UmaBirch Instream Design and Construction Oversight Project

Project Area 4 Birch Creek Instream Enhancement and Floodplain Restoration

Appendix B

Engineering Analyses

90 Percent Design

Prepared for:

Confederated Tribes of the Umatilla Indian Reservation
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May 2021

TETRA TECH

TECHNICAL MEMORANDUM

To:	Confederated Tribes of the Umatilla Indian Reservation
Cc:	
From:	Chad McKinney, PE, CFM, Jeremy Andrews, PE, and Chris James, CWM, CERP (Tetra Tech, Inc.)
Date:	May 7, 2021
Subject:	Engineering Analyses: Project Area 4 Birch Creek Floodplain Restoration and Instream Enhancement – 90 Percent Design

1. Introduction

Tetra Tech submitted a 60 percent design accompanied with the original version of this technical memorandum (Appendix B-1) on March 20, 2020. Based on series of comments, meetings, and requests for revisions from the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and Bonneville Power Administration (BPA) during the summer of 2020, Tetra Tech submitted a revised Appendix B-1 on September 11, 2020. Following subsequent review comments and meetings with the CTUIR and BPA, the design approach was revised by March 10, 2021. These revisions were then presented to the CTUIR and BPA on March 10, 2021. Additional comments and further directions were provided by BPA in notes provided on March 16, 2021. Part of the direction included in the notes was instructions to further revise Appendix B-1. The results of those required revisions have been incorporated and are reflected below and throughout the entire 90 percent submittal.

This technical memorandum provides a summary of the engineering analyses performed for the Project Area 4 Birch Creek Floodplain Restoration and Instream Enhancement (Project), 90 percent design. Engineering analyses include a hydrologic analysis and hydraulic modeling to provide design peak flow rates, water surface elevations, velocities, and flow depths necessary to perform the calculations and analyses detailed in the sections below. The results of the proposed hydraulic model were extracted, and the information utilized to evaluate sediment mobility for streambed gravel, grade stabilization measures in the proposed channel, large woody material (LWM) ballast boulder sizing, and LWM stability for the Project. An incipient motion analysis was performed to evaluate sediment mobility and vertical stability of the existing and proposed channel conditions. In addition, a general scour analysis was performed to evaluate the grade stabilization measures in the proposed channel, boulder sizing calculations were performed to size the boulders to be used for LWM ballast, and LWM buoyancy and sliding calculations were performed to evaluate stability for each LWM structure. The 10-Log, 11-Log, and Bank Habitat structures were designed to be stable up to and including the 25-year recurrence interval. The Channel Spanning and Debris Jam structures were designed to be stable up to and including the 100-year recurrence interval, or inflow design flood (IDF).

1.1 Objective

The objective of this technical memorandum is to document the calculations and design for channel stability, including channel gravel and grade stabilization measure material, LWM ballast boulder sizing, and LWM structure stability in the event of an IDF. The components covered in this technical memorandum are outlined below:

- Analyze the sediment mobility of the existing and proposed channel;
- Calculate the size of the proposed conditions channel gravel;
- Calculate the size and dimensions of the grade stabilization measures;
- Calculate the size of the boulders for LWM ballast; and
- Evaluate LWM structure stability.

2. Methodology and Analyses

The subsequent sections describe the design criteria, engineering calculations, and results of the engineering analyses performed.

2.1 Design Criteria

As developed and agreed upon through a series of documents and meeting notes dated January 21, 2021, as well as additional BPA direction in notes from March 16, 2021, design criteria includes:

- Velocities and shear stresses shall demonstrate the creation of depositional/slow-water environments in the existing channel alignment and across the floodplain. Typical shear stresses shall range between less than 0.1 pound per square foot (lb/ft^2)and 0.3 lb/ft^2 and velocities shall range between less than 3 feet per second (ft/sec) and 5 ft/sec across the entire floodplain and the existing channel alignment. This will include demonstrating that stability -erosion thresholds are not exceeded based on the particle size of existing and/or placed materials. Particular focus shall include locations of hydraulic control (e.g., colluvial fan development locations) and locations where flows (channel or overland) converge with or diverge from the existing channel alignment. The focus for flow evaluation shall be with the 2-and 10-year recurrence interval. Results may demonstrate localized scour/erosion at LWM at locations of proposed LWM structures, but overall conditions shall be shown to be stable or depositional based on desired conditions at a given location within the reach.
- Primary hydraulic control within the existing channel alignment shall be through emulation of natural processes including colluvial fan development, beaver complex creation, and debris jams. Secondary hydraulic control will be demonstrated through increased roughness, and the analyses shall provide justification for assigned friction values and hydraulic results.
- Valley-wide cross sections shall be evaluated at flows greater than the 5-year recurrence interval. Maximum water surface elevations will vary by flow; however, there will be less than 1-foot of water surface elevation variation for all flows equal to or greater than the 5-year recurrence interval across any valley-wide cross section. Partitioned flow that overtops features will not result in erosion or head cutting based on shear stresses less than 0.1 lb/ft^2 and velocities less than 3 ft/sec.
- Streambed gravel mobility initiation above the Ordinary High Water (OHW) event.

- Grade stabilization measures stable to the IDF.
- LWM ballast boulders stable to the IDF.
- Habitat LWM structures stable to the 25-year recurrence interval.
- Channel Spanning and Debris Jam LWM structure stable to the IDF.

The hydrologic inputs, hydraulic model results, and engineering calculations described in the subsequent sections satisfied the design criteria above for the proposed Project actions.

2.2 Hydrologic Analysis

The Project is located within a FEMA Approximate Zone A floodplain as shown on the Flood Insurance Rate Map (FIRM) panel 41059C1013G (FEMA 2010a). The Flood Insurance Study (FIS) for the Umatilla County, Oregon and Incorporated Areas (FEMA 2010b) reports how the study defined peak flow data for the Umatilla River and Birch Creek. The peak flow data calculated for the Umatilla River was determined using streamflow data from the Pendleton gage, USGS 14020850, while the peak flow data calculated for Birch Creek utilized a regional relationship between basin characteristics and streamflow statistics. The peak flow values utilized in the FIS are tabulated below (Table 2-1).

Table 2-1. FIS Umatilla River and Birch Creek Peak Flows

Recurrence Interval (year)	Peak Flow (cfs)	
	Umatilla River	Birch Creek
10	11,200	2,775
50	18,400	4,500
100	22,200	5,310
500	32,700	7,570

cfs – cubic feet per second

The hydrologic analysis for this Project began by utilizing the Oregon Water Resources Department (OWRD) Peak Discharge Estimation Mapping Tool. USGS 14025000 was identified as an inactive site on Birch Creek near Rieth, Oregon. The gage recorded streamflow data for a period of 47 years from 1928 to 1976, is located near the Taylor Lane bridge on Birch Creek, and is within the Project limits. The recorded data for this gage was used to determine the peak flows on Birch Creek utilizing Hydrologic Engineering Center's Statistical Software Package (HEC-SSP) to perform a flood flow frequency analysis of the gage data based on Guidelines for Determining Flood Flow Frequency Bulletin 17C, a generalized frequency analysis of flow data, volume frequency analysis on high and low flows, duration analysis, coincident frequency analysis, and a balanced hydrograph analysis (USGS 2019). Results of the HEC-SSP Bulletin 17C analysis are tabulated below (Table 2-2).

Table 2-2. Birch Creek Peak Flows

Recurrence Interval (year)	Peak Flow (cfs)
2	573
5	1,090
10	1,570
25	2,360
50	3,050
100	3,800

cfs – cubic feet per second

The Birch Creek peak flows utilized in the FIS were significantly higher than those recorded by the gage. Based on the period of record for USGS 1402500 (47 years) on Birch Creek, it was determined that gage data was the most accurate representation of the peak flows, rather than a regional relationship and regression analysis.

Lastly, the OHW event was determined using survey data and model calibration relationships. The final flow values utilized in the hydraulic analysis are provided in Table 2-4.

Table 2-4. Birch Creek Modeled Flows

Recurrence Interval (year)	Birch Creek Flow (cfs)
OHW/1	375
2	573
10	1,570
25	2,360
50	3,050
100	3,800

cfs – cubic feet per second
/1 OHW was determined using survey data and model calibration relationships

2.2 Hydraulic Analysis

Restoration designs require a fundamental model to evaluate the hydraulic behavior of the existing and proposed conditions. A detailed two-dimensional (2D) model utilizing GeoHECRAS version 3.1 (March 25, 2021 release) was generated, coupled with AutoCAD Civil 3D (Civil 3D) 2020 as the primary software applications. GeoHECRAS combines Geographic Information Systems (GIS) and Hydraulic Engineering Center – River Analysis System (HEC-RAS) version 5.0.7 software (USACE 2019) into one user interface for efficient task management, while Civil 3D was used as the main engine behind surface generation.

2.2.1 Existing Conditions Modeling

Existing conditions hydraulic modeling was conducted for flow recurrences for the OHW, 2-, 10-, 25-, and 100-year peak flows. Topobathymetric survey and light detection and ranging (LiDAR) data were used for the existing terrain. Modifications to the existing terrain were created based on the proposed Project actions.

The Geolocation feature within GeoHECRAS was used to overlay an aerial map on the Project extents. Based on the aerial map, a land cover file was generated for Manning's roughness values (Table 2-5). The existing channel roughness was estimated at 0.040 based on site observations and engineering judgement.

Table 2-5. Manning's Roughness Values by Land Use

Land Use/Land Cover	Manning's n Value
Scrub	0.050
Road	0.020
Agriculture	0.040
Residential	0.100
Channel	0.040

Boundary conditions were set for each terminus, including inflow at the upstream end representing the Birch Creek flow rate, and normal depth at the downstream end representing the energy slope measured downstream. After entering the geometry and hydraulic parameter information, unsteady flow analyses were computed to review geometry input parameters and model results for the existing conditions.

2.2.2 Proposed Conditions Modeling

Proposed design conditions were modeled at the OHW, 2-year, 10-year, 25-year, and 100-year modeled flow events to identify outcomes of proposed actions. As a result of the design, terrain modifications were inserted into the model to represent the proposed conditions. Roughness values were updated based on proposed channel alignments, grade stabilization measures, wetlands, and LWM structures. Hydraulic model results are provided in Attachment 1.

Table 2-6. Manning's Roughness Values by Land Use

Land Use/Land Cover	Manning's n Value
Scrub	0.050
Road	0.020
Agriculture	0.040
Residential	0.100
Channel	0.040
Grade Stabilization Measures	0.060
Wetland	0.045
LWM	0.150

Results of the hydraulic model produced depth, velocity, and shear stress raster data sets to be utilized in the engineering design calculations. See Attachment 1 for detailed comparisons of modeled existing and proposed inundation depth and shear stress and proposed 100-year velocity conditions. Additionally, water surface elevation (WSE) profiles of existing and proposed hydraulic modeling, are provided in Attachment 2.

The proposed overview plan sheet with five cross section plots at stations 11+00, 18+00, 23+50, 30+50, and 37+50 of the existing channel alignment is provided in Attachment 3. A comparison of the existing versus proposed terrain is provided for each cross section. Proposed hydraulic model results for WSE and flow split calculations for the proposed new channel and existing channel are provided in Attachment 3. See below for a list of the data provided for each cross section in addition to the existing and proposed terrain comparison:

- 11+00: OHW, 2-, 10-, 25-, and 100-year WSE and Flow Split;
- 18+00: OHW, 2-, 10-, 25-, and 100-year WSE;
- 23+50: OHW, 2-, 10-, 25-, and 100-year WSE;

- 30+50: OHW, 2-, 10-, 25-, and 100-year WSE; and
- 37+50: OHW, 2-, 10-, 25-, and 100-year WSE and Flow Split.

Table 2-7 below is a summarized table taken from the 90 percent Basis of Design Report, with updated proposed conditions floodplain connectivity metrics based on the hydraulic model results.

Table 2-7. Objectives, Metrics, and Existing, Target, and Proposed Conditions

Objective	Metric	Existing Condition	Target Condition	Proposed Condition
Increased floodplain connectivity	Percent of available floodplain area inundated at 100-year flood	41%	60-80%	61%
	Percent of available floodplain area inundated at 10-year flood	8%	30-40%	44%
	Percent of available floodplain area inundated at 2-year flood	5%	25-35%	30%

2.3 Vertical Stability

A sediment mobility and vertical stability analysis was performed for the existing channel, both upstream and downstream of the proposed project, and for the proposed channel geometry. Both analyses were evaluated using incipient motion calculations.

There are four grade stabilization measures at the downstream end of the proposed new main channel. The purpose of these measures is to prevent head cutting and vertical instability at this location. A general scour analysis was performed to design the depth of each measure and results of the incipient motion calculations sized the proposed material.

2.3.1 Incipient Motion

Incipient motion analysis evaluates the effective hydraulic shear stress on the channel bed with the shear stress required to mobilize the streambed materials (critical shear). The shear stress required for bed material mobilization was estimated using Shields relationship for particle motion (Shields 1936).

The Shields relationship is represented by:

$$\tau_c = \tau^*(\Upsilon_s - \Upsilon_w)D_{50}$$

Where:

τ_c = critical shear stress for particle motion
τ^* = dimensionless Shields Parameter
Υ_s = unit weight of the sediment
Υ_w = unit weight water

D_{50} = median particle size of the bed material

In gravel and cobble bed streams, when the critical shear stress for the median particle size is exceeded, the bed is mobilized and all sizes up to about five times the median size are capable of being transported by the flow (Parker et al. 1982; Andrews 1984).

Values for the Shields parameter (τ^*) can range from 0.02 for frequently moved loosely, packed gravel to 0.12 for tightly packed, imbricated material that results when transport is infrequent, and the framework gravel is in-filled with fines (Hey 1979). Research by Neil (1968) indicates that a Shields parameter value of 0.03 corresponds to particle incipient motion and a value of 0.047 represents low but measurable transport. In this analysis, a value of τ^* = 0.05 was used to represent the “threshold” or “incipient” motion condition while a value of τ^* = 0.052 was used to represent a low but measurable transport condition. For the grade stabilization measure material values of 0.052 and 0.054 were selected for the analysis.

The total hydraulic shear stress can be partitioned into grain shear stress (the stress acting on the grains) and the bedform stress (the stress acting on the bedforms) (Einstein 1950). The grain shear is the component that is responsible for bedload transport. The remaining shear stress is used to overcome the flow resistance of the bed forms.

The relationship for total bed shear stress is represented by:

$$\tau = \tau' + \tau'' = \Upsilon_w RS$$

Where:

τ' = grain shear stress
τ'' = form shear stress
Υ_w = unit weight water
R = channel hydraulic radius
S = energy slope

Einstein (1950) also determined that the hydraulic radius terms could be partitioned into a grain component and a form component such that:

$$\tau' = \Upsilon_w R'S$$
$$\tau'' = \Upsilon_w R''S$$

Where:

R’ = hydraulic radius associated with the grain roughness
R’’ = hydraulic radius associated with the form roughness

The value of R’ is solved iteratively by solving the semi-logarithmic velocity profile equation (Mussetter et al. 1994):

$$\frac{V}{V_*'} = 5.75LOG\left(12.27\frac{R'}{k_s}\right)$$

Where:

V = mean flow velocity
k_s = characteristic bed grain roughness
V_*' = shear velocity given by:

$$V_*' = \sqrt{gR'S}$$

Where:

g = acceleration due to gravity
S = energy slope

The characteristic bed grain roughness (Hey 1979) is k_s = 3.5D_{84}.

Critical discharge is the discharge at which the incipient motion threshold is exceeded. The critical discharge required for incipient motion (τ^* = 0.05) and for measurable transport (τ^* = 0.052) was estimated for each reach using the reach-averaged hydraulics.

2.3.2 Results

The attached Incipient Motion calculations provides the results of the sediment mobility and vertical stability analysis performed for the existing and proposed conditions. The analysis included parameters taken from several locations identified to best represent the Project reach and its proposed Project actions.

The analysis included average grain size distributions from multiple pebble counts for the Project reach. The existing streambed gravel has a D_{50} of 42.9 millimeters (mm) or 1.7 inches. The existing streambed gravel particle size was evaluated for the proposed streambed gravel utilizing incipient of motion at several recurrence intervals, including the OHW, 2-, 10-, 25-, and 100-year events. The results suggest that under existing conditions, the sampled bed material is transported at the OHW event for the grain shear and explains the incised creek under existing conditions. Under the proposed conditions, the existing streambed material is right at initiation of incipient motion and should maintain an equilibrium bed condition. If the underlying material in the proposed new channel does not resemble the old main channel material, or is finer than the old main channel material, proposed streambed sediment and cobble material shall be replaced meeting the requirements specified in Section 35 49 50 LWM AND CHANNEL STRUCTURES of the construction specifications.

2.3.3 General Scour

General scour estimates were performed via established empirical models (NRCS, Technical Supplement 14B Scour Calculations, 2007). Design flow, flow width, and median size of bed material served as inputs to the calculations. The critical grade stabilization measure used for the design of all four is located at a right-angle bend, therefore constants in the calculations resembled a right-angle bend condition. The general scour calculations were used to design the depth of the grade stabilization measure, while the incipient motion analysis was used to design the gradation of the proposed material.

2.3.4 Results

Results of the general scour calculations suggest a depth of 4.5 ft. for the grade stabilization measures. This depth was increased to 5.5 ft. to remain conservative and implore a factor of safety to the design. The results of the incipient motion calculation for grade stabilization measures suggest an 8-inch size cobble gradation, with the majority of the material to be 3.5-inch cobbles with some large stones in the 6-inch to 8-inch range. The specified gradation will resist measurable transport and be stable during the IDF. Detailed results of the general scour and incipient motion calculations are provided in Attachment 4.

2.4 Boulder Sizing

Two methods were used for sizing the LWM ballast boulders. The first method was the Highway Research Board (HRB) (1970) method. The HRB method uses an empirical equation relating critical shear and D_{50}. This empirical equation is a tractive force-based method and is given as:

$$\tau_c = 4D_{50};$$

Where τ_c is the critical shear stress in pounds per square foot and D_{50} is in feet.

In order to estimate the size of a boulder that cannot be mobilized by the IDF, the D_{50} is selected such that the critical shear of the stone matches the actual shear stress exerted by the IDF on the boulders in the LWM structure. The maximum shear stress was estimated as 1.5 times the average boundary shear stress (Chang 1992). The average boundary shear stress is calculated in HEC-RAS as:

$$\tau_{ave} = \gamma RS;$$

Where:

γ = the specific weight of water;
R = the hydraulic radius; and
S = the energy grade slope.

The D_{50} was calculated and the D_{100} was estimated by multiplying by a factor of 1.5.

The second method is a force balance method (Equation 7-1) from the Rock Ramp Design Guidelines (BOR 2007). Detailed calculations are provided in Attachment 4 and the results are discussed below.

2.4.1 Results

Boulders will be placed for added stability to the LWM structures designed to be stable to the IDF. Results of the stability calculations to size the boulders is provided in Attachment 4. The two analyses show a minimum FOS of 1.5 and 3.1 for 2.0 feet spherical diameter rocks and minimum weight of 691 pounds and 2.1 to 4.1 for 3.0 feet spherical diameter rocks and minimum weight of 2,333 pounds for LWM ballast boulders. Detailed results of the boulder sizing calculations are provided in Attachment 4.

2.5 LWM Stability

The ballasted LWM structures were evaluated for stability against buoyancy and sliding. These structures include the 10-Log, 11-Log, and Bank Habitat structures and the Channel Spanning and Debris Jam structures. The proposed LWM structure placements follow the BPA HIP conservation measures for Category 2d (Install Habitat-Forming Natural Material Instream Structures [Large Wood, Boulders, and Spawning Gravel]). In addition, all proposed LWM structures have been designed to generally follow placement strategies and size requirements outlined in the Oregon Guide to Placement of Wood, Boulders, and Gravel for Habitat Restoration (ODFW/ODF 2010), and the National Large Woody Material – Risk Based Design Guidelines (USBR 2014). All LWM structures have been designed for specific functions within the riverine ecosystem. The 10-Log, 11-Log, and Bank Habitat structures have been designed to withstand the forces generated by the 25-year recurrence interval, and the Channel Spanning and Debris Jam structures have been designed to withstand forces generated by the IDF, while continuing to perform their intended function.

The habitat structures are positioned throughout the reach to add hydraulic complexity, cover for juvenile rearing, support for pool formation and sediment sorting, while providing additional bank stability. The channel spanning structures are positioned to trap mobile wood and develop complex instream habitat and sediment sorting. The debris jam structures have been positioned throughout the Project reach at and in between proposed colluvial fan locations to assist with the creation of a depositional/slow-water environment in the existing channel alignment and across the floodplain, and promote beaver activity for further enhancement of the natural process. The debris jams have been positioned throughout the existing channel to meet design criteria for desirable velocities, shear stresses, and hydraulic control for the Project. The habitat structures were not evaluated for stability against the IDF as these structures are designed to be mobile and represent natural wood recruitment processes at high flows.

2.5.1 Buoyancy

Stability calculations for the proposed LWM structures, based on the standard force balance approach derived from D'Aoust and Millar (D'Aoust and Millar, 2000) coupled with the USBR USACE National Large Wood Manual (USBR 2016), are provided in Attachment 4. All structures were evaluated for a minimum FOS of 2.0.

2.5.2 Sliding

Siding calculations for these structures, based on the standard force balance approach derived from D'Aoust and Millar (D'Aoust and Millar, 2000) coupled with the USBR USACE National Large Wood Manual (2016), are provided in Attachment 4. All structures were evaluated for a minimum FOS of 1.75.

2.5.3 Results

Buoyancy calculations assumed that the entire structure was submerged while sliding calculations assumed a maximum drag force as water begins to flow over the structure and an average approach velocity and depth taken from the proposed 2D hydraulic model results. A summary of results of the LWM stability analysis are tabulated below.

Table 2-8. LWM Stability Results

LWM Structure	FOS Buoyancy	FOS Sliding
10-Log Habitat	2.03	1.93
11-Log Habitat	2.19	1.84
Bank Habitat	2.15	1.75
Channel Spanning	4.31	1.76
Debris Jam	2.02	11.1

Results indicate that each LWM structure will be stable to their respective design flows and are anticipated to function as designed. Detailed results of the LWM structure stability calculation are provided in Attachment 4.

3. Design Correspondence

Between March 2020 and April 2021, Tetra Tech completed several design iterations based on review and direction given in progress meetings with the CTUIR and BPA. The timeline of meetings and deliverables is provided below:

- March 20th, 2020 – Submitted 60 Percent Design
- April 14th, 2020 – 60 Percent Design Meeting with BPA and CTUIR
- April 15th, 2020 – Submitted JPA and Attachments to CTUIR
- April 30th, 2020 – Provided Success Criteria and Design Revisions Punch List to CTUIR
- June 11th, 2020 – BPA Provided HIP Review Comments
- August 19th, 2020 – Presented Design Overview and LWM Structure Types to CTUIR
- September 2nd, 2020 – CTUIR and BPA Design Coordination Meeting
- September 4th, 2020 – Hydraulic Modeling Engineering Review Meeting with BPA
- September 11th, 2020 – Submitted Revised 60 Percent Appendix B-1, Engineering Analyses
- November 11th, 2020 – BPA Provided Revised 60 Percent HIP Comments
- November 18th, 2020 – Environmental Compliance Kickoff Call with BPA and CTUIR
- November 18th, 2020 – PA 4 Design Comment Meeting with BPA and CTUIR
- November 18th, 2020 – BPA Provided Design Alternative Approach Figures
- November 23rd, 2020 – CTUIR Provided Comment Responses, Low Flow Fish Passage, and Planting Plan Details to BPA
- December 16th, 2020 – Technical Design Meeting with BPA and CTUIR
- January 7th, 2021 – BPA Provided Draft Hydraulic Design Criteria
- January 19th, 2021 – Provided Revised Design Criteria Vision Document

- January 20th, 2021 – Revised Design Criteria Vision Document Review Meeting with BPA and CTUIR
- February 10th, 2021 – BPA Provided Updated HIP Comments and January 20th 2021 Meeting Notes
- March 4th, 2021 – Presented Debris Jam Detail to CTUIR
- March 10th, 2021 – Presented PA 4 Revised Design Concepts, Hydraulic Modeling, and Groundwater Analysis Review Meeting with BPA and CTUIR
- March 10th, 2021 – Provided Design Concept Exhibits
- March 16th, 2021 – BPA Provided Design Concept Comments and Direction to Move Forward with 90 Percent Design
- April 6th, 2021 – BPA Provided Updated HIP Comments

Tetra Tech presented the design iteration, supporting analyses, and hydraulic modeling methods to represent the status of the design at each progress meeting. Multiple exhibits were utilized for presentation and submittal purposes. Updates to the exhibits based on the 90 percent design submittal are provided as Attachment 5.

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USBR, 2014. Pacific Northwest Region Resource & Technical Services Large Woody Material – Risk Based Design Guidelines.

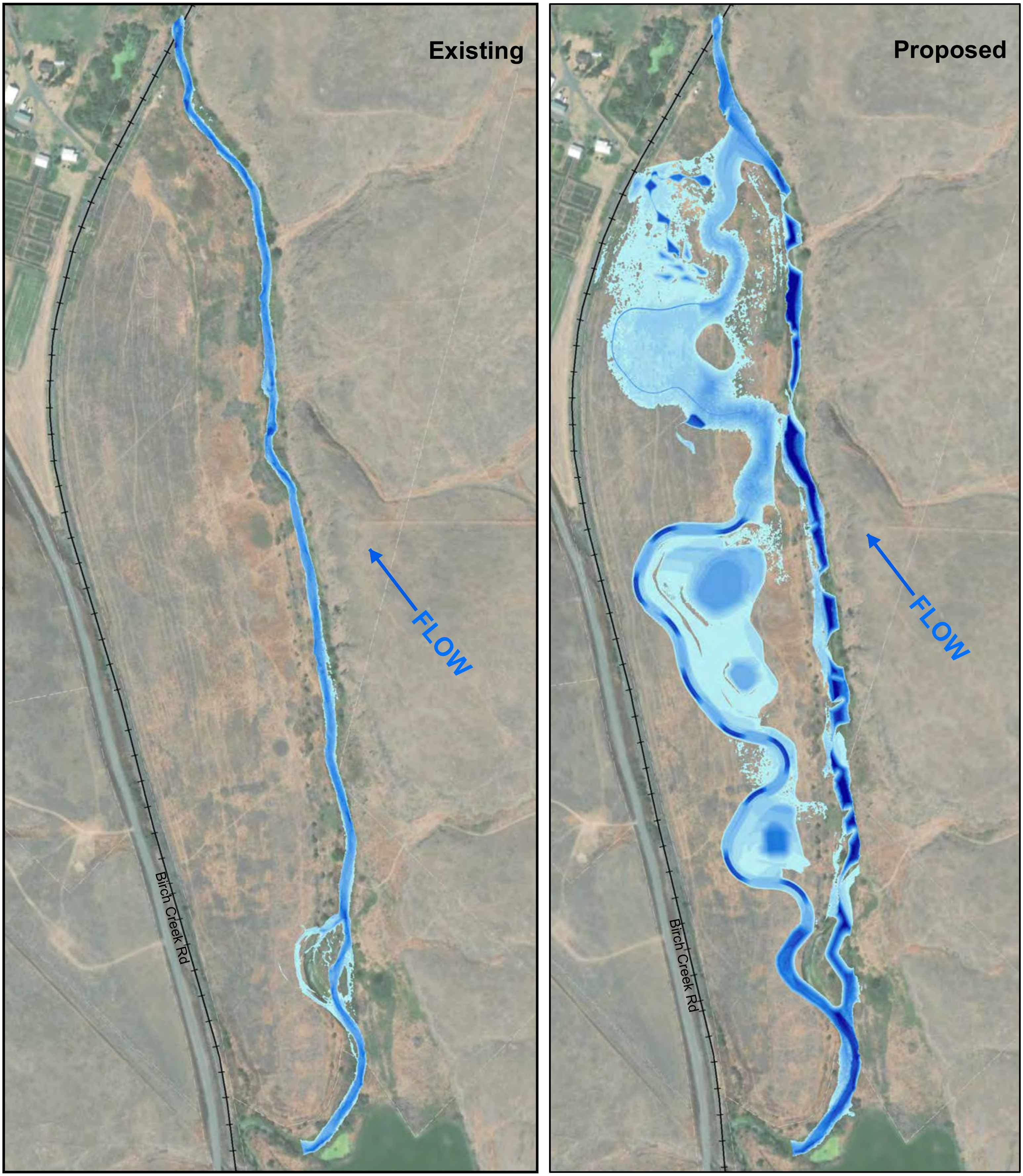
USBR, 2007. Rock Ramp Design Guidelines.

USGS, 2019. Guidelines for Determining Flood Flow Frequency Bulletin 17C.

Attachment 1

HYDRAULIC MODELING FIGURES

- Existing vs Proposed 2-Year Inundation Depth
- Existing vs Proposed 2-Year Velocity
- Existing vs Proposed 2-Year Shear Stress
- Existing vs Proposed 10-Year Inundation Depth
- Existing vs Proposed 10-Year Velocity
- Existing vs Proposed 10-Year Shear Stress
- Existing vs Proposed 25-Year Inundation Depth
- Existing vs Proposed 25-Year Velocity
- Existing vs Proposed 25-Year Shear Stress
- Existing vs Proposed 100-Year Inundation Depth
- Existing vs Proposed 100-Year Velocity
- Existing vs Proposed 100-Year Shear Stress

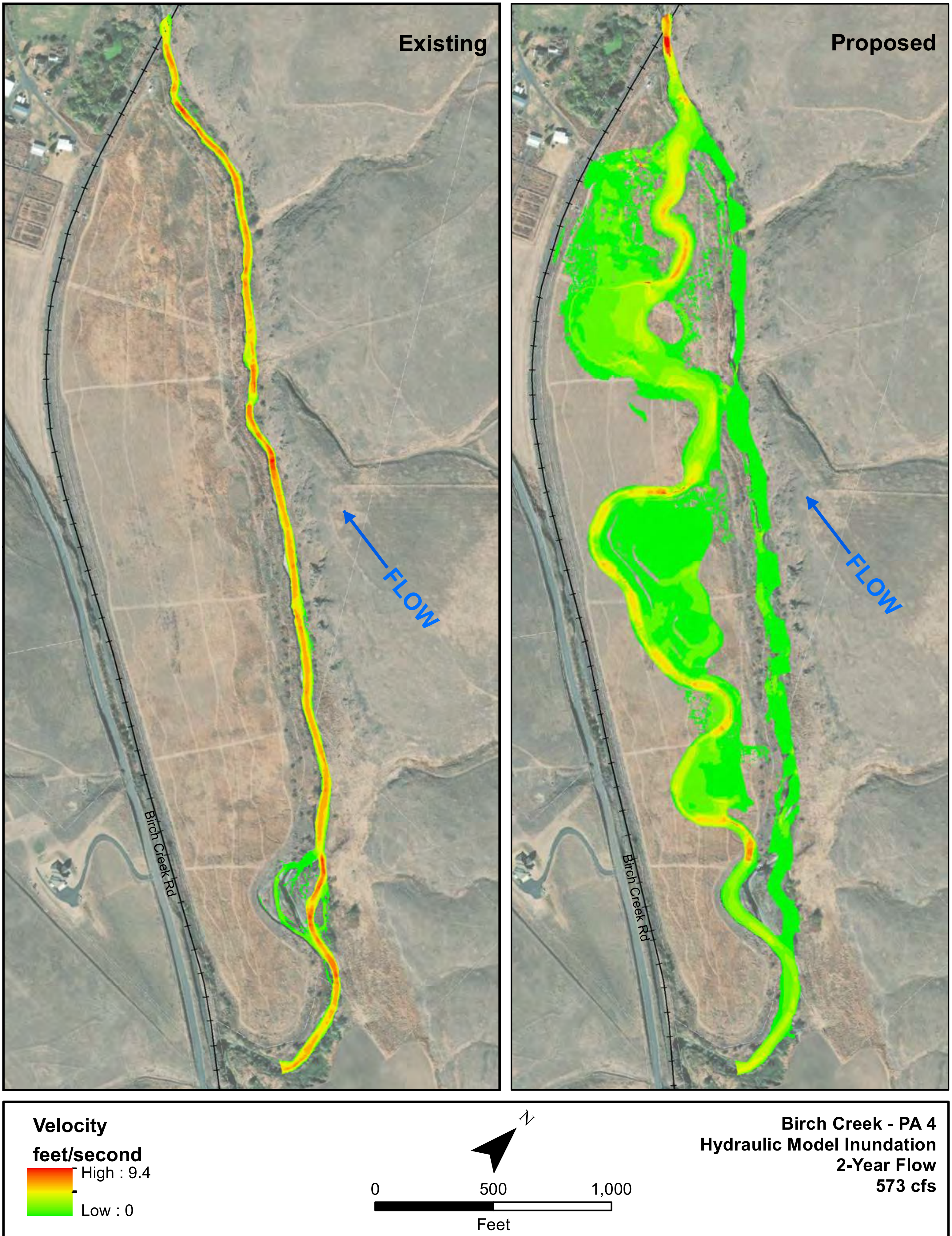


Inundation Depth (ft)
High : 13.7
Low : 0

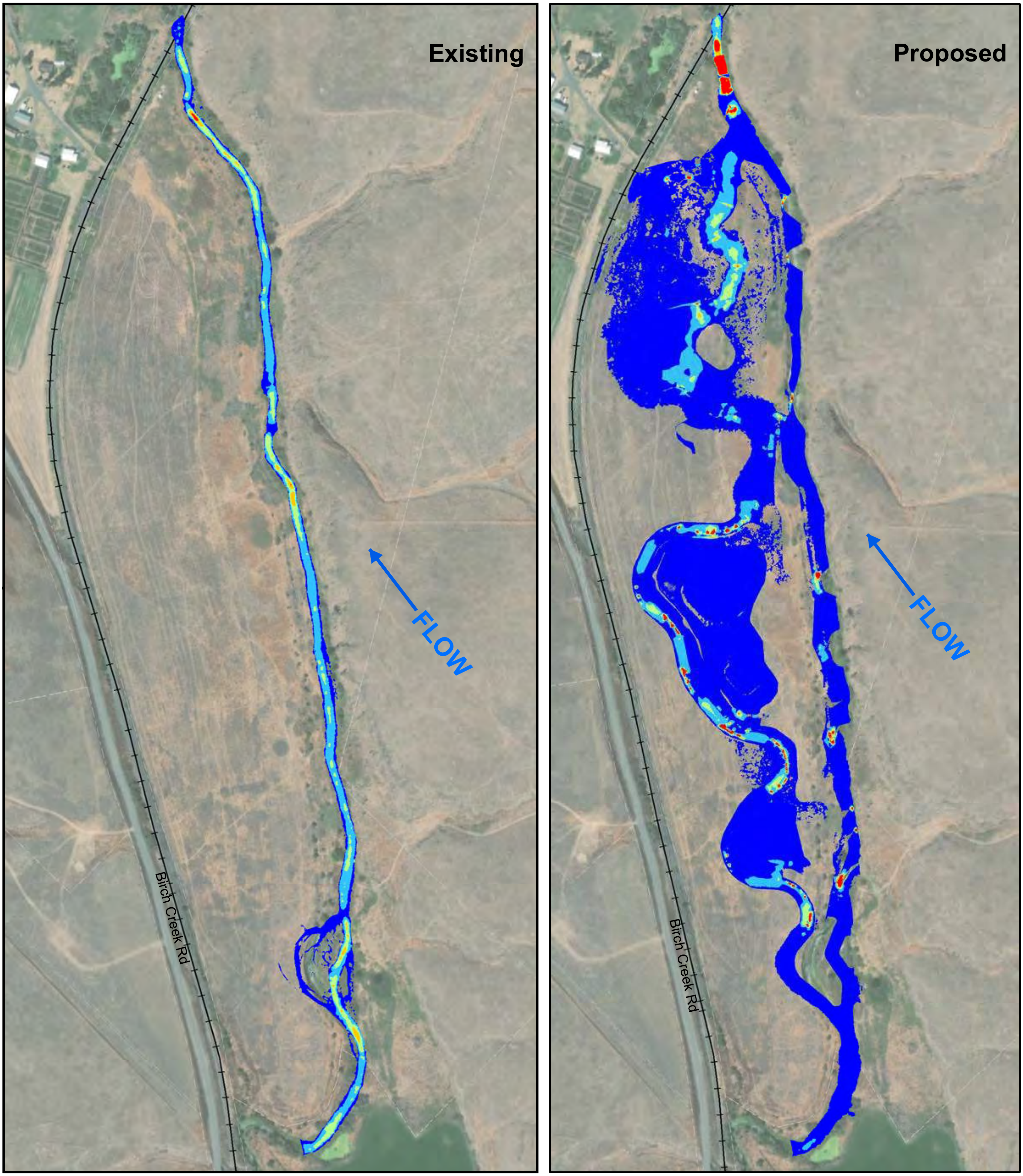
N

0 500 1,000
Feet

Birch Creek - PA 4
Hydraulic Model Inundation
2-Year Flow
573 cfs



P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\2YR_Comp_Velo.mxd

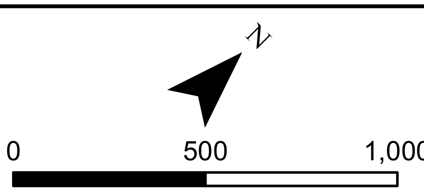


Shear Stress

lbs/sq. ft.

High : 2.5

Low : 0



Birch Creek - PA 4
Hydraulic Model Inundation
2-Year Flow
573 cfs

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\2YR_Comp_Shear.mxd

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\10YR_Comp.mxd

Velocity
feet/second

High : 12.8

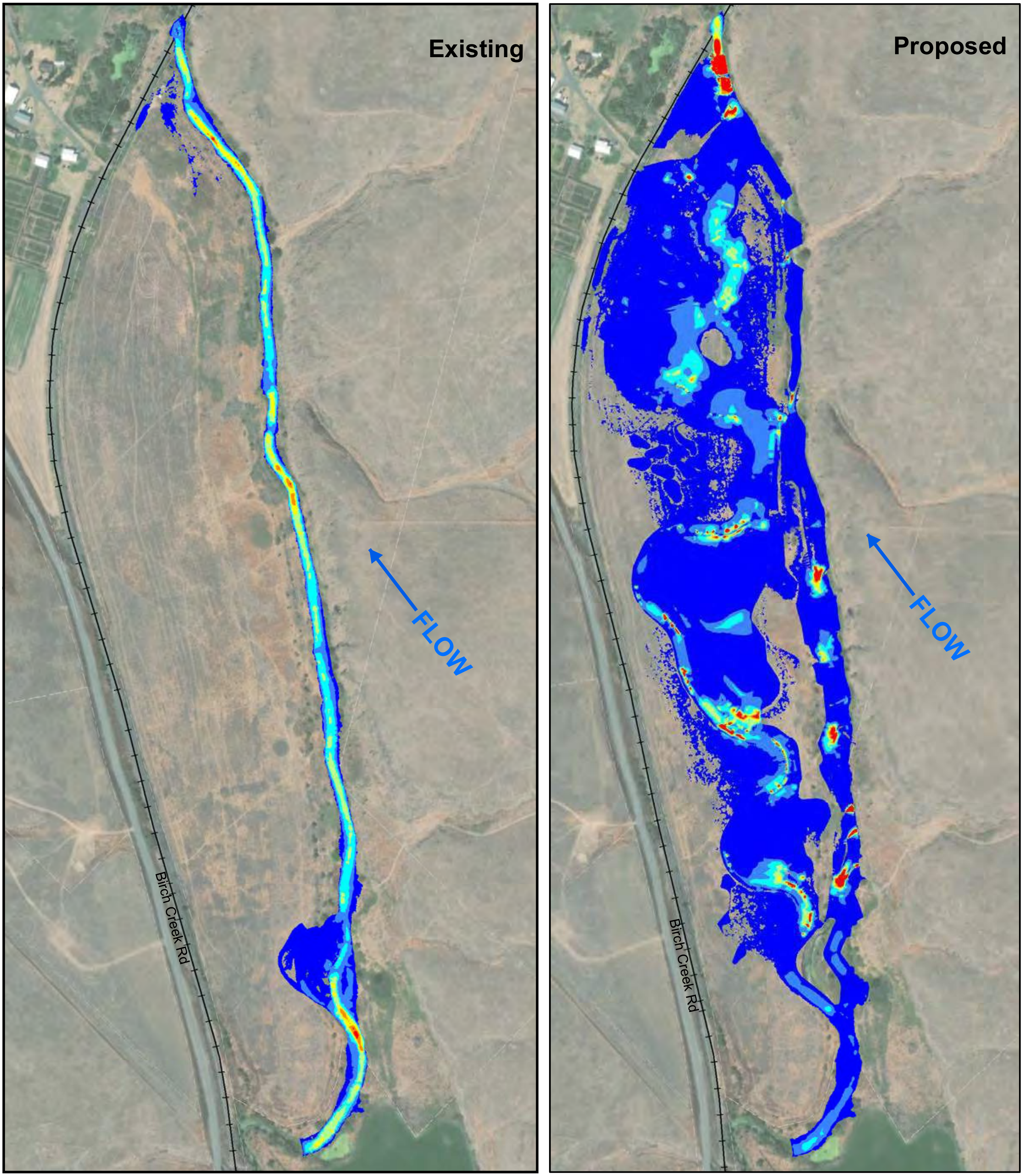
Low : 0

N

0 500 1,000
Feet

Birch Creek - PA 4
Hydraulic Model Inundation
10-Year Flow
1,570 cfs

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\10YR_Comp_Velo.mxd



Shear Stress

lbs/sq. ft.

High : 3.5

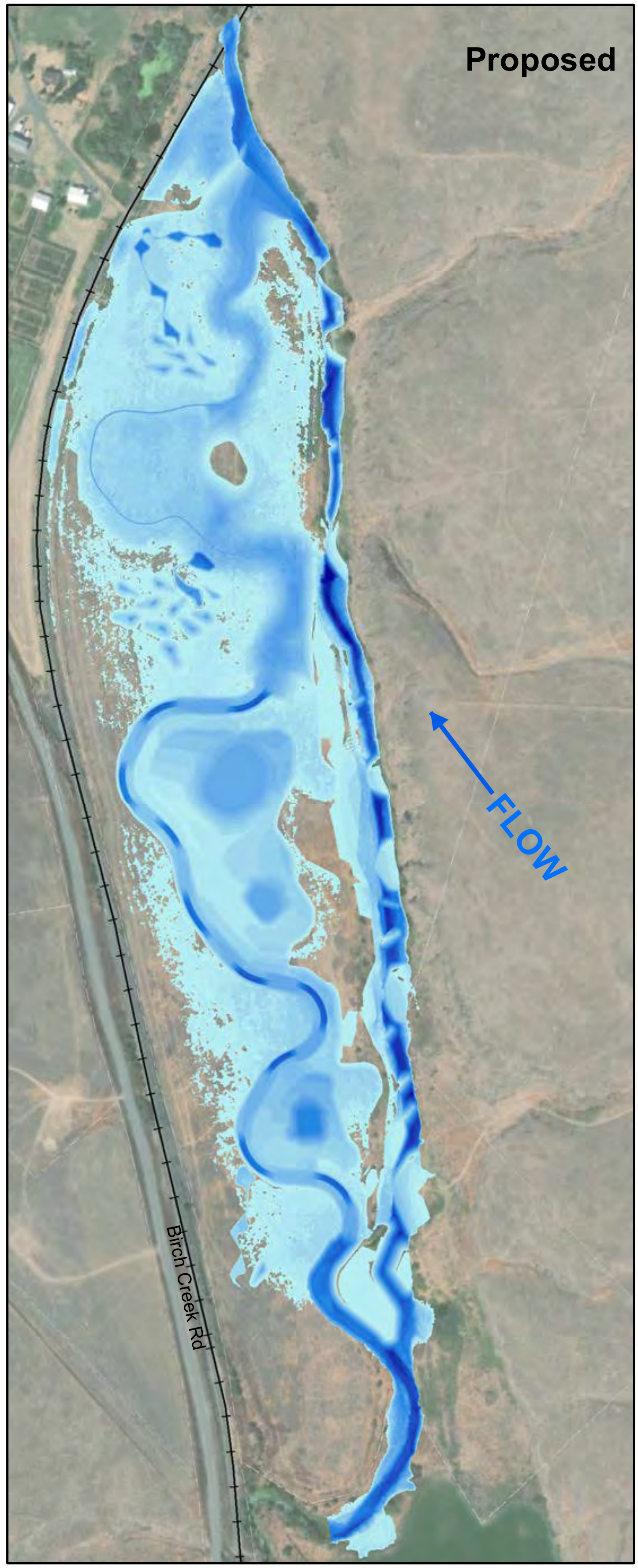
Low : 0

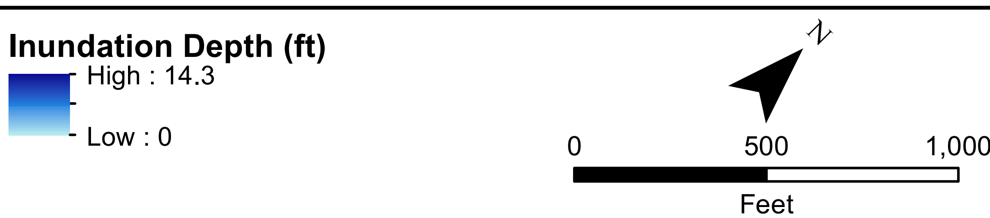
N

0 500 1,000

Feet

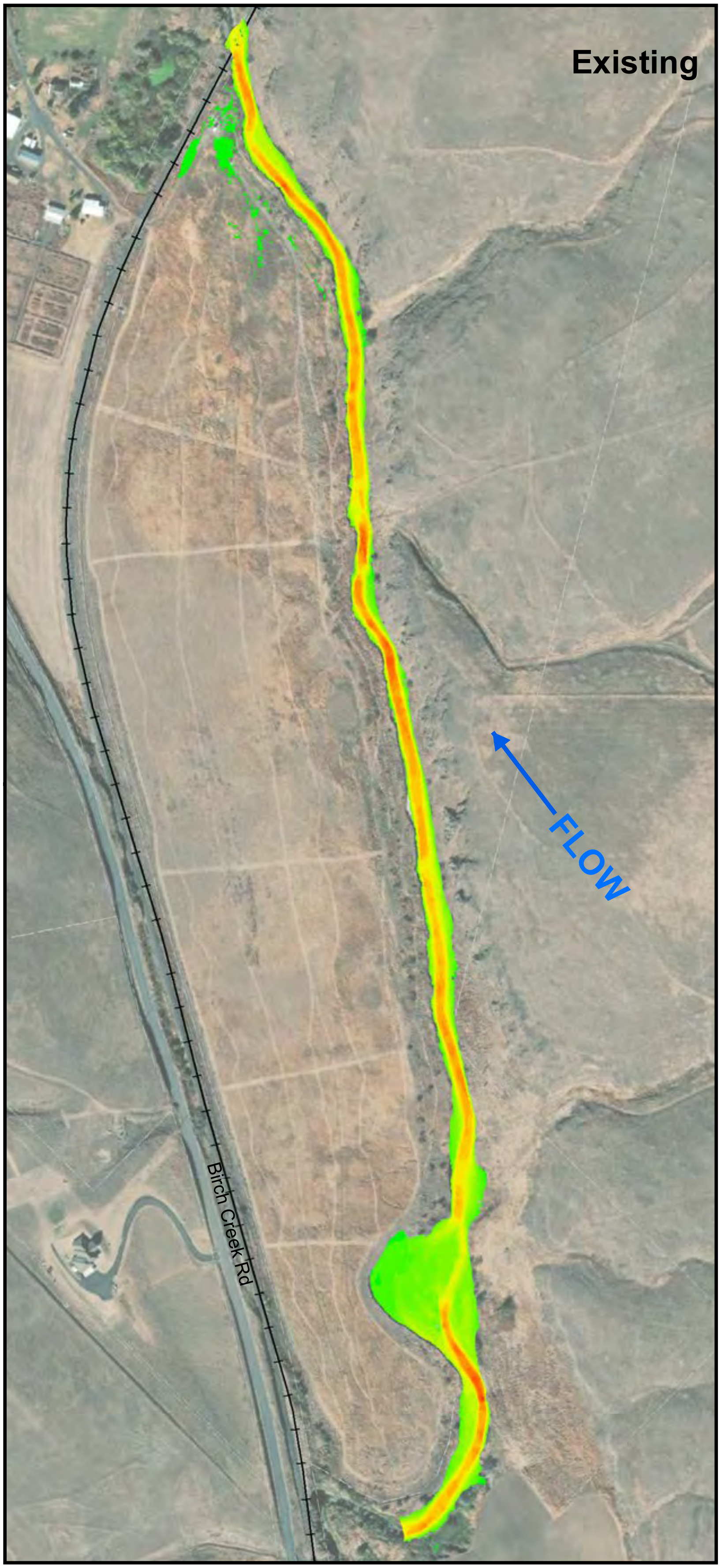
Birch Creek - PA 4
Hydraulic Model Inundation
10-Year Flow
1,570 cfs

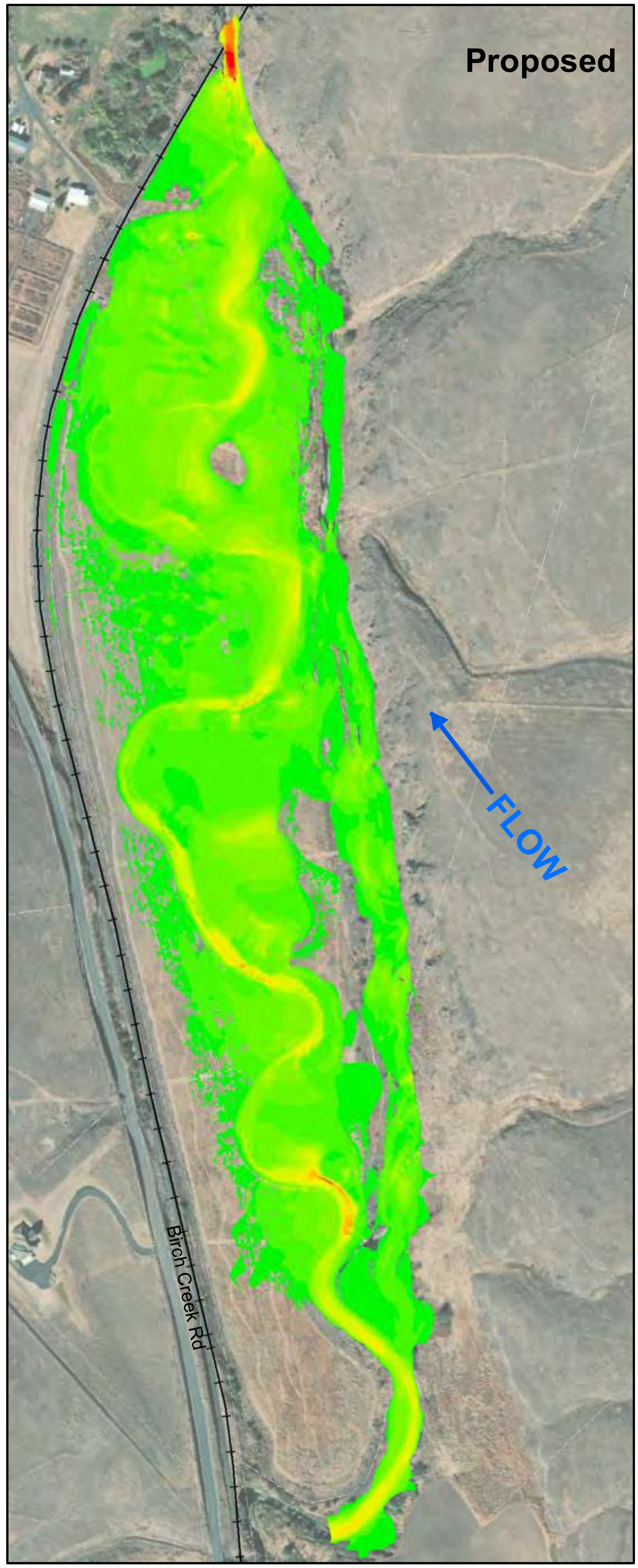




Birch Creek - PA 4
Hydraulic Model Inundation
25-Year Flow
2,360 cfs

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\25YR_Comp.mxd





Velocity

feet/second

High : 15.1

Low : 0

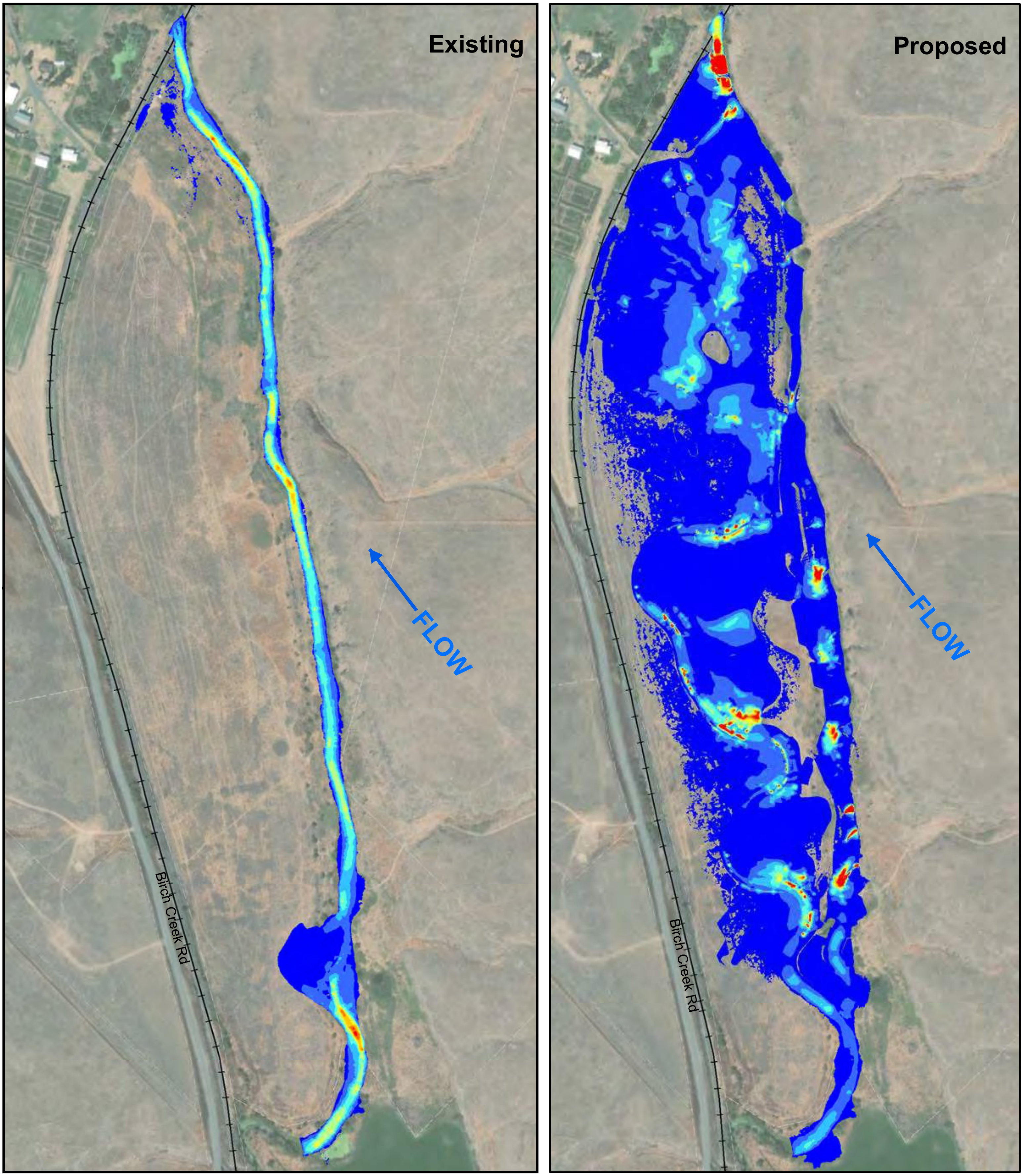
N

0 500 1,000

Feet

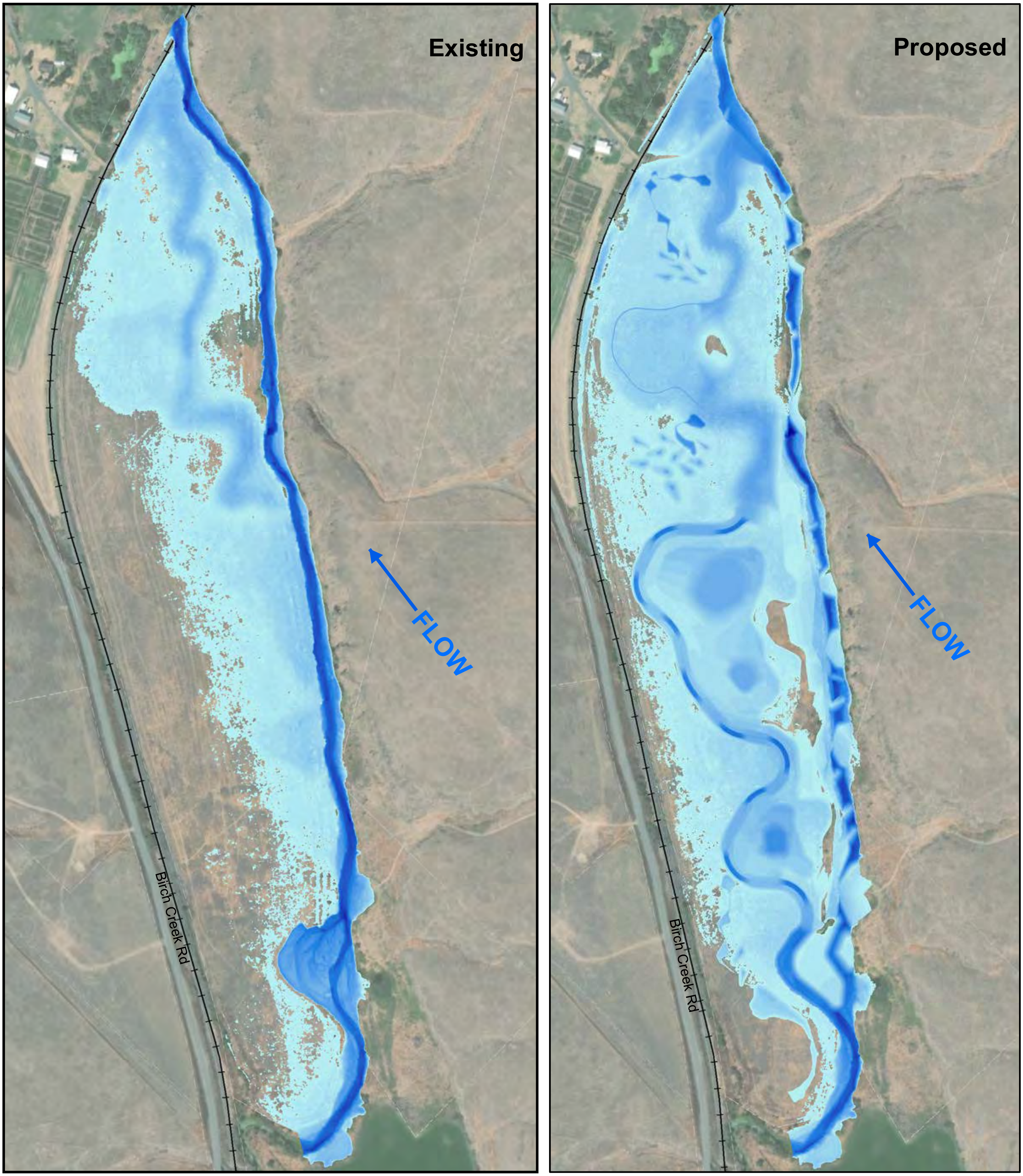
Birch Creek - PA 4
Hydraulic Model Inundation
25-Year Flow
2,360 cfs

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\25YR_Comp_Velo.mxd



Birch Creek - PA 4
Hydraulic Model Inundation
25-Year Flow
2,360 cfs

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\25YR_Comp_Shear.mxd



Inundation Depth (ft)

High : 14.5

Low : 0

N

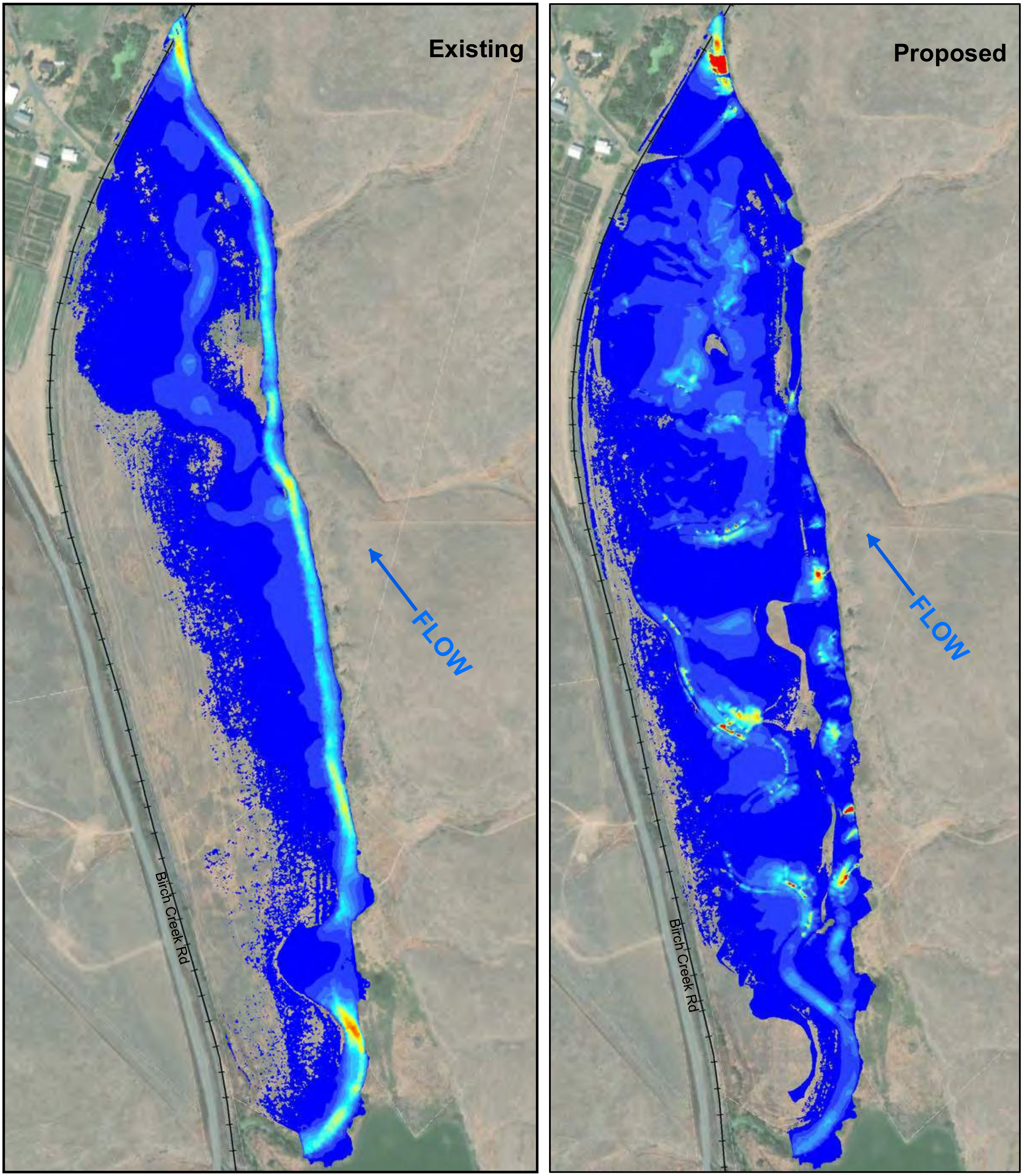
0 500 1,000

Feet

Birch Creek - PA 4
Hydraulic Model Inundation
100-Year Flow
3,800 cfs

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\100YR_Comp.mxd

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\100YR_Velo.mxd



Shear Stress

lbs/sq. ft.

High : 8.5

Low : 0

0 500 1,000

Feet

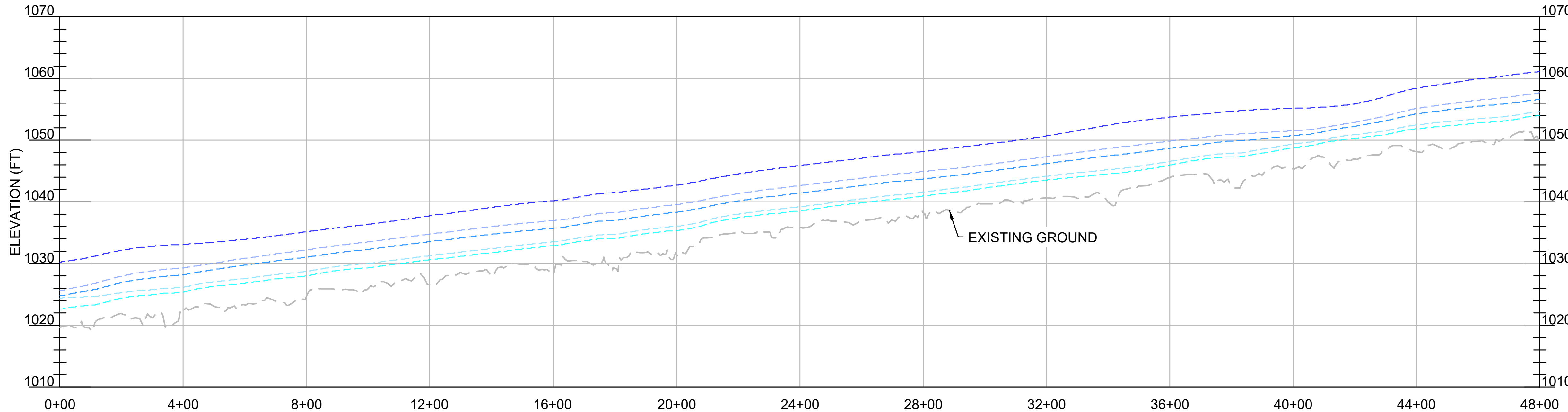
Birch Creek - PA 4
Hydraulic Model Inundation
100-Year Flow
3,800 cfs

P:\194-6817 CTUIR UmaBirch In-Stream Design\GIS\Inundation Maps\UpperBirchCreek\MXD\100YR_Comp_Shear.mxd

Attachment 2

Water Surface Elevation Profiles

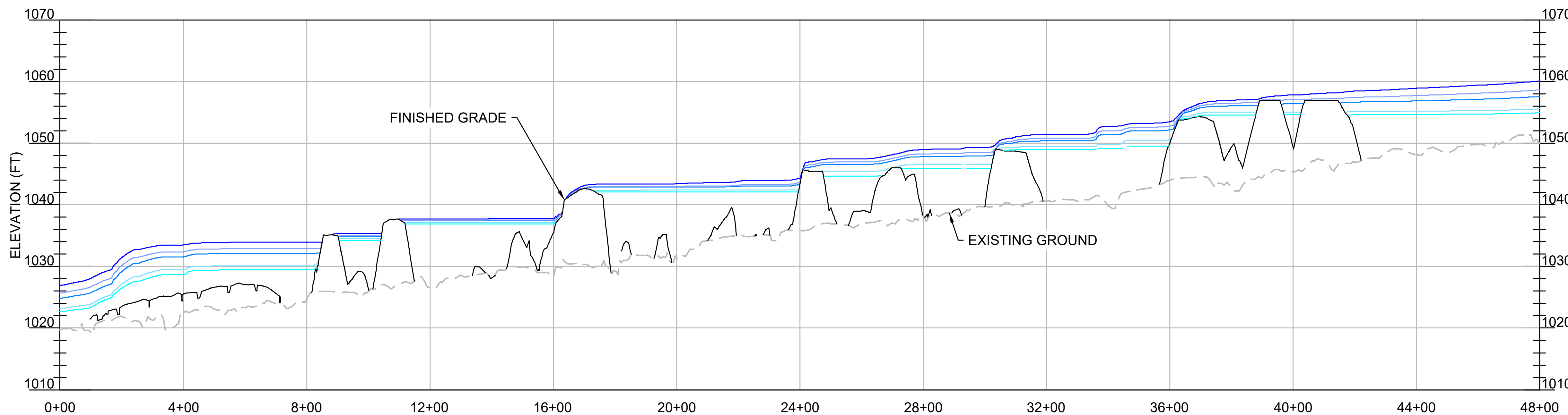
- Existing Conditions
- Proposed Conditions



EXISTING CONDITIONS - EXISTING BIRCH CREEK ALIGNMENT PROFILE VIEW (FT)
(SCALE 1" = 400', 1H:20V)

LEGEND

- EXISTING GROUND
- EXISTING OHW
- EXISTING 2-YEAR WSE
- EXISTING 10-YEAR WSE
- EXISTING 25-YEAR WSE
- EXISTING 100-YEAR WSE
- FINISHED GRADE
- PROPOSED OHW
- PROPOSED 2-YEAR WSE
- PROPOSED 10-YEAR WSE
- PROPOSED 25-YEAR WSE
- PROPOSED 100-YEAR WSE



PROPOSED CONDITIONS - EXISTING BIRCH CREEK ALIGNMENT PROFILE VIEW (FT)
(SCALE 1" = 400', 1H:20V)

D:\CDM FILES\ENGINEERING_TETRA TECH\PROJECTS\UMA\BIRCH\CAD\90%\SHEET FILES\DBR PROFILES.DWG
PLOT DETAILS: MCKINNEY, CHAD1 April 26, 2021 12:26 PM

TETRA TECH
www.tetratech.com
19803 North Creek Parkway
Bothell, Washington 98011
Phone: 425-482-7600 Fax: 425-482-7652

NOT FOR CONSTRUCTION

PLAN SHEET SIZE ANSI B (11" X 17")

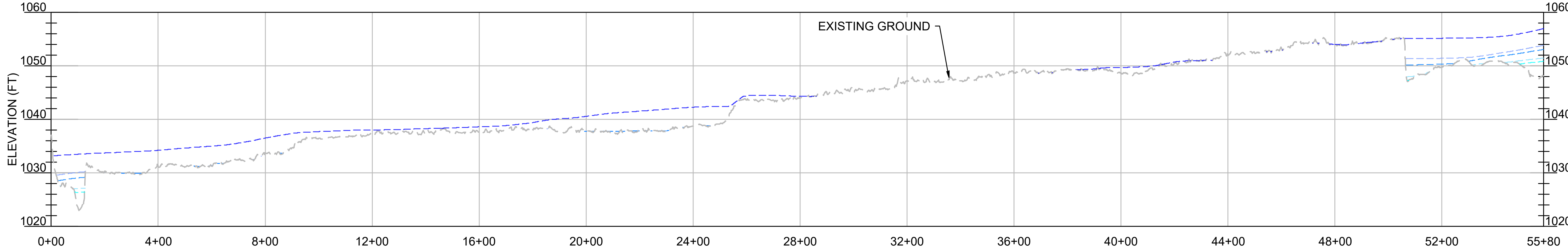
REV.	DATE	REVISION DESCRIPTION	DRW	ENG	CHK	APP
4	4/30/21	90% DESIGN	JA	JA	CM	CJ
3	3/12/20	60% DESIGN	JA	JA	CM	CJ
2	9/10/19	30% DESIGN	JA	JA	CM	CJ
1	6/18/19	15% ALTERNATIVE ANALYSIS	JA	JA	CM	CJ

CTUIR - PA 4 BIRCH CREEK INSTREAM ENHANCEMENT AND FLOODPLAIN RESTORATION

EXISTING BIRCH CREEK ALIGNMENT WATER SURFACE PROFILES

DWG. NO.:

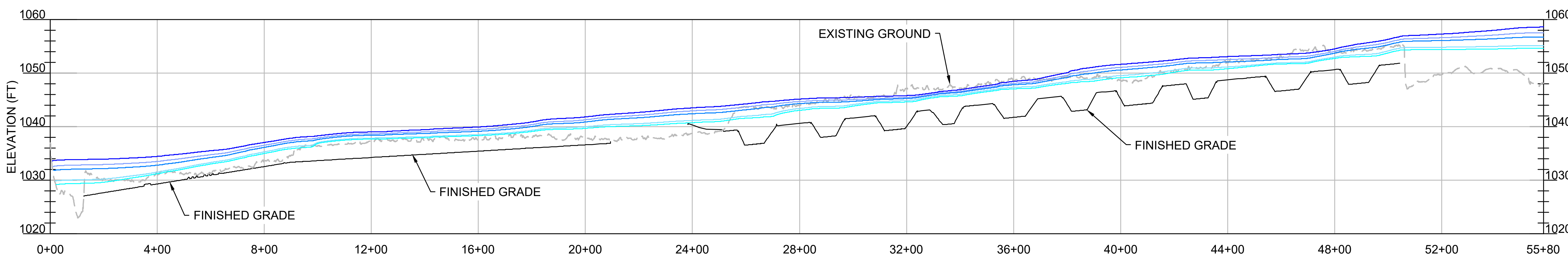
CREATED: 4/15/21



EXISTING CONDITIONS - EXISTING BIRCH CREEK ALIGNMENT PROFILE VIEW (FT)
(SCALE 1" = 400', 1H:20V)

LEGEND

EXISTING GROUND	FINISHED GRADE
EXISTING OHW	PROPOSED OHW
EXISTING 2-YEAR WSE	PROPOSED 2-YEAR WSE
EXISTING 10-YEAR WSE	PROPOSED 10-YEAR WSE
EXISTING 25-YEAR WSE	PROPOSED 25-YEAR WSE
EXISTING 100-YEAR WSE	PROPOSED 100-YEAR WSE



EXISTING CONDITIONS - EXISTING BIRCH CREEK ALIGNMENT PROFILE VIEW (FT)
(SCALE 1" = 400', 1H:20V)

D:\CDM FILES\ENGINEERING_TETRA TECH\PROJECTS\UMABIRCH\CAD\90%\SHEET FILES\DBR PROFILES.DWG
PLOT DETAILS: MCKINNEY, CHAD1 April 26, 2021 12:31 PM

TETRA TECH
www.tetratech.com
19803 North Creek Parkway
Bothell, Washington 98011
Phone: 425-482-7600 Fax: 425-482-7652

NOT FOR CONSTRUCTION

PLAN SHEET SIZE ANSI B (11" X 17")

REV.	DATE	REVISION DESCRIPTION	DRW	ENG	CHK	APP
4	4/30/21	90% DESIGN	JA	JA	CM	CJ
3	3/12/20	60% DESIGN	JA	JA	CM	CJ
2	9/10/19	30% DESIGN	JA	JA	CM	CJ
1	6/18/19	15% ALTERNATIVE ANALYSIS	JA	JA	CM	CJ

CTUIR - PA 4 BIRCH CREEK INSTREAM ENHANCEMENT AND FLOODPLAIN RESTORATION

PROPOSED BIRCH CREEK ALIGNMENT WATER SURFACE PROFILES

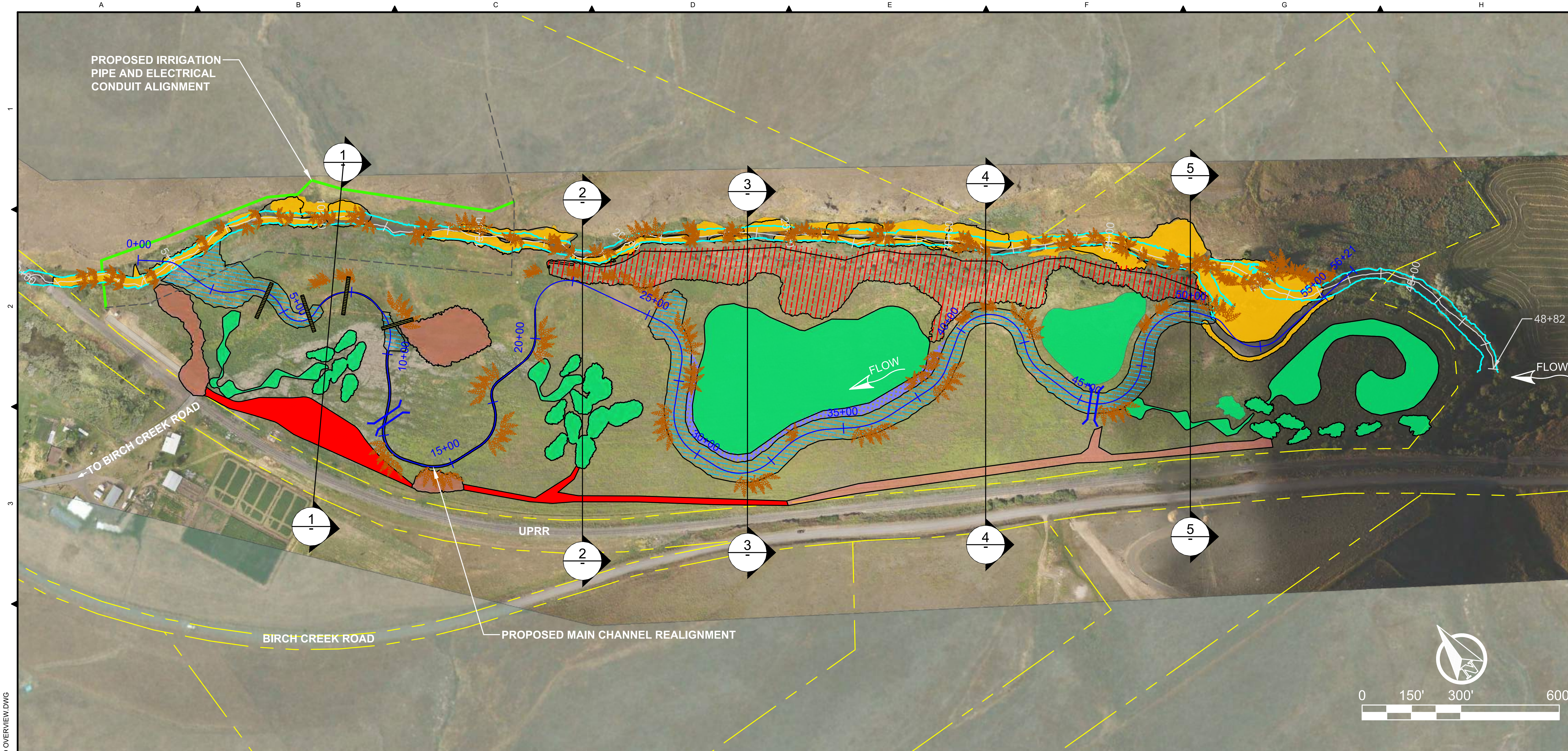
DWG. NO.:

CREATED: 4/15/21

Attachment 3

HEC-RAS 2D Cross Section Results

- Proposed Overview Plan Sheet & Cross Sections
- Cross Section #1 STA: 11+00 WSE and Flow Split
- Cross Section #2 STA: 18+00 WSE
- Cross Section #3 STA: 23+50 WSE
- Cross Section #4 STA: 30+50 WSE
- Cross Section #5 STA: 37+50 WSE and Flow Split



LEGEND

- EXISTING IRRIGATION PIPE
- EXISTING BIRCH CREEK ALIGNMENT
- PROPERTY BOUNDARY
- EXISTING OHW
- PROPOSED BIRCH CREEK ALIGNMENT
- PROPOSED IRRIGATION PIPE ALIGNMENT
- PROPOSED FLOODPLAIN BENCHING
- PROPOSED SCOUR CUTOFF TRENCH
- PROPOSED CHANNEL REALIGNMENT
- PROPOSED CHANNEL FILL
- PROPOSED TERRACE
- PROPOSED WETLAND AREAS
- PROPOSED STAGING AREA AND ACCESS ROUTES
- PROPOSED FLOODPLAIN TOPOGRAPHY
- PROPOSED LWM
- PROPOSED TEMPORARY CROSSING

TETRA TECH
www.tetratech.com
19803 North Creek Parkway
Bothell, Washington 98011
Phone: 425-482-7600 Fax: 425-482-7652

NOT FOR CONSTRUCTION

PLAN SHEET SIZE ANSI B (11" X 17")

REV.	DATE	REVISION DESCRIPTION	DRW	ENG	CHK	APP
4	8/28/20	60% DESIGN REV 1	JA	JA	CM	CJ
3	3/12/20	60% DESIGN	JA	JA	CM	CJ
2	9/10/19	30% DESIGN	JA	JA	CM	CJ
1	6/18/19	15% ALTERNATIVE ANALYSIS	JA	JA	CM	CJ

CTUIR - PA 4 BIRCH CREEK INSTREAM ENHANCEMENT AND FLOODPLAIN RESTORATION

PROPOSED CONDITIONS

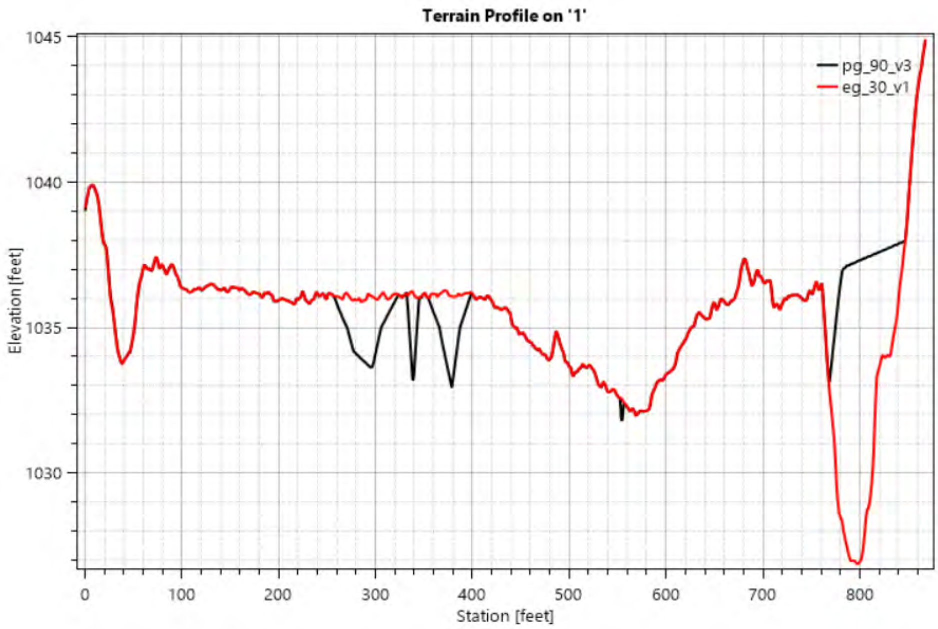
DWG. NO.: C-402

CREATED: 8/24/20

Z:\PROJECTS\194-6817 UMABIRCH IN-STREAM DESIGN\90%\SHEET FILES\PROPOSED OVERVIEW.DWG
PLOT DETAILS: ANDREWS, JEREMY April 9, 2021 9:03 AM

Cross Section #1 STA: 11+00

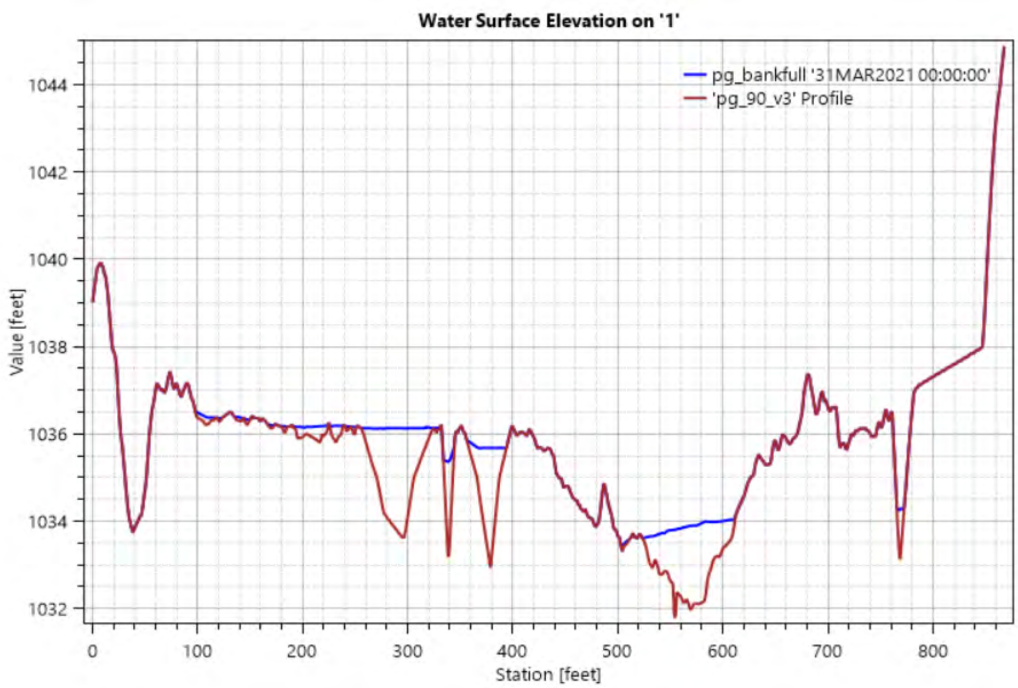
Existing vs Proposed Terrain



OHW (375 cfs)

Existing Channel = 5 cfs

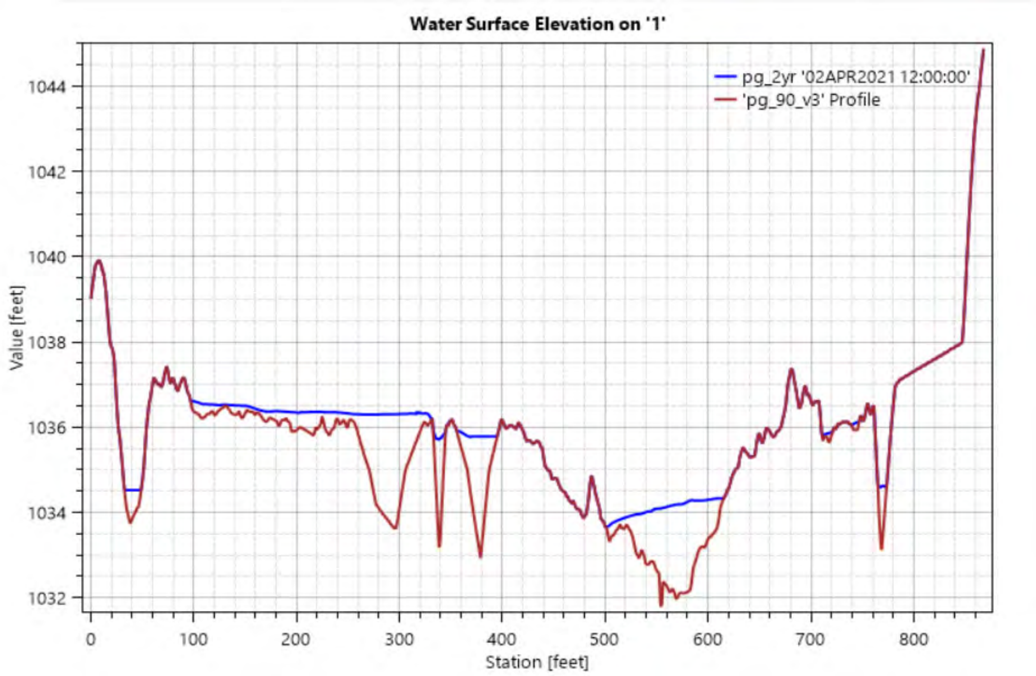
Proposed New Main Channel = 370 cfs



Cross Section #1 STA: 11+00

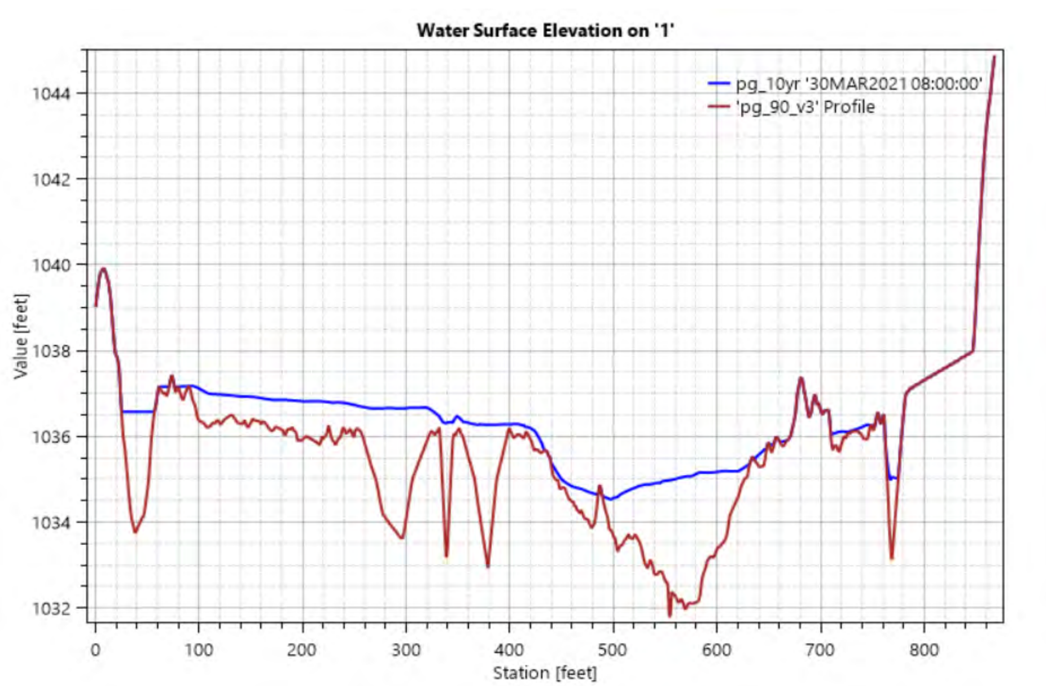
2-Year (573 cfs)

Existing Channel = 11 cfs
Proposed New Main Channel = 562 cfs



10-Year (1,570 cfs)

Existing Channel = 28 cfs
Proposed New Main Channel = 1,542 cfs

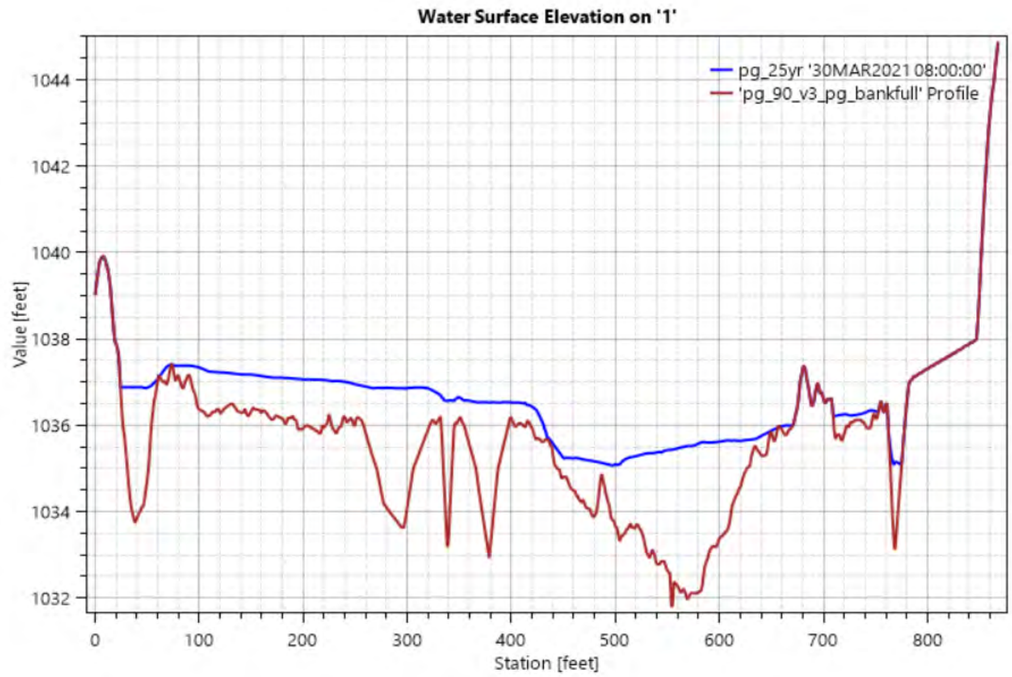


Cross Section #1 STA: 11+00

25-Year (2,360 cfs)

Existing Channel = 37 cfs

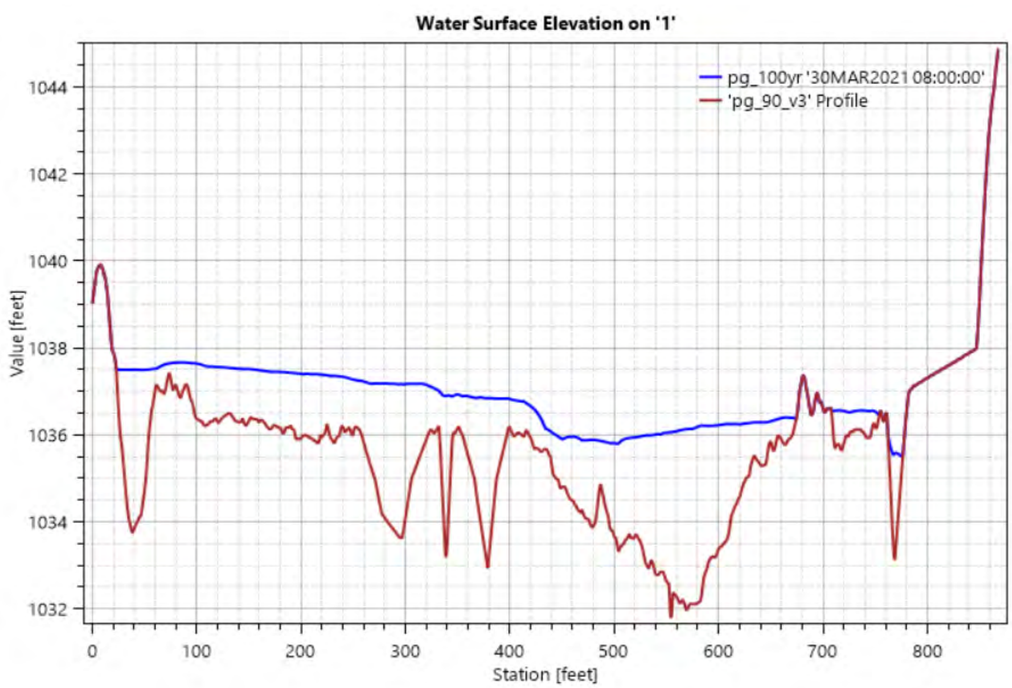
Proposed New Main Channel = 2,323 cfs



100-Year (3,800 cfs)

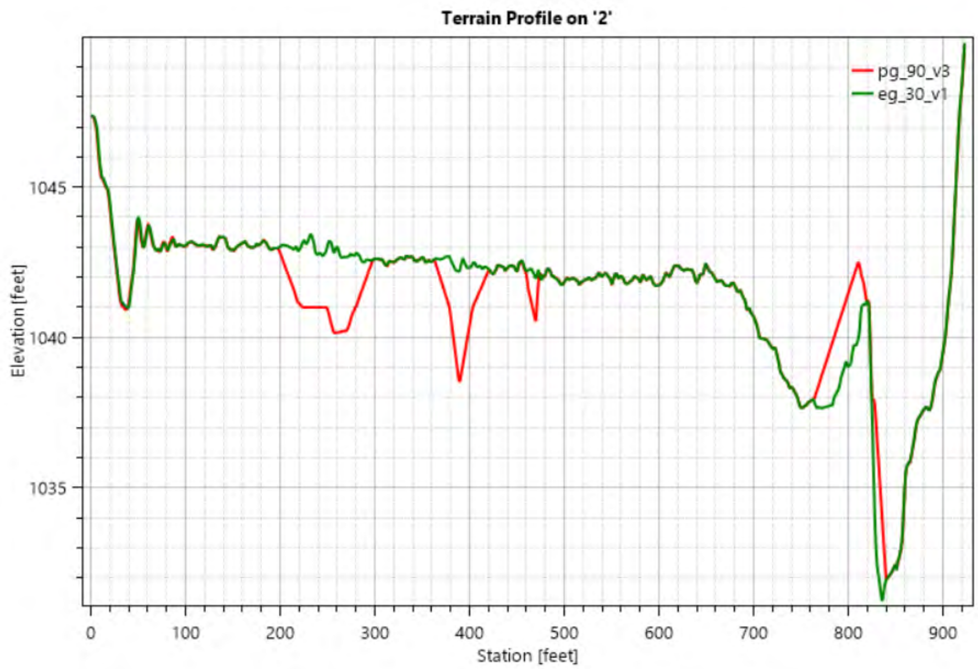
Existing Channel = 100 cfs

Proposed New Main Channel = 3,700 cfs

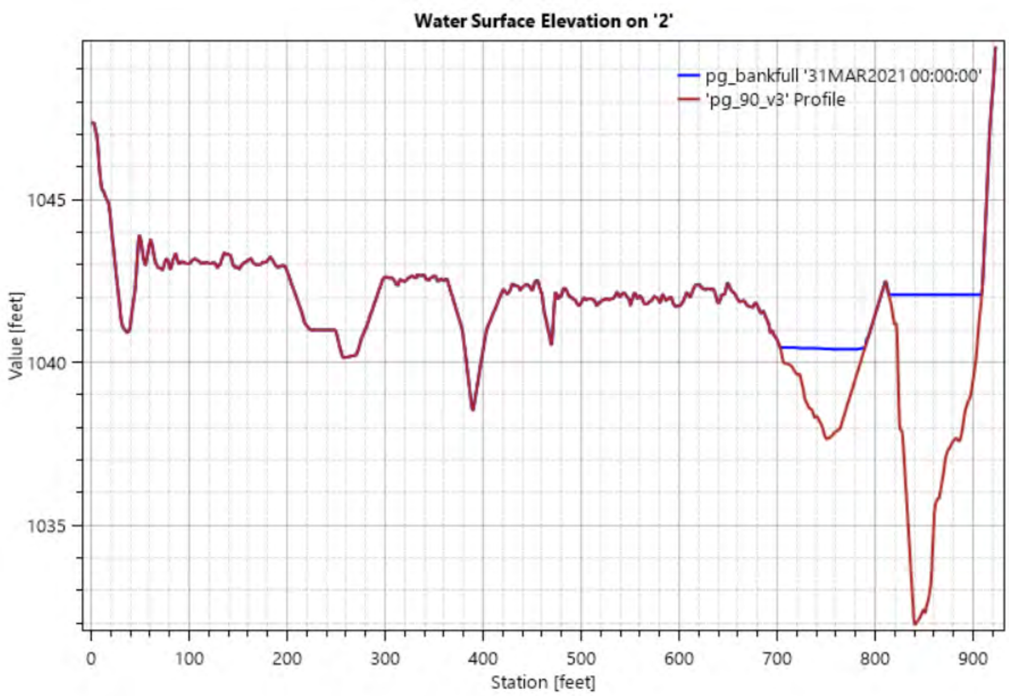


Cross Section #2 STA: 18+00

Existing vs Proposed Terrain

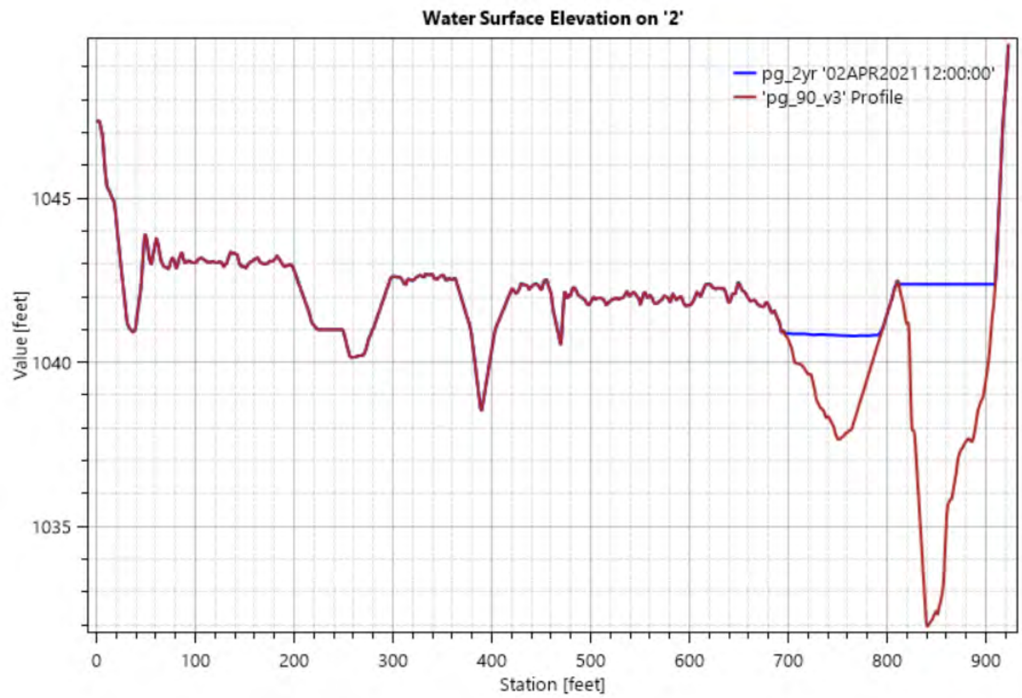


OHW (375 cfs)

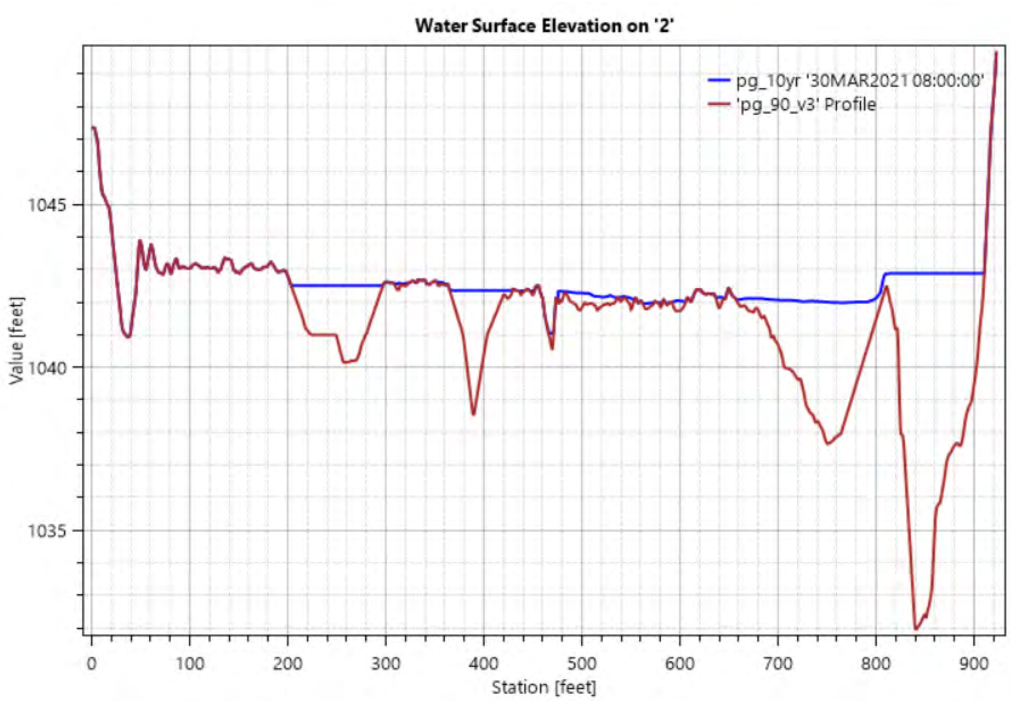


Cross Section #2 STA: 18+00

2-Year (573 cfs)

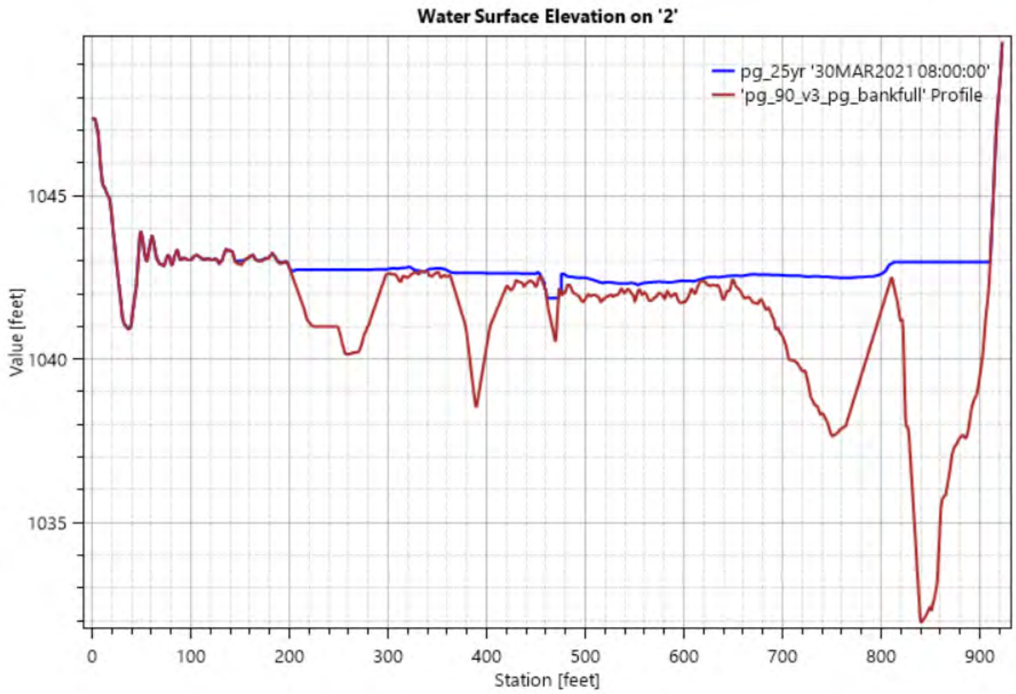


10-Year (1,570 cfs)

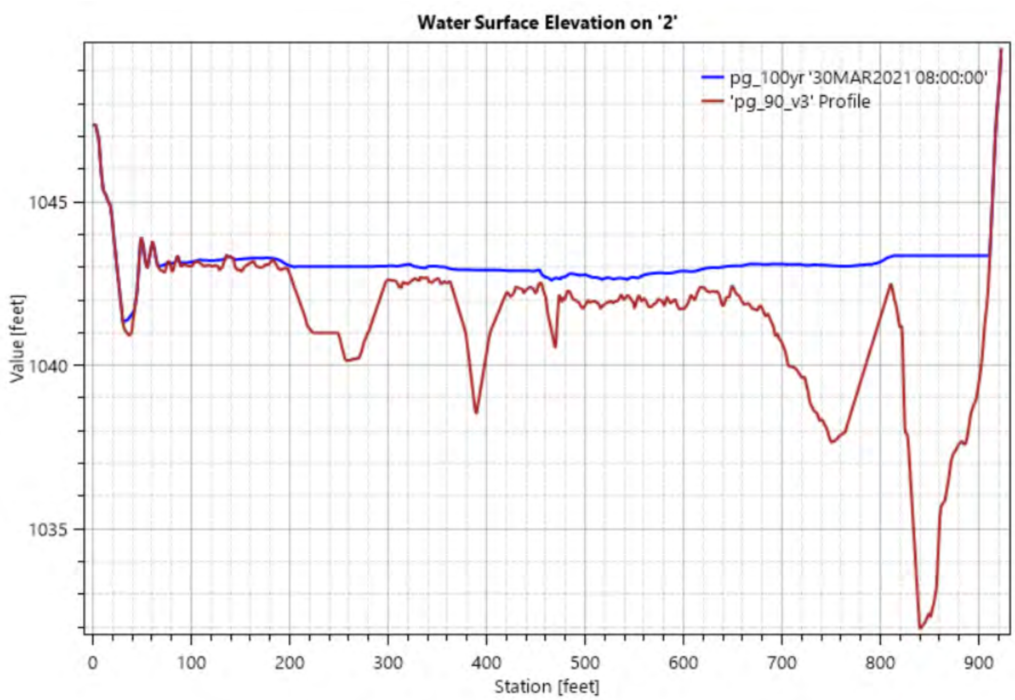


Cross Section #2 STA: 18+00

25-Year (2,360 cfs)

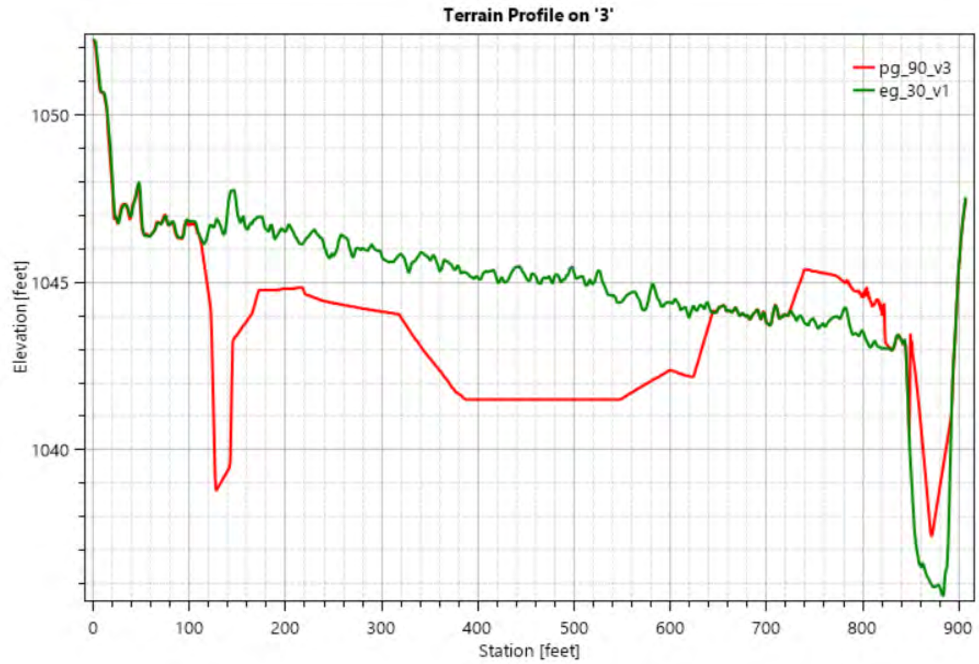


100-Year (3,800 cfs)

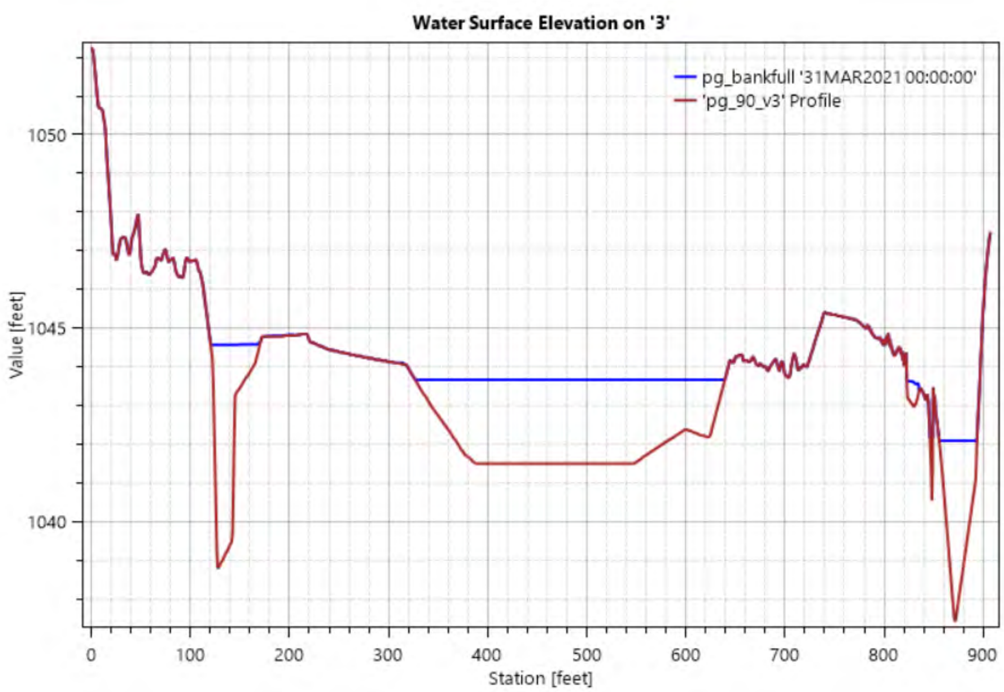


Cross Section #3 STA: 23+50

Existing vs Proposed Terrain

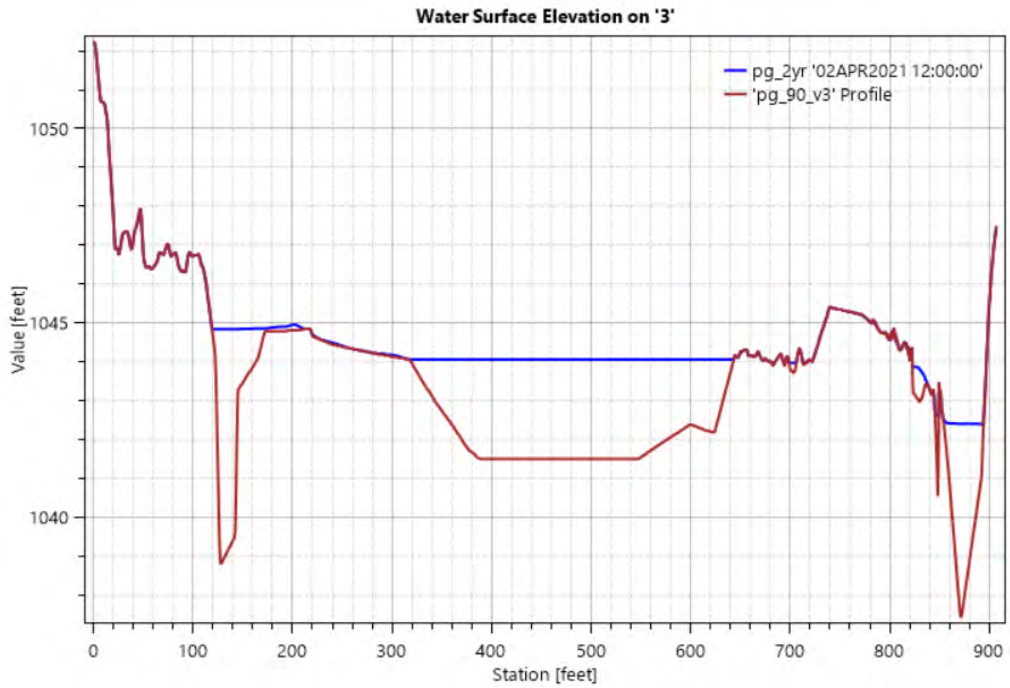


OHW (375 cfs)

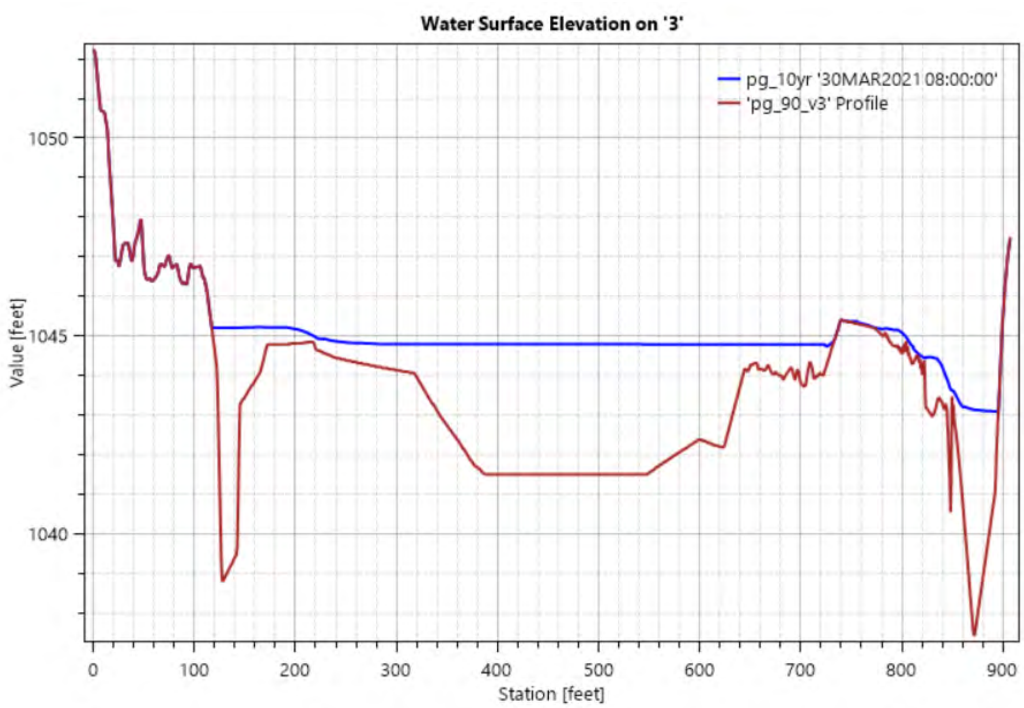


Cross Section #3 STA: 23+50

2-Year (573 cfs)

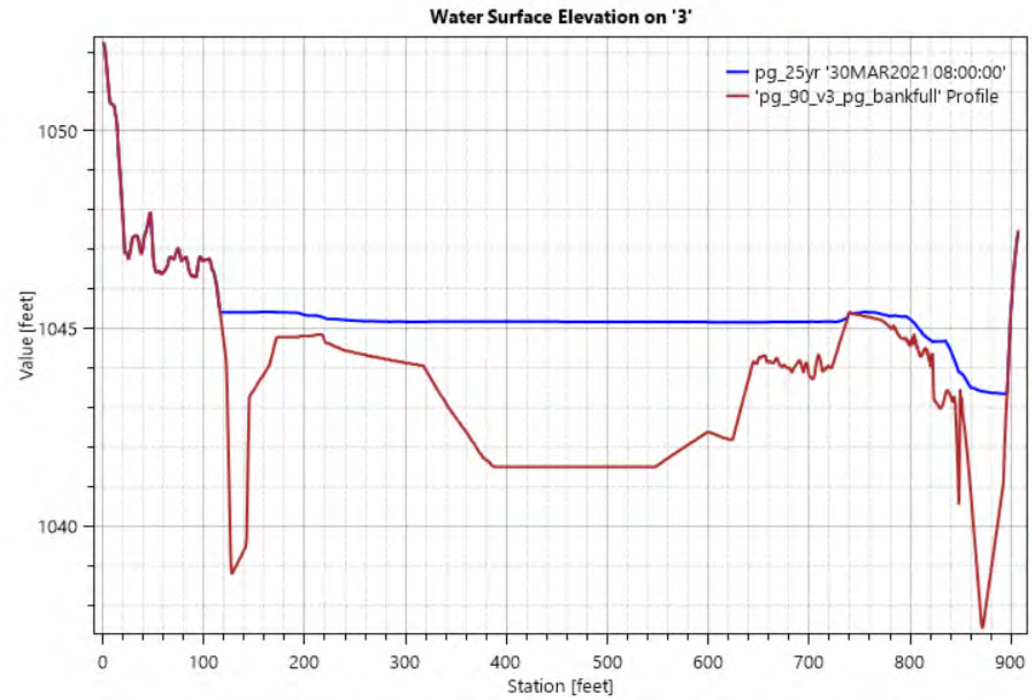


10-Year (1,570 cfs)

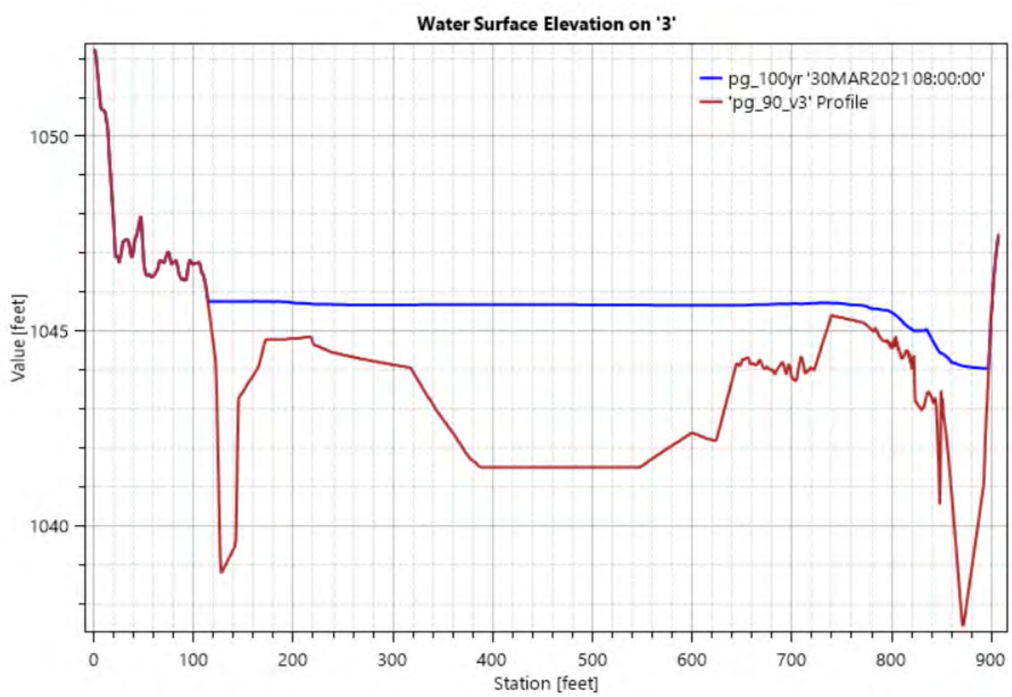


Cross Section #3 STA: 23+50

25-Year (2,360 cfs)

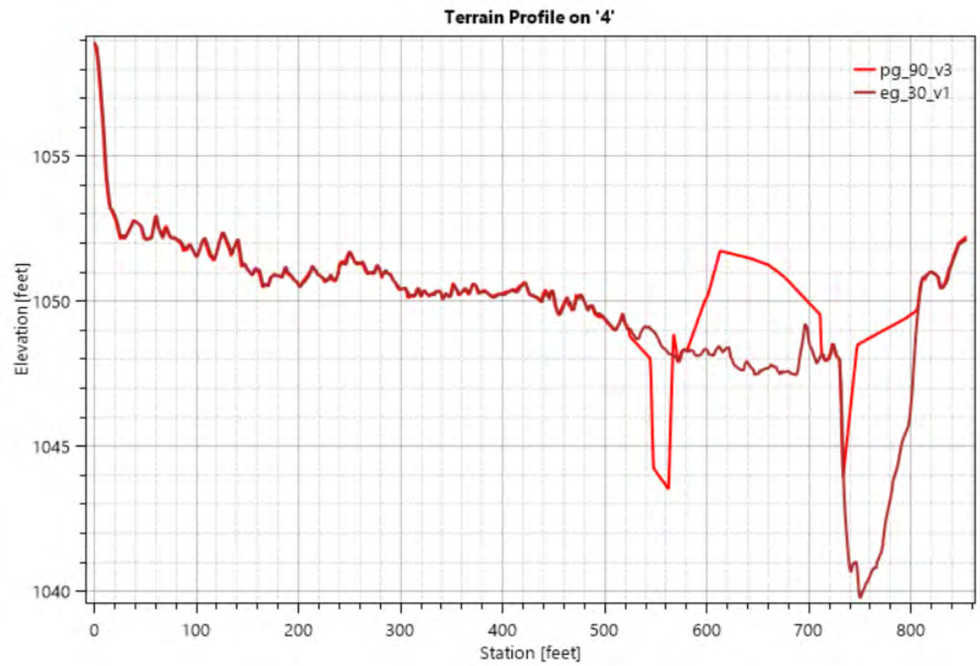


100-Year (3,800 cfs)

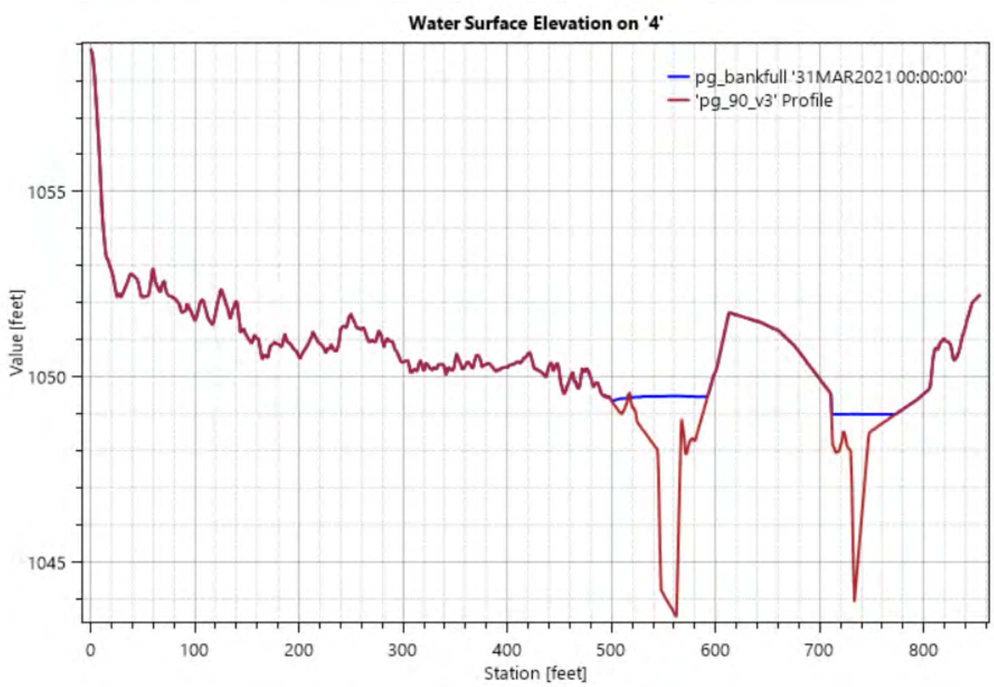


Cross Section #4 STA: 30+50

Existing vs Proposed Terrain

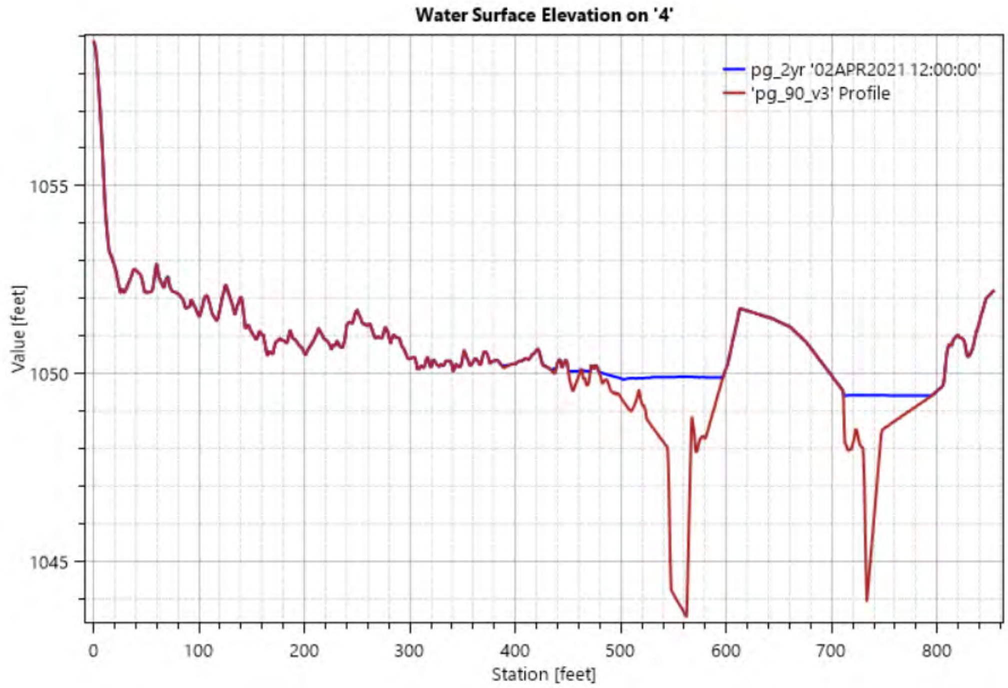


OHW (375 cfs)

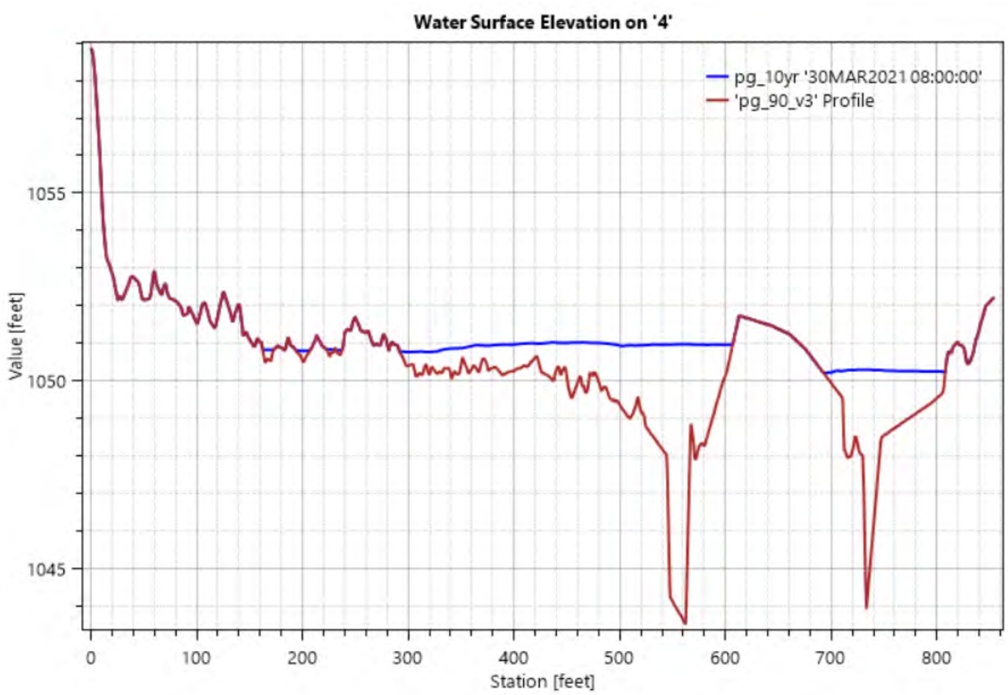


Cross Section #4 STA: 30+50

2-Year (573 cfs)

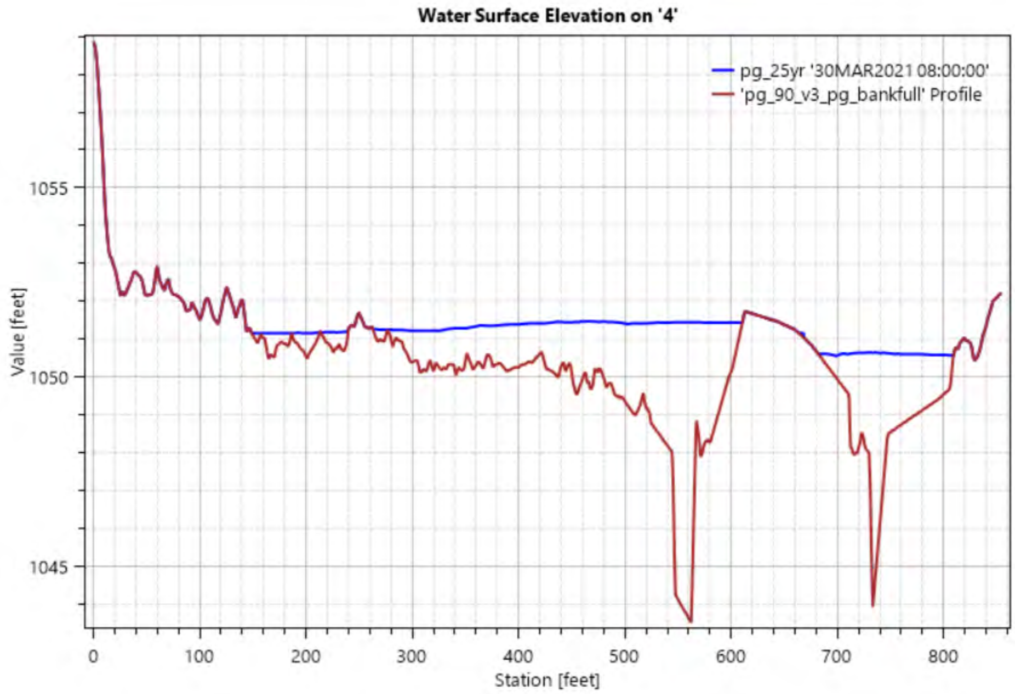


10-Year (1,570 cfs)

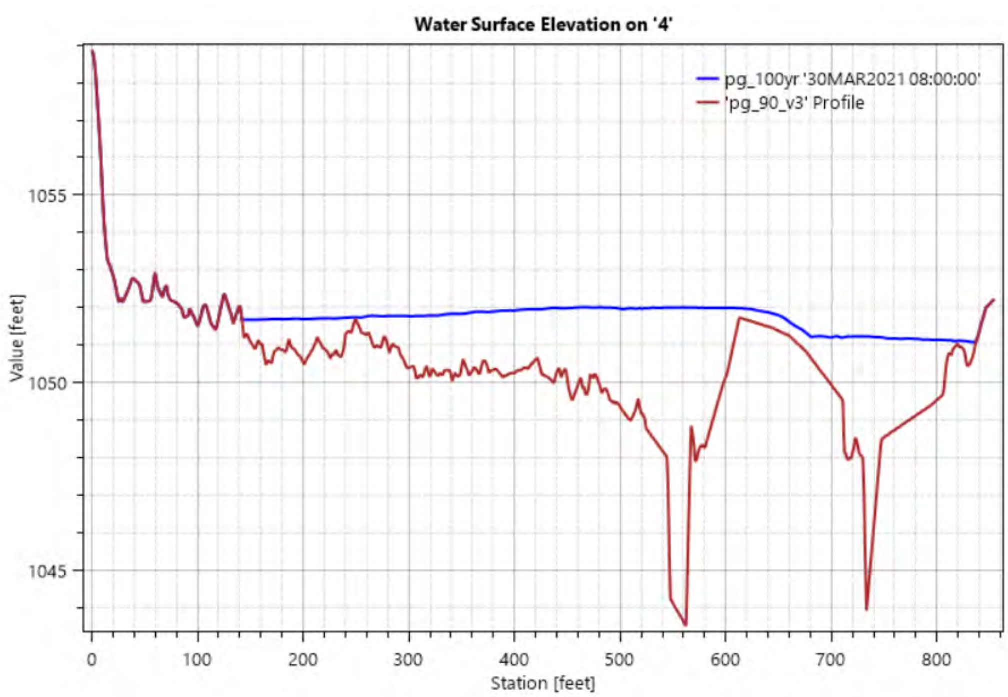


Cross Section #4 STA: 30+50

25-Year (2,360 cfs)

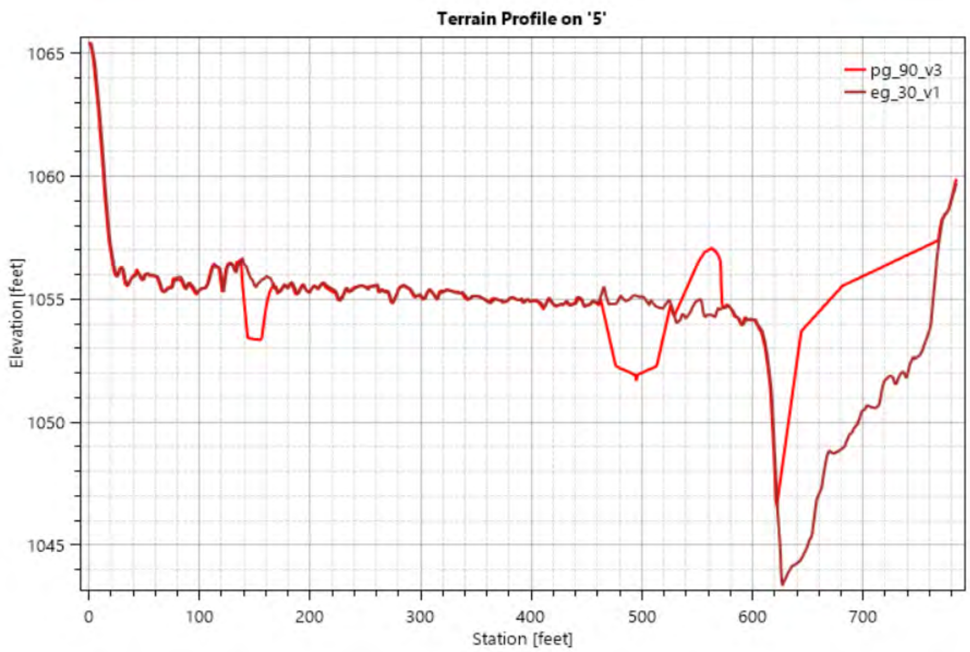


100-Year (3,800 cfs)



Cross Section #5 STA: 37+50

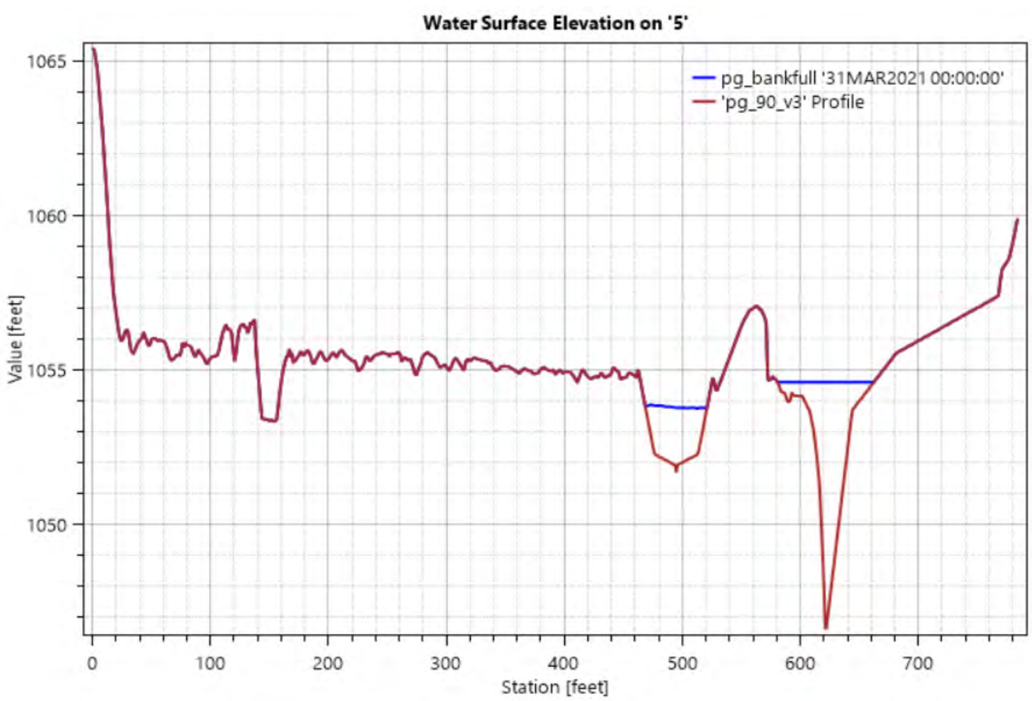
Existing vs Proposed Terrain



OHW (375 cfs)

Existing Channel = 18 cfs

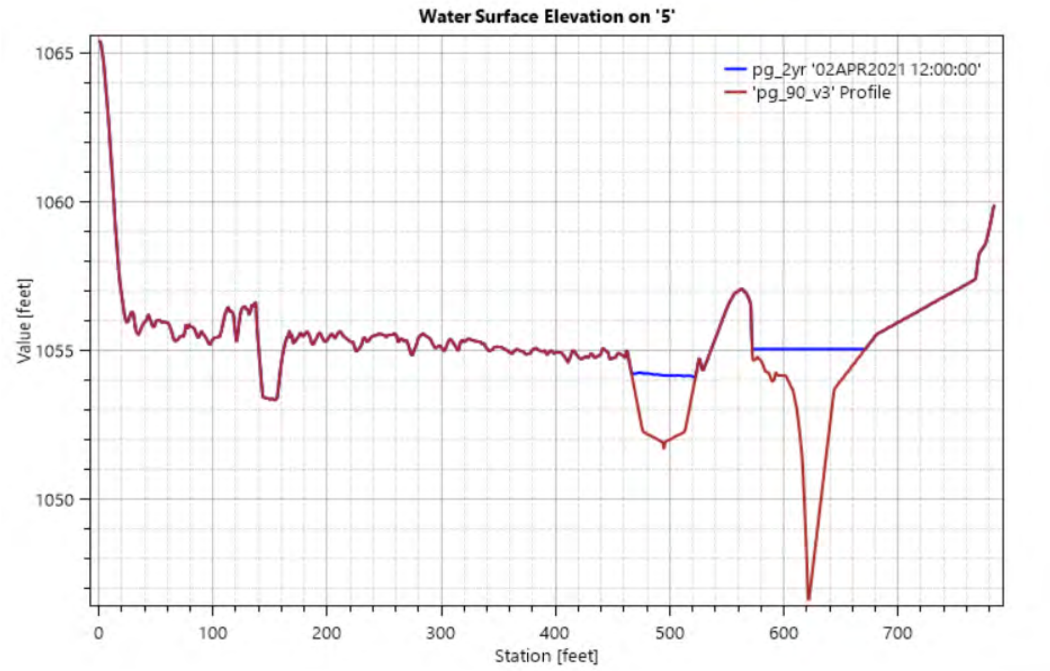
Proposed New Main Channel = 357 cfs



Cross Section #5 STA: 37+50

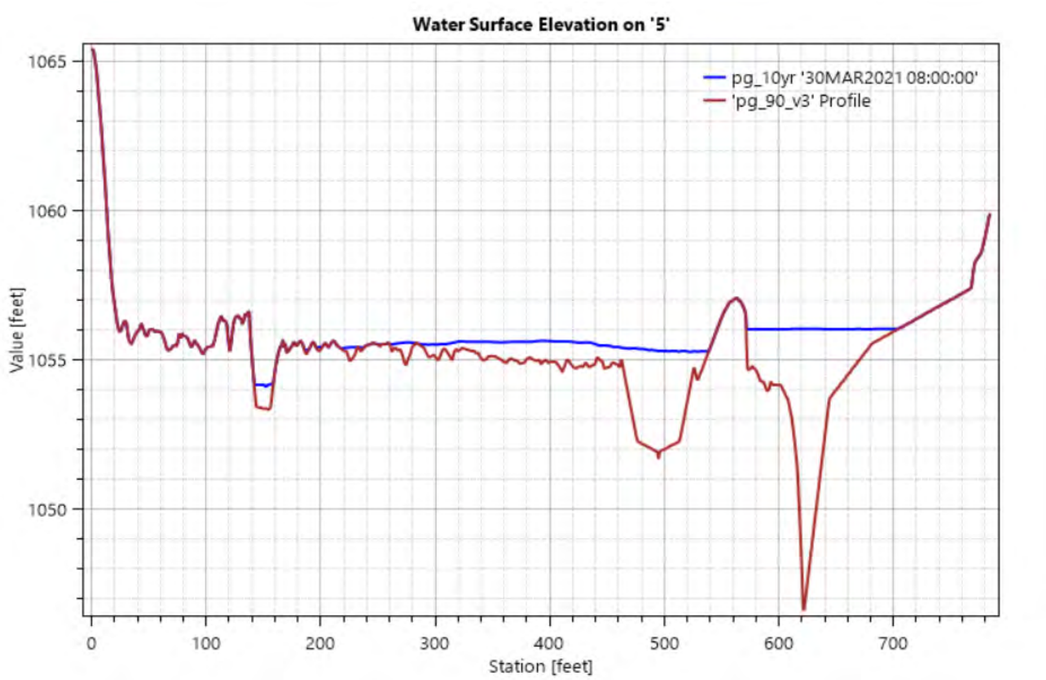
2-Year (573 cfs)

Existing Channel = 59 cfs
Proposed New Main Channel = 514 cfs



10-Year (1,570 cfs)

Existing Channel = 297 cfs
Proposed New Main Channel = 1,273 cfs

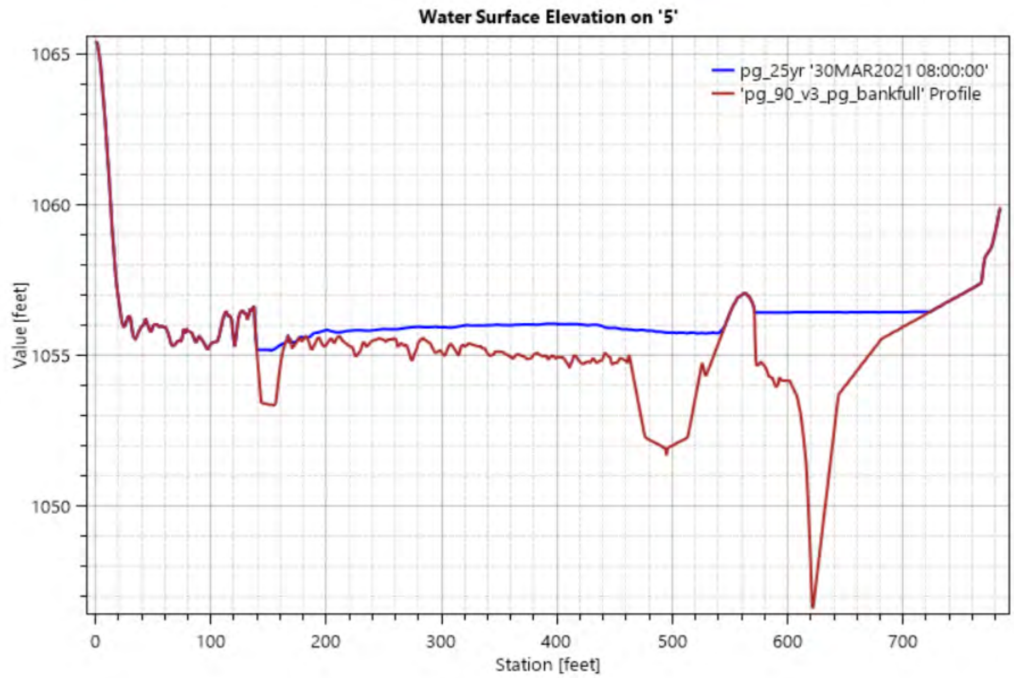


Cross Section #5 STA: 37+50

25-Year (2,360 cfs)

Existing Channel = 475 cfs

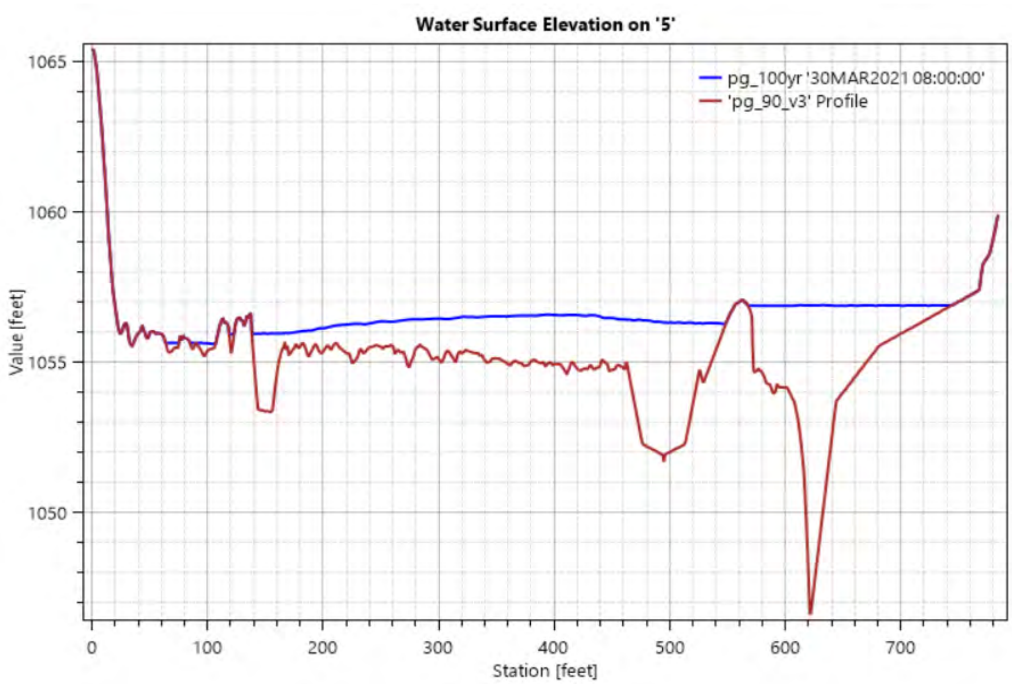
Proposed New Main Channel = 1,885 cfs



100-Year (3,800 cfs)

Existing Channel = 785 cfs

Proposed New Main Channel = 3,015 cfs



Attachment 4

Engineering Calculations

- Incipient Motion
- General Scour
- Boulder Sizing
- LWM Stability

Incipient Motion - Existing Conditions

% Finer		Average Streambed Gravel (mm)	Average Streambed Gravel (in)	Critical Shear (lb/sq ft)
D10	10	NA	NA	NA
D16	16	25.4	1.0	NA
D50	50	42.9	1.7	0.72
D84	84	70.5	2.8	1.23
D90	90	81.6	3.2	NA

1: IM = Incipient Motion (τ* = 0.03)
2: MT = Measureable Transport (τ* = 0.05)

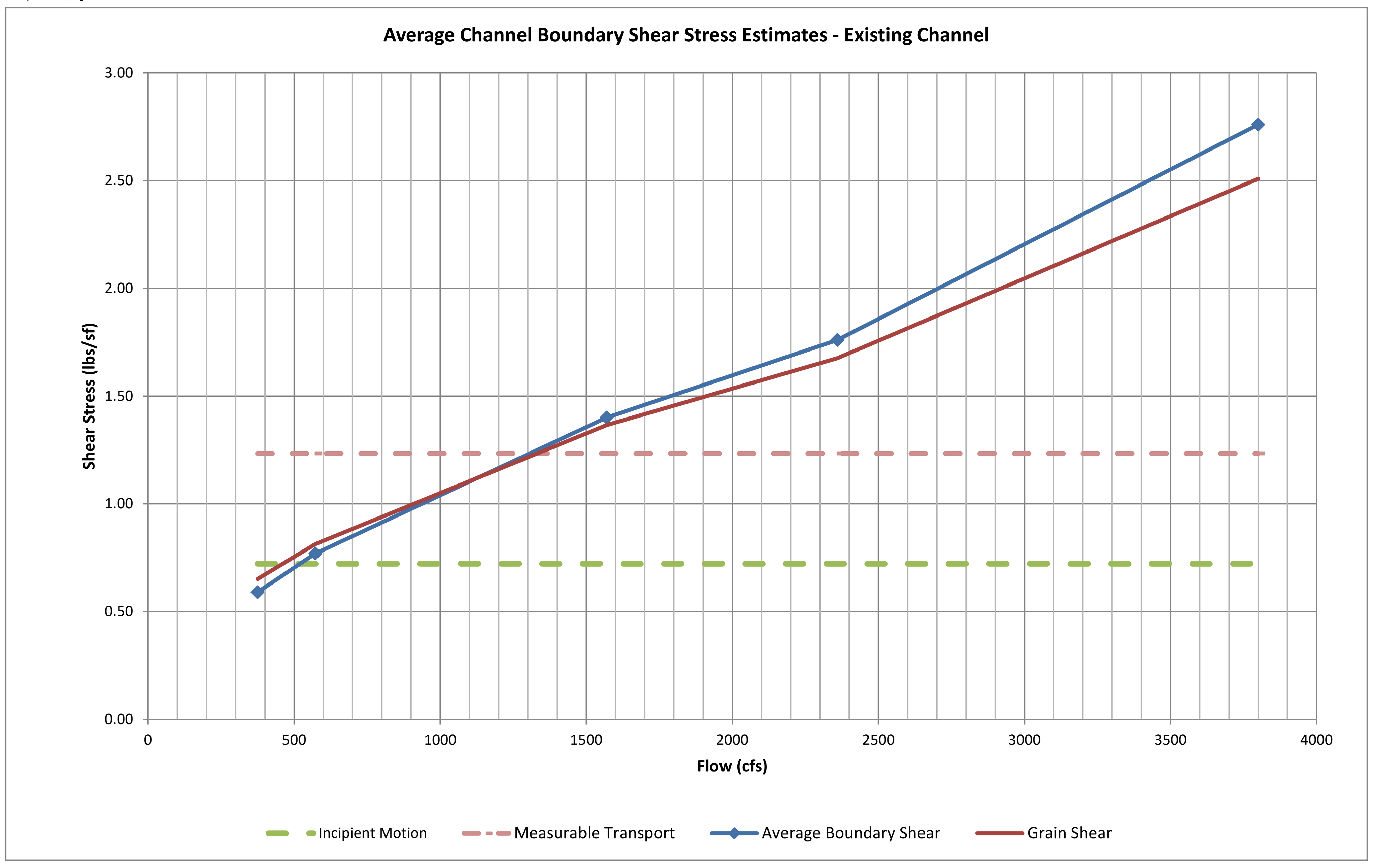
	OHW Mean Channel Shear (psf)	2-Year Mean Channel Shear (psf)	10-Year Mean Channel Shear (psf)	25-Year Mean Channel Shear (psf)	100-Year Mean Channel Shear (psf)	
	Main Channel	Main Channel	Main Channel	Main Channel	Main Channel	
	0.59	0.77	1.40	1.76	2.76	
Surplus Total Shear						
	0.13	-0.05	-0.68	-1.04	-2.04	IM
	0.64	0.46	-0.17	-0.53	-1.53	MT

k_s- 3.5 D84 (ft) "ks" 0.810
Mean Riffle Slope 0.0070 ft/ft

Method I³ Grain Shear Calculations

Q	V	R'	V*	V/V* Log Fxn I	V/V*	Diff	τ'	τ'/τ	φ'	Surplus Grain Shear	
375	4.51	1.49	0.579	7.783	7.784	0.000	0.651	85%	0.90	-0.1	IM
573	5.4	1.86	0.648	8.339	8.339	0.000	0.814	106%	1.13	0.1	
1570	8.08	3.12	0.839	9.632	9.632	0.000	1.365	177%	1.89	0.6	
2360	9.43	3.83	0.930	10.144	10.144	0.000	1.676	218%	2.32	1.0	
3800	12.68	5.74	1.137	11.151	11.151	0.000	2.509	326%	3.47	1.8	MT

Notes: 1: IM = Insipient Motion
3: φ' = τ'/$τ_c$



Incipient Motion - Proposed Conditions (Old Channel)

% Finer		Average Streambed Gravel (mm)	Average Streambed Gravel (in)	Critical Shear (lb/sq ft)
D10	10	NA	NA	NA
D16	16	25.4	NA	NA
D50	50	42.9	1.7	0.72
D84	84	70.5	2.8	1.23
D90	90	81.6	NA	NA

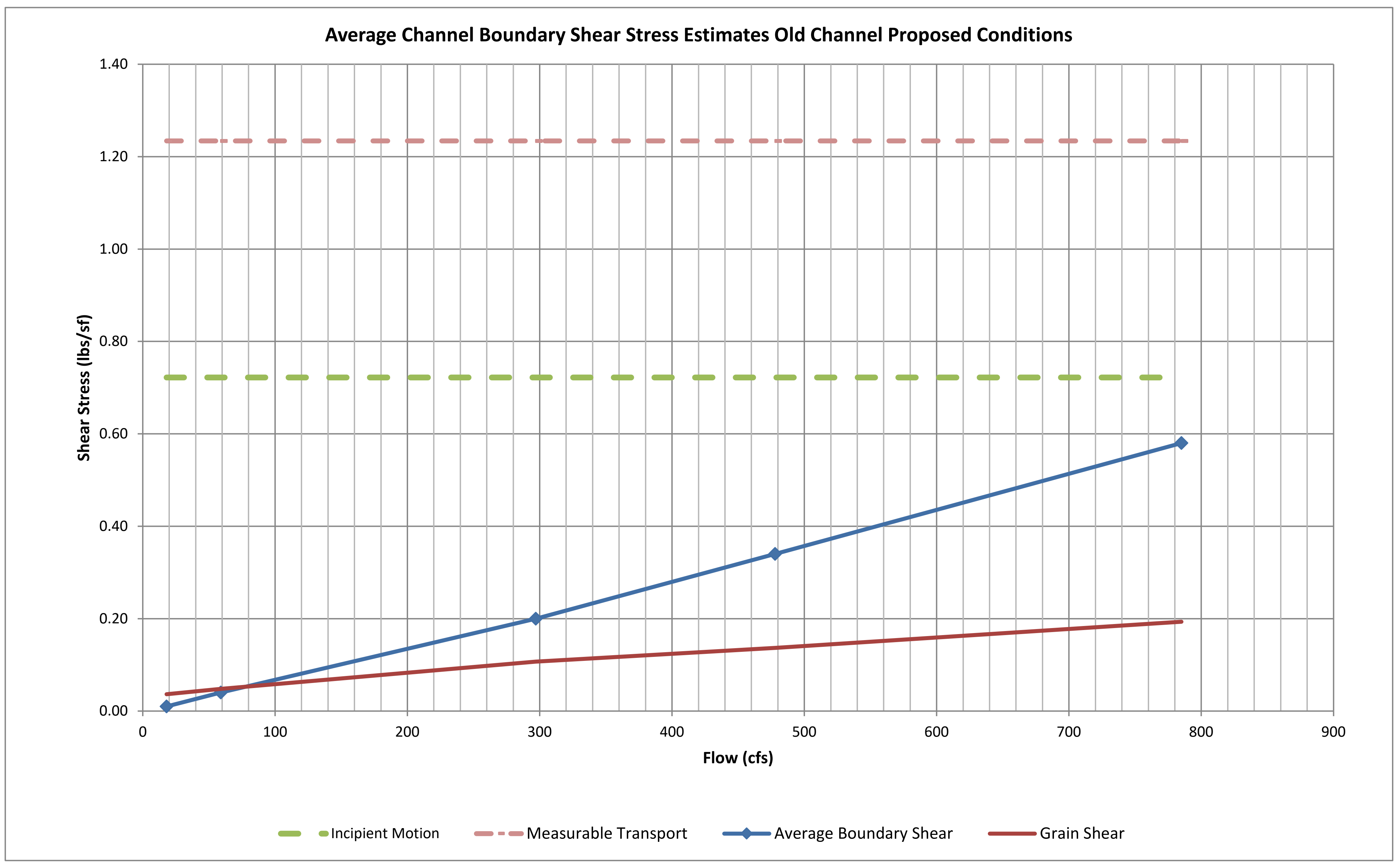
1: IM = Incipient Motion (τ* = 0.03)
2: MT = Measureable Transport (τ* = 0.05)

OHW Mean Channel Shear (psf)	2-Year Mean Channel Shear (psf)	10-Year Mean Channel Shear (psf)	25-Year Mean Channel Shear (psf)	100-Year Mean Channel Shear (psf)	
Main Channel	Main Channel	Main Channel	Main Channel	Main Channel	
0.01	0.04	0.20	0.34	0.58	
		Surplus Total Shear			
0.71	0.68	0.52	0.38	0.14	IM
1.22	1.19	1.03	0.89	0.65	MT

k_s- 3.5 D84 (ft) "ks" 0.810
Mean Riffle Slope 0.0070 ft/ft

Method I³ Grain Shear Calculations										Surplus Grain Shear	
Q	V	R'	V*	V/V* Log Fxn I	V/V*	Diff	τ'	τ'/τ	φ'		
18	0.08	0.08	0.137	0.584	0.584	0.000	0.036	91%	0.05	-0.7	IM
59	0.2	0.11	0.157	1.272	1.271	-0.001	0.048	120%	0.07	-0.7	
297	0.77	0.25	0.235	3.276	3.276	0.000	0.107	268%	0.15	-0.6	
478	1.03	0.31	0.265	3.882	3.882	0.000	0.137	341%	0.19	-0.6	
785	1.5	0.44	0.316	4.751	4.751	0.001	0.193	483%	0.27	-0.5	MT

Notes: 1: IM = Insipient Motion
3: $\phi' = \tau'/\tau_c$



Incipient Motion - Proposed Conditions New Channel

% Finer		Average Streambed Gravel (mm)	Average Streambed Gravel (in)	Critical Shear (lb/sq ft)
D10	10	NA	NA	NA
D16	16	25.4	NA	NA
D50	50	42.9	1.7	0.72
D84	84	70.5	2.8	1.23
D90	90	81.6	NA	NA

1: IM = Incipient Motion (τ* = 0.03)
2: MT = Measureable Transport (τ* = 0.05)

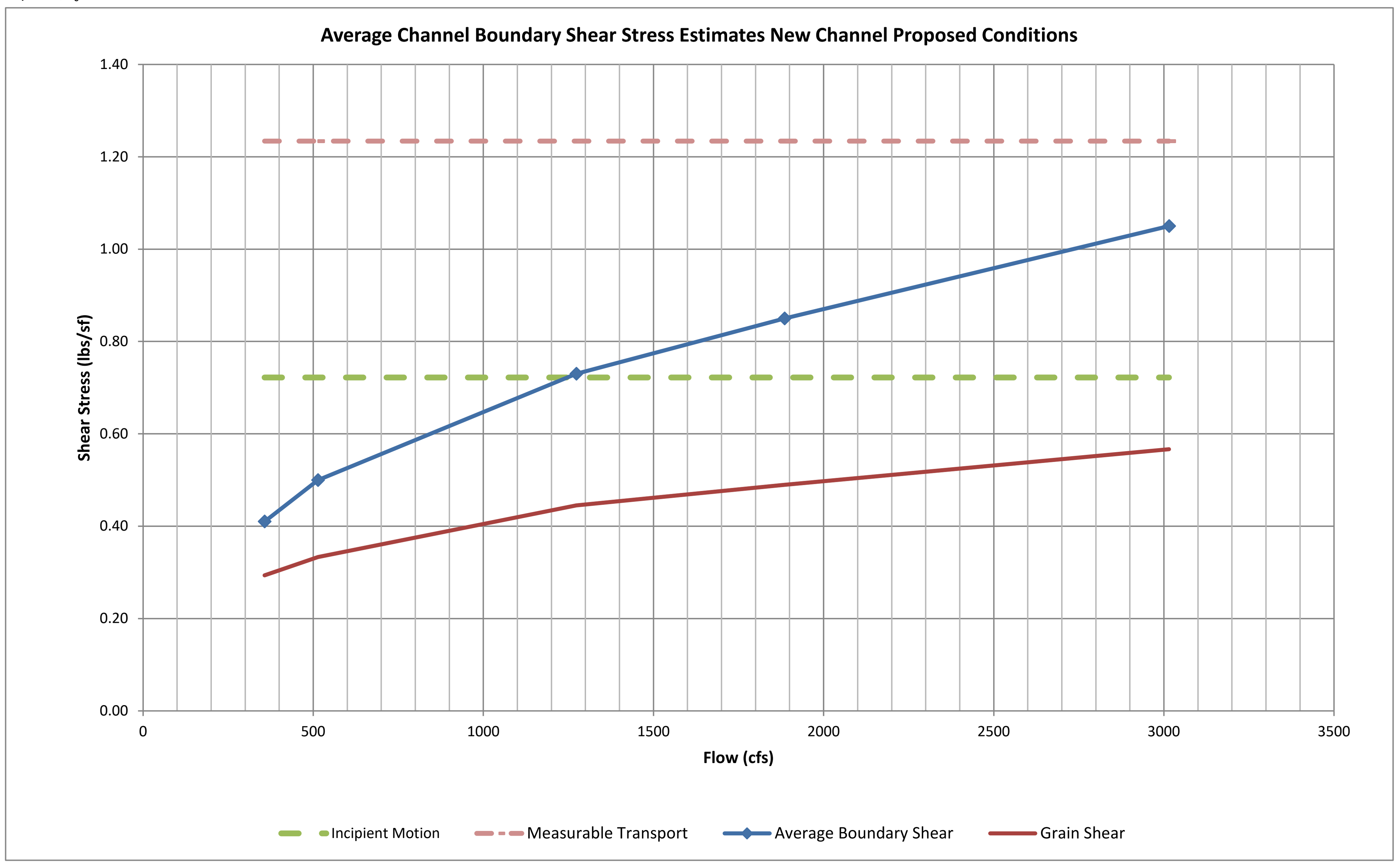
	OHW Mean Channel Shear (psf)	2-Year Mean Channel Shear (psf)	10-Year Mean Channel Shear (psf)	25-Year Mean Channel Shear (psf)	100-Year Mean Channel Shear (psf)	
	Main Channel	Main Channel	Main Channel	Main Channel	Main Channel	
	0.41	0.50	0.73	0.85	1.05	
Surplus Total Shear						
	0.31	0.22	-0.01	-0.13	-0.33	IM
	0.82	0.73	0.50	0.38	0.18	MT

k_s- 3.5 D84 (ft) "ks" 0.810
Mean Riffle Slope 0.0049 ft/ft

Method I[3]
Grain Shear Calculations

Q	V	R'	V*	V/V* Log Fxn I	V/V*	Diff	τ'	τ'/τ	φ'	Surplus Grain Shear	
357	2.6	0.96	0.389	6.684	6.684	0.000	0.294	59%	0.41	-0.4	IM
514	2.9	1.09	0.414	6.999	7.000	0.001	0.333	67%	0.46	-0.4	
1273	3.7	1.45	0.479	7.724	7.724	0.000	0.445	89%	0.62	-0.3	
1885	4	1.60	0.502	7.962	7.962	0.000	0.490	98%	0.68	-0.2	
3015	4.5	1.85	0.540	8.326	8.326	0.000	0.567	113%	0.78	-0.2	MT

Notes: 1: IM = Insipient Motion
3: $\phi' = \tau'/\tau_c$



Incipient Motion - Proposed Conditions Grade Stabilization Measure Material

% Finer		Average Streambed Gravel (mm)	Average Streambed Gravel (in)	Critical Shear (lb/sq ft)
D10	10	NA	NA	NA
D16	16	25.4	1.0	NA
D50	50	127.0	3.5	1.56
D84	84	253.0	6.0	2.77
D90	90	305.0	8.0	NA

1: IM = Incipient Motion (τ^* = 0.052)
2: MT = Measureable Transport (τ^* = 0.054)

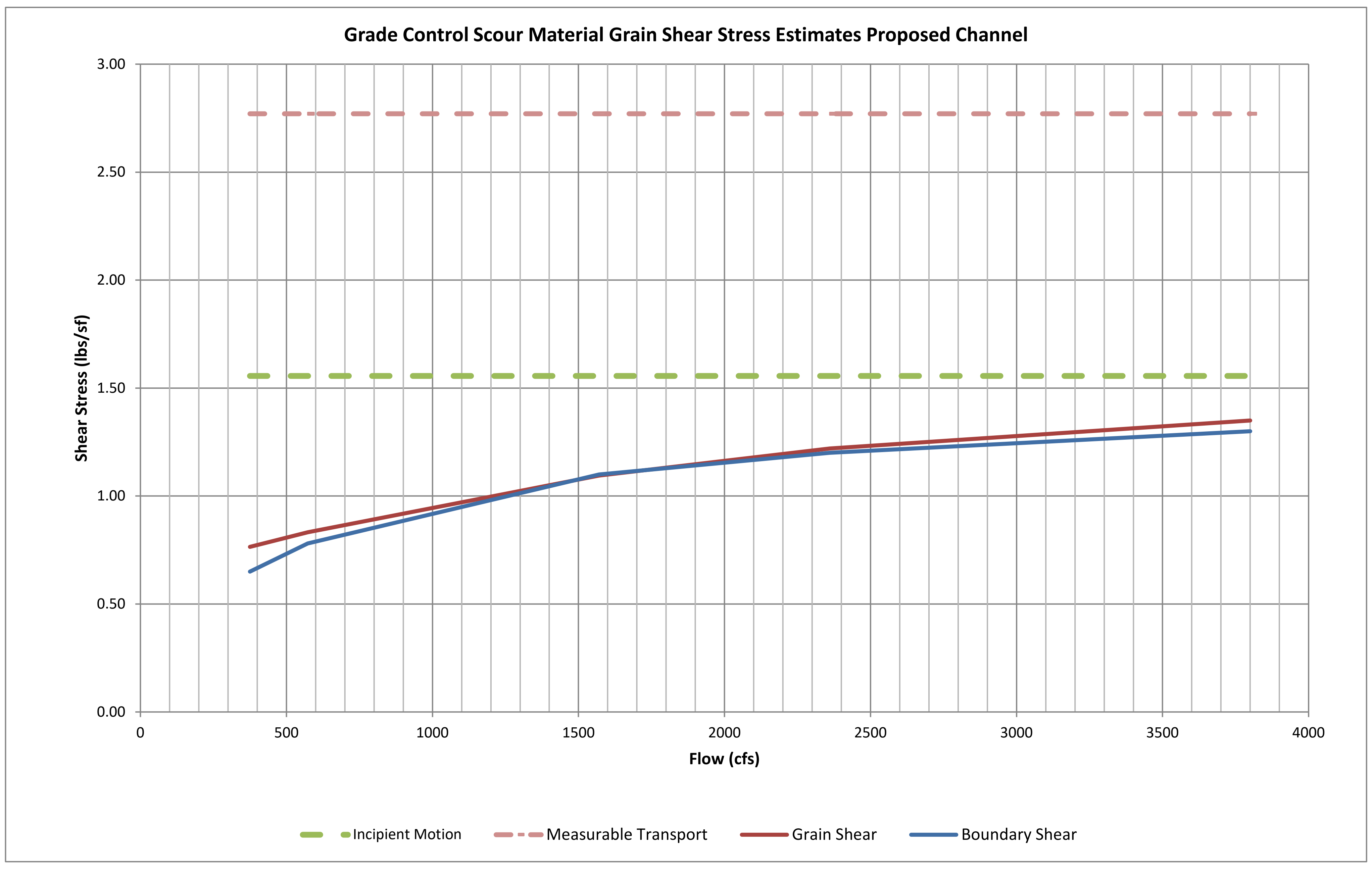
	Bankfull Mean Riffle Shear (psf)	2-Year Mean Riffle Shear (psf)	10-Year Mean Channel Shear (psf)	25-Year Mean Riffle Shear (psf)	100-Year Mean Riffle Shear (psf)	
	Main Channel	Main Channel	Main Channel	Main Channel	Main Channel	
	0.65	0.78	1.10	1.2	1.30	
			Surplus Total Shear			
	0.91	0.78	0.46	0.36	0.26	IM
	2.12	1.99	1.67	1.57	1.47	MT

k_s- 3.5 D84 (ft) "ks" 1.750
Mean Riffle Slope 0.0081 ft/ft

Method I[3]
Grain Shear Calculations

Q	V	R'	V*	V/V* Log Fxn I	V/V*	Diff	τ'	τ'/τ	φ'	Surplus Grain Shear	
375	3.7	1.51	0.628	5.894	5.894	0.000	0.765	98%	0.49	-0.8	IM
573	4	1.65	0.655	6.107	6.106	0.000	0.832	107%	0.53	-0.7	
1570	5.1	2.16	0.751	6.790	6.790	0.000	1.095	140%	0.70	-0.5	
2360	5.6	2.41	0.793	7.061	7.061	0.000	1.220	156%	0.78	-0.3	
3800	6.1	2.67	0.834	7.313	7.313	0.000	1.350	173%	0.87	-0.2	MT

Notes: 1: IM = Insipient Motion
3: $\phi' = \tau'/\tau_c$



Channel Spanner LWM Structure Boulder Sizing

Boulder		Channel Shear	Max Shear			FOS	Boulder Weight	Boulder Diameter
Dia.	Section	(psf)	(psf)	D[1]50	D100	D100	(lb)	(in)
3.0		2.60	3.90	0.98	1.46	2.1	2333	36

1. HRB Method

Force Balance

Unit Weight Water = 62.4 pcf
Unit Weight Stone = 165 pcf
Riffle Slope = 0.0129 ft/ft

Rock Riffle Force Balance USBR Eqn 7-1 42 0.733038286

η0	λ	ϴ0	ϴ1	ϴ	ao	β	η1	SF
0.152	0	0.013	0	1.571	0.999916805	5.15E-17	0.228	4.13

$$SF = \frac{a_0 \cdot \tan(\phi)}{\eta_1 \cdot \tan(\phi) + \sqrt{1 - a_0^2} \cdot \cos(\beta)}$$ **Equation 7-1**

$$a_0 = \sqrt{\cos^2(\theta_1) - \sin^2(\theta_0)}$$

$$\theta = \tan^{-1}\left(\frac{\sin(\theta_0)}{\sin(\theta_1)}\right)$$

$$\eta_1 = \eta_0 \left[\frac{\left(\frac{A}{B}\right) + \sin(\lambda + \beta + \theta)}{1 + \left(\frac{A}{B}\right)}\right] \cong \eta_0 \left[\frac{1 + \sin(\lambda + \beta + \theta)}{2}\right]$$

$$\eta_0 \cong \frac{18 \cdot \tau_0}{(\gamma_s - \gamma_w) \cdot D_s}$$

$$\beta = \tan^{-1}\left(\frac{\cos(\lambda + \theta)}{\frac{(A + B) \cdot \sqrt{1 - a_0^2}}{B \cdot \eta_0 \cdot \tan(\phi)} + \sin(\lambda + \theta)}\right) \cong \tan^{-1}\left(\frac{\cos(\lambda + \theta)}{\frac{2 \cdot \sqrt{1 - a_0^2}}{\eta_0 \cdot \tan(\phi)} + \sin(\lambda + \theta)}\right)$$

$$A = \left(\frac{l_4}{l_2}\right) \cdot \left(\frac{F_L}{F_S}\right)$$

$$B = \left(\frac{l_3}{l_4}\right) \cdot \left(\frac{F_D}{F_S}\right)$$

$$\frac{A}{B} \approx 1$$

Where,

SF = Safety factor;
D_s = rock diameter;
θ_0 = longitudinal bed slope;
θ_1 = bank side slope;
ϕ = Angle of repose (≅42 Degrees);
λ = angle of vertical stream line deviation from horizontal, must be ≥ 0 (outside of a bend);
τ_0 = bed shear stress = $\gamma \cdot R \cdot S_f$;
γ = unit weight of water;
R = hydraulic radius;
S_f = friction slope;
θ = down-slope angle including bed and bank slope;
η_0 = shear force acting on the rock;
β = correction for side slope, bed slope, and secondary currents;
η_1 = correction for side slope, bed slope, and secondary currents; and
$l_{1,2,3,4}$ = moment arms between riprap particles (canceled through lift and drag assumptions.
A, B = lever arm ratios. The ratio A/B is assumed to equal 1.

Debris Jam LWM Structure Boulder Sizing 100-year Recurrence Interval

Boulder		Channel Shear	Max Shear			FOS	Boulder Weight	Boulder Diameter
Dia.	Section	(psf)	(psf)	$D^1$50	D100	D100	(lb)	(in)
2.0		2.40	3.60	0.90	1.35	1.5	691	24

1. HRB Method

Force Balance

Unit Weight Water =	62.4	pcf
Unit Weight Stone =	165	pcf
Riffle Slope =	0.0081	ft/ft

Rock Riffle Force Balance USBR Eqn 7-1 42 0.733038286

η0	λ	θ0	θ1	θ	ao	β	η1	SF
0.211	0	0.008	0	1.571	0.999967197	5.64E-17	0.316	3.08

$$SF = \frac{a_\theta \cdot \tan(\phi)}{\eta_1 \cdot \tan(\phi) + \sqrt{1 - a_\theta^{\,2}} \cdot \cos(\beta)}$$

Equation 7-1

$$a_\theta = \sqrt{\cos^2(\theta_1) - \sin^2(\theta_0)}$$

$$\theta = \tan^{-1}\left(\frac{\sin(\theta_0)}{\sin(\theta_1)}\right)$$

$$\eta_1 = \eta_0 \left[\frac{\left(\frac{A}{B}\right) + \sin(\lambda + \beta + \theta)}{1 + \left(\frac{A}{B}\right)}\right] \cong \eta_0 \left[\frac{1 + \sin(\lambda + \beta + \theta)}{2}\right]$$

$$\eta_0 \cong \frac{18 \cdot \tau_0}{(\gamma_s - \gamma_w) \cdot D_s}$$

$$\beta = \tan^{-1}\left(\frac{\cos(\lambda + \theta)}{\frac{(A+B) \cdot \sqrt{1 - a_\theta^{\,2}}}{B \cdot \eta_0 \cdot \tan(\phi)} + \sin(\lambda + \theta)}\right) \cong \tan^{-1}\left(\frac{\cos(\lambda + \theta)}{\frac{2 \cdot \sqrt{1 - a_\theta^{\,2}}}{\eta_0 \cdot \tan(\phi)} + \sin(\lambda + \theta)}\right)$$

$$A = \left(\frac{l_4}{l_2}\right) \cdot \left(\frac{F_L}{F_S}\right)$$

$$B = \left(\frac{l_3}{l_4}\right) \cdot \left(\frac{F_D}{F_S}\right)$$

$$\frac{A}{B} \approx 1$$

Where,

- SF = Safety factor;
- D_s = rock diameter;
- θ_0 = longitudinal bed slope;
- θ_1 = bank side slope;
- ϕ = Angle of repose (≅42 Degrees);
- λ = angle of vertical stream line deviation from horizontal, must be ≥ 0 (outside of a bend);
- τ_0 = bed shear stress = $\gamma \cdot R \cdot S_f$;
- γ = unit weight of water;
- R = hydraulic radius;
- S_f = friction slope;
- θ = down-slope angle including bed and bank slope;
- η_0 = shear force acting on the rock;
- β = correction for side slope, bed slope, and secondary currents;
- η_1 = correction for side slope, bed slope, and secondary currents; and
- $l_{1,2,3,4}$ = moment arms between riprap particles (canceled through lift and drag assumptions.
- A, B = lever arm ratios. The ratio A/B is assumed to equal 1.

UmaBirch PA-4 Project

Summary of Scour Calculations

Project:	PA-4
Date:	4/8/2021
Computed:	JA
Checked:	CM

Resources:

NRCS, 2007. Technical Supplement 14B, Scour Calculations

Objectives: Calculate General Scour

Design Assumptions:

Design 100yr Qd	1,730	cfs
Flow Width at Design Discharge Wf	115	ft
Median Size of Bed Material D50	43	mm

NRCS Technical Supplment 14B

Blodgett (1986)

Kmean	1.42	
Kmax	6.5	
Zt(mean)	1.0	ft
Zt(max)	4.3	ft

$$z_t\,(\text{mean}) = K\,D_{50}^{-0.1} \qquad \text{(eq. TS14B–21)}$$

$$z_t\,(\text{max}) = K\,D_{50}^{-0.11} \qquad \text{(eq. TS14B–22)}$$

where:
z_t (mean) = best fit curve (fig. TS14B–1) for observed scour depth, ft
z_t (max) = enveloping curve (fig. TS14B–1) for maximum scour depth, ft
K = coefficient = 1.42 and 6.5 for z_t mean and z_t max, respectively (0.84 and 3.8 for SI units), and D_{50} is the median size of the bed material, ft (mm)

NRCS Technical Supplment 14B

Pemberton and Lara (1984)

Lacey (1931)

K	0.389
Right Angle Bend	
a	1/3
b	0
c	- 1/6
Zt	2.5 ft

$$z_t = KQ_d^a\,W_f^b\,D_{50}^{\ c} \qquad \text{(eq. TS14B–23)}$$

where:
z_t = maximum scour depth at the cross section or reach in question, ft (m)
K = coefficient (table TS14B–8)
Q_d = design discharge, ft^3/s (m^3/s)
W_f = flow width at design discharge, ft (m)
D_{50} = median size of bed material (mm)
a, b, c = exponents (table TS14B–8)

Blech (1970)

K	1.105
Right angle Bend	
a	2/3
b	- 2/3
c	-0.1092
Zt	4.5 ft

Zt(avg)	3.5 ft

Table TS14B–8 Constants for Lacey and Blench relations, U.S. units (D_{50} in mm)

Condition	Lacey				Blench			
	K	a	b	c	K	a	b	c
Straight reach	0.097	1/3	0	–1/6	0.530	2/3	–2/3	–0.1092
Moderate bend	0.195	1/3	0	–1/6	0.530	2/3	–2/3	–0.1092
Severe bend	0.292	1/3	0	–1/6	0.530	2/3	–2/3	–0.1092
Right angle bend	0.389	1/3	0	–1/6	1.105	2/3	–2/3	–0.1092
Vertical rock wall	0.487	1/3	0	–1/6				

Engineered Log Jam Buoyancy Factor of Safety Calculations - 10-Log Habitat Structure

Methodology based on standard force balance approach, information adapted from D'aoust & Millar (2000), and USBR USACE 2016 National Large Wood Manual.

KEY "BASE" MEMBERS

Number of Logs with Rootwads	N_L =	**6**		
DOUG-FIR	S_L =	**0.40**	specific gravity	
Average Rootwad Fan Diameter	D_{RW} =	**4**	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	**4**	feet	
Proportion of Voids in Rootwad	p =	**0.2**	decimal %	
Tree Stem Average Diameter	D_{TS} =	**1.5**	feet	
Tree Stem Average Length	L_{TS} =	**40**	feet	**F_{BL} = 23,312** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1-S_L) \cdot N_L$$

STACKED "MIDDLE" MEMBERS

Number of Logs with Rootwads	N_L =	**2**		
pine, ponderosa	S_L =	**0.40**		
Average Rootwad Fan Diameter	D_{RW} =	**4**	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	**4**	feet	
Proportion of Voids in Rootwad	p =	**0.2**	decimal %	
Tree Stem Average Diameter	D_{TS} =	**1.5**	feet	
Tree Stem Average Length	L_{TS} =	**40**	feet	**F_{BL} = 7,771** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1-S_L) \cdot N_L$$

TOP MEMBERS

Number of Logs with Rootwads	N_L =	**2**		
pine, ponderosa	S_L =	**0.40**		
Average Rootwad Fan Diameter	D_{RW} =	**4**	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	**4**	feet	
Proportion of Voids in Rootwad	p =	**0.2**	decimal %	
Tree Stem Average Diameter	D_{TS} =	**1.5**	feet	
Tree Stem Average Length	L_{TS} =	**40**	feet	**F_{BL} = 7,771** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1-S_L) \cdot N_L$$

SUBMERGED WEIGHT OF TREES

Base Members	Wt	**17,443**	lbs
Staked Middle Members	Wt	**5,814**	lbs
Key Top Memebers	Wt	**5,814**	lbs
Total		**29,072**	(pounds) effective weight for all trees

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	**2.66**				
equivalent Diameter of Boulder	D_B =	**2.0**	feet			
Number of Boulders Submerged	N_B =	**0**				
Number of Boulders above water level	N_{BU} =	**0**		**W' =**	**434**	(pounds) effective weight per submerged boulder
				W =	**695**	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	**0**	pounds

$$W' = \frac{\pi D_B^3}{6} \cdot \rho_w g (S_S - 1)$$

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	**2.66**				
equivalent Diameter of Boulder	D_B =	**3.0**	feet			
Number of Boulders Submerged	N_B =	**0**				
Number of Boulders above water level	N_{BU} =	**0**		**W' =**	**1,465**	(pounds) effective weight per submerged boulder
				W =	**2,347**	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	**0**	pounds

$$W' = \frac{\pi D_B^3}{6} \cdot \rho_w g (S_S - 1)$$

SOIL BALLAST

Specific Gravity of Soil Particles	S_{soil} =	**2.65**				
Minimum Soil Dry Density	$\gamma_{d\ min}$=	**90**	lbs/ft^3			
Maximum Soil Dry Density	$\gamma_{d\ max}$=	**115**	lbs/ft^3			
Compaction	Dr =	**90%**	Percent Relative Density			
Unit Weight of Dry Soil Backfill	γ_d=	**130**	lbs/ft^3			
Void Ratio	e=	**0.27**				
Porosity	n=	**0.21**				
Degree of Saturation Below Water Level	S=	**100%**				
Weight of Pore Water	*w*=	**10.26**	lbs/ft^3			
Saturated Unit Weight of Soil Backfill	γ_{sat}=	**140.26**	lbs/ft^3			
Buoyant Unit Weight of Soil Backfill	γ'_b	**77.864**	lbs/ft^3			
Nominal Footprint Area of Soil Backfill	A_{BF}=	**560.0**	ft^2			
Depth of Soil Backfill Submerged	Z_B =	**3.0**	feet			
Depth of Soil Backfill above Water Level	Z_{BU} =	**0.0**	feet	**W' =**	**49,966**	(pounds effective weight per 50 cubic feet of Soil Ballast
Total Volume of Wood	V_d =	**1038.3**	ft^3	**W =**	**0**	(pounds) weight per 50 cubic feet of Soil Ballast
				Total Effective Weight for all Soil Lifts =	**49,966**	pounds

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the log jam are fully submerged. In addition, the log jam and boulders act as a composite structure and are assumed fully connected. Water velocity inside the log jam is highly turbulent and near zero, therefore vertical uplift forces are assumed negligible.

A minimum factor of safety against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$$FS_B = \frac{\sum(W + W')}{\sum F_{BL}}$$

FS_B = 2.03

HORIZONTAL FORCES: FRICTION

Bed Sediment Friction Angle	ϕ=	33	Degrees
Bed Stress	μ_{bed}=	0.64940759	
Submerged Weight of Ballast	$W_{bl(sub)}$=	49,966	lbs.
Specific Weight of Water	γw=	62.43	lbs./ft^3
Buoyancy Force	F_b=	38854.1088	lbs.
Drag Coefficient	C_L=	1.5	
Area of Structure Perpendicular to Flow	A=	120	ft^2
Approach Flow Velocity	Uo=	4	fps
Gravitational Constant	g=	32.17	ft/s^2
Lift Force	F_L=	2794.5042	lbs.
Normal Force	F_n=	8,317	lbs.
Friction Force	Ff=	5401.18475	lbs.

$$\vec{F}_L = \frac{C_L A \gamma_w U_o^2}{2g}$$

$$\vec{F}_n = W_{bl(sub)} - \vec{F}_b - \vec{F}_L$$

Assumes maximum drag coefficient

Length 40 ft Depth 3 ft

$$\vec{F}_f = \mu_{bed} F_n$$

HORIZONTAL FORCES: DRAG

Drag Coefficient	C_D=	1.5	
Drag Force	F_d=	2794.50	lbs.

Assumes maximum drag coefficient

$$\vec{F}_d = \frac{C_D A \gamma_w U_o^2}{2g}$$

LATERAL RESISTANCE FORCES: VERTICAL PILINGS

Number of Piles	N=	0	
Length of Pile Buried Below Scoured Bed	L_{em}=	0	ft
Pile Diameter	dp=	0	ft
Distance Above Scoured Bed Applied Load	h_{load}=	4	ft
Effective Angle of Internal Friction	ϕ'=	33	Degrees
Rankine Coefficient of Passive Earth Pressure	K_p=	3.39212	
Horizontal Restraint Force (Pilings)	Fgh=	0	lbs.

$$K_p = \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$F_{gh(piles)} = N\left(\frac{\frac{1}{2}L_{em}^3 d_p K_p(\gamma_s - \gamma_w)}{(h_{load} + L_{em})}\right)$$

FACTOR OF SAFETY: SLIDING

Target factor of safety for sliding is 1.75

F_{sh} = 1.93

$$F_{sh} = \frac{\vec{F}_f + \vec{F}_{gh} + \vec{F}_{ah}}{\vec{F}_d}$$

Engineered Log Jam Buoyancy Factor of Safety Calculations - 11-Log Habitat Structure

Methodology based on standard force balance approach, information adapted from D'aoust & Millar (2000), and USBR USACE 2016 National Large Wood Manual.

KEY "BASE" MEMBERS

Number of Logs with Rootwads	N_L =	4	
DOUG-FIR	S_L =	0.40	specific gravity
Average Rootwad Fan Diameter	D_{RW} =	4	feet
Average Rootwad Length	L_{RW} =	4	feet
Proportion of Voids in Rootwad	p =	0.2	decimal %
Tree Stem Average Diameter	D_{TS} =	1.5	feet
Tree Stem Average Length	L_{TS} =	40	feet

Wood Volume = 104 cubic feet per member

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

F_{BL} = 15,542 pounds

STACKED "MIDDLE" MEMBERS

Number of Logs without Rootwads	N_L =	4	
pine, ponderosa	S_L =	0.40	
Average Rootwad Fan Diameter	D_{RW} =	0	feet
Average Rootwad Length	L_{RW} =	0	feet
Proportion of Voids in Rootwad	p =	0.2	decimal %
Tree Stem Average Diameter	D_{TS} =	1.5	feet
Tree Stem Average Length	L_{TS} =	40	feet

Wood Volume = 71 cubic feet per member

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

F_{BL} = 10,581 pounds

TOP MEMBERS

Number of Logs with Rootwads	N_L =	3	
pine, ponderosa	S_L =	0.40	
Average Rootwad Fan Diameter	D_{RW} =	4	feet
Average Rootwad Length	L_{RW} =	4	feet
Proportion of Voids in Rootwad	p =	0.2	decimal %
Tree Stem Average Diameter	D_{TS} =	1.5	feet
Tree Stem Average Length	L_{TS} =	40	feet

Wood Volume = 104 cubic feet per member

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

F_{BL} = 11,656 pounds

SUBMERGED WEIGHT OF TREES

Base Members	Wt	11,629	lbs
Staked Middle Members	Wt	7,917	lbs
Key Top Memebers	Wt	8,722	lbs
Total		28,267	(pounds) effective weight for all trees

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66	
equivalent Diameter of Boulder	D_B =	2.0	feet
Number of Boulders Submerged	N_B =	0	
Number of Boulders above water level	N_{BU} =	0	

$$W'=\frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

W' =	434	(pounds) effective weight per submerged boulder
W =	695	(pounds) weight per boulder
Total Effective Weight for all Boulders =	0	pounds

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66	
equivalent Diameter of Boulder	D_B =	3.0	feet
Number of Boulders Submerged	N_B =	0	
Number of Boulders above water level	N_{BU} =	0	

$$W'=\frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

W' =	1,465	(pounds) effective weight per submerged boulder
W =	2,347	(pounds) weight per boulder
Total Effective Weight for all Boulders =	0	pounds

SOIL BALLAST

Specific Gravity of Soil Particles	S_{soil} =	2.65	
Minimum Soil Dry Density	$\gamma_{d\,min}$=	90	lbs/ft^3
Maximum Soil Dry Density	$\gamma_{d\,max}$=	115	lbs/ft^3
Compaction	Dr =	90%	Percent Relative Density
Unit Weight of Dry Soil Backfill	γ_d=	130	lbs/ft^3
Void Ratio	e=	0.27	
Porosity	n=	0.21	
Degree of Saturation Below Water Level	S=	100%	
Weight of Pore Water	*w*=	10.26	lbs/ft^3
Saturated Unit Weight of Soil Backfill	γ_{sat}=	140.26	lbs/ft^3
Buoyant Unit Weight of Soil Backfill	γ'_b	77.864	lbs/ft^3
Nominal Footprint Area of Soil Backfill	A_{BF}=	570.0	ft^2
Depth of Soil Backfill Submerged	Z_B =	3.0	feet
Depth of Soil Backfill above Water Level	Z_{BU} =	0.0	feet
Total Volume of Wood	V_d =	1009.6	ft^3

W' =	54,540	(pounds effective weight per 50 cubic feet of Soil Ballast
W =	0	(pounds) weight per 50 cubic feet of Soil Ballast
Total Effective Weight for all Soil Lifts =	54,540	pounds

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the log jam are fully submerged. In addition, the log jam and boulders act as a composite structure and are assumed fully connected. Water velocity inside the log jam is highly turbulent and near zero, therefore vertical uplift forces are assumed negligible.

A minimum factor of safety against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$$FS_B = \frac{\sum(W + W')}{\sum F_{BL}}$$

FS_B = 2.19

HORIZONTAL FORCES: FRICTION

Bed Sediment Friction Angle	ϕ=	33	Degrees
Bed Stress	μ_{bed}=	0.64940759	
Submerged Weight of Ballast	$W_{bl(sub)}$=	54,540	lbs.
Specific Weight of Water	γw=	62.43	$lbs./ft^3$
Buoyancy Force	F_b=	37778.4202	lbs.
Drag Coefficient	C_L=	1.5	
Area of Structure Perpendicular to Flow	A=	120	ft^2
Approach Flow Velocity	Uo=	5	fps
Gravitational Constant	g=	32.17	ft/s^2
Lift Force	F_L=	4366.41281	lbs.
Normal Force	F_n=	12,395	lbs.
Friction Force	Ff=	8049.43915	lbs.

$$\vec{F}_L = \frac{C_L A \gamma_w U_o^2}{2g}$$

$$\vec{F}_n = W_{bl(sub)} - \vec{F}_b - \vec{F}_L$$

Assumes maximum drag coefficient

Length 40 ft   Depth 3 ft

$$\vec{F}_f = \mu_{bed} F_n$$

HORIZONTAL FORCES: DRAG

Drag Coefficient	C_D=	1.5	
Drag Force	F_d=	4366.41	lbs.

Assumes maximum drag coefficient

$$\vec{F}_d = \frac{C_D A \gamma_w U_o^2}{2g}$$

LATERAL RESISTANCE FORCES: VERTICAL PILINGS

Number of Piles	N=	0	
Length of Pile Buried Below Scoured Bed	L_{em}=	0	ft
Pile Diameter	dp=	0	ft
Distance Above Scoured Bed Applied Load	h_{load}=	4	ft
Effective Angle of Internal Friction	ϕ'=	33	Degrees
Rankine Coefficient of Passive Earth Pressure	K_p=	3.39212	
Horizontal Restraint Force (Pilings)	Fgh=	0	lbs.

$$K_p = \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$F_{gh(piles)} = N\left(\frac{\frac{1}{2}L_{em}^3 d_p K_p(\gamma_s - \gamma_w)}{(h_{load} + L_{em})}\right)$$

FACTOR OF SAFETY: SLIDING

Target factor of safety for sliding is 1.75

F_{sh} = 1.84

$$F_{sh} = \frac{\vec{F}_f + \vec{F}_{gh} + \vec{F}_{ah}}{\vec{F}_d}$$

Engineered Log Jam Buoyancy Factor of Safety Calculations - Bank Habitat Structure

Methodology based on standard force balance approach, information adapted from D'aoust & Millar (2000), and USBR USACE 2016 National Large Wood Manual.

KEY "BASE" MEMBERS

Number of Logs with Rootwads	N_L =	1		
DOUG-FIR	S_L =	0.40	specific gravity	
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume =** **104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} =** **3,885** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1 - S_L) \cdot N_L$$

STACKED "MIDDLE" MEMBERS

Number of Logs with Rootwads	N_L =	2		
pine, ponderosa	S_L =	0.40		
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume =** **104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} =** **7,771** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1 - S_L) \cdot N_L$$

TOP MEMBERS

Number of Logs with Rootwads	N_L =	2		
pine, ponderosa	S_L =	0.40		
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume =** **104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} =** **7,771** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1 - S_L) \cdot N_L$$

SUBMERGED WEIGHT OF TREES

Base Members	Wt	2,907	lbs
Staked Middle Members	Wt	5,814	lbs
Key Top Memebers	Wt	5,814	lbs
Total		14,536	(pounds) effective weight for all trees

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	2.0	feet			
Number of Boulders Submerged	N_B =	0				
Number of Boulders above water level	N_{BU} =	0		**W' =**	**434**	(pounds) effective weight per submerged boulder
				W =	**695**	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	**0**	pounds

$$W' = \frac{\pi D_B^3}{6} \cdot \rho_w g (S_S - 1)$$

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	3.0	feet			
Number of Boulders Submerged	N_B =	0				
Number of Boulders above water level	N_{BU} =	0		**W' =**	**1,465**	(pounds) effective weight per submerged boulder
				W =	**2,347**	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	**0**	pounds

$$W' = \frac{\pi D_B^3}{6} \cdot \rho_w g (S_S - 1)$$

SOIL BALLAST

Specific Gravity of Soil Particles	S_{soil} =	2.65				
Minimum Soil Dry Density	$\gamma_{d\ min}$=	90	lbs/ft^3			
Maximum Soil Dry Density	$\gamma_{d\ max}$=	115	lbs/ft^3			
Compaction	Dr =	90%	Percent Relative Density			
Unit Weight of Dry Soil Backfill	γ_d=	130	lbs/ft^3			
Void Ratio	e=	0.27				
Porosity	n=	0.21				
Degree of Saturation Below Water Level	S=	100%				
Weight of Pore Water	*w*=	10.26	lbs/ft^3			
Saturated Unit Weight of Soil Backfill	γ_{sat}=	140.26	lbs/ft^3			
Buoyant Unit Weight of Soil Backfill	γ'_b	77.864	lbs/ft^3			
Nominal Footprint Area of Soil Backfill	A_{BF}=	290.0	ft^2			
Depth of Soil Backfill Submerged	Z_B =	3.0	feet			
Depth of Soil Backfill above Water Level	Z_{BU} =	0.0	feet	**W' =**	**27,319**	(pounds effective weight per 50 cubic feet of Soil Ballast
Total Volume of Wood	V_d =	519.1	ft^3	**W =**	**0**	(pounds) weight per 50 cubic feet of Soil Ballast
				Total Effective Weight for all Soil Lifts =	**27,319**	pounds

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the log jam are fully submerged. In addition, the log jam and boulders act as a composite structure and are assumed fully connected. Water velocity inside the log jam is highly turbulent and near zero, therefore vertical uplift forces are assumed negligible.

A minimum factor of safety against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$$FS_B = \frac{\sum (W + W')}{\sum F_{BL}}$$

FS_B = 2.15

HORIZONTAL FORCES: FRICTION

Bed Sediment Friction Angle	ϕ=	33	Degrees
Bed Stress	μ_{bed}=	0.64940759	
Submerged Weight of Ballast	$W_{bl(sub)}$=	27,319	lbs.
Specific Weight of Water	γw=	62.43	lbs./ft^3
Buoyancy Force	F_b=	19427.0544	lbs.
Drag Coefficient	C_L=	1.5	
Area of Structure Perpendicular to Flow	A=	120	ft^2
Approach Flow Velocity	Uo=	3.5	fps
Gravitational Constant	g=	32.17	ft/s^2
Lift Force	F_L=	2139.54228	lbs.
Normal Force	F_n=	5,752	lbs.
Friction Force	Ff=	3735.51062	lbs.

$$\vec{F}_L = \frac{C_L A \gamma_w U_o^2}{2g}$$

$$\vec{F}_n = W_{bl(sub)} - \vec{F}_b - \vec{F}_L$$

Assumes maximum drag coefficient

Length 40 ft   Depth 3 ft

$$\vec{F}_f = \mu_{bed} F_n$$

HORIZONTAL FORCES: DRAG

Drag Coefficient	C_D=	1.5	
Drag Force	F_d=	2139.54	lbs.

Assumes maximum drag coefficient

$$\vec{F}_d = \frac{C_D A \gamma_w U_o^2}{2g}$$

LATERAL RESISTANCE FORCES: VERTICAL PILINGS

Number of Piles	N=	0	
Length of Pile Buried Below Scoured Bed	L_{em}=	0	ft
Pile Diameter	dp=	0	ft
Distance Above Scoured Bed Applied Load	h_{load}=	4	ft
Effective Angle of Internal Friction	ϕ'=	33	Degrees
Rankine Coefficient of Passive Earth Pressure	K_p=	3.39212	
Horizontal Restraint Force (Pilings)	Fgh=	0	lbs.

$$K_p = tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$F_{gh(piles)} = N\left(\frac{\frac{1}{2} L_{em}^3 d_p K_p (\gamma_s - \gamma_w)}{(h_{load} + L_{em})}\right)$$

FACTOR OF SAFETY: SLIDING

Target factor of safety for sliding is 1.75

F_{sh} = 1.75

$$F_{sh} = \frac{\vec{F}_f + \vec{F}_{gh} + \vec{F}_{ah}}{\vec{F}_d}$$

Engineered Log Jam Buoyancy Factor of Safety Calculations - Channel Spanning Structure

Methodology based on standard force balance approach, information adapted from D'aoust & Millar (2000), and USBR USACE 2016 National Large Wood Manual.

KEY "BASE" MEMBERS

Number of Logs with Rootwads	N_L =	2				
DOUG-FIR	S_L =	0.40	specific gravity			
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume =**	**104**	cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet			
Proportion of Voids in Rootwad	p =	0.2	decimal %			
Tree Stem Average Diameter	D_{TS} =	1.5	feet			
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} =**	**7,771**	pounds

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

STACKED "MIDDLE" MEMBERS

Number of Logs with Rootwads	N_L =	5				
pine, ponderosa	S_L =	0.40				
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume =**	**104**	cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet			
Proportion of Voids in Rootwad	p =	0.2	decimal %			
Tree Stem Average Diameter	D_{TS} =	1.5	feet			
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} =**	**19,427**	pounds

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

TOP MEMBERS

Number of Logs with Rootwads	N_L =	2				
pine, ponderosa	S_L =	0.40				
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume =**	**104**	cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet			
Proportion of Voids in Rootwad	p =	0.2	decimal %			
Tree Stem Average Diameter	D_{TS} =	1.5	feet			
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} =**	**7,771**	pounds

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

SUBMERGED WEIGHT OF TREES

Base Members	Wt	5,814	lbs
Staked Middle Members	Wt	14,536	lbs
Key Top Memebers	Wt	5,814	lbs
Total		26,165	(pounds) effective weight for all trees

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	2.0	feet			
Number of Boulders Submerged	N_B =	0				
Number of Boulders above water level	N_{BU} =	0		**W' =**	434	(pounds) effective weight per submerged boulder
				W =	695	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	0	pounds

$$W' = \frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	3.0	feet			
Number of Boulders Submerged	N_B =	12				
Number of Boulders above water level	N_{BU} =	0		**W' =**	1,465	(pounds) effective weight per submerged boulder
				W =	2,347	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	17,578	pounds

$$W' = \frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

SOIL BALLAST

Specific Gravity of Soil Particles	S_{soil} =	2.65				
Minimum Soil Dry Density	$\gamma_{d\ min}$=	90	lbs/ft^3			
Maximum Soil Dry Density	$\gamma_{d\ max}$=	115	lbs/ft^3			
Compaction	Dr =	90%	Percent Relative Density			
Unit Weight of Dry Soil Backfill	γ_d=	130	lbs/ft^3			
Void Ratio	e=	0.27				
Porosity	n=	0.21				
Degree of Saturation Below Water Level	S=	100%				
Weight of Pore Water	*w*=	10.26	lbs/ft^3			
Saturated Unit Weight of Soil Backfill	γ_{sat}=	140.26	lbs/ft^3			
Buoyant Unit Weight of Soil Backfill	γ'_b	77.864	lbs/ft^3			
Nominal Footprint Area of Soil Backfill	A_{BF}=	770.0	ft^2			
Depth of Soil Backfill Submerged	Z_B =	3.0	feet			
Depth of Soil Backfill above Water Level	Z_{BU} =	0.0	feet	**W' =**	107,105	(pounds effective weight per 50 cubic feet of Soil Ballast
Total Volume of Wood	V_d =	934.5	ft^3	**W =**	0	(pounds) weight per 50 cubic feet of Soil Ballast
				Total Effective Weight for all Soil Lifts =	107,105	pounds

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the log jam are fully submerged. In addition, the log jam and boulders act as a composite structure and are assumed fully connected. Water velocity inside the log jam is highly turbulent and near zero, therefore vertical uplift forces are assumed negligible.

A minimum factor of safety against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$$FS_B = \frac{\sum(W + W')}{\sum F_{BL}}$$

FS_B = 4.31

HORIZONTAL FORCES: FRICTION

Bed Sediment Friction Angle	ϕ=	33	Degrees
Bed Stress	μ_{bed}=	0.64940759	
Submerged Weight of Ballast	$W_{bl(sub)}$=	124,682	lbs.
Specific Weight of Water	γw=	62.43	lbs./ft^3
Buoyancy Force	F_b=	34968.6979	lbs.
Drag Coefficient	C_L=	1.5	
Area of Structure Perpendicular to Flow	A=	260	ft^2
Approach Flow Velocity	Uo=	8	fps
Gravitational Constant	g=	32.17	ft/s^2
Lift Force	F_L=	24219.0364	lbs.
Normal Force	F_n=	65,495	lbs.
Friction Force	Ff=	42532.6595	lbs.

$$\vec{F}_L = \frac{C_L A \gamma_w U_o^2}{2g}$$

$$\vec{F}_n = W_{bl(sub)} - \vec{F}_b - \vec{F}_L$$

Assumes maximum drag coefficient

Length 40 ft   Depth 6.5 ft

$$\vec{F}_f = \mu_{bed} F_n$$

HORIZONTAL FORCES: DRAG

Drag Coefficient	C_D=	1.5	
Drag Force	F_d=	24219.04	lbs.

Assumes maximum drag coefficient

$$\vec{F}_d = \frac{C_D A \gamma_w U_o^2}{2g}$$

LATERAL RESISTANCE FORCES: VERTICAL PILINGS

Number of Piles	N=	0	
Length of Pile Buried Below Scoured Bed	L_{em}=	0	ft
Pile Diameter	dp=	0	ft
Distance Above Scoured Bed Applied Load	h_{load}=	4	ft
Effective Angle of Internal Friction	ϕ'=	33	Degrees
Rankine Coefficient of Passive Earth Pressure	K_p=	3.39212	
Horizontal Restraint Force (Pilings)	Fgh=	0	lbs.

$$K_p = \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$F_{gh(piles)} = N\left(\frac{\frac{1}{2}L_{em}^3 d_p K_p(\gamma_s - \gamma_w)}{(h_{load} + L_{em})}\right)$$

FACTOR OF SAFETY: SLIDING

Target factor of safety for sliding is 1.75

F_{sh} = 1.76

$$F_{sh} = \frac{\vec{F}_f + \vec{F}_{gh} + \vec{F}_{ah}}{\vec{F}_d}$$

Engineered Log Jam Buoyancy Factor of Safety Calculations - Debris Jam Type 1 Structure

Methodology based on standard force balance approach, information adapted from D'aoust & Millar (2000), and USBR USACE 2016 National Large Wood Manual.

KEY "BASE" MEMBERS

Number of Logs with Rootwads	N_L =	3		
DOUG-FIR	S_L =	0.40	specific gravity	
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} = 11,656** pounds

STACKED "MIDDLE" MEMBERS

Number of Logs with Rootwads	N_L =	8		
pine, ponderosa	S_L =	0.40		
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} = 31,083** pounds

TOP MEMBERS

Number of Logs with Rootwads	N_L =	4		
pine, ponderosa	S_L =	0.40		
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} = 15,542** pounds

SUBMERGED WEIGHT OF TREES

Base Members	Wt	8,722	lbs
Staked Middle Members	Wt	23,258	lbs
Key Top Memebers	Wt	11,629	lbs
Total		43,608	(pounds) effective weight for all trees

BOULDER BALLAST

$$W'=\frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	2.0	feet			
Number of Boulders Submerged	N_B =	20				
Number of Boulders above water level	N_{BU} =	0		W' =	434	(pounds) effective weight per submerged boulder
				W =	695	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	8,680	pounds

BOULDER BALLAST

$$W'=\frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	3.0	feet			
Number of Boulders Submerged	N_B =	0				
Number of Boulders above water level	N_{BU} =	0		W' =	1,465	(pounds) effective weight per submerged boulder
				W =	2,347	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	0	pounds

SOIL BALLAST

Specific Gravity of Soil Particles	S_{soil} =	2.65				
Minimum Soil Dry Density	$\gamma_{d\ min}$=	90	lbs/ft^3			
Maximum Soil Dry Density	$\gamma_{d\ max}$=	115	lbs/ft^3			
Compaction	Dr =	90%	Percent Relative Density			
Unit Weight of Dry Soil Backfill	γ_d=	130	lbs/ft^3			
Void Ratio	e=	0.27				
Porosity	n=	0.21				
Degree of Saturation Below Water Level	S=	100%				
Weight of Pore Water	*w*=	10.26	lbs/ft^3			
Saturated Unit Weight of Soil Backfill	γ_{sat}=	140.26	lbs/ft^3			
Buoyant Unit Weight of Soil Backfill	γ'_b	77.864	lbs/ft^3			
Nominal Footprint Area of Soil Backfill	A_{BF}=	300.0	ft^2			
Depth of Soil Backfill Submerged	Z_B =	8.0	feet			
Depth of Soil Backfill above Water Level	Z_{BU} =	0.0	feet	W' =	65,605	(pounds effective weight per 50 cubic feet of Soil Ballast
Total Volume of Wood	V_d =	1557.4	ft^3	W =	0	(pounds) weight per 50 cubic feet of Soil Ballast
				Total Effective Weight for all Soil Lifts =	65,605	pounds

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the log jam are fully submerged. In addition, the log jam and boulders act as a composite structure and are assumed fully connected. Water velocity inside the log jam is highly turbulent and near zero, therefore vertical uplift forces are assumed negligible.

A minimum factor of safety against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$$FS_B = \frac{\sum(W + W')}{\sum F_{BL}}$$

FS_B = 2.02

HORIZONTAL FORCES: FRICTION

Bed Sediment Friction Angle	ϕ=	33	Degrees
Bed Stress	μ_{bed}=	0.64940759	
Submerged Weight of Ballast	$W_{bl(sub)}$=	74,285	lbs.
Specific Weight of Water	γw=	62.43	lbs./ft^3
Buoyancy Force	F_b=	58281.1632	lbs.
Drag Coefficient	C_L=	1.5	
Area of Structure Perpendicular to Flow	A=	30	ft^2
Approach Flow Velocity	Uo=	4.5	fps
Gravitational Constant	g=	32.17	ft/s^2
Lift Force	F_L=	884.198593	lbs.
Normal Force	F_n=	15,120	lbs.
Friction Force	Ff=	9818.89815	lbs.

Assumes maximum drag coefficient

Length 12 ft   Depth 2.5 ft

$$\vec{F}_L = \frac{C_L A \gamma_w U_o^2}{2g}$$

$$\vec{F}_n = W_{bl(sub)} - \vec{F}_b - \vec{F}_L$$

$$\vec{F}_f = \mu_{bed} F_n$$

HORIZONTAL FORCES: DRAG

Drag Coefficient	C_D=	1.5	
Drag Force	F_d=	884.20	lbs.

Assumes maximum drag coefficient

$$\vec{F}_d = \frac{C_D A \gamma_w U_o^2}{2g}$$

LATERAL RESISTANCE FORCES: VERTICAL PILINGS

Number of Piles	N=	0	
Length of Pile Buried Below Scoured Bed	L_{em}=	0	ft
Pile Diameter	dp=	0	ft
Distance Above Scoured Bed Applied Load	h_{load}=	4	ft
Effective Angle of Internal Friction	ϕ'=	33	Degrees
Rankine Coefficient of Passive Earth Pressure	K_p=	3.39212	
Horizontal Restraint Force (Pilings)	Fgh=	0	lbs.

$$K_p = tan^2\left(45 + \frac{\emptyset'}{2}\right)$$

$$F_{gh(piles)} = N\left(\frac{\frac{1}{2}L_{em}^3 d_p K_p(\gamma_s - \gamma_w)}{(h_{load} + L_{em})}\right)$$

FACTOR OF SAFETY: SLIDING

Target factor of safety for sliding is 1.75

F_{sh} = 11.10

$$F_{sh} = \frac{\vec{F}_f + \vec{F}_{gh} + \vec{F}_{ah}}{\vec{F}_d}$$

Engineered Log Jam Buoyancy Factor of Safety Calculations - Debris Jam Type 2 Structure

Methodology based on standard force balance approach, information adapted from D'aoust & Millar (2000), and USBR USACE 2016 National Large Wood Manual.

KEY "BASE" MEMBERS

Number of Logs with Rootwads	N_L =	3		
DOUG-FIR	S_L =	0.40	specific gravity	
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} = 11,656** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot \rho_w g(1-S_L)\cdot N_L$$

STACKED "MIDDLE" MEMBERS

Number of Logs with Rootwads	N_L =	8		
pine, ponderosa	S_L =	0.40		
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} = 31,083** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot \rho_w g(1-S_L)\cdot N_L$$

TOP MEMBERS

Number of Logs with Rootwads	N_L =	4		
pine, ponderosa	S_L =	0.40		
Average Rootwad Fan Diameter	D_{RW} =	4	feet	**Wood Volume = 104** cubic feet per member
Average Rootwad Length	L_{RW} =	4	feet	
Proportion of Voids in Rootwad	p =	0.2	decimal %	
Tree Stem Average Diameter	D_{TS} =	1.5	feet	
Tree Stem Average Length	L_{TS} =	40	feet	**F_{BL} = 15,542** pounds

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot \rho_w g(1-S_L)\cdot N_L$$

SUBMERGED WEIGHT OF TREES

Base Members	Wt	8,722	lbs
Staked Middle Members	Wt	23,258	lbs
Key Top Memebers	Wt	11,629	lbs
Total		43,608	(pounds) effective weight for all trees

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	2.0	feet			
Number of Boulders Submerged	N_B =	20				
Number of Boulders above water level	N_{BU} =	0		**W' =**	434	(pounds) effective weight per submerged boulder
				W =	695	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	8,680	pounds

$$W' = \frac{\pi D_B^3}{6}\cdot \rho_w g(S_S-1)$$

BOULDER BALLAST

Specific Gravity of Boulders	S_S =	2.66				
equivalent Diameter of Boulder	D_B =	3.0	feet			
Number of Boulders Submerged	N_B =	0				
Number of Boulders above water level	N_{BU} =	0		**W' =**	1,465	(pounds) effective weight per submerged boulder
				W =	2,347	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	0	pounds

$$W' = \frac{\pi D_B^3}{6}\cdot \rho_w g(S_S-1)$$

SOIL BALLAST

Specific Gravity of Soil Particles	S_{soil} =	2.65				
Minimum Soil Dry Density	$\gamma_{d\ min}$=	90	lbs/ft^3			
Maximum Soil Dry Density	$\gamma_{d\ max}$=	115	lbs/ft^3			
Compaction	Dr =	90%	Percent Relative Density			
Unit Weight of Dry Soil Backfill	γ_d=	130	lbs/ft^3			
Void Ratio	e=	0.27				
Porosity	n=	0.21				
Degree of Saturation Below Water Level	S=	100%				
Weight of Pore Water	*w*=	10.26	lbs/ft^3			
Saturated Unit Weight of Soil Backfill	γ_{sat}=	140.26	lbs/ft^3			
Buoyant Unit Weight of Soil Backfill	γ'_b	77.864	lbs/ft^3			
Nominal Footprint Area of Soil Backfill	A_{BF}=	300.0	ft^2			
Depth of Soil Backfill Submerged	Z_B =	9.0	feet			
Depth of Soil Backfill above Water Level	Z_{BU} =	0.0	feet	**W' =**	88,964	(pounds effective weight per 50 cubic feet of Soil Ballast
Total Volume of Wood	V_d =	1557.4	ft^3	**W =**	0	(pounds) weight per 50 cubic feet of Soil Ballast
				Total Effective Weight for all Soil Lifts =	88,964	pounds

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the log jam are fully submerged. In addition, the log jam and boulders act as a composite structure and are assumed fully connected. Water velocity inside the log jam is highly turbulent and near zero, therefore vertical uplift forces are assumed negligible.

A minimum factor of safety against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$$FS_B = \frac{\sum(W + W')}{\sum F_{BL}}$$

FS_B = 2.42

HORIZONTAL FORCES: FRICTION

Bed Sediment Friction Angle	ϕ=	33	Degrees
Bed Stress	μ_{bed}=	0.64940759	
Submerged Weight of Ballast	$W_{bl(sub)}$=	97,644	lbs.
Specific Weight of Water	γw=	62.43	lbs./ft^3
Buoyancy Force	F_b=	58281.1632	lbs.
Drag Coefficient	C_L=	1.5	
Area of Structure Perpendicular to Flow	A=	30	ft^2
Approach Flow Velocity	Uo=	5	fps
Gravitational Constant	g=	32.17	ft/s^2
Lift Force	F_L=	1091.6032	lbs.
Normal Force	F_n=	38,272	lbs.
Friction Force	Ff=	24853.8793	lbs.

$$\vec{F}_L = \frac{C_L A \gamma_w U_o^2}{2g}$$

$$\vec{F}_n = W_{bl(sub)} - \vec{F}_b - \vec{F}_L$$

Assumes maximum drag coefficient

Length 12 ft Depth 2.5 ft

$$\vec{F}_f = \mu_{bed} F_n$$

HORIZONTAL FORCES: DRAG

Drag Coefficient	C_D=	1.5	
Drag Force	F_d=	1091.60	lbs.

Assumes maximum drag coefficient

$$\vec{F}_d = \frac{C_D A \gamma_w U_o^2}{2g}$$

LATERAL RESISTANCE FORCES: VERTICAL PILINGS

Number of Piles	N=	0	
Length of Pile Buried Below Scoured Bed	L_{em}=	0	ft
Pile Diameter	dp=	0	ft
Distance Above Scoured Bed Applied Load	h_{load}=	4	ft
Effective Angle of Internal Friction	ϕ'=	33	Degrees
Rankine Coefficient of Passive Earth Pressure	K_p=	3.39212	
Horizontal Restraint Force (Pilings)	Fgh=	0	lbs.

$$K_p = tan^2\left(45 + \frac{\emptyset'}{2}\right)$$

$$F_{gh(piles)} = N\left(\frac{\frac{1}{2}L_{em}^3 d_p K_p(\gamma_s - \gamma_w)}{(h_{load} + L_{em})}\right)$$

FACTOR OF SAFETY: SLIDING

Target factor of safety for sliding is 1.75

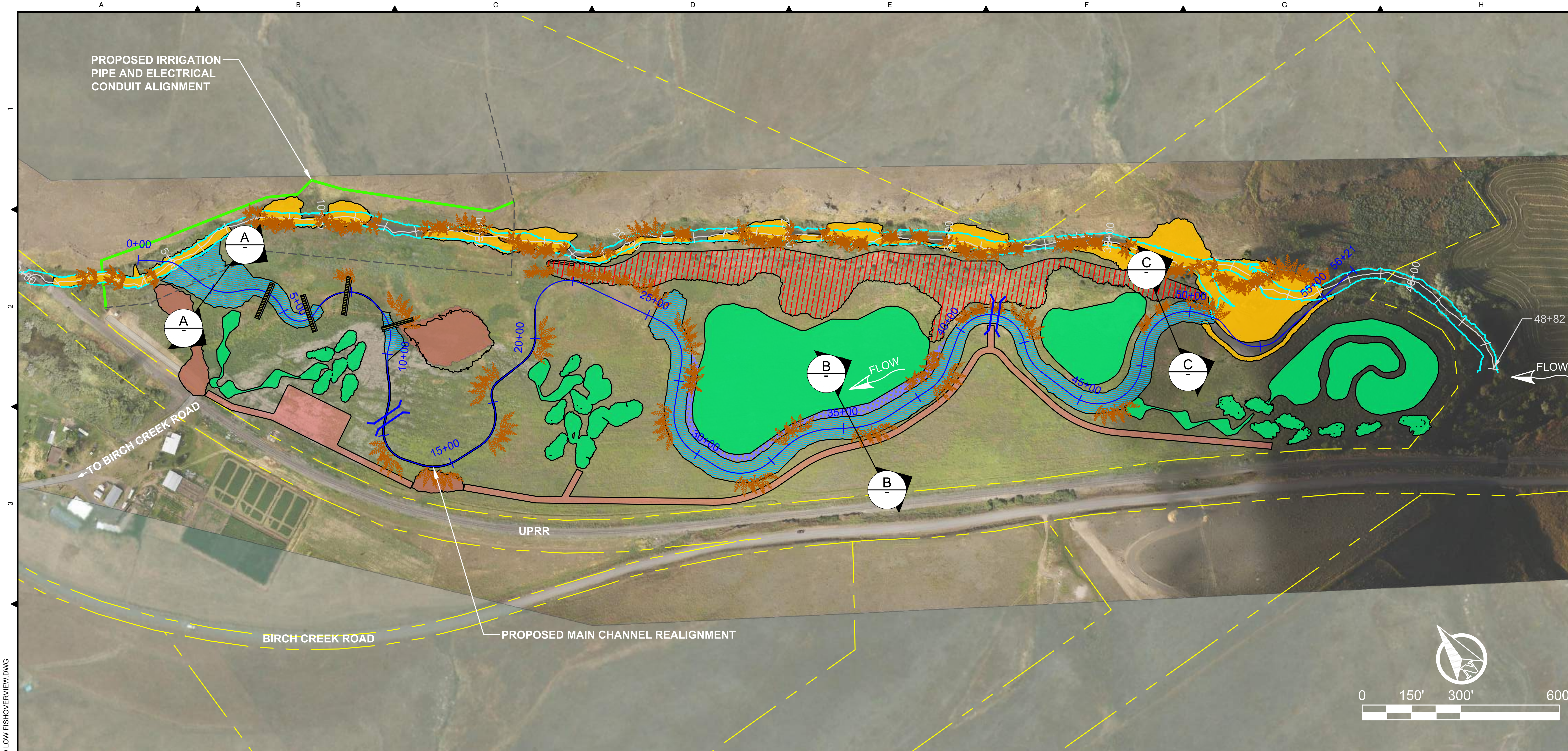
F_{sh} = 22.77

$$F_{sh} = \frac{\vec{F}_f + \vec{F}_{gh} + \vec{F}_{ah}}{\vec{F}_d}$$

Attachment 5

Presentation Exhibits

- Low-Flow Fish Passage
- Design Terrain Comparison
- Design 5-Year Proposed Hydraulic Model Results
    - Shear Stress
    - Existing Channel Velocity Profile
    - Existing Channel WSE Profile
- Design 25-Year WSE Contours
- Design 25-Year Average Shear Stress



LEGEND

- EXISTING IRRIGATION PIPE
- EXISTING BIRCH CREEK ALIGNMENT
- PROPERTY BOUNDARY
- EXISTING OHW
- PROPOSED BIRCH CREEK ALIGNMENT
- PROPOSED IRRIGATION PIPE ALIGNMENT
- PROPOSED FLOODPLAIN BENCHING
- PROPOSED SCOUR CUTOFF TRENCH
- PROPOSED CHANNEL REALIGNMENT
- PROPOSED CHANNEL FILL
- PROPOSED TERRACE
- PROPOSED WETLAND AREAS
- PROPOSED STAGING AREA AND ACCESS ROUTES
- PROPOSED FLOODPLAIN TOPOGRAPHY
- PROPOSED LWM
- PROPOSED TEMPORARY CROSSING

TETRA TECH
www.tetratech.com
19803 North Creek Parkway
Bothell, Washington 98011
Phone: 425-482-7600 Fax: 425-482-7652

NOT FOR CONSTRUCTION

PLAN SHEET SIZE ANSI B (11" X 17")

REV.	DATE	REVISION DESCRIPTION	DRW	ENG	CHK	APP
4	4/30/21	90% DESIGN	JA	JA	CM	CJ
3	3/12/20	60% DESIGN	JA	JA	CM	CJ
2	9/10/19	30% DESIGN	JA	JA	CM	CJ
1	6/18/19	15% ALTERNATIVE ANALYSIS	JA	JA	CM	CJ

CTUIR - PA 4 BIRCH CREEK INSTREAM ENHANCEMENT AND FLOODPLAIN RESTORATION

PROPOSED CONDITIONS

DWG. NO.: C-402

CREATED: 4/15/21

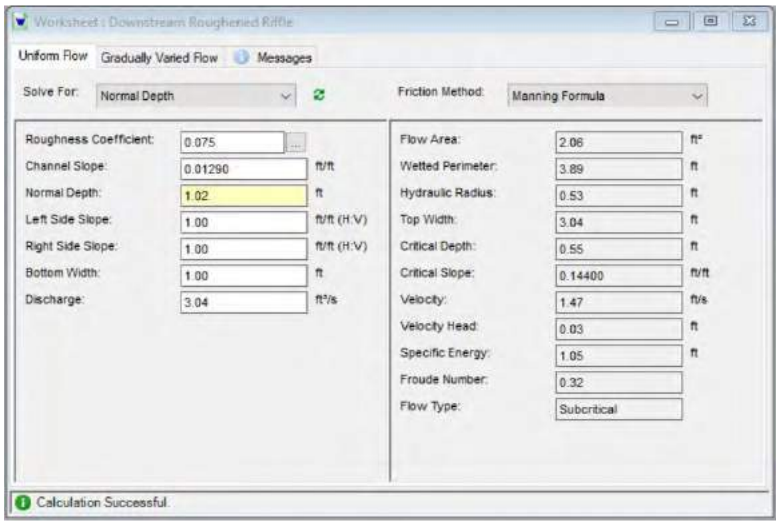
Z:\PROJECTS\194-6817 UMABIRCH IN-STREAM DESIGN\90%\SHEET FILES\PROPOSED LOW FISHOVERVIEW.DWG
PLOT DETAILS: ANDREWS, JEREMY April 27, 2021 3:03 PM

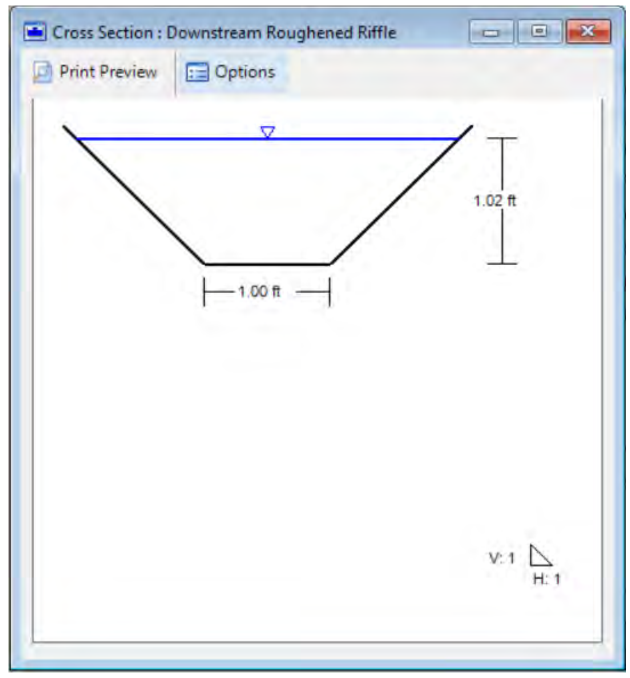
Proposed Low Flow WSE (3 cfs)

Cross Section A STA: 3+00 (Roughened Riffle Section)

Existing Channel = 0 cfs

Proposed New Main Channel = 3 cfs

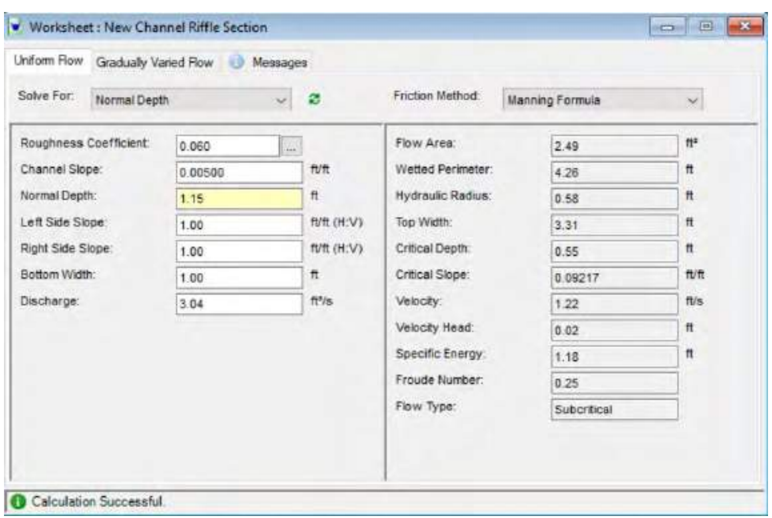


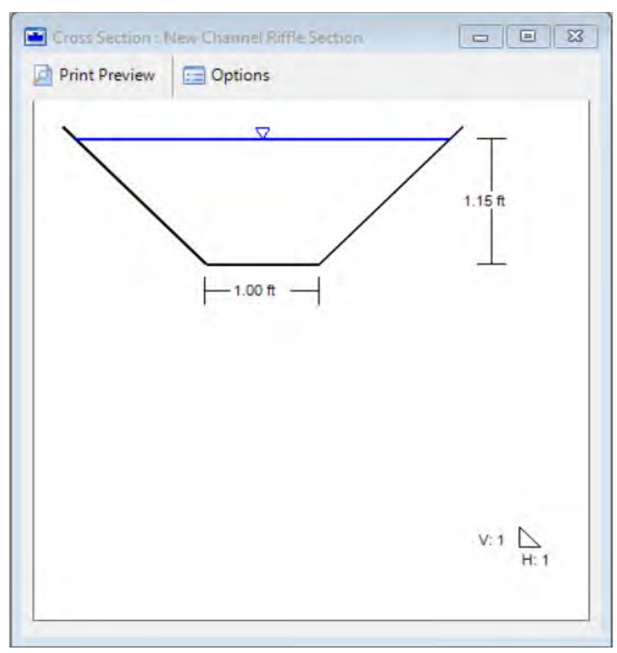


Cross Section B STA: 35+50 (Riffle Section)

Existing Channel = 0 cfs

Proposed New Main Channel = 3 cfs



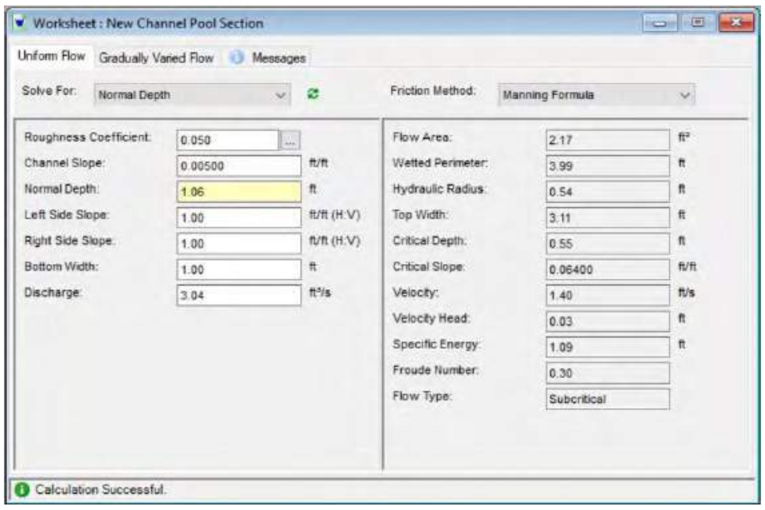


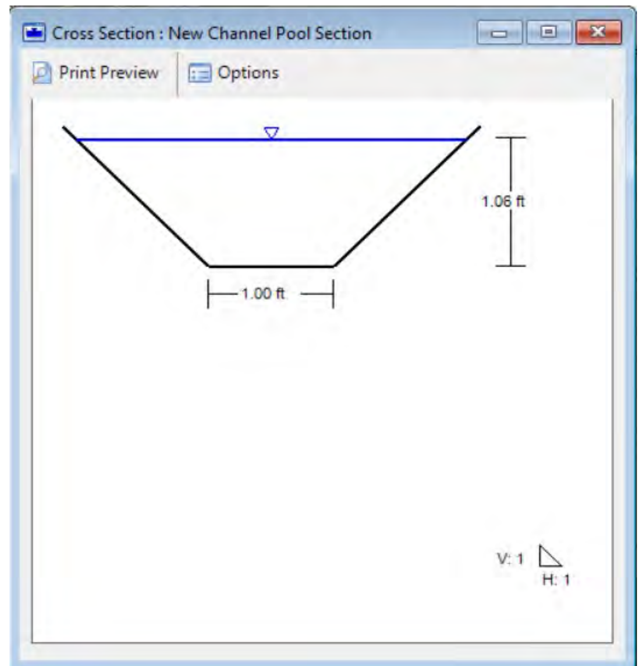
Proposed Low Flow WSE (3 cfs)

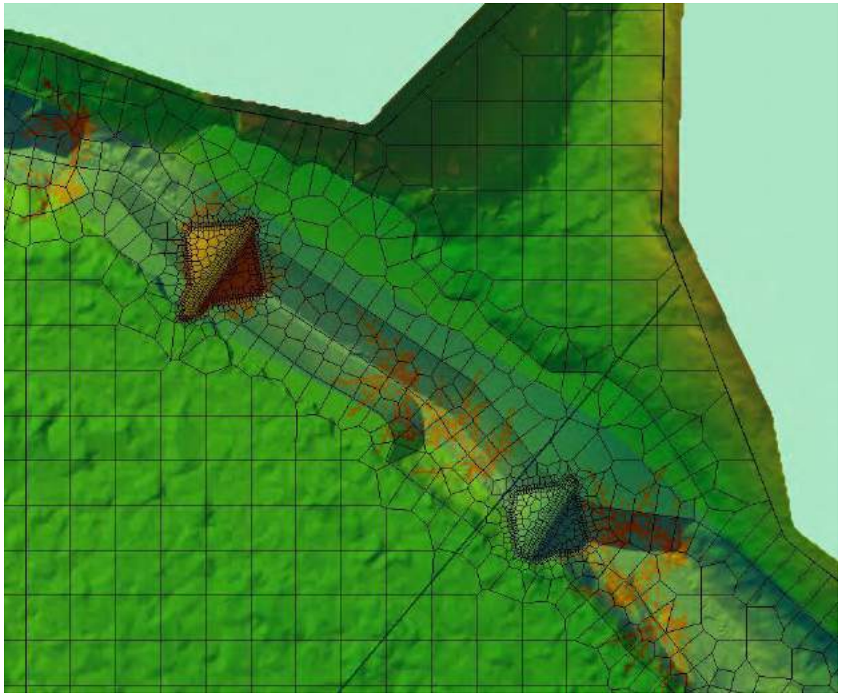
Cross Section C STA: 50+00 (Pool Section)

Existing Channel = 0 cfs

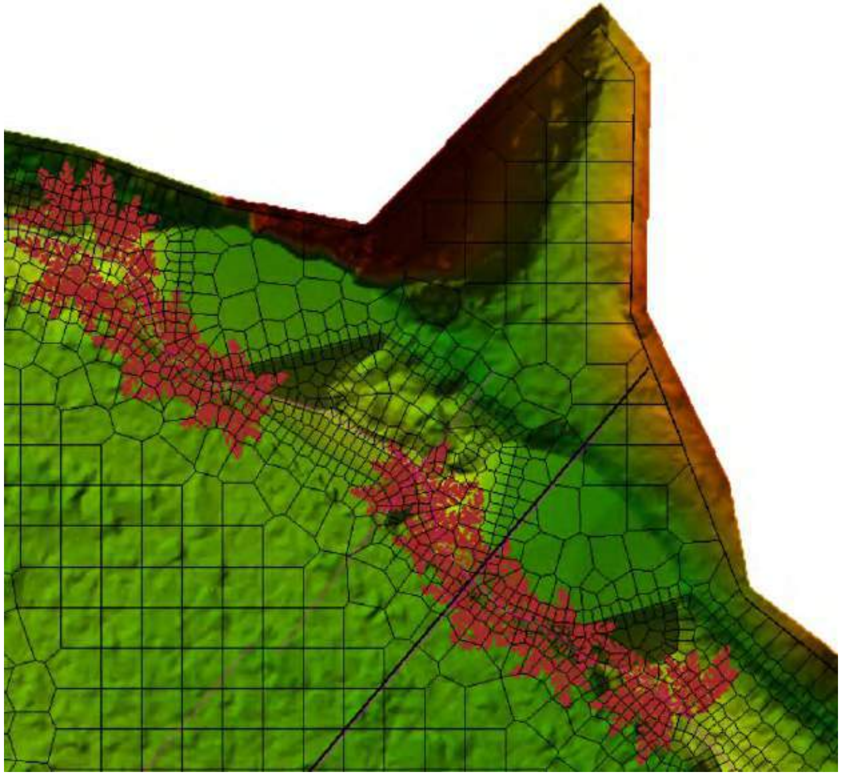
Proposed New Main Channel = 3 cfs



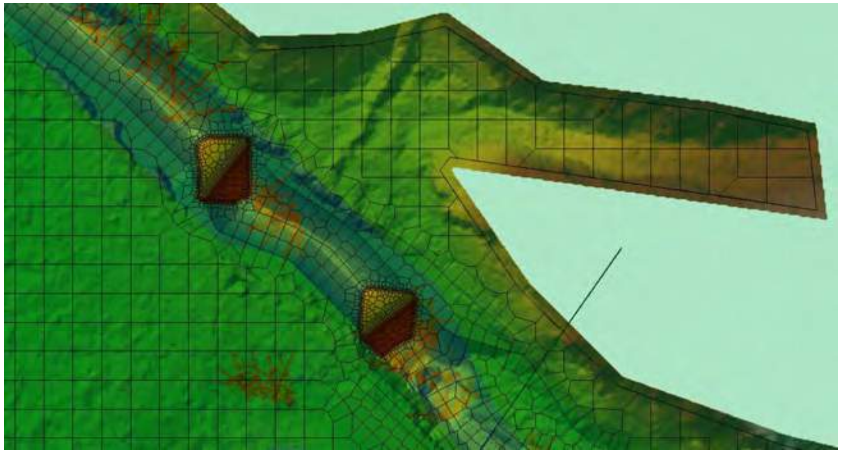




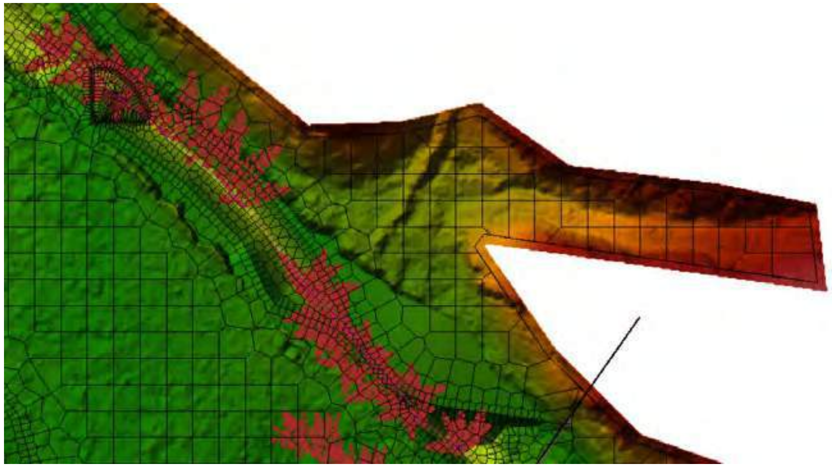
March 16, 2021



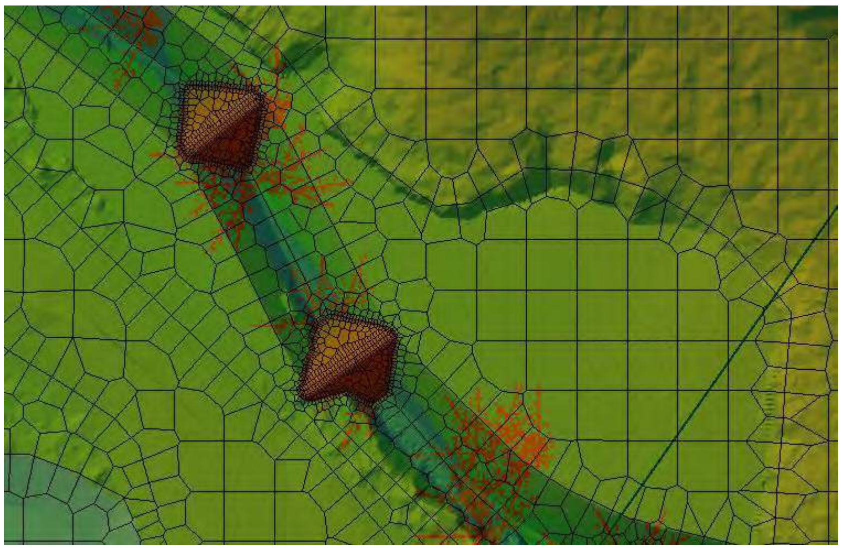
April 14, 2021

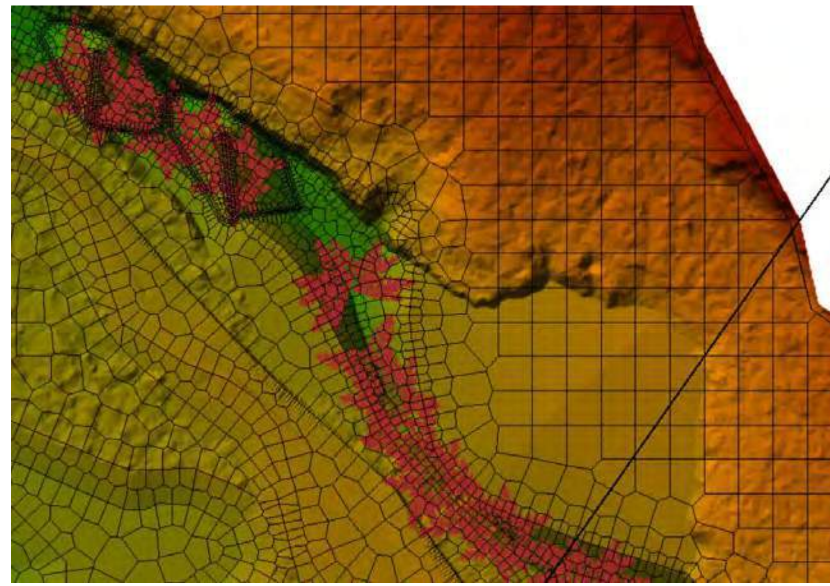


March 16, 2021



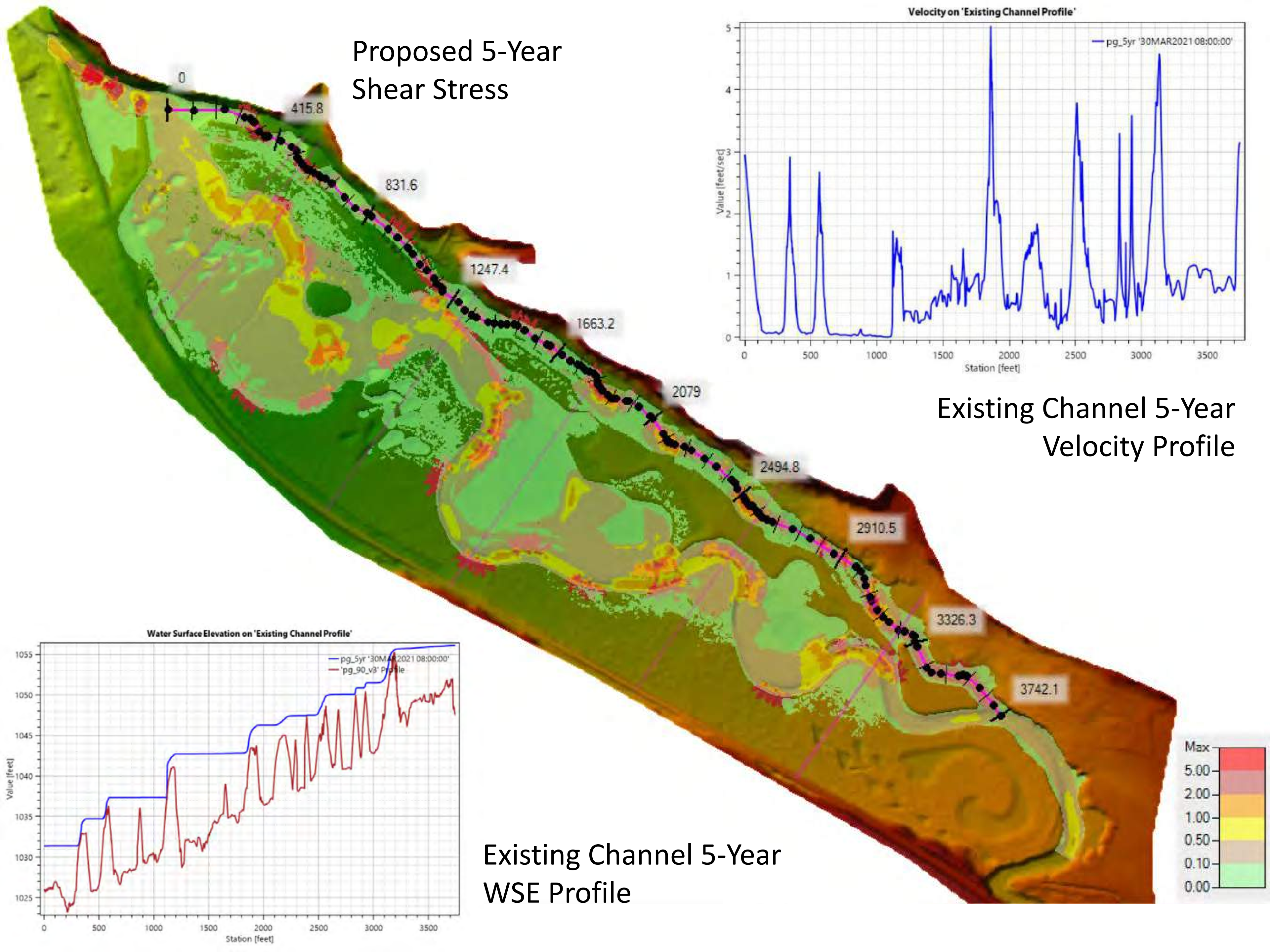
April 14, 2021





March 16, 2021

April 14, 2021


Proposed 5-Year
Shear Stress
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415.8
831.6
1247.4
1663.2
2079
2494.8
2910.5
3326.3
3742.1
Velocity on 'Existing Channel Profile'
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Value [feet/sec]
Station [feet]
Existing Channel 5-Year
Velocity Profile
Water Surface Elevation on 'Existing Channel Profile'
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'pg_90_v3' Profile
Value [feet]
Station [feet]
Existing Channel 5-Year
WSE Profile
Max
5.00
2.00
1.00
0.50
0.10
0.00

N

0 300 600
Feet

Birch Creek - PA 4
25-Year 1-FT Water Surface Contours

TETRA TECH

P:\194-6817 CTUIR UmaBirch In-Stream Design\Engineering\Analyses\PA 4 90%\SummaryFig2.mxd

Proposed Floodplain		
Peak Flow	Mean Shear, lb-ft2	Mean Velocity, ft/s
100-Year	0.40	2.3
50-Year	0.34	2.1
25-Year	0.29	1.8
10-Year	0.23	1.5
5-Year	0.19	1.3
2-Year	0.13	0.9

Birch Creek - PA 4
25-Year Average Shear Stress

TETRA TECH

P:\194-6817 CTUIR UmaBirch In-Stream Design\Engineering\Analyses\PA 4 90%\SummaryFig1.mxd