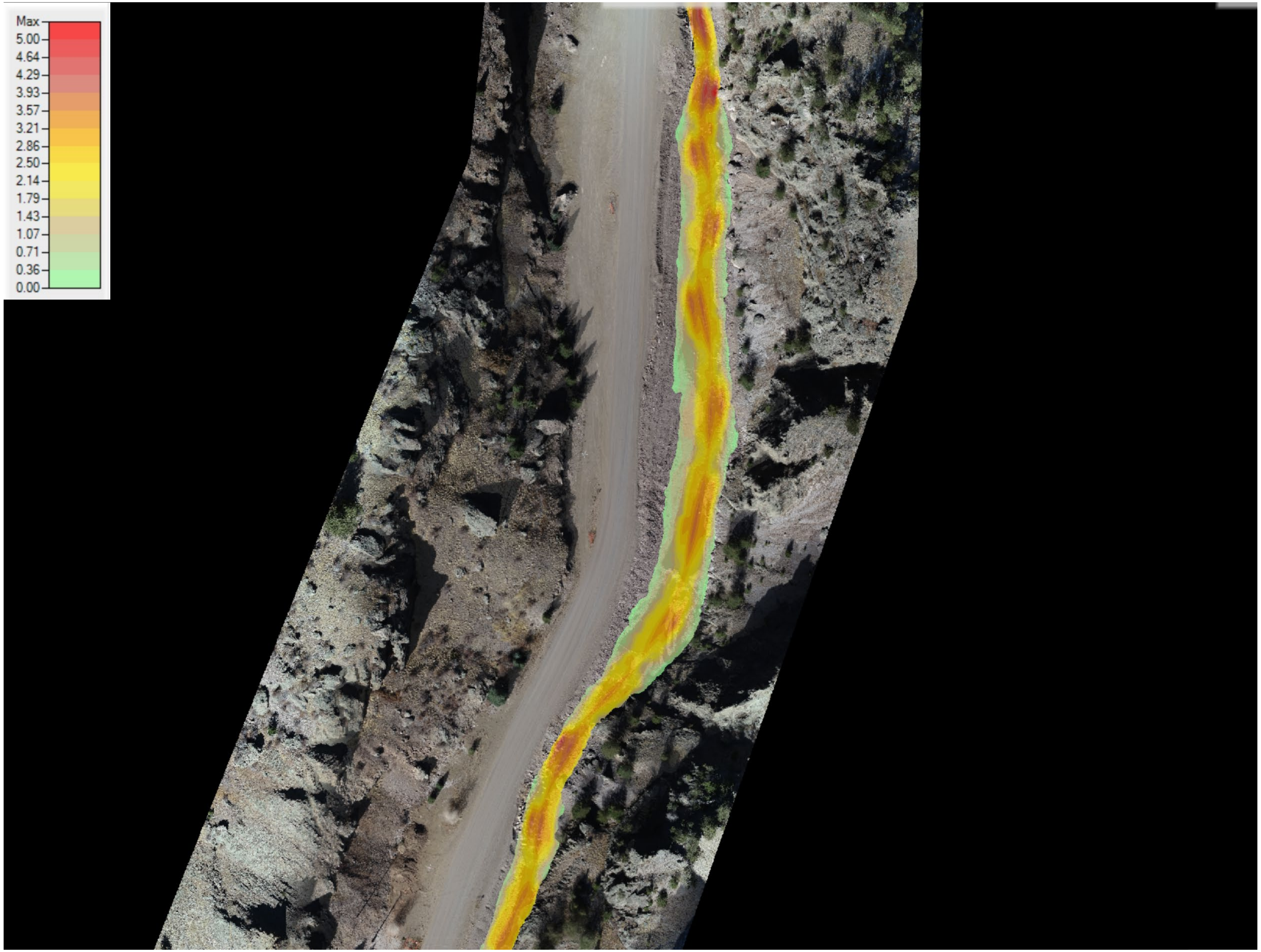
Hydraulic Analysis

The proposed bankfull channel cross section has an average flood prone width of approximately 52 feet. The flood prone area (geomorphic floodplain) was optimized to convey as much flow as within the lateral constraints imposed throughout the Project corridor. Vegetated floodplains can generally withstand a maximum shear stress of 2 pounds-per-square foot, which for this Project corresponds to the 10-year flood. Average shear stress values on the proposed floodplain for the 100-year flood are about 2.5-3 pounds-per-square-foot and will likely cause some floodplain erosion. A comparison of shear stress values for existing and proposed conditions is shown on Figure 9. The maximum shear stress will occur in the deepest portion of the channel and the average, to lower, shear stress values will occur on the floodplain benches.

Figure 10. Cross Section Shear Stress Comparison



Graphics showing shear stress values for the 10-year flow are provided on the following pages. The-year flood is approximately the largest flood that be conveyed on the proposed floodplain prior to floodplain erosion occurring.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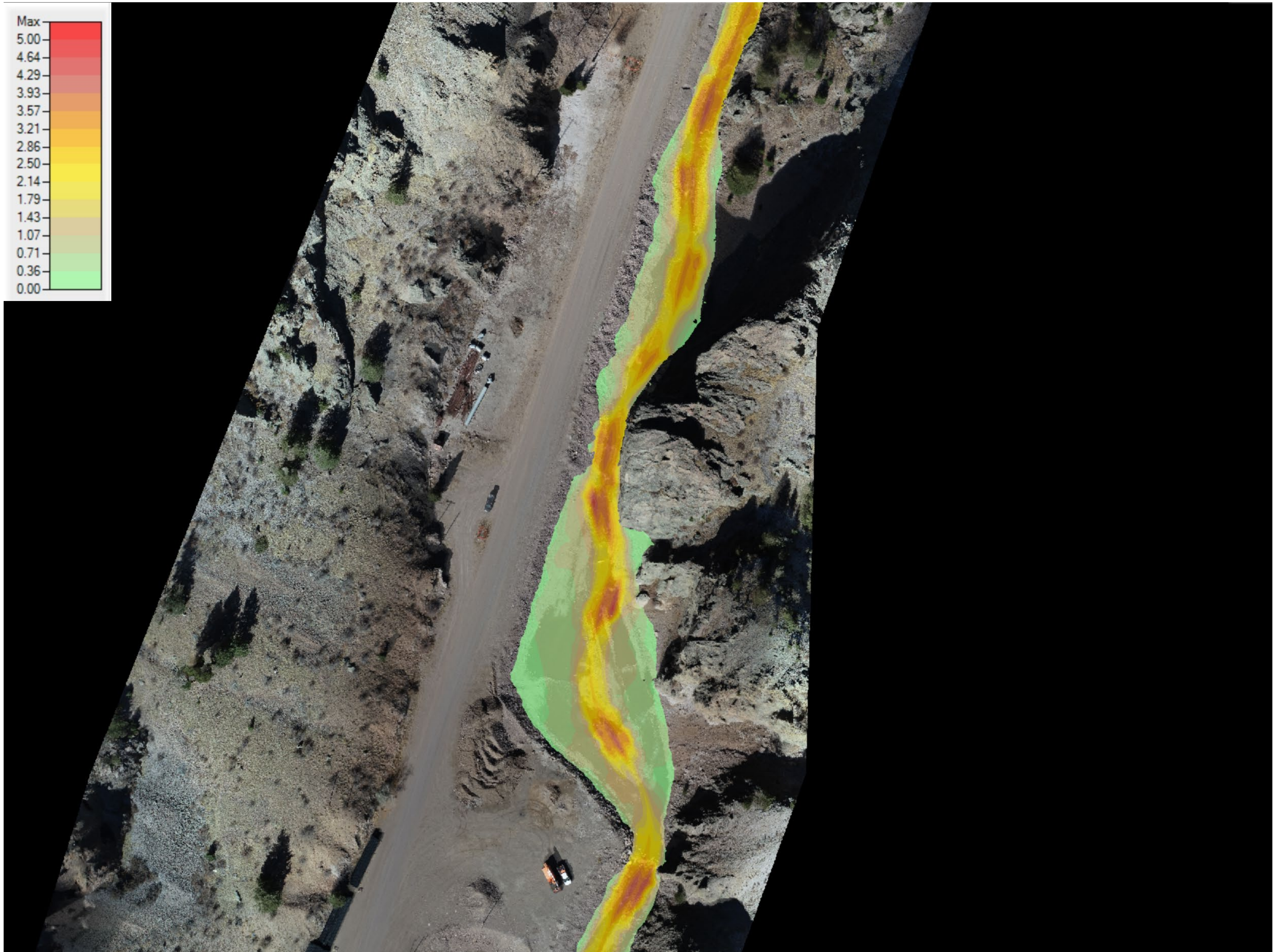
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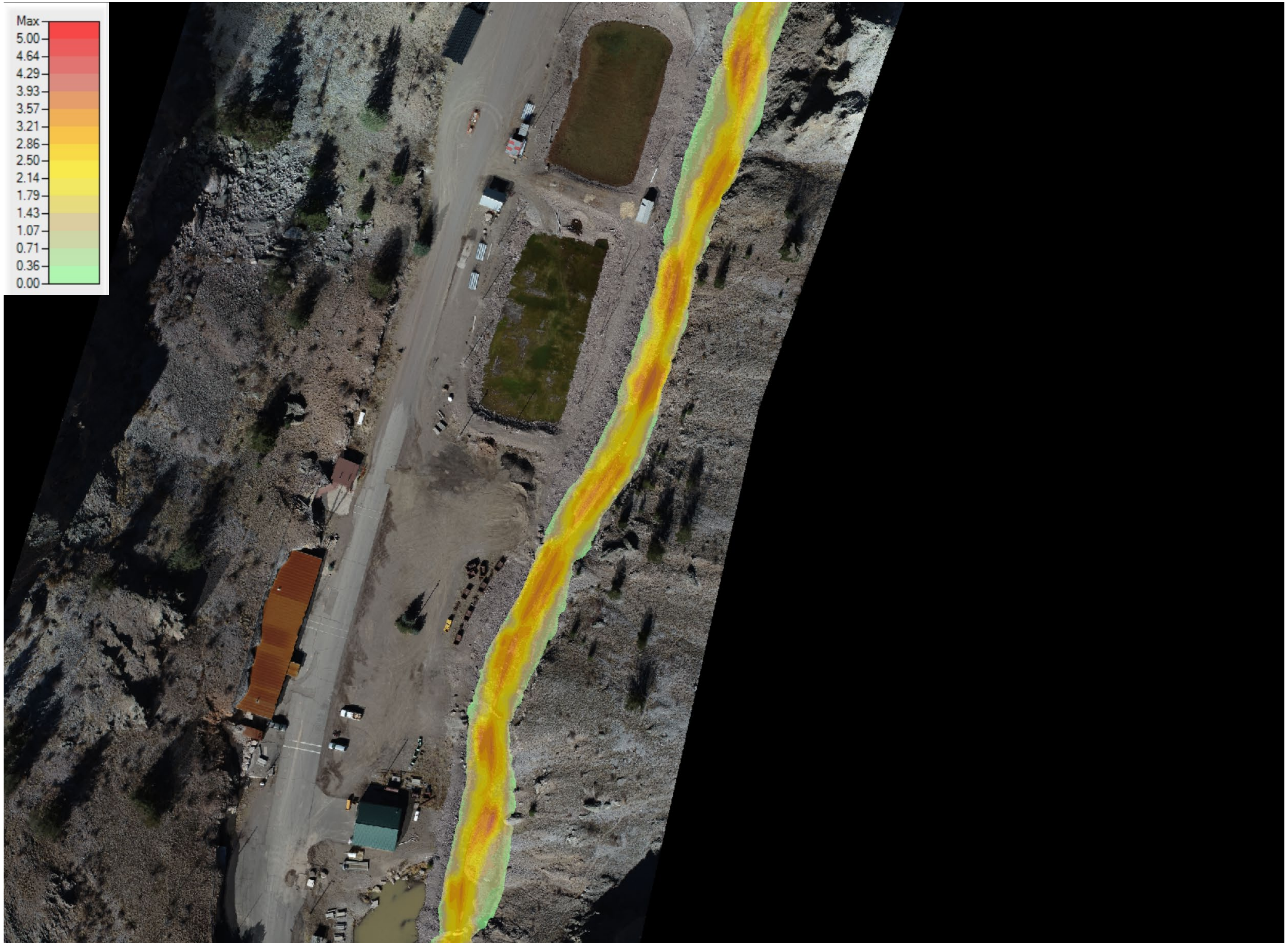
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In-Stream & Channel Bank Structures

Structures are incorporated into stream restoration projects to:

- Provide additional stability to the channel dimension, pattern, and profile.
- Incorporate planform and bedform diversity.
- Provide aquatic and terrestrial habitat.

Boulder Riffles

Boulder riffle structures were placed at locations where there are risks of vertical instability and serve to protect against this instability. Boulder riffle structures serve to establish grade control and to provide varied flow vectors throughout a riffle section by implementation of a series of boulder sills and small pocket pools. The sills help to protect the channel banks by directing the flow away from the bank and dissipating energy in the pocket pools. Footer boulders are placed under the sills in the channel bottom for stability with the top of the footer boulder at the channel invert elevation. The header boulders are placed on top of the footer boulders and extend above the channel invert elevation to create a complex and dynamic flow pattern and increase the roughness of the channel bottom to dissipate energy. Constructed riffles oxygenate the water, provide cover for macroinvertebrates, and scour small pools that provide habitat for other aquatic wildlife.

Note that not all riffles will be constructed as static boulder riffles. All other riffles shown on the design plans will be constructed from native, screened, alluvium.

Brush Toe Bank Protection

Brush toe bank protection is a structure consisting of natural materials to reinforce the channel bank, typically along the outside of a meander bend. The overlapping rows of layered coarse woody material, live stakes and/or willow whips, and soil lifts create an interlocking matrix. A layer of soil with riparian plantings and live stakes are installed on top to provide further reinforcement. Brush to bank protection was placed on the outside of most meander bends, except in locations that would adversely impact other proposed restoration treatments.

Floodplain Assemblage

Anchored wood floodplain assemblages are intended to mimic the natural roughness imparted by natural floodplain vegetation during flood flows. These structures were placed in locations where the floodplain will be re-graded and have a short-term elevated risk to floodplain erosion while vegetation becomes established. Anchored wood floodplain assemblages were placed outside of the limits of the bankfull channel on the adjacent floodplain.

J-Hook

J-Hook vane structures are used for stream bank stabilization and flow vector control by redistributing velocity, shear stress, and stream power towards the center of the channel. These structures also improve aquatic habitat in perennial channels by creating holding pools and promoting the development of spawning habitat in the glides downstream of the pool. These structures are typically constructed with two rows of boulders.

Revegetation Plan

The revegetation plan for the Project was developed around using the native, on-site plant materials. The design maximized the size of lower floodplain benches whenever possible. These benches were designed to frequently flood during high flow events or be positioned low enough to consistently receive alluvial groundwater, which will provide the appropriate water regime to support a diverse and productive wetland and riparian system. The restored system will mimic the natural system that was lost or impaired and is comprised of three vegetation "zones." These zones generally include channel edge (mainly herbaceous plants or emergent wetland), lower riparian (shrub-dominated, often wetlands, typically willow), and upper riparian (shrubs and trees--mainly willow and cottonwood but usually non-wetland). These habitats are essential for the health of any watershed and are mainly supported by high alluvial groundwater or regular overbank flooding. They provide key habitat for a myriad of wildlife species, serve as movement corridors to link areas of larger habitats, provide bank protection and overall channel stability, enhance water quality, reduce flooding in downstream areas, and promote groundwater recharge.

Coordination with Adjacent Projects

The City of Creede is working with Rentricity to design a hydroelectric facility at the upstream entrance of the Willow Creek Flume. The proposed diversion structure will be placed at the entrance of the flume and will connect to the downstream terminus of this Project. WaterVation had two preliminary design coordination meetings with Rentricity to discuss high-level coordination logistics such as horizontal alignment, vertical alignment, and cross section configuration of the proposed stream and flume. At this time it does not appear that there will be any issues implementing both projects as they are currently designed. It is recommended that additional design coordination happen as both designs progress.

Stream Gage Relocation

The existing USGS stream gage at the upstream entrance of the Willow Creek Flume will be relocated as a part of this Project. It is recommended that this gage be relocated approximately 25 feet upstream of the existing flume entrance where a new boulder riffle structure will be installed. This structure will serve as a stable hydraulic control cross section where a reliable stage-discharge relationship can be established for long-term readings.

Alternately, the gage could be installed within the diversion structure proposed for the hydroelectric project. This concept was discussed with the Rentricity team, who were amenable to the idea. Additional discussions about gage relocation will be had with both design teams as each design progresses.

Amethyst 5 Mine Site

The existing culvert under the access road for the Amethyst 5 Mine (red line shown in Figure 10) is currently impeding stream flows and trapping flood debris. The constriction of flood flows is causing downstream channel degradation and the trapping of flood debris is partially blocking the entrance to the culvert. Both of these conditions are exacerbating flood-related risks and should be mitigated.

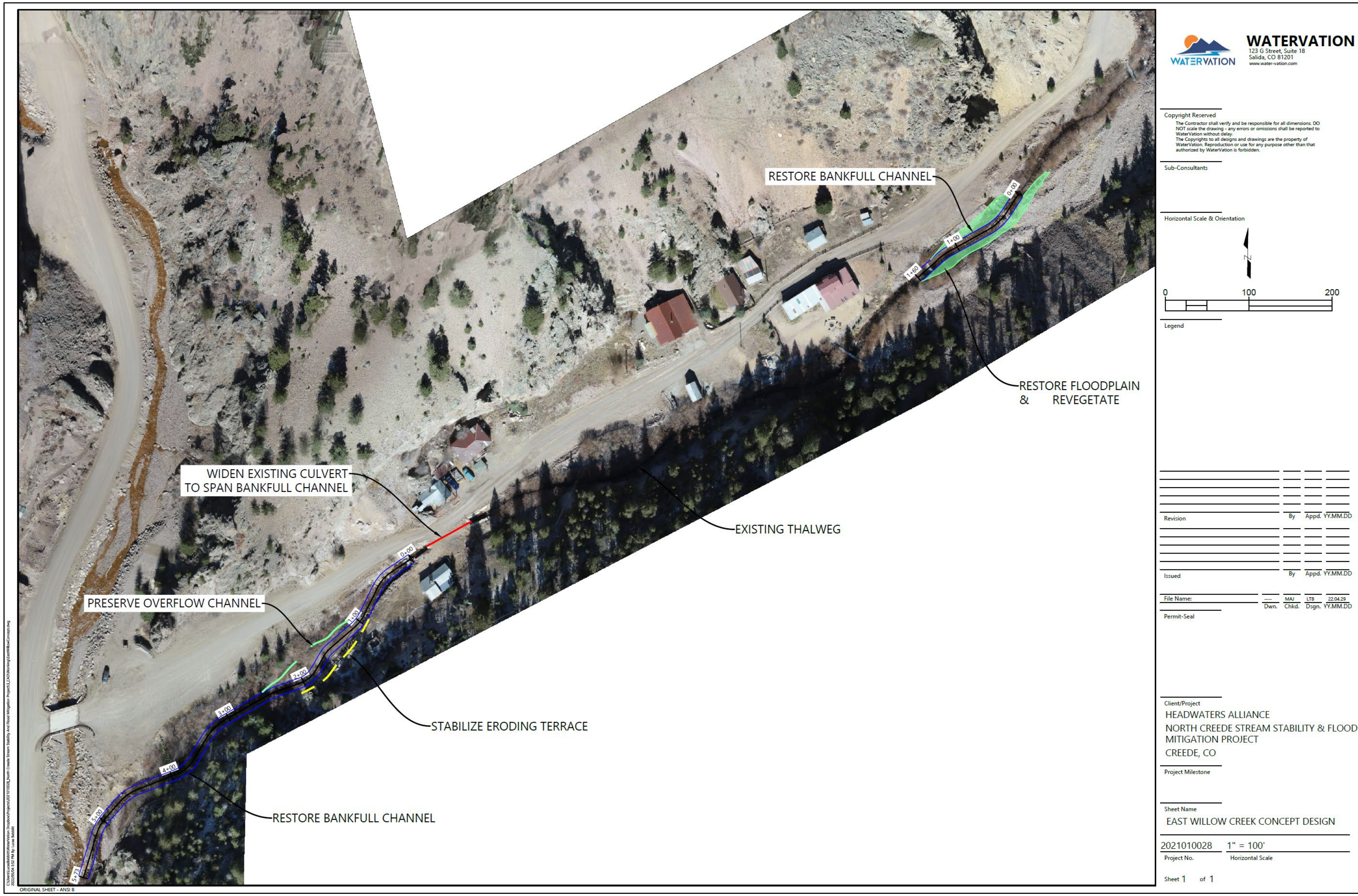
There are a couple of options to address the issue at this location, both are contingent on the removal of the existing culvert and debris screen. The crossing could then be replaced with a low-water crossing or three-sided soft bottom culvert that spans the bankfull channel. With either option, the downstream end of the crossing could be enhanced by transitioning stream grade with a step-pool boulder structure to more gently transition flows and reduce erosion risk.

The construction cost associated with either improvement option will likely range between $50,000 to $100,000.

Figure 11. Amethyst Mine Culvert

East Willow Creek Concept Design

The conceptual design for East Willow Creek is provided on the following page.


RESTORE BANKFULL CHANNEL
RESTORE FLOODPLAIN & REVEGETATE
WIDEN EXISTING CULVERT TO SPAN BANKFULL CHANNEL
EXISTING THALWEG
PRESERVE OVERFLOW CHANNEL
STABILIZE ERODING TERRACE
RESTORE BANKFULL CHANNEL
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Sub-Consultants
Horizontal Scale & Orientation
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NORTH CREEDE STREAM STABILITY & FLOOD MITIGATION PROJECT
CREEDE, CO
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1" = 100'
Project No.
Horizontal Scale
Sheet 1 of 1
ORIGINAL SHEET - ANSI B

References

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Appendix

Calculations to be provided here for final submittal.