San Juan National Forest ERFO

CO ERFO FS SNJUAN 2026-1(1)

Final Hydraulic Report

In Partnership With:

San Juan National Forest

United States Department of Transportation
Federal Highway Administration
Central Federal Lands Highway Division

May 28 2026

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Revisions

Date	Report	File Path
March 27 2026	Draft Hydraulic Report	Hydraulics\8_Draft_Report
May 28 2026	Final Hydraulic Report	Hydraulics\9_Final_Report

Executive Summary

Project Description:

The Federal Highway Administration (FHWA) Central Federal Lands Highway Division (CFLHD) in cooperation with the U.S. Forest Service (USFS) San Juan National Forest (SJNF) plans to conduct repairs to restore vehicle access at five damaged roads within the forest. The sites were damaged during flood events that impacted southwestern Colorado from October 10th to 14th, 2025. The hydraulics scope includes hydraulic evaluations to support culvert replacement, bridge scour mitigation, and bank protection designs.

Design Criteria:

The hydraulic design criteria were based on the Federal Lands Highway Project Development and Design Manual (PDDM) low standard designation. This assumes that project roads have an average daily traffic (ADT) of less than 1500 vehicles, the speed limit is less than 45 mph, and they are not considered critical access roads.

Hydrologic Analysis:

Two methods were evaluated and compared to establish the design flows for the project sites: USGS regression equations via StreamStats and index flood methods using the Flood Potential Portal. A comparative analysis resulted in the Flood Potential Portal flows being adopted for the project.

Hydraulics Analyses & Recommendations:

Two-dimensional hydraulic modeling using SMS and SRH-2D was conducted for all sites to support the design of the repairs. Other tools used included HY-8 and the Hydraulic Toolbox. The analyses included: culvert sizing at 039 Fall Creek Road, bridge scour estimates at 648 West Fork Road, bend scour and bank protection estimates at 033 Hatcher Road, 667 East Fork Road, and 621 Lower Piedra Road. In addition, a base flood elevation comparison was conducted at Lower Piedra Road to satisfy floodplain policy requirements. Hydraulic recommendations are summarized below. Additional details are provided in the project plans.

Summary of Hydraulic Recommendations

Site	Recommended Action	Proposed Repair	Notes
039 Fall Creek Road	Construct concrete box culvert (CBC)	• L = 76 ft W = 16 ft H = 8 ft CBC, headwall/wingwalls (inlet and outlet) • Embedment: 3.5 ft • Infill: Class 4 riprap (2.5 ft thick) Streambed material (1 ft thick) • Class 6 riprap apron, L = 20 ft (outlet)	Streambed material sourced on-site or supplemented from external source
648 West Fork Road	Abutment Repair	• Abutment repair: grout fill footing cavity • Abutment protection: Class 6 riprap (3.5 ft thick), extend 10' horizontally from footing	Wrap abutment protection around footing and wingwalls
033 Hatcher Road	Bank Protection	• Class 6 Riprap, L = 370 ft • Toe Embedment: 5 ft • Reinforced Soil Slope above riprap per CFLHD Geotechnical Engineering recommendations.	See Geotechnical Report and plans for additional slope repair details.
667 East Fork Road	Bank Protection, slope repair	• Class 6 riprap, L = 170 ft • Toe Embedment: 5 ft	See Geotechnical Report and plans for additional slope repair details.
621 Lower Piedra Road	Bank Protection	• Class 6 Riprap, L = 420 ft • Toe Embedment: 7 ft	See Geotechnical Report and plans for additional slope repair details.

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1 PROJECT BACKGROUND INFORMATION

1.1 PROJECT INFORMATION

The Federal Highway Administration (FHWA) Central Federal Lands Highway Division (CFLHD) in cooperation with the U.S. Forest Service (USFS) San Juan National Forest (SJNF) plans to conduct repairs to restore vehicle access at five damaged roads within the forest. The sites were damaged during flood events that impacted southwestern Colorado from October 10th to 14th, 2025. The hydraulics scope includes hydraulic evaluations to support culvert replacement, bridge scour mitigation, and bank protection designs. Figure 1 shows the project location map. Site photos are included in Appendix A.

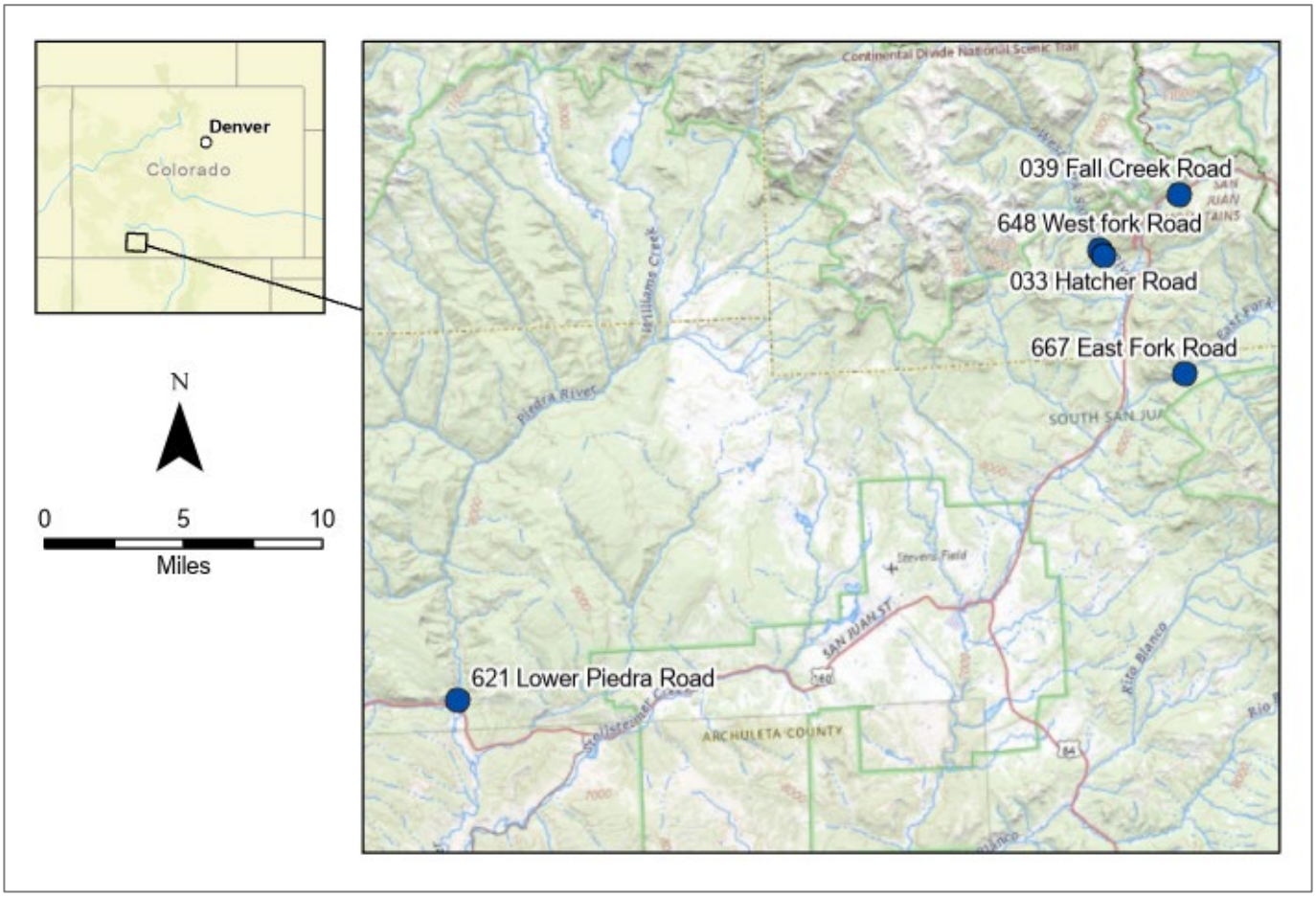

Figure 1: Project Location Map

1.2 EXISTING DRAINAGE FEATURES

Existing drainage features at the sites include major culverts, a bridge, and roadway embankments. Detailed Damage Inspection Reports (DDIR) were produced for the sites prior to project scoping. Except for East Fork Road (Forest Road 667), all sites are currently closed to vehicle access. Site locations and a summary of the damage sustained are provided in Table 1. Additional descriptions are provided in Section 5, Site- Specific Evaluations.

Table 1: Damage Site Locations

Site	Forest Road No.	Latitude (deg)	Longitude (deg)	Damage Sustained
Fall Creek Road	039	37.476567	-106.857310	Culvert and embankment failure
West Fork Road	648	37.449897	-106.911134	Scour-caused undermining of Abutment 2 (right abutment looking downstream)
Hatcher Road	033	37.447044	-106.908865	Embankment slope and roadway failure
East Fork Road	667	37.379706	-106.872357	Embankment slope and roadway failure
Lower Piedra road	621	37.230954	-107.343573	Embankment slope and roadway failure

1.3 FLOODPLAINS

Special Flood Hazard Areas (SFHA) delineated by the Federal Emergency Management Agency (FEMA) are shown in Flood Insurance Rate Maps (FIRMs). The maps depict lands inundated by the base flood (1% annual chance of flooding or 100-year floodplain) that are subject to National Flood Insurance Program (NFIP) floodplain management regulations. Since the project is located entirely on National Forest System lands within the San Juan National Forest, a local floodplain development permit is not required. The project is subject to Federal floodplain policy as described in 23 CFR Part 650.

A review of applicable FIRMs for the project sites shows only the Lower Piedra site lies within a SFHA. This area is mapped as an approximate Zone A floodplain without base flood elevations. The remaining sites are within areas of undetermined flood hazards, classified as Zone D, or areas of minimal flood hazard, classified as Zone X. The project will comply with the floodplain encroachment criteria listed in the Federal Lands Highway Project Development and Design Manual (PDDM) (Federal Lands Highway, 2012) for approximate Zone A and unmapped zones, which allows a maximum one-foot water surface elevation increase over existing conditions. Section 5.5.3 describes the floodplain encroachment evaluation conducted for the Lower Piedra site. Conveyance capacity will be increased at Fall Creek Road by installing a larger culvert, therefore water surface elevations are expected to decrease. For the remaining sites it is assumed that flood repairs will return the site geometry to pre-flood conditions and will not result in water surface elevation increases exceeding 1-foot. FEMA FIRM excerpts for the project sites are included in Appendix A.

2 HYDRAULIC DESIGN CRITERIA

The hydraulic design criteria were based on the Federal Lands Highway Project Development and Design Manual (PDDM) a low standard designation. This assumes that project roads have an average daily traffic (ADT) of less than 1500 vehicles, the speed limit is less than 45 mph, and they are not considered critical access roads. The hydraulic design criteria for project elements are detailed in Table 2 below.

Table 2: PDDM Hydraulic Design Criteria

Low-Standard Roadway	Design Frequency	Check Frequency	Design Criteria
Bridges	50-year	Greater of 100-year and overtopping (≤ 500-year)	Minimum 2 ft. of freeboard at the design flood
Bridge Scour	100-year	200-year	Countermeasure design flood frequency: 200-year
Floodplain Encroachment	100-year	Overtopping (≤ 500-year)	No floodway defined or unregulated base floodplain: rise ≤ 1.0 ft.
Roadway Culverts	25-year	Overtopping	New: AHW ≤ bottom of aggregate base layer
			Existing: AHW ≤ shoulder hinge point
			Where D ≤ 48", HW/D ≤ 1.5 & Where D > 48", HW/D ≤ 1.2
			Heavy debris or sediment load concerns: 0.8 ≤ HW/D ≤ 1.0
			Crossing is stable at the design flood
Longitudinal Embankments	25-year	Greater of 100-year and overtopping	Stability design flood: 25-year

3 HYDROLOGY

3.1 HYDROLOGIC SETTING AND BASIN DELINEATION

According to the U.S. Geological Survey (USGS) Watershed Boundary Dataset (WBD), the project sites belong to several subwatersheds: Wolf Creek (140801010203) West Fork San Juan River (140801010204), East Fork San Juan River (140801010104), and Piedra River (140801020206). All sites ultimately drain to the Upper San Juan River Basin (HUC6 140801). Contributing drainage basin delineation for each site was performed using StreamStats (U.S. Geological Survey, 2019) and the Flood Potential Portal (FPP) web application (Yochum, 2025). Due to their proximity, the basin delineation for West Fork and Hatcher Road sites was combined at the most downstream site. Table 3 shows basin areas and peak flow equation parameters for the sites, basin maps are included in Appendix B.

Table 3: Drainage Basins

Site	Drainage Area (mi^2)	Area above 7,500 ft (%)	Mean Monthly Precipitation for January (in)
039 Fall Creek Road	8	100	8.6
648 West Fork Road	52	100	5.1
033 Hatcher Road	52	100	5.1
667 East Fork Road	86	100	4.1
621 Lower Piedra Road	369	97	2.7

3.2 AVAILABLE STREAMGAGE DATA

There are no nearby streamgages suitable for use on this project. The nearest streamgage is located on the San Juan River (USGS 09342500) near Pagosa Springs, CO. The drainage area to the gage is 281 square miles and the period of record extends from 1935 to 2026. Due to the distance from the individual sites this gage was not used in

the analysis. Note that data from this gage was included in development of the USGS regression equations and Flood Potential Portal methods described below.

3.3 USGS Regression Equation Estimates

USGS regression equations for Colorado presented in the USGS Scientific Investigations Report 2009-5136 (Capesius & Stephens, 2009) were used to estimate peak flows to the site via the StreamStats web application. The project lies within the southwest hydrologic region. The equations developed for this region are applicable for basins with a drainage area from 1 to 4,390 square miles and percentage of the drainage area above 7,500 feet 0 to 100%. Equation standard errors are reported as varying from 66 to 90%. Regression results are provided in Appendix B.

3.4 Flood Potential Portal Estimates

Except for the Lower Piedra site all study basins lie entirely above 7,500 feet in elevation. For this reason, additional peak flow estimates were carried out using the watershed analysis module of the FPP. The FPP applies the index-flood method to estimate peak flow at ungaged sites. Flood indices used for the Southern Rocky Mountain South zone are drainage area and mean average monthly precipitation for January. Index flood results are provided in Appendix B.

3.5 Adopted Design Flows

The peak flows estimated using the FPP were adopted for the sites. In general, the FPP peak flows were higher than the USGS regional regression estimates, with average percent differences ranging from 33 to 67 percent. Except for West Fork/Hatcher Road, the FPP flows were within the standard error bounds of the USGS regression equations. For West Fork/Hatcher Road the FPP flows fell slightly above the standard error upper bound for the 2-to-200-year return periods. A comparative analysis is included in Appendix B. Adopted project flows are shown in Table 4.

Table 4: Adopted Design Flows

Exceedance Probability (%)	Return Period (yr)	039 Fall Creek Road	648 West Fork Road	033 Hatcher Road	667 East Fork Road	621 Lower Piedra Road
50	2	205	841	841	1,000	1,920
20	5	336	1,370	1,370	1,630	3,130
10	10	437	1,790	1,790	2,130	4,080
4	25	584	2,390	2,390	2,840	5,450
2	50	709	2,910	2,910	3,450	6,620
1	100	850	3,480	3,480	4,140	7,930
0.5	200	1,010	4,120	4,120	4,900	9,400
0.2	500	1,240	5,090	5,090	6,060	11,600

4 Hydraulic Analyses

A summary of the hydraulic analyses conducted for each site is provided in the following sections. Two-dimensional hydraulic modeling using SMS (Aquaveo, 2026) and SRH-2D (U.S. Bureau of Reclamation, 2025) was conducted for all sites. HY-8 (FHWA, 2024) was used to conduct preliminary culvert sizing at Fall Creek Road. The Hydraulic Toolbox (FHWA, 2024) was used to estimate bridge scour at West Fork Road, and to estimate bank protection riprap at

Hatcher Road, East Fork Road, and Lower Piedra Road. Other analyses such as bend scour estimates and abutment scour protection were carried out using spreadsheets. Additional details are provided in Appendix C.

4.1 TOPOGRAPHIC INFORMATION

Due to adverse weather conditions, ground survey was not initially collected for the project. The preliminary hydraulic analysis relied entirely on bare earth LIDAR data downloaded from the USGS National Map (U.S. Geological Survey, 2018). The National Map metadata indicate that the LIDAR data is classified as Quality Level 2 and was collected between 2018 and 2020 during multiple airborne LIDAR acquisition projects. All elevations are referenced to the North American Vertical Datum of 1988. October 2025 flood impacts such as embankment failures, scour holes, and channel migration are not represented in the LIDAR data. It was assumed that the pre-flood LIDAR data provided sufficient information to simulate pertinent hydraulic variables (e.g. water depth and velocity) to support design recommendations for the ERFO project. In April 2026, a limited amount of ground topographic survey data was collected by the CFLHD survey group. The survey included limited channel information at the West Fork bridge and Fall Creek culvert sites, and road embankment at Hatcher Road, East Fork, and Lower Piedra Sites. Due to the limited nature of the survey, the final hydraulic analyses relied primarily on the LIDAR information, but the survey data was merged or used to inform the recommendations as described in Section 5.

4.2 MESH DEVELOPMENT

SRH-2D uses a network of elements known as a mesh to represent the geometry of the underlying terrain and solve the two-dimensional depth-averaged continuity and momentum flow equations (2D St. Venant equations). The results produced are water surface elevation and velocity at each element, from which other hydraulic variables such as depth and Froude number, are computed. The unstructured mesh format of SRH-2D allows for a combination of triangles and quadrilaterals to represent the terrain and capture important hydraulic controls. All mesh development for the project was conducted using SMS. In general, quadrilateral elements were used at linear features such as channels and embankments, and triangular elements were used for the remaining portions of the model domain. Meshes for all sites are included in Appendix C.

4.3 LAND COVER

SRH-2D uses Manning's roughness coefficients (n) to estimate bed shear. Land use types were delineated using aerial imagery and topographic information. Appendix C includes land cover type maps for the model areas. The roughness value selected for the main channel represents high gradient mountain streams with beds composed of cobbles and boulders. Table 5 provides Manning's n values associated with material types.

Table 5: Manning's N Values

Land Use Type - Material	Manning's n
Channel (Mountain)	0.07
Floodplain Trees	0.1
Floodplain Cleared	0.08
Gravel Road	0.026
Gravel Point Bars	0.05
Concrete Box Culvert (ceiling)	0.013
Concrete Box Culvert (Natural Bottom)	0.07

4.4 Boundary Conditions

In SRH-2D the upstream boundary condition was specified as constant discharge using peak flow values for each event analyzed, as described in section 3.5. Downstream boundary conditions were specified as Exit-H constant water surface elevation, obtained by calculating the normal depth using Manning's equation and the slope of the channel near the downstream boundary.

4.5 Additional Modeling Considerations

At the 039 Fall Creek and 648 West Fork sites the 3D structure tool within SMS was used to model the proposed culvert and existing bridge, respectively. This tool creates pressure flow boundary conditions by representing the culvert ceiling or bridge low chord elevation. Pressurized flow and, if it exists, overtopping flow, are computed in the pressure flow region.

The existing geometry for the West Fork bridge was obtained using data provided by USFS including existing plans from 1953, 2018 and 2024 bridge inspection reports, post-flood October 2025 Critical Findings Inspection Report, and survey collected by CFLHD in April 2026. The reports generally used assumed vertical datums. LIDAR elevations at the top of road in the vicinity of the bridge were used to translate the assumed data to elevations. Based on the survey data, a bridge low chord of 7,931.1 feet and bridge crest elevation of 7,935 feet were used in the hydraulic model.

5 Site-Specific Evaluations

Site specific considerations, results, and recommendations are provided below.

5.1 039 Fall Creek Road

The existing site consisted of a double 72-inch corrugated metal pipe (CMP). The culvert and surrounding road embankment were destroyed during the flood. No detailed hydraulic modeling of existing conditions was conducted. Based on an HY-8 analysis using assumed geometry, the existing culvert had an approximate headwater to depth ratio (HW/D) of 1.6 for the 25-year flow and overtopped between a 50- and 100-year flow. Therefore, the existing culvert was undersized which, in addition to debris loading, likely led to embankment piping and failure during the flood. The project will replace the culvert with one adequately sized for the 25-year flow, while also considering SJNF's requests for reducing aquatic organism barriers by providing a natural bottom and additional capacity.

5.1.1 Culvert Capacity

The proposed culvert configuration is a 16-ft span by 8-ft height concrete box culvert (CBC) embedded to provide a natural streambed bottom. A comparison between the limited survey and LIDAR information at this site revealed good agreement, therefore, the LIDAR information was used to develop the hydraulic model as it covered a larger area. The survey collected by CFLHD was used to develop the plans for this site. The CBC capacity was evaluated in SRH-2D using the methods discussed in Section 4. A HW/D of less than 1.0, indicating the water level is at the top of the culvert inlet, for the 25-year flow was targeted. This combined with the elimination of the multi-barrel configuration will improve the passage of debris.

The culvert span was based primarily on the required hydraulic capacity but bankfull width based on hydraulic geometry relationships (Bieger, Rathjens, Allen, & Arnold, 2015) was estimated as 16 to 18 feet. The CBC slope was set matching an average stream slope of 3.9 percent. The effective CBC height after embedment is 4.5 feet. Manning's roughness for the natural bottom of the barrel was set according to Table 5, matching the channel roughness. Selected hydraulic results are shown in Table 6.

Table 6: Fall Creek Culvert Hydraulic Results

Return Period (yr)	Culvert Flow (cfs)	Headwater Elevation (ft)	Tailwater Elevation (ft)	Crest Elevation(ft)	CBC Inlet Invert (ft)	CBC Outlet Invert (ft)	Streambed Inlet Invert (ft)	Streambed Outlet Invert (ft)	HW/D
25	425	9627.5	9622.5	9637.1	9619.5	9616.5	9623	9620	0.99
50	523	9628.1	9622.8						1.14
100	629	9629.6	9623.2						1.47

5.1.2 Culvert Embedment and Stability

No site bed material information was collected. The required culvert embedment was estimated by evaluating the mobility of proposed materials for the 25-year design flow. The embedment will follow a layered configuration with a stable riprap layer overlain by streambed materials matching site characteristics. The median size (D_{50}) of the riprap layer was estimated by multiple methods and averaged to obtain a reasonable recommendation. Methods evaluated include: the Isbash (U.S. Department of Agriculture, 2007) equation for low and high turbulence scenarios, the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1994) steep slope equation, and the HEC-14 (Kilgore & Thompson, 2006) equation 10.4 for culvert outlet protection. Table 7 shows the results for each method evaluated.

Table 7: Riprap Sizing Methods and Results

Stone Sizing Method	D_{50} (in)
Isbash – Low Turbulence	10
Isbash – High Turbulence	20
USACE Steep Slope	13
HEC-14 (Subcritical)	10
HEC-14 (Supercritical)	16
Average D_{50} (in)	**14**
Riprap Class	**4**

The recommended culvert infill riprap thickness is 2.5 feet which corresponds to the nominal D_{100} of Class 4 riprap. The remaining embedment depth should be backfilled with streambed material according to the plans. Culvert outlet scour protection should be Class 6 riprap and extend 20 feet from the culvert outlet. This is approximately the distance where modeled 25-year velocities are no greater than 30% above the natural stream velocity. A summary of recommendations is shown in Table 8.

Table 8: Fall Creek Culvert Recommendations

Parameter	Value
Length (ft)	76
Span (ft)	16
Height (ft)	8
Slope (%)	3.9
CBC Inlet Invert (ft)	9619.5
CBC Outlet Invert (ft)	9616.5
Streambed Inlet Invert (ft)	9623
Streambed Outlet Invert (ft)	9620
CBC Embedment (ft)	3.5
Riprap Class	4
Riprap Thickness (ft)	2.5
Streambed Material Thickness (ft)	1
Outlet Apron Length (ft)	20

5.2 648 WEST FORK ROAD

Due to their proximity, the West Fork Road and Hatcher Road sites were included in a single SRH-2D hydraulic model. For clarity, analyses and recommendations for each site are discussed separately. The existing West Fork Road bridge experienced significant scour, undermining of the right (looking downstream) abutment, and overtopping during the flood event and is currently closed to vehicles. In addition, the channel upstream and downstream of the bridge widened and lowered, especially near the bridge, as evidenced by eroded banks and exposed tree root systems along the banks. USFS provided photos of the site pre- and post-flood that showed significant lowering of the stream bed level, especially at the right abutment. The current channel geometry was developed by combining the LIDAR data with the CFLHD ground survey. The survey consisted of four channel cross sections: two located immediately upstream and downstream of the bridge, and two located approximately 80 feet upstream and downstream. These cross sections were used to generate a local terrain surface, which was then merged into the LIDAR dataset. The survey showed that channel elevations were generally 3 feet lower than the LIDAR data. To provide an adequate transition with the survey data, the channel elevations in the LIDAR terrain were lowered by 3 feet for an approximate distance of 250 feet upstream and downstream of the bridge. In the USFS October 2025 Critical Findings Report maximum scour hole depth at the right abutment was estimated at 4.5 feet below the top of the footing. Material that was above the footing was washed away in the flood event. Figure 2 shows a comparison between the LIDAR terrain data, the ground survey data showing the lowered channel, and the resulting channel geometry at the bridge.

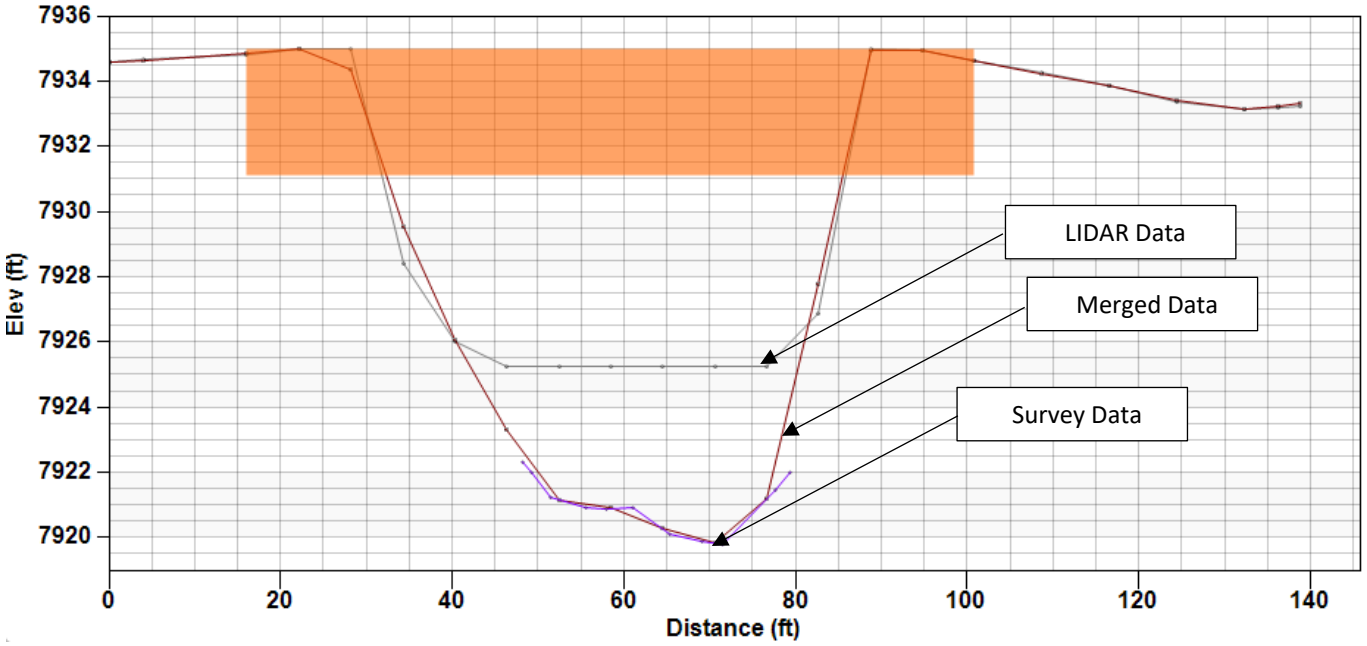

Figure 2: West Fork Survey and LIDAR Comparison

5.2.1 Hydraulic Results

PDDM criteria for bridges, listed in Table 2, specify scour design and check floods of 100-year and 200-year, respectively. Since the bridge experienced pressure flow and overtopping, there is the potential for a flood of lesser magnitude to produce the greatest scour, therefore, bridge hydraulics were evaluated for the 2- to 200-year events. The hydraulic modeling results indicate that with the currently degraded channel geometry at the bridge opening, the bridge is under pressure flow for the 200-year event. In addition, except for the 2-year event, all other events modeled showed right embankment overtopping. USFS personnel indicated both approach embankments overtopped during the event. The discrepancy between the model and observed behavior is likely attributed to flood debris accumulation during the storm event, reducing bridge conveyance area, and the currently degraded streambed near the bridge adding conveyance capacity. Maximum values for selected hydraulic results are shown in Table 9. The values are reported at the upstream face of the bridge and only consider flow through the bridge opening.

Table 9: West Fork Bridge Hydraulic Results

Return Period (yr)	Velocity (ft/s)		Depth (ft)		Water Surface Elevation (ft)	
	Average	Maximum	Average	Maximum	Average	Maximum
2	4.4	6.0	3.9	6.1	7925.9	7925.9
25	6.9	8.7	6.4	9.3	7929.1	7929.4
50	7.6	9.4	7.1	10.0	7929.8	7929.9
100	8.4	10.2	7.8	10.7	7930.5	7930.5
200	9.3	11.1	9.3	11.1	7931.1	7931.2

5.2.2 Scour Analysis

The West Fork bridge scour depths were estimated in accordance with HEC-18 (Zevenbergen, Arneson, Lagasse, & Clopper, 2012). Events from the 25-year to 200-year were evaluated. Total scour is defined as the combination of

long-term degradation, contraction scour, and local (abutment) scour. Long-term degradation was assumed to be zero for this evaluation but should be evaluated to properly design the foundation if the bridge is replaced in the future. SRH-2D hydraulic results were exported to the Hydraulic Toolbox using the Bridge Scour tools in SMS.

Due to the lack of a geotechnical investigation, scour was evaluated for multiple bed material sizes from fine sand with a median size (D_{50}) of 0.2 mm to small cobbles with a median size of 96 mm. Only small cobbles produced a clear water scour condition. Based on site observations it is expected that scour will occur under live-bed conditions, where sediment from the upstream reach is being transported into the bridge section.

The controlling contraction scour condition was vertical contraction scour (i.e. pressure flow) for the 200-year event. To estimate abutment scour HEC-18 recommends the NCHRP 24-20 method which applies an amplification factor to the contraction scour at the abutments, but this method was not developed for pressure flow conditions. Research is being conducted by FHWA to address this limitation, but no official guidance is yet available. In this case, abutment scour is unknown and a scour countermeasure meeting the requirements in HEC-23 (Lagasse, et al., 2009) would be needed to remove the bridge from a scour critical classification. To obtain an estimate for potential scour, the NCHRP method and corresponding free-surface flow amplification factor was applied to contraction scour results, which were computed by adjusting the flow depth to account for the pressure flow conditions. The results of this adjustment are presented for guidance in selecting abutment repair parameters only as they extend beyond the accepted application of the NCHRP method. The results are summarized in Table 10. The scour results were used as a guide to inform the repair design described in Section 5.2.3 with the limitations listed in Section 5.2.4.

Table 10: West Fork Bridge Scour Results

Return Period (yr)	Vertical Contraction Scour (ft)	Total Pressure Flow Abutment Scour - including contraction scour (ft)
200	2.6	6.7

5.2.3 Scour Repair Recommendations

For this site a scour countermeasure meeting all the requirements of HEC-23 would likely require full channel riprap installed below the contraction scour elevation. Since this is not feasible with this project, the proposed scour repair is based on a modification of HEC-23 Design Guideline 13. The recommended repair uses grout to fill the cavity below the footing and riprap in front and around the abutment to protect the foundation from future scour. Riprap was sized using HEC-23 Design Guideline 14 using spill-through and vertical wall abutment configurations, resulting in Class 6 and Class 7 riprap, respectively. For contractibility and ease of sourcing Class 6 riprap is recommended. Class 6 has a median size of 20 to 23 inches and a maximum size of 39 to 45 inches. The riprap should extend 10 feet horizontally from the edge of the footing and have a minimum thickness of 3.5 feet. The riprap will wrap around the abutment and wingwalls up to the banks upstream and downstream. Additional details are provided in the project plans.

5.2.4 Additional Scour Considerations

National Bridge Inspection Standards (NBIS) *Item 113- Scour Critical Bridges* in the 2024 Bridge Inspection Report coded the bridge as a 5, meaning the bridge foundations have been determined to be stable for assessed or calculated scour conditions, or scour has been mitigated using a countermeasure meeting the requirements of HEC-23. Since the proposed scour repair doesn't fully satisfy HEC-23, it is recommended that vulnerability to scour is re-appraised following the requirements of 23 CFR 650.313. A scour Plan of Action (POA) would be required if the bridge is re-coded as scour critical.

5.3 033 HATCHER ROAD

Hatcher Road experienced a slope failure during the flood event. The road is currently closed to traffic approximately 0.25 miles south of West Fork Road. The failure is located on the outside of a bend in the West Fork San Juan River. Minor channel avulsion was observed in this reach, with some flows leaving the main channel via a left overbank meander cutoff. Hydraulic results, such as velocity and water depths, were extracted from the combined West Fork and Hatcher Road SRH-2D hydraulic model and used to estimate bank protection requirements as discussed below. A limited amount of ground survey was collected at this site. The survey was focused on the embankment failure but also provided limited channel information. When comparing the surveyed channel elevations to the LIDAR data, the channel appeared to be approximately 0.2 feet lower. Since the intent of the project is to reconstruct the embankment, it was assumed that the pre-flood LIDAR better represented the hydraulic conditions that will be experienced at the site post-construction. Therefore, the survey data was not incorporated in the hydraulic model.

5.3.1 Bank Protection

HEC-23 Design Guideline 4 equation 4.1 was used to estimate the required riprap size. The PDDM specifies a 25-year design flood for embankment stability but both 25-year and 50-year events were evaluated. A simplified HEC-23 equation and the SMS data calculator were used to estimate the required riprap size based on the modeled water depth and velocity results. Assumptions include angular rock, a bank slope of 1V:1.5H, a specific gravity of riprap of 2.65, and a safety factor of 1.2. A bend radius of curvature of 245 feet was estimated from aerial imagery. The required size was assumed as the maximum median size in the nearby river reach. Although the required median size varies from 12 to 14 inches and corresponds to Class 4 riprap, Class 6 with median size range of 20 to 23 inches is recommended for consistency with the other project sites. The minimum riprap thickness should be 3.5 feet and extend approximately 420 linear feet along the bank. The riprap should be keyed into the bank at both upstream and downstream ends according to the termination details shown in the plans. Above the riprap slope a reinforced soil slope (RSS) will be installed to reconstruct the slope accordingly, see the project Geotechnical Report for additional information.

5.3.2 Bend Scour

Riprap revetment should extend below the depth of anticipated scour, which includes the long-term degradation and local or bend scour. As above, long-term degradation was not estimated for the site. Bend scour was estimated using multiple empirical equations: Maynord, USACE EM 1110-2-1601 for gravel, and Thorne (Howard, et al., 2021). The equations were applied using 25-year and 50-year hydraulic results within the main channel banks. Table 11 shows bend scour results for the methods evaluated. Scour depths in the table represent the additional anticipated scour at the bend. While the scour depths range from 1.3 to 2.7 feet, the recommended embedment depth is 5 feet below the post-flood channel elevation at the bend. For this project a 5-foot minimum embedment was selected at all sites to account for uncertainty in the analysis and provide additional resiliency.

Table 11: Hatcher Road Bend Scour Results

Equation	25-year	50-year
Maynord Bend Scour (ft)	1.3	1.5
USACE (Gravel) Bend Scour (ft)	2.5	2.7
Thorne Bend Scour (ft)	2.2	2.5
Maximum (ft)	**2.5**	**2.7**
Average (ft)	**2.0**	**2.3**

5.4 667 East Fork Road

East Fork Road experienced a slope failure during the flood event. The road is currently open with a reduced width for an approximate 70 ft length near the failure site. Minor repairs were conducted post-flood by Xcel Energy to reestablish access to power utility infrastructure. The failure is located on the outside of a bend in the East Fork San Juan River. Hydraulic results, such as velocity and water depths, were extracted from the SRH-2D hydraulic model and used to estimate bank protection requirements as discussed below. A limited amount of ground survey was collected at this site. The survey was focused on the embankment failure and provided no channel information. It was assumed that the pre-flood LIDAR better represented the hydraulic conditions that will be experienced at the site post-construction. Therefore, the survey data was not incorporated in the hydraulic model.

5.4.1 Bank Protection

HEC-23 Design Guideline 4 was used to estimate the required riprap size. The PDDM specifies a 25-year design flood for embankment stability but both 25-year and 50-year events were evaluated. A simplified HEC-23 equation and the SMS data calculator were used to estimate the required riprap size based on the modeled water depth and velocity results. Assumptions include angular rock, a bank slope of 1V:1.5H, a specific gravity of riprap of 2.65, and a safety factor of 1.2. A bend radius of curvature of 622 feet was estimated from aerial imagery. The required size was assumed as the maximum median size in the nearby river reach. The required median size varies from 10 to 17 inches along the bank. Although the required median size corresponds to Class 5 riprap, Class 6 with median size range of 20 to 23 inches is recommended for consistency with the other project sites. The minimum riprap thickness should be 3.5 feet and extend approximately 170 linear feet along the bank. The riprap should be keyed into the bank at both upstream and downstream ends according to the termination details shown in the plans.

5.4.2 Bend Scour

Riprap revetment should extend below the depth of anticipated scour, which includes the long-term degradation and local or bend scour. As above, long-term degradation was not estimated for the site. Bend scour was estimated using multiple empirical equations: Maynord, USACE EM 1110-2-1601 for gravel, and Thorne. The equations were applied using 25-year and 50-year hydraulic results within the main channel banks. Table 12 shows bend scour results for the methods evaluated. Scour depths in the table represent the additional anticipated scour at the bend with negative values indicating that no scour was computed by the corresponding equation. While the scour depths range from 0 to 0.7 feet, the recommended embedment depth is 5 feet below the post-flood channel elevation at the bend. For this project a 5-foot minimum embedment was selected at all sites to account for uncertainty in the analysis and provide additional resiliency.

Table 12: East Fork Bend Scour Results

Equation	25-year	50-year
Maynord Bend Scour (ft)	-0.8	-0.5
USACE (Gravel) Bend Scour (ft)	-2.2	-2.0
Thorne Bend Scour (ft)	0.3	0.7
Maximum (ft)	**0.3**	**0.7**
Average (ft)	**-0.9**	**-0.6**

5.5 Lower Piedra Road

The Lower Piedra Road site experienced significant bank and road failure during the flood event. The failure is located on the outside of a bend in the Lower Piedra River. Roadway realignment approximately 15 feet to the west is proposed at this location to provide resiliency against future bank erosion. The bank will be protected along the bend near its current post-flood location. Hydraulic results, such as velocity and water depths, were extracted from

the SRH-2D hydraulic model and used to estimate bank protection requirements as discussed below. A limited amount of ground survey was collected at this site. The survey was focused on the embankment failure but also provided limited channel information upstream of the failure site. A comparison between the channel elevations and LIDAR data revealed that the channel was typically about 1 foot lower, however, this difference was not uniform across the data. It was assumed that the pre-flood LIDAR better represented the hydraulic conditions that will be experienced at the site post-construction, therefore the LIDAR-only model results were used to design the bank protection. The survey data was incorporated into the hydraulic model to simulate the post-flood condition in the floodplain evaluation described in Section 5.5.3.

5.5.1 Bank Protection

HEC-23 Design Guideline 4 was used to estimate the required riprap size. The PDDM specifies a 25-year design flood for embankment stability but both 25-year and 50-year events were evaluated. A simplified HEC-23 equation and the SMS data calculator were used to estimate the required riprap size based on the modeled water depth and velocity results. Assumptions include angular rock, a bank slope of 1V:1.5H, a specific gravity of riprap of 2.65, and a safety factor of 1.2. A bend radius of curvature of 392 feet was estimated from aerial imagery. The required size was assumed as the maximum median size in the nearby river reach which varies from 12 to 14 inches and corresponds to Class 4 riprap. Although the required median size corresponds to Class 4 riprap, Class 6 with median size range of 20 to 23 inches is recommended for consistency with the other project sites. The minimum riprap thickness should be 3.5 feet and extend approximately 390 linear feet along the bank. The riprap should be keyed into the bank at both upstream and downstream ends according to the termination details shown in the plans.

5.5.2 Bend Scour

Riprap revetment should extend below the depth of anticipated scour, which includes the long-term degradation and local or bend scour. As above, long-term degradation was not estimated for the site. Bend scour was estimated using multiple empirical equations: Maynord, USACE EM 1110-2-1601 for gravel, and Thorne. The equations were applied using 25-year and 50-year hydraulic results within the main channel banks. Table 13 shows bend scour results for the methods evaluated. Scour depths in the table represent the additional anticipated scour at the bend. While the scour depths range from 3.4 to 7 feet, the recommended embedment depth is 7 feet below the post-flood channel elevation at the bend.

Table 13: Lower Piedra Bend Scour Results

Equation	25-year	50-year
Maynord Bend Scour (ft)	3.4	3.7
USACE (Gravel) Bend Scour (ft)	6.4	7.0
Thorne Bend Scour (ft)	4.8	5.3
Maximum (ft)	**6.4**	**7.0**
Average (ft)	**4.9**	**5.3**

5.5.3 Floodplain Evaluation

As discussed in Section 1.3, the Lower Piedra Site is located within an approximate Zone A floodplain where no base flood elevations (BFE) are available. To satisfy the policy in 23 CFR Part 650, PDDM criteria limit the allowable rise in base flood elevation to 1-foot when no detailed study is available. The purpose of the project is to restore the Lower Piedra embankment to its pre-flood condition, therefore, no change in BFE from the pre-flood to the post-project condition is expected. In addition, the project action is unavoidable as it is required to restore access to Forest lands.

Due to the lack of pre-flood survey and to evaluate all possible encroachment scenarios, the LIDAR-based terrain dataset used in the hydraulic model described in Section 4.1 and 5.5 and the post-flood survey data were used to evaluate water surface elevations for the 100-year flood event or base flood. Figure 3 shows the terrain data near the failure site used in the SRH-2D hydraulic model for each scenario.

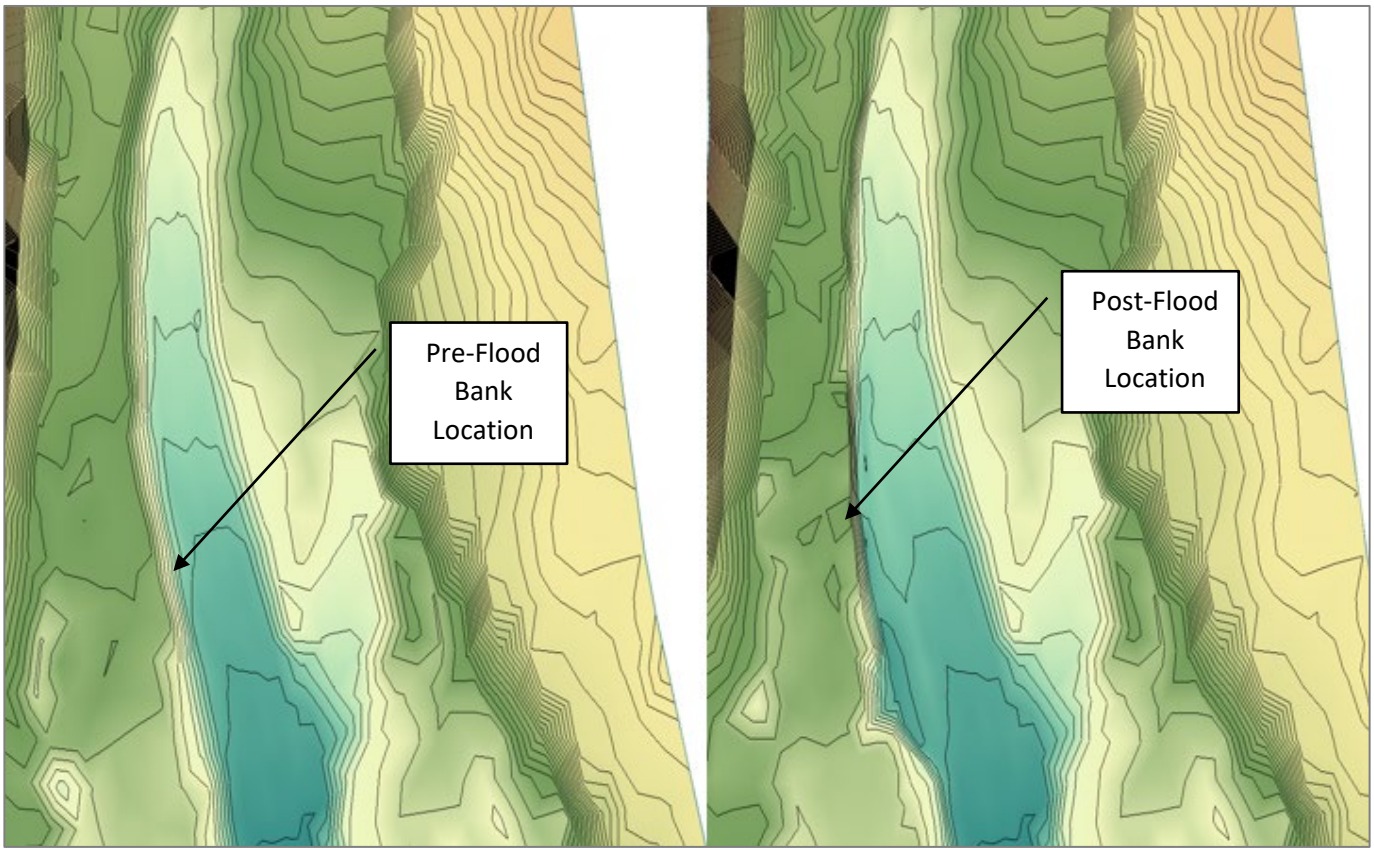

Figure 3: Lower Piedra Terrain Comparison

Model simulations using 100-year peak flows were conducted and average water surface elevations (BFEs) extracted at multiple evaluation lines across the reach, as shown in Appendix C. Two scenarios were considered:

1) Post-Flood condition – this served as the baseline or "existing condition" for the BFE comparison.
2) Pre-Flood/Post-project condition – This served as the "proposed condition" and assumes that the project will restore the Lower Piedra bank to its pre-flood geometry.

The results of the BFE comparison are shown in Table 14. The results show that the maximum increase in BFE is 0.55 feet. A similar comparison was carried out using the maximum water surface elevations obtained in the evaluation lines. Since the model used is two-dimensional, these values represent local differences, and generally not used for regulatory purposes. The results show that the maximum water surface elevation increase is 0.96 feet. The comparison table is shown in Appendix C. Based on the results the maximum BFE increase criteria is satisfied.

Table 14: Lower Piedra BFE Comparison

Evaluation Line Station (ft)	Existing Condition (Post Flood Event Failure)	Proposed Conditions (Post Project Repair)	Difference (Post Project - Existing Condition)
	100-Year Average Water Surface Elevation (ft)	100-Year Average Water Surface Elevation (ft)	100-Year Average Water Surface Elevation (ft)
20.5	6548.0	6548.0	-0.02
98.8	6549.0	6548.9	-0.14
306.2	6550.0	6550.6	0.55
393.6	6551.0	6551.4	0.42
437.2	6552.0	6552.3	0.32
494.0	6553.0	6553.3	0.26
546.0	6554.0	6554.2	0.24
601.2	6555.0	6555.2	0.18
663.1	6556.0	6556.2	0.18
706.4	6557.0	6557.2	0.20
738.7	6558.0	6558.1	0.09
801.4	6559.0	6558.9	-0.14
923.5	6560.0	6559.8	-0.17
1084.8	6561.0	6560.9	-0.11
1350.3	6562.0	6561.9	-0.12
		Average:	**0.12**
		Maximum:	**0.55**

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Appendix A

Background Information

Site Photos

November 2025

039 Fall Creek Road – Culvert and Embankment Failure

648 West Fork Road Bridge – Abutment Undermining

648 West Fork Road Bridge – Abutment Undermining (USFS Photo)

033 Hatcher Road – Embankment Slope Failure

667 East Fork Road – Embankment Slope Failure

667 East Fork Road – Embankment Slope Failure

FEMA FIRM

National Flood Hazard Layer FIRMette

FEMA

106°51'45"W 37°28'49"N

106°51'7"W 37°28'21"N

0 250 500 1,000 1,500 2,000 Feet

1:6,000

Basemap Imagery Source: USGS National Map 2023

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 Cross Sections with 1% Annual Chance
- 17.5 Water Surface Elevation
- Coastal Transect
- Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

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National Flood Hazard Layer FIRMette

FEMA

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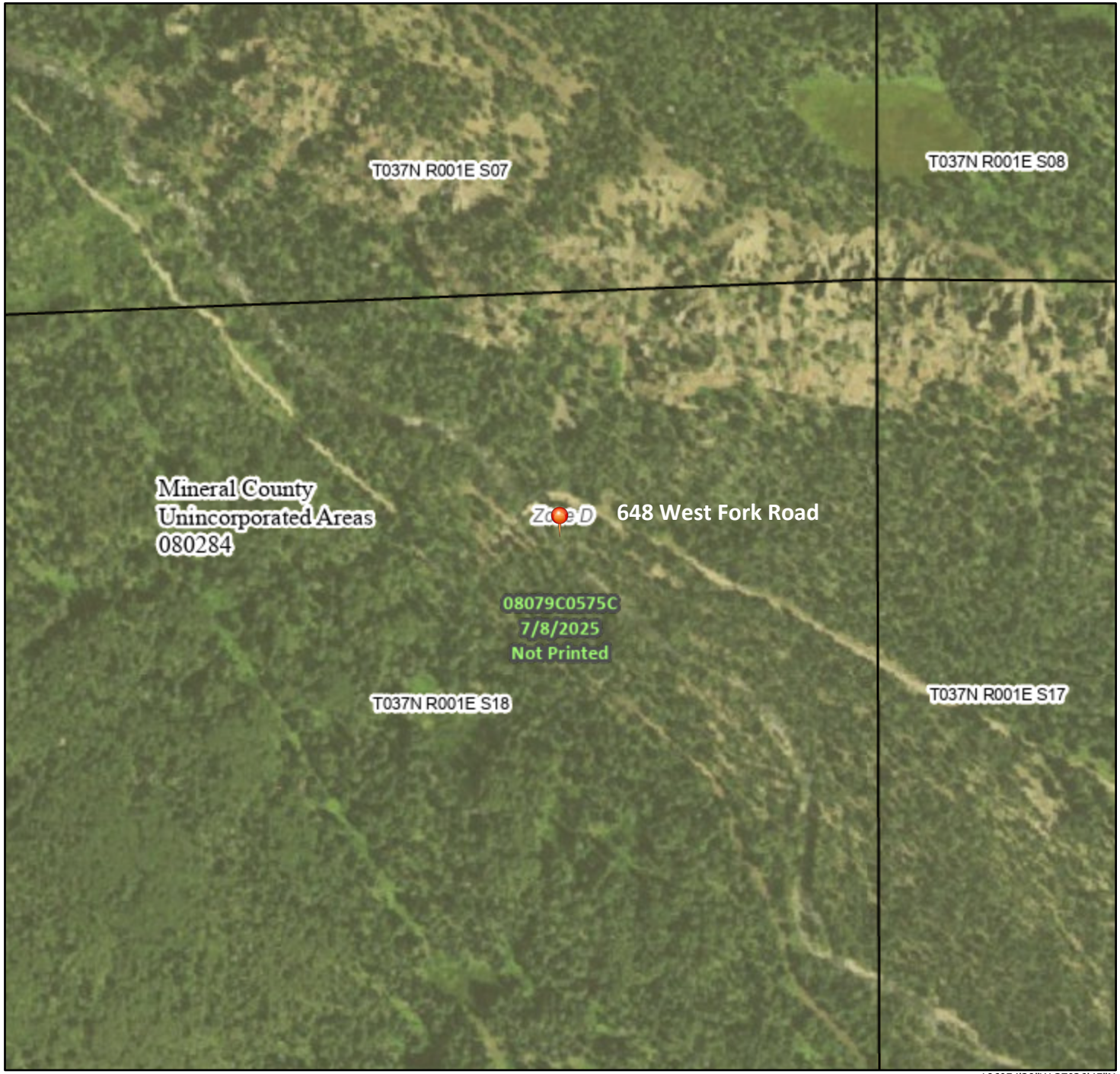

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Feet

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Basemap Imagery Source: USGS National Map 2023

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 / 17.5 Cross Sections with 1% Annual Chance / Water Surface Elevation
- Coastal Transect
- Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

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National Flood Hazard Layer FIRMette

FEMA

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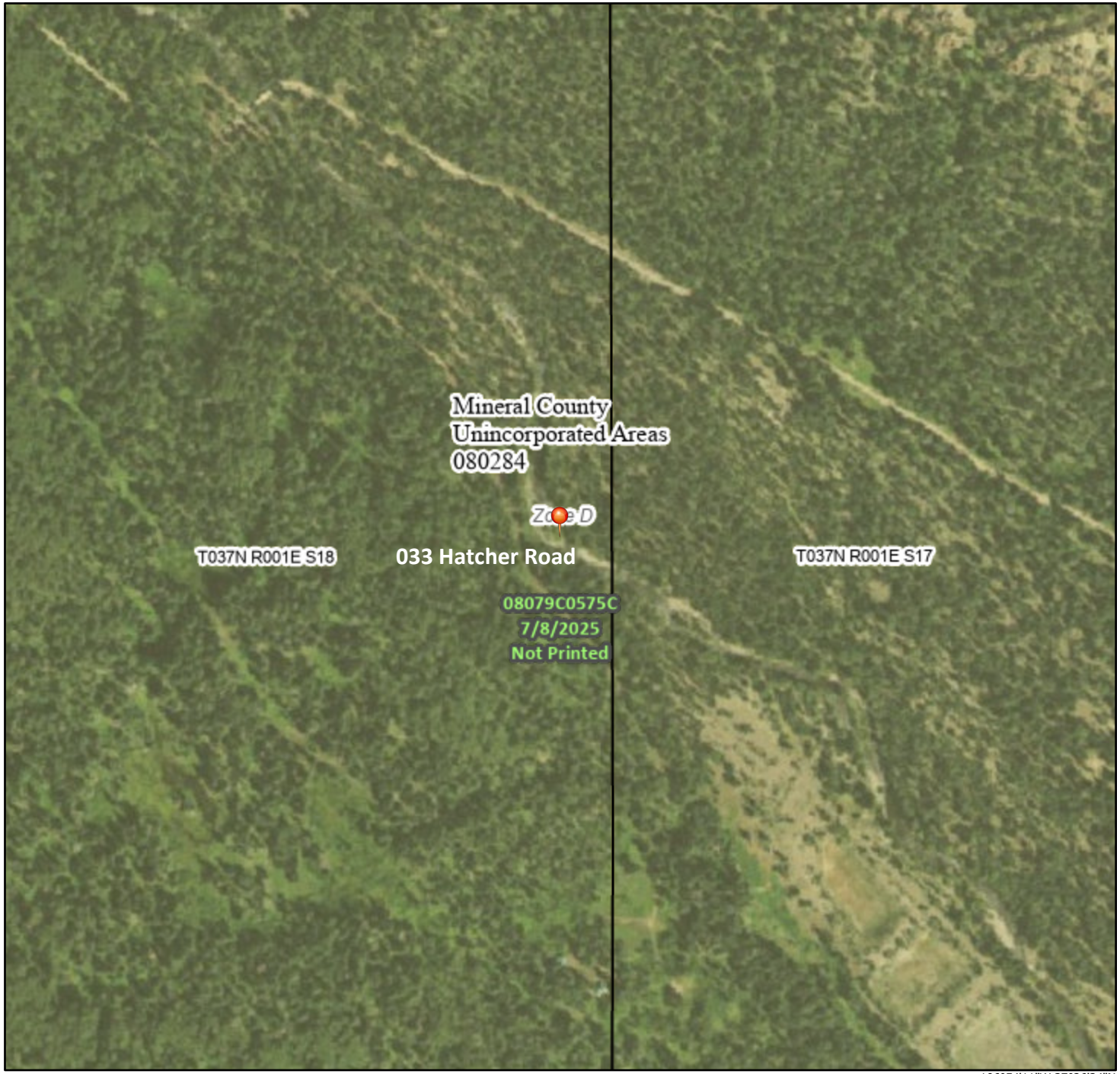

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Basemap Imagery Source: USGS National Map 2023

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 Cross Sections with 1% Annual Chance
- 17.5 Water Surface Elevation
- Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

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National Flood Hazard Layer FIRMette

FEMA

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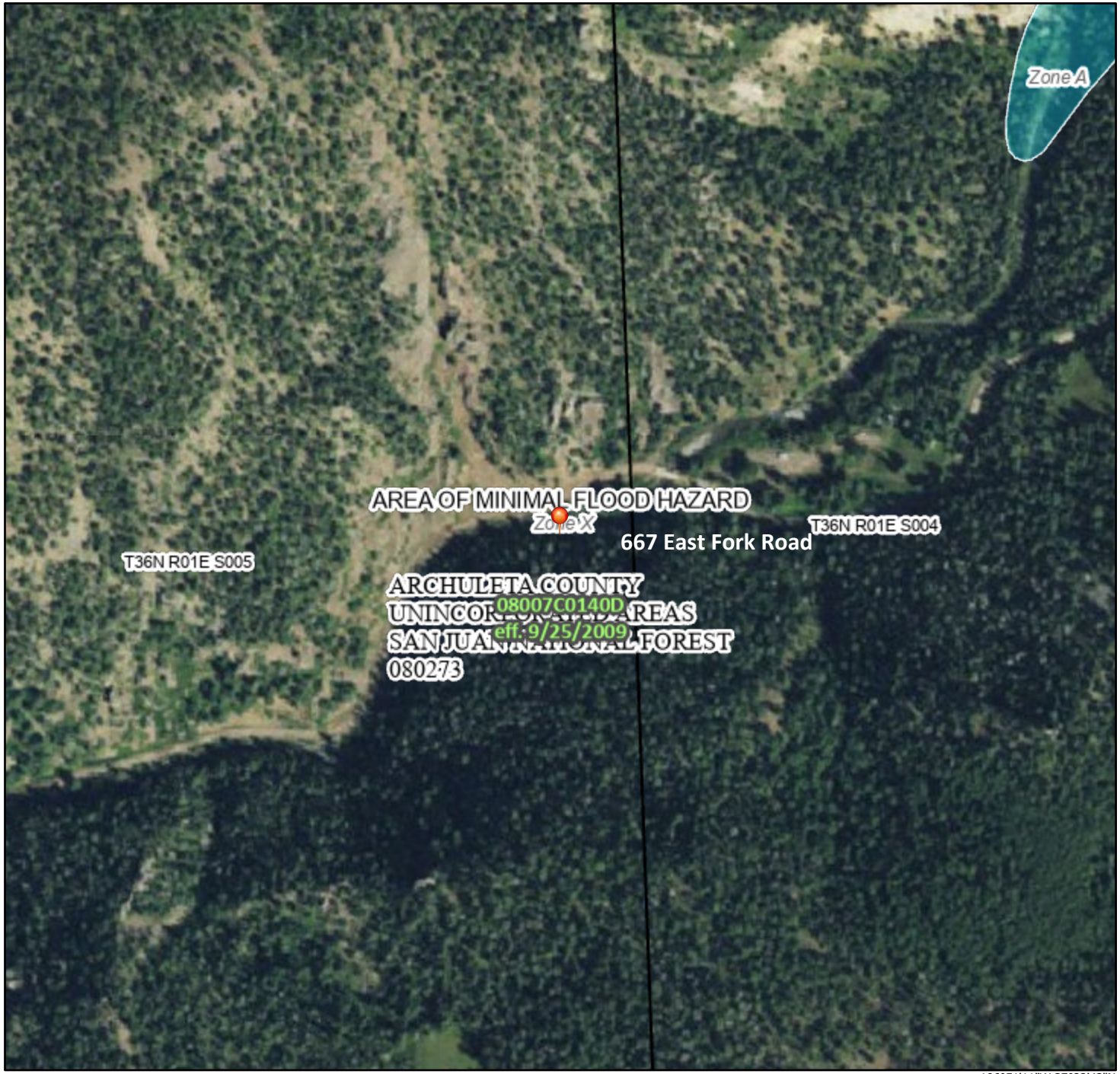

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Feet

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Basemap Imagery Source: USGS National Map 2023

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 Cross Sections with 1% Annual Chance
- 17.5 Water Surface Elevation
- Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

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National Flood Hazard Layer FIRMette

FEMA

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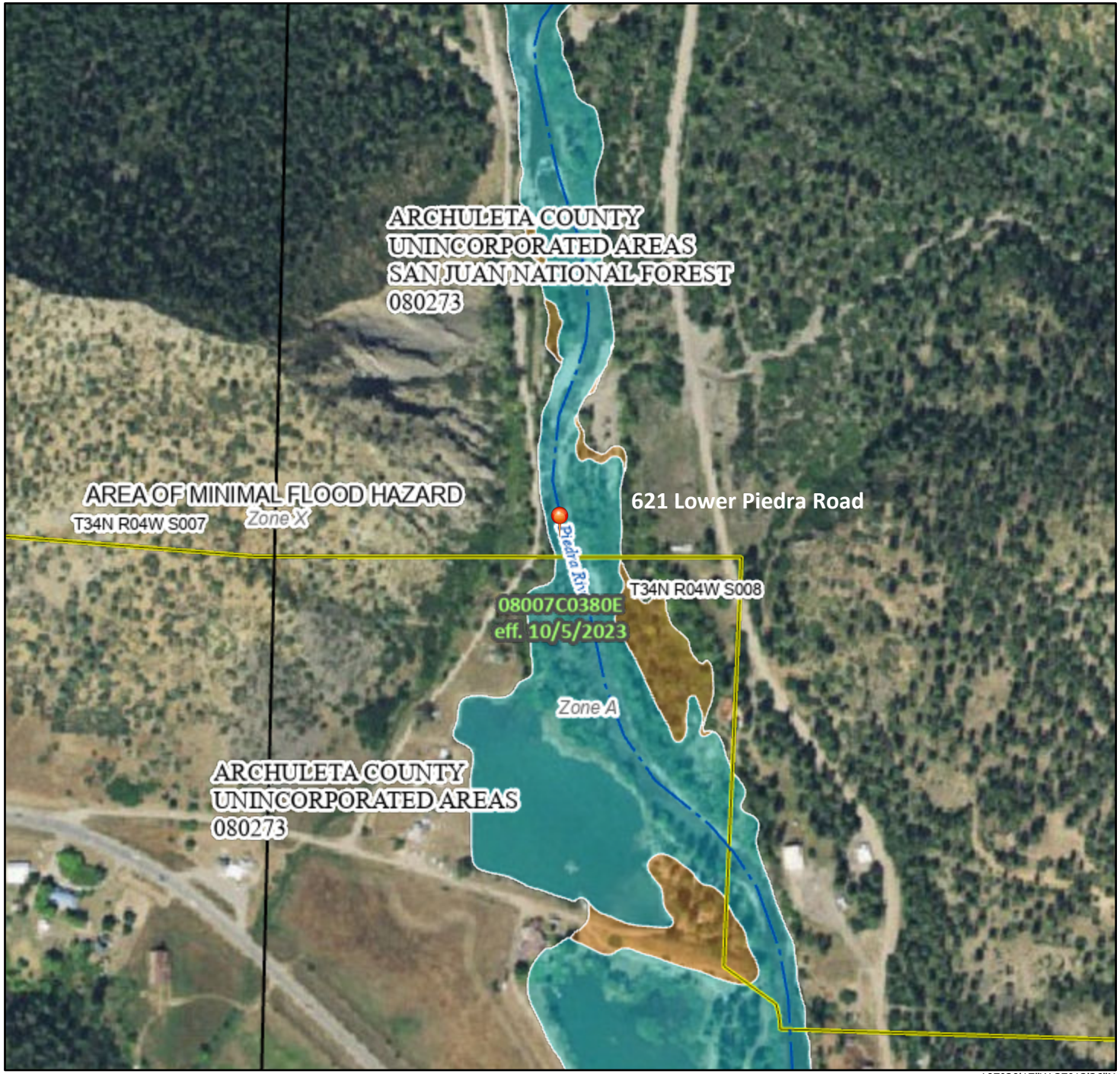

107°20'17"W 37°13'36"N

Feet

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1:6,000

Basemap Imagery Source: USGS National Map 2023

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 / 17.5 Cross Sections with 1% Annual Chance / Water Surface Elevation
- Coastal Transect
- Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 2/10/2026 at 9:35 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Appendix B

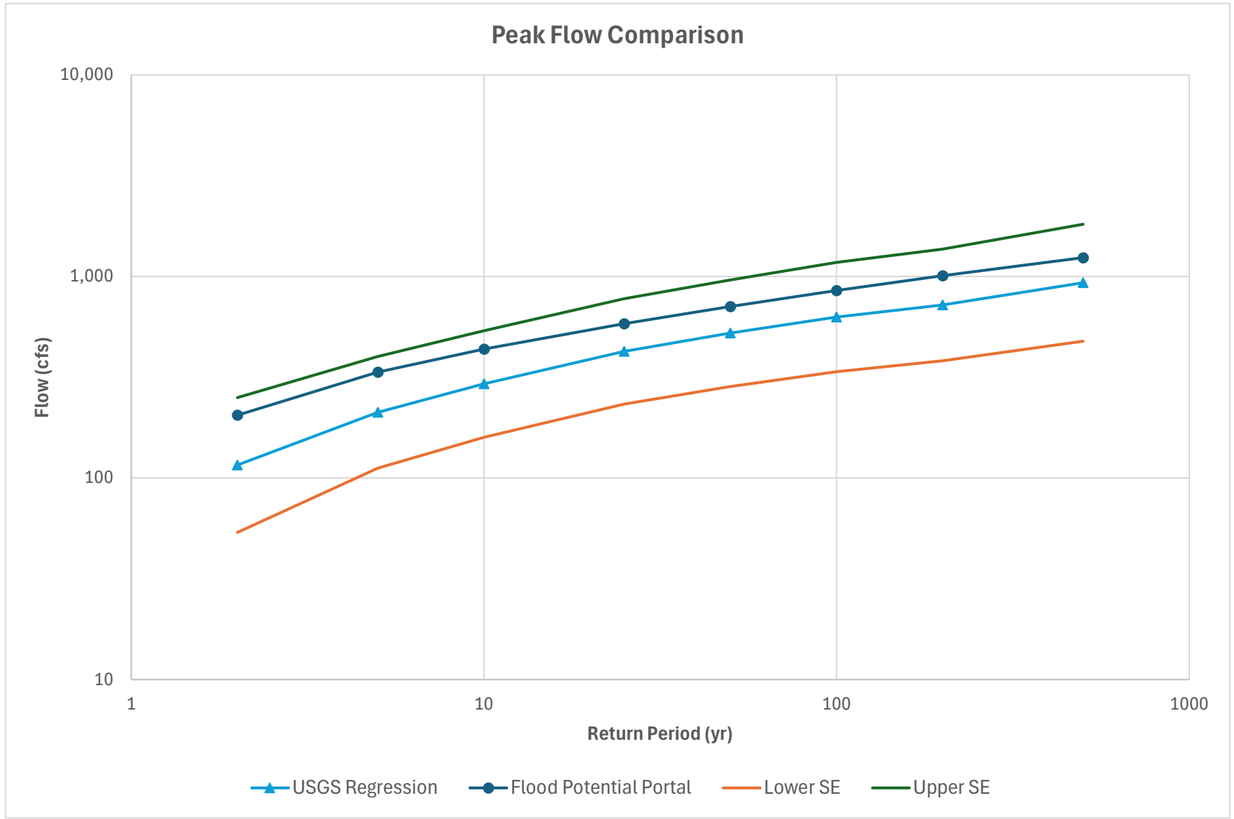
Hydrology

Appendix B-1

039 Fall Creek Road

039 Fall Creek Road - Peak Flow Estimate Comparison

Exceedance Probability (%)	Return Period (yr)	USGS Regression Peak Flow (cfs)	SE (%)	SE(log)	SE (+%)	SE (-%)	Upper (cfs)	Lower (cfs)	FPP Peak Flow (cfs)	Adopted Flows (cfs)
50%	2	116	90	0.33	116	-54	251	54	205	205
20%	5	212	71	0.28	89	-47	402	112	336	336
10%	10	293	67	0.26	84	-46	539	159	437	437
4%	25	425	66	0.26	82	-45	775	233	584	584
2%	50	523	67	0.26	84	-46	961	284	709	709
1%	100	629	69	0.27	87	-46	1,174	337	850	850
0.5%	200	723	71	0.28	89	-47	1,370	382	1,010	1,010
0.2%	500	931	75	0.29	95	-49	1,816	477	1,240	1,240

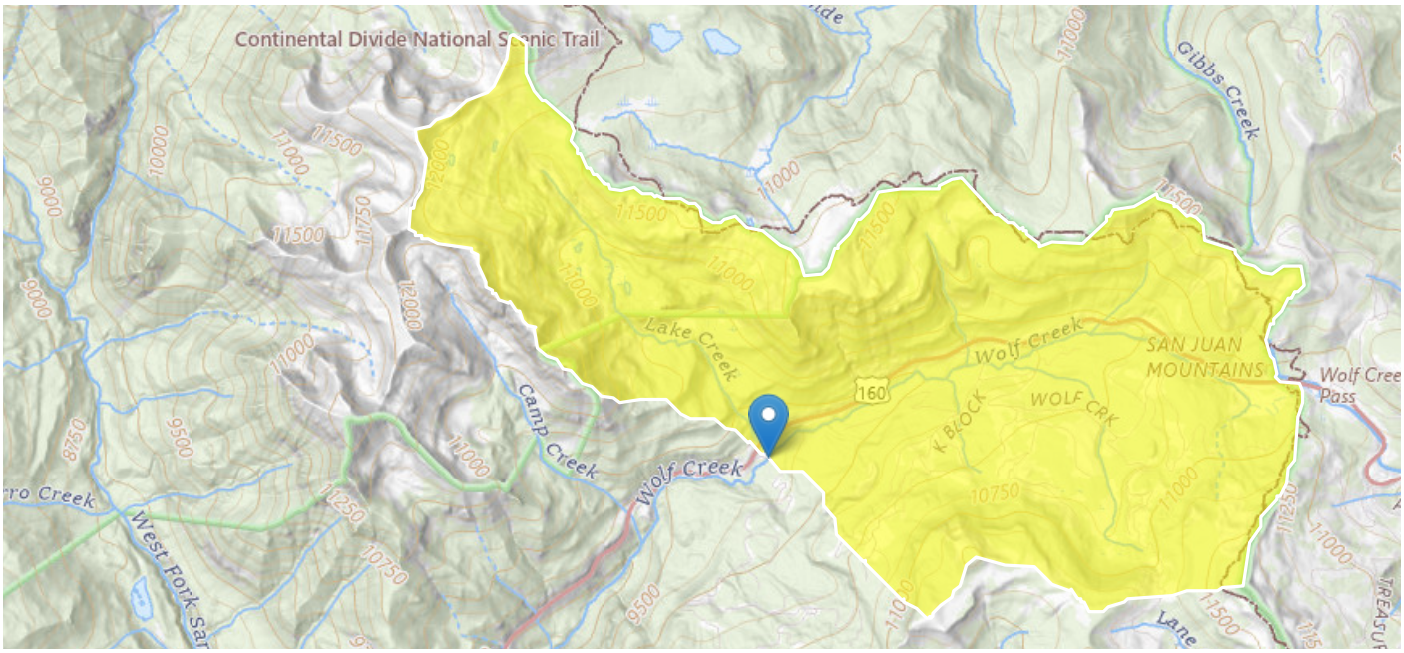


Comparisons:

Return Period (yr)	Difference USGS-FPP (cfs)	% Increase from USGS (%)	% Difference (%)
2	-89	77%	55%
5	-124	58%	45%
10	-144	49%	39%
25	-159	37%	32%
50	-186	36%	30%
100	-221	35%	30%
200	-287	40%	33%
500	-309	33%	28%
Average	-190	46%	37%
Minimum	-309	33%	28%
Maximum	-89	77%	55%

Wolf Creek at Fall River Road

Region ID: CO
Workspace ID: CO20251125222942515000
Clicked Point (Latitude, Longitude): 37.47658, -106.85740
Time: 2025-11-25 15:30:06 -0700



Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	8.55	square miles
EL7500	Percent of area above 7500 ft	100	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Southwest Region Peak Flow]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	8.55	square miles	1	4390
EL7500	Percent above 7500 ft	100	percent	0	99

Peak-Flow Statistics Disclaimers [Southwest Region Peak Flow]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

Peak-Flow Statistics Flow Report [Southwest Region Peak Flow]

Statistic	Value	Unit
50-percent AEP flood	116	ft^3/s
20-percent AEP flood	212	ft^3/s
10-percent AEP flood	293	ft^3/s
4-percent AEP flood	425	ft^3/s
2-percent AEP flood	523	ft^3/s
1-percent AEP flood	629	ft^3/s
0.5-percent AEP flood	723	ft^3/s
0.2-percent AEP flood	931	ft^3/s

Peak-Flow Statistics Citations

Capesius, J.P., and Stephens, V. C.,2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p. (http://pubs.usgs.gov/sir/2009/5136/)

Bankfull Statistics

Bankfull Statistics Parameters [Rocky Mountain System D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	8.55	square miles	0.15444	9730.1061

Bankfull Statistics Parameters [Southern Rocky Mountains P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	8.55	square miles	1.540539	9729.943938

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	8.55	square miles	0.07722	59927.7393

Bankfull Statistics Flow Report [Rocky Mountain System D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	15.7	ft
Bieger_D_channel_depth	1.52	ft
Bieger_D_channel_cross_sectional_area	18.1	ft^2

Bankfull Statistics Flow Report [Southern Rocky Mountains P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	17.4	ft
Bieger_P_channel_depth	1.16	ft

Statistic	Value	Unit
Bieger_P_channel_cross_sectional_area	17.8	ft^2

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	26.4	ft
Bieger_USA_channel_depth	1.9	ft
Bieger_USA_channel_cross_sectional_area	54.4	ft^2

Bankfull Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit
Bieger_D_channel_width	15.7	ft
Bieger_D_channel_depth	1.52	ft
Bieger_D_channel_cross_sectional_area	18.1	ft^2
Bieger_P_channel_width	17.4	ft
Bieger_P_channel_depth	1.16	ft
Bieger_P_channel_cross_sectional_area	17.8	ft^2
Bieger_USA_channel_width	26.4	ft
Bieger_USA_channel_depth	1.9	ft
Bieger_USA_channel_cross_sectional_area	54.4	ft^2

Bankfull Statistics Citations

Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_campaign=PDFCoverPages)

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Application Version: 4.29.4
StreamStats Services Version: 1.2.22
NSS Services Version: 2.2.1

Flood Potential Portal - Overview

Date Generated: 02/09/2026
Version: 2.6.0
Latitude: 37.47658
Longitude: -106.85740

Indices -- Watershed Flooding Characteristics	Values	Percentile [Range]
Flood Potential Index (Pf)	3	18.0th [0.25 - 164.7]
Watershed Scale Ratio (Rf)	1.43	79.0th [0 - 5.79]
Beard Flashiness Index (F)	0.61	35.0th [0.37 - 2.82]
Richards-Baker Flashiness Index (R-B)	0.109	12.0th [0.039 - 1.621]
Bimodality Index (Bi)	4.8	39.0th [2.1344 - 182.8173]
Flood Variability Index (Vf)	1.94	88.0th [1.15 - 2.86]
Flood Hazard Index (Hf)	1.84	12.0th [0.1 - 164.7]

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest (5%) of annual peak discharges (percent change = -1.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest quarter (Q4, >4 yr RI) of annual peak discharges (percent change = 0.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of moderate quarter (Q3, 4 to 2 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of ~bankfull quarter (Q2, 2 to 1.33 yr RI) of annual peak discharges.

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of < bankfull quarter (Q1, <1.33 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the annual frequency of floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the event frequency of large floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a possible decreasing trend in flood flashiness.

Flood Discharge Estimates (cfs)	Unadjusted	Trend-Adjusted
Expected Flood Potential (Qefp)	580	574
Maximum Likely Flood Potential (Qmlf)	1050	1040

Return Interval (yr)	Annual Exceedance Probability	Index Flood	USGS Equations (StreamStats)
500	0.2	1240	931
200	0.5	1010	723
100	1	850	629
50	2	709	523
25	4	584	425
10	10	437	293
5	20	336	212
2	50	205	116
1.5	66.7	159	----

Flood Potential Portal - Calculations

Flood Potential									
Zone Name (Zone ID)	**Area (mi2)**	**Second Predictor**	**Predictor Value**	**Trends in Frequency**	**Trends in Magnitude**	**Qefp (cfs)**	**Trend-Adjusted Qefp (cfs)**	**Qmlf (cfs)**	**Trend-Adjusted Qmlf (cfs)**
Southern Rocky Mountains, South (3S)	8.11	P9	4.21 (inches)	No trends	Significantly Decreasing	580	574	1050	1040
Total	8.11					580	574	1050	1040

Index Flood Frequency												
Zone Name (Zone ID)	**Area (mi2)**	**Second Predictor**	**Predictor Value**	**1.5 Year**	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**	**200 Year**	**500 Year**
Southern Rocky Mountains, South (3S)	8.11	P1	5.51 (inches)	159	205	336	437	584	709	850	1010	1240
Total	8.11			159	205	336	437	584	709	850	1010	1240

USGS Regional Regression Flood Frequency (StreamStats)										
USGS Regression Region	**Area (mi2)**	**1.5 Year**	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**	**200 Year**	**500 Year**
Southwest_Region_Peak_Flow	8.55	----	116	212	293	425	523	629	723	931
Total	8.55	----	116	212	293	425	523	629	723	931

Footnotes
P1 = mean average watershed monthly precipitation for January (in)

Footnotes
P9 = mean average watershed monthly precipitation for September (in)
Qefp = expected flood potential discharge
Qmlf> = maximum likely flood potential discharge
* The peak flow estimates from the USGS regional regressions (StreamStats) include a warning: One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

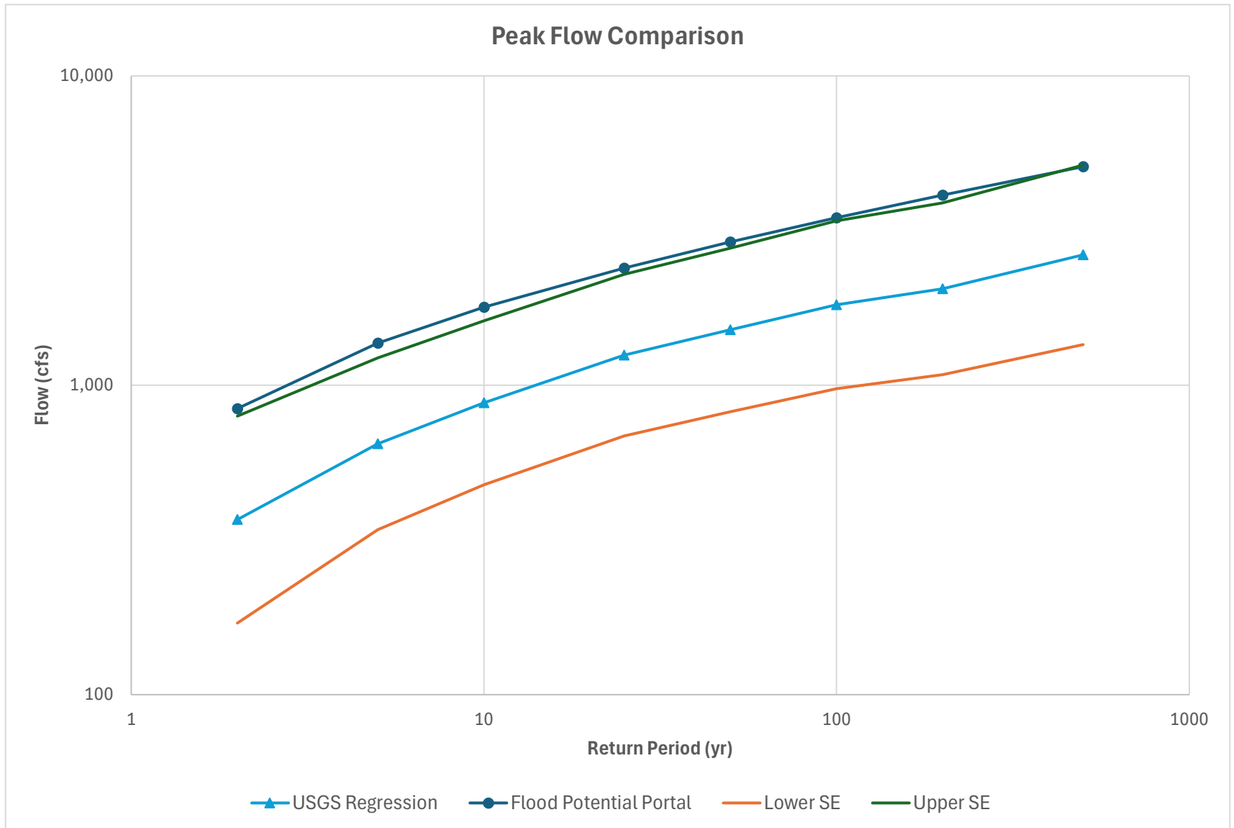
Citations
Capesius, J.P., and Stephens, V. C., 2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p.
Yochum, S.E., Scott, J.A., and Levinson, D.H., 2019, Methods for Assessing Expected Flood Potential and Variability: Southern Rocky Mountains Region. Water Resources Research, vol. 55, no. 8, pp. 6392-6416.
Yochum, S.E., Wible, T., Korsa, M., Ghanbari, M., Arabi, M. 2024, Flood Potential Portal: A web tool for understanding flood variability and predicting peak discharges. River Research and Applications. Wiley. https://doi.org/10.1002/rra.4354

Appendix B-2

648 West Fork Road and 033 Hatcher Road

648 West Fork/ 033 Hatcher Road - Peak Flow Estimate Comparison

Exceedance Probability (%)	Return Period (yr)	USGS Regression Peak Flow (cfs)	SE (%)	SE(log)	SE (+%)	SE (-%)	Upper (cfs)	Lower (cfs)	FPP Peak Flow (cfs)	Adopted Flows (cfs)
50%	2	368	90	0.33	116	-54	795	170	841	841
20%	5	647	71	0.28	89	-47	1,226	342	1,370	1,370
10%	10	878	67	0.26	84	-46	1,614	478	1,790	1,790
4%	25	1,250	66	0.26	82	-45	2,281	685	2,390	2,390
2%	50	1,510	67	0.26	84	-46	2,776	821	2,910	2,910
1%	100	1,820	69	0.27	87	-46	3,397	975	3,480	3,480
0.5%	200	2,050	71	0.28	89	-47	3,883	1,082	4,120	4,120
0.2%	500	2,640	75	0.29	95	-49	5,149	1,354	5,090	5,090

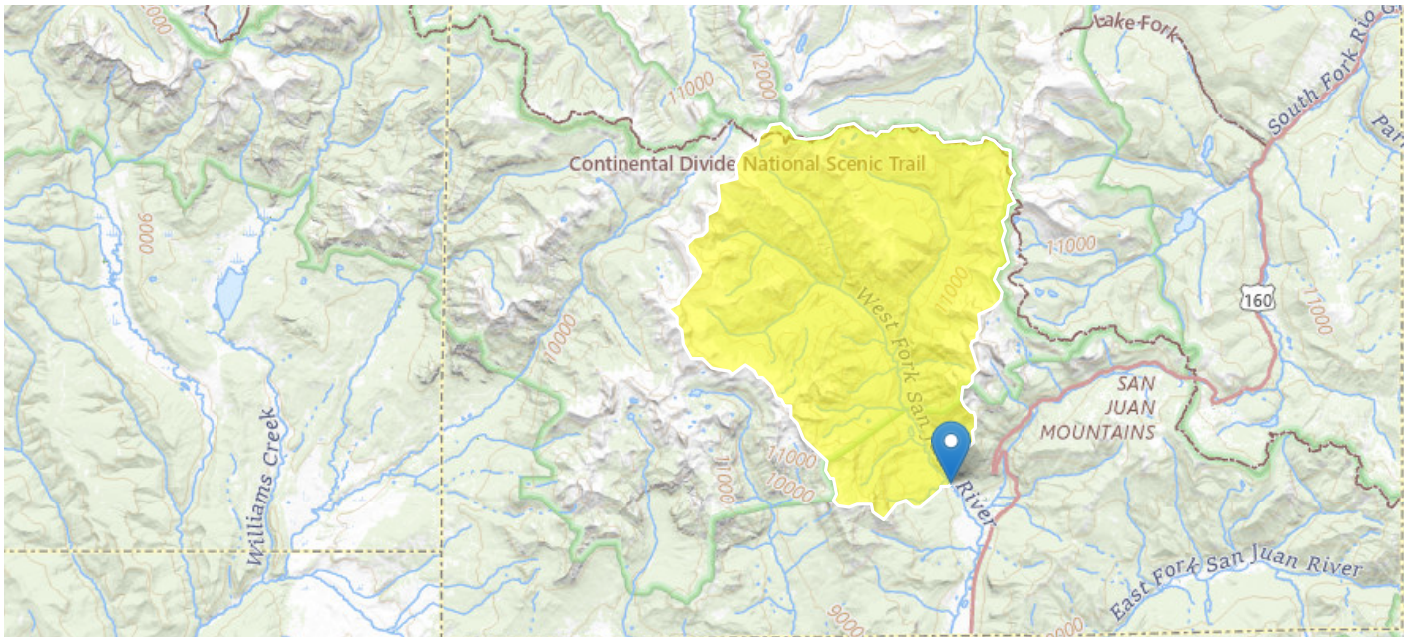


Comparisons:

Return Period (yr)	Difference USGS-FPP (cfs)	% Increase from USGS (%)	% Difference (%)
2	-473	129%	78%
5	-723	112%	72%
10	-912	104%	68%
25	-1,140	91%	63%
50	-1,400	93%	63%
100	-1,660	91%	63%
200	-2,070	101%	67%
500	-2,450	93%	63%
Average	-1,354	102%	67%
Minimum	-2,450	91%	63%
Maximum	-473	129%	78%

West Fork San Juan at Hatcher Road StreamStats Report

Region ID: CO
Clicked Point (Latitude, Longitude): 37.44594, -106.90736
Time: 2026-02-20 08:34:53 -0700



StreamStats Update

Starting with version 4.30.0, the StreamStats application uses services that were redeveloped with open-source software components. Users may observe minor variations in computed results when compared to those from previous versions. These differences are expected and do not reflect errors in the underlying data or analytical methods. Users are advised to consider these potential variations when interpreting or comparing results generated across different versions of StreamStats. Please email streamstats@usgs.gov with any questions or concerns. A full list of changes can be found at **https://www.usgs.gov/streamstats/news/streamstats-data-updates-open-source-code-release (https://www.usgs.gov/streamstats/news/streamstats-data-updates-open-source-code-release)** .

Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	51.6	square miles
EL7500	Percent of area above 7500 ft	100	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Southwest Region Peak Flow]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	51.6	square miles	1	4390
EL7500	Percent above 7500 ft	100	percent	0	99

Peak-Flow Statistics Disclaimers [Southwest Region Peak Flow]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

Peak-Flow Statistics Flow Report [Southwest Region Peak Flow]

Statistic	Value	Unit
50-percent AEP flood	368	ft^3/s
20-percent AEP flood	647	ft^3/s
10-percent AEP flood	878	ft^3/s
4-percent AEP flood	1250	ft^3/s
2-percent AEP flood	1510	ft^3/s
1-percent AEP flood	1820	ft^3/s
0.5-percent AEP flood	2050	ft^3/s
0.2-percent AEP flood	2640	ft^3/s

Peak-Flow Statistics Citations

Capesius, J.P., and Stephens, V. C.,2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p. (http://pubs.usgs.gov/sir/2009/5136/)

Bankfull Statistics

Bankfull Statistics Parameters [Rocky Mountain System D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	51.6	square miles	0.15444	9730.1061

Bankfull Statistics Parameters [Southern Rocky Mountains P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	51.6	square miles	1.540539	9729.943938

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	51.6	square miles	0.07722	59927.7393

Bankfull Statistics Flow Report [Rocky Mountain System D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	34.2	ft
Bieger_D_channel_depth	2.27	ft
Bieger_D_channel_cross_sectional_area	62.4	ft^2

Bankfull Statistics Flow Report [Southern Rocky Mountains P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	32.1	ft
Bieger_P_channel_depth	1.66	ft
Bieger_P_channel_cross_sectional_area	46.1	ft^2

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	49.6	ft
Bieger_USA_channel_depth	2.79	ft
Bieger_USA_channel_cross_sectional_area	144	ft^2

Bankfull Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit
Bieger_D_channel_width	34.2	ft
Bieger_D_channel_depth	2.27	ft
Bieger_D_channel_cross_sectional_area	62.4	ft^2
Bieger_P_channel_width	32.1	ft
Bieger_P_channel_depth	1.66	ft
Bieger_P_channel_cross_sectional_area	46.1	ft^2
Bieger_USA_channel_width	49.6	ft
Bieger_USA_channel_depth	2.79	ft
Bieger_USA_channel_cross_sectional_area	144	ft^2

Bankfull Statistics Citations

Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_campaign=PDFCoverPages)

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Application Version: 4.31.0
SSHydro Services Version: 1.1.0
SSDelineate Services Version: 1.0.1
NSS Services Version: 2.2.1
GageStats Services Version: 1.2.1
Pourpoint Services Version: 1.2.0
Batch Processor Version: 1.6.1

Flood Potential Portal - Overview

Date Generated: 02/20/2026
Version: 2.6.2
Latitude: 37.445962852286186
Longitude: -106.90737839690132

Indices -- Watershed Flooding Characteristics	Values	Percentile [Range]
Flood Potential Index (Pf)	3	18.0th [0.25 - 164.7]
Watershed Scale Ratio (Rf)	1.43	79.0th [0 - 5.79]
Beard Flashiness Index (F)	0.61	35.0th [0.37 - 2.82]
Richards-Baker Flashiness Index (R-B)	0.109	12.0th [0.039 - 1.621]
Bimodality Index (Bi)	4.8	39.0th [2.1344 - 182.8173]
Flood Variability Index (Vf)	1.94	88.0th [1.15 - 2.86]
Flood Hazard Index (Hf)	1.84	12.0th [0.1 - 164.7]

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest (5%) of annual peak discharges (percent change = -1.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest quarter (Q4, >4 yr RI) of annual peak discharges (percent change = 0.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of moderate quarter (Q3, 4 to 2 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of ~bankfull quarter (Q2, 2 to 1.33 yr RI) of annual peak discharges.

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of < bankfull quarter (Q1, <1.33 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the annual frequency of floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the event frequency of large floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a possible decreasing trend in flood flashiness.

Flood Discharge Estimates (cfs)	Unadjusted	Trend-Adjusted
Expected Flood Potential (Qefp)	2450	2430
Maximum Likely Flood Potential (Qmlf)	4440	4400

Return Interval (yr)	Annual Exceedance Probability	Index Flood	USGS Equations (StreamStats)
500	0.2	5090	2640
200	0.5	4120	2050
100	1	3480	1820
50	2	2910	1510
25	4	2390	1250
10	10	1790	878
5	20	1370	647
2	50	841	368
1.5	66.7	652	----

Flood Potential Portal - Calculations

Flood Potential									
Zone Name (Zone ID)	**Area (mi2)**	**Second Predictor**	**Predictor Value**	**Trends in Frequency**	**Trends in Magnitude**	**Qefp (cfs)**	**Trend-Adjusted Qefp (cfs)**	**Qmlf (cfs)**	**Trend-Adjusted Qmlf (cfs)**
Southern Rocky Mountains, South (3S)	51	P9	4.15 (inches)	No trends	Significantly Decreasing	2450	2430	4440	4400
Total	51					2450	2430	4440	4400

Index Flood Frequency												
Zone Name (Zone ID)	**Area (mi2)**	**Second Predictor**	**Predictor Value**	**1.5 Year**	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**	**200 Year**	**500 Year**
Southern Rocky Mountains, South (3S)	51	P1	5.07 (inches)	652	841	1370	1790	2390	2910	3480	4120	5090
Total	51			652	841	1370	1790	2390	2910	3480	4120	5090

USGS Regional Regression Flood Frequency (StreamStats)										
USGS Regression Region	**Area (mi2)**	**1.5 Year**	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**	**200 Year**	**500 Year**
Southwest_Region_Peak_Flow	51.6	----	368	647	878	1250	1510	1820	2050	2640
Total	51.6	----	368	647	878	1250	1510	1820	2050	2640

Footnotes
P1 = mean average watershed monthly precipitation for January (in)

Footnotes
P9 = mean average watershed monthly precipitation for September (in)
Qefp = expected flood potential discharge
Qmlf> = maximum likely flood potential discharge
* The peak flow estimates from the USGS regional regressions (StreamStats) include a warning: One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

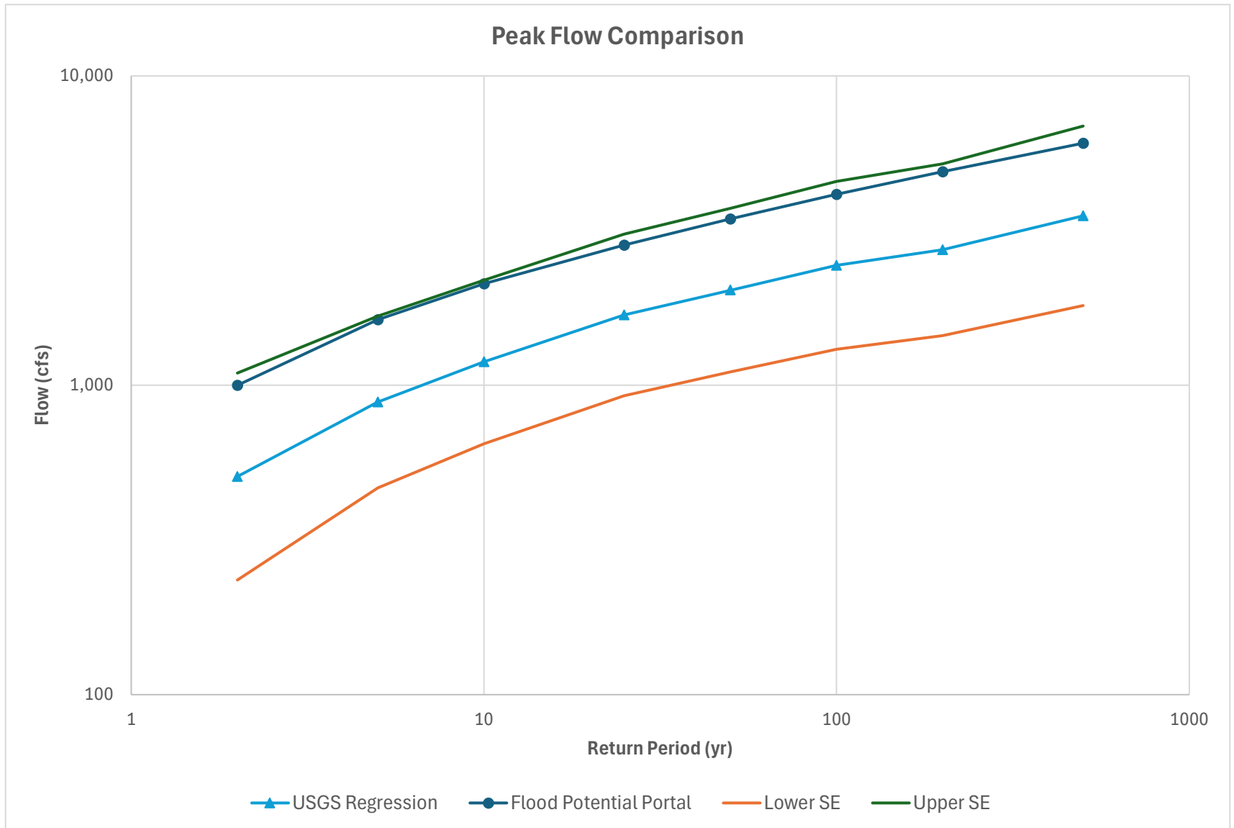
Citations
Capesius, J.P., and Stephens, V. C., 2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p.
Yochum, S.E., Scott, J.A., and Levinson, D.H., 2019, Methods for Assessing Expected Flood Potential and Variability: Southern Rocky Mountains Region. Water Resources Research, vol. 55, no. 8, pp. 6392-6416.
Yochum, S.E., Wible, T., Korsa, M., Ghanbari, M., Arabi, M. 2024, Flood Potential Portal: A web tool for understanding flood variability and predicting peak discharges. River Research and Applications. Wiley. https://doi.org/10.1002/rra.4354

Appendix B-3

667 East Fork Road

667 East Fork Road - Peak Flow Estimate Comparison

Exceedance Probability (%)	Return Period (yr)	USGS Regression Peak Flow (cfs)	SE (%)	SE(log)	SE (+%)	SE (-%)	Upper (cfs)	Lower (cfs)	FPP Peak Flow (cfs)	Adopted Flows (cfs)
50%	2	507	90	0.33	116	-54	1,095	235	1,000	1,000
20%	5	884	71	0.28	89	-47	1,675	467	1,630	1,630
10%	10	1,190	67	0.26	84	-46	2,188	647	2,130	2,130
4%	25	1,690	66	0.26	82	-45	3,083	926	2,840	2,840
2%	50	2,030	67	0.26	84	-46	3,732	1,104	3,450	3,450
1%	100	2,440	69	0.27	87	-46	4,554	1,307	4,140	4,140
0.5%	200	2,740	71	0.28	89	-47	5,190	1,446	4,900	4,900
0.2%	500	3,530	75	0.29	95	-49	6,885	1,810	6,060	6,060

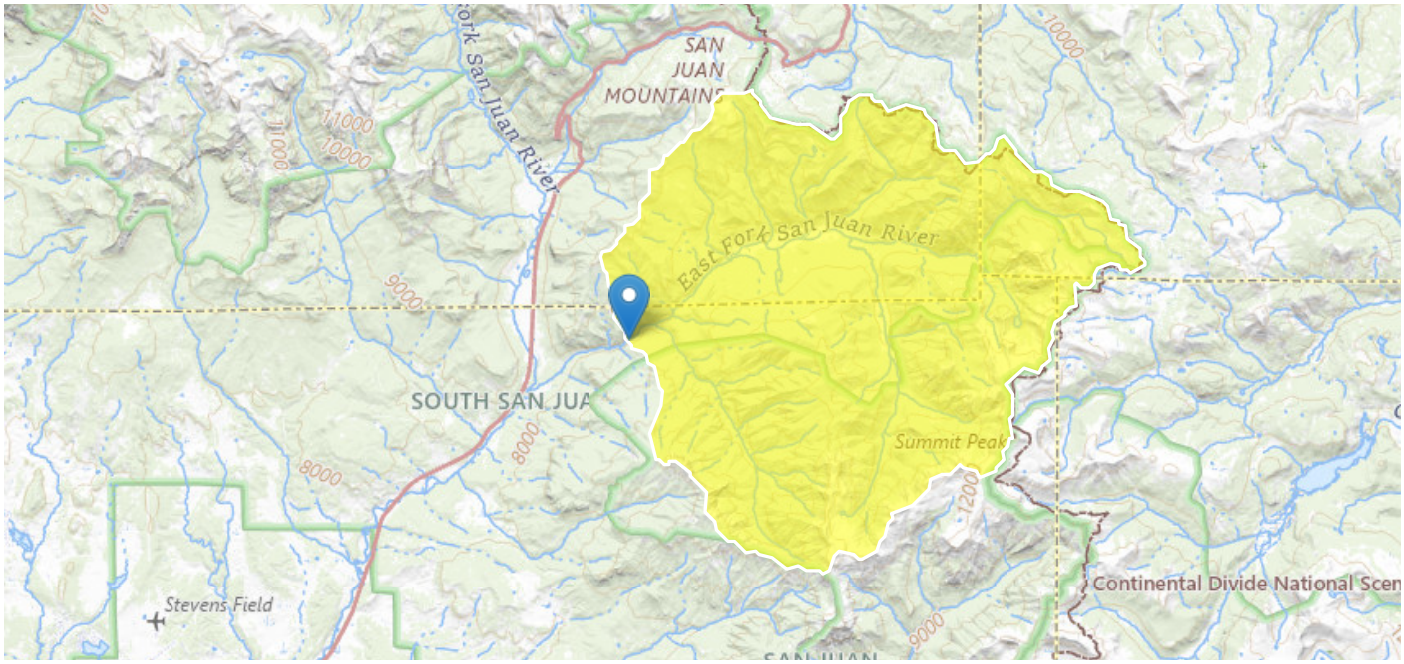


Comparisons:

Return Period (yr)	Difference USGS-FPP (cfs)	% Increase from USGS (%)	% Difference (%)
2	-493	97%	65%
5	-746	84%	59%
10	-940	79%	57%
25	-1,150	68%	51%
50	-1,420	70%	52%
100	-1,700	70%	52%
200	-2,160	79%	57%
500	-2,530	72%	53%
Average	-1,392	77%	56%
Minimum	-2,530	68%	51%
Maximum	-493	97%	65%

East Fork San Juan River at East Fork Road

Region ID: CO
Clicked Point (Latitude, Longitude): 37.38260, -106.85876
Time: 2026-02-20 07:32:02 -0700



StreamStats Update

Starting with version 4.30.0, the StreamStats application uses services that were redeveloped with open-source software components. Users may observe minor variations in computed results when compared to those from previous versions. These differences are expected and do not reflect errors in the underlying data or analytical methods. Users are advised to consider these potential variations when interpreting or comparing results generated across different versions of StreamStats. Please email streamstats@usgs.gov with any questions or concerns. A full list of changes can be found at **https://www.usgs.gov/streamstats/news/streamstats-data-updates-open-source-code-release (https://www.usgs.gov/streamstats/news/streamstats-data-updates-open-source-code-release)** .

Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	85.3	square miles
EL7500	Percent of area above 7500 ft	100	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Southwest Region Peak Flow]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	85.3	square miles	1	4390
EL7500	Percent above 7500 ft	100	percent	0	99

Peak-Flow Statistics Disclaimers [Southwest Region Peak Flow]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

Peak-Flow Statistics Flow Report [Southwest Region Peak Flow]

Statistic	Value	Unit
50-percent AEP flood	507	ft^3/s
20-percent AEP flood	884	ft^3/s
10-percent AEP flood	1190	ft^3/s
4-percent AEP flood	1690	ft^3/s
2-percent AEP flood	2030	ft^3/s
1-percent AEP flood	2440	ft^3/s
0.5-percent AEP flood	2740	ft^3/s
0.2-percent AEP flood	3530	ft^3/s

Peak-Flow Statistics Citations

Capesius, J.P., and Stephens, V. C.,2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p. (http://pubs.usgs.gov/sir/2009/5136/)

Bankfull Statistics

Bankfull Statistics Parameters [Rocky Mountain System D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	85.3	square miles	0.15444	9730.1061

Bankfull Statistics Parameters [Southern Rocky Mountains P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	85.3	square miles	1.540539	9729.943938

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	85.3	square miles	0.07722	59927.7393

Bankfull Statistics Flow Report [Rocky Mountain System D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	42.6	ft
Bieger_D_channel_depth	2.54	ft
Bieger_D_channel_cross_sectional_area	88.2	ft^2

Bankfull Statistics Flow Report [Southern Rocky Mountains P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	38	ft
Bieger_P_channel_depth	1.83	ft
Bieger_P_channel_cross_sectional_area	60.2	ft^2

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	59.2	ft
Bieger_USA_channel_depth	3.11	ft
Bieger_USA_channel_cross_sectional_area	189	ft^2

Bankfull Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit
Bieger_D_channel_width	42.6	ft
Bieger_D_channel_depth	2.54	ft
Bieger_D_channel_cross_sectional_area	88.2	ft^2
Bieger_P_channel_width	38	ft
Bieger_P_channel_depth	1.83	ft
Bieger_P_channel_cross_sectional_area	60.2	ft^2
Bieger_USA_channel_width	59.2	ft
Bieger_USA_channel_depth	3.11	ft
Bieger_USA_channel_cross_sectional_area	189	ft^2

Bankfull Statistics Citations

Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_campaign=PDFCoverPages)

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USGS Product Names Disclaimer: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Application Version: 4.31.0
SSHydro Services Version: 1.1.0
SSDelineate Services Version: 1.0.1
NSS Services Version: 2.2.1
GageStats Services Version: 1.2.1
Pourpoint Services Version: 1.2.0
Batch Processor Version: 1.6.1

Flood Potential Portal - Overview

Date Generated: 02/20/2026
Version: 2.6.2
Latitude: 37.38270297382972
Longitude: -106.85833605252891

Indices -- Watershed Flooding Characteristics	Values	Percentile [Range]
Flood Potential Index (Pf)	3	18.0th [0.25 - 164.7]
Watershed Scale Ratio (Rf)	1.43	79.0th [0 - 5.79]
Beard Flashiness Index (F)	0.61	35.0th [0.37 - 2.82]
Richards-Baker Flashiness Index (R-B)	0.109	12.0th [0.039 - 1.621]
Bimodality Index (Bi)	4.8	39.0th [2.1344 - 182.8173]
Flood Variability Index (Vf)	1.94	88.0th [1.15 - 2.86]
Flood Hazard Index (Hf)	1.84	12.0th [0.1 - 164.7]

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest (5%) of annual peak discharges (percent change = -1.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest quarter (Q4, >4 yr RI) of annual peak discharges (percent change = 0.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of moderate quarter (Q3, 4 to 2 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of ~bankfull quarter (Q2, 2 to 1.33 yr RI) of annual peak discharges.

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of < bankfull quarter (Q1, <1.33 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the annual frequency of floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the event frequency of large floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a possible decreasing trend in flood flashiness.

Flood Discharge Estimates (cfs)	Unadjusted	Trend-Adjusted
Expected Flood Potential (Qefp)	3210	3180
Maximum Likely Flood Potential (Qmlf)	5840	5780

Return Interval (yr)	Annual Exceedance Probability	Index Flood	USGS Equations (StreamStats)
500	0.2	6060	3530
200	0.5	4900	2740
100	1	4140	2440
50	2	3450	2030
25	4	2840	1690
10	10	2130	1190
5	20	1630	884
2	50	1000	507
1.5	66.7	775	----

Flood Potential Portal - Calculations

Flood Potential

Zone Name (Zone ID)	Area (mi2)	Second Predictor	Predictor Value	Trends in Frequency	Trends in Magnitude	Qefp (cfs)	Trend-Adjusted Qefp (cfs)	Qmlf (cfs)	Trend-Adjusted Qmlf (cfs)
Southern Rocky Mountains, South (3S)	85.5	P9	3.69 (inches)	No trends	Significantly Decreasing	3210	3180	5840	5780
Total	85.5					3210	3180	5840	5780

Index Flood Frequency

Zone Name (Zone ID)	Area (mi2)	Second Predictor	Predictor Value	1.5 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	200 Year	500 Year
Southern Rocky Mountains, South (3S)	85.5	P1	4.14 (inches)	775	1000	1630	2130	2840	3450	4140	4900	6060
Total	85.5			775	1000	1630	2130	2840	3450	4140	4900	6060

USGS Regional Regression Flood Frequency (StreamStats)

USGS Regression Region	Area (mi2)	1.5 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	200 Year	500 Year
Southwest_Region_Peak_Flow	85.3	----	507	884	1190	1690	2030	2440	2740	3530
Total	85.3	----	507	884	1190	1690	2030	2440	2740	3530

Footnotes

P1 = mean average watershed monthly precipitation for January (in)

Footnotes
P9 = mean average watershed monthly precipitation for September (in)
Qefp = expected flood potential discharge
Qmlf> = maximum likely flood potential discharge
* The peak flow estimates from the USGS regional regressions (StreamStats) include a warning: One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

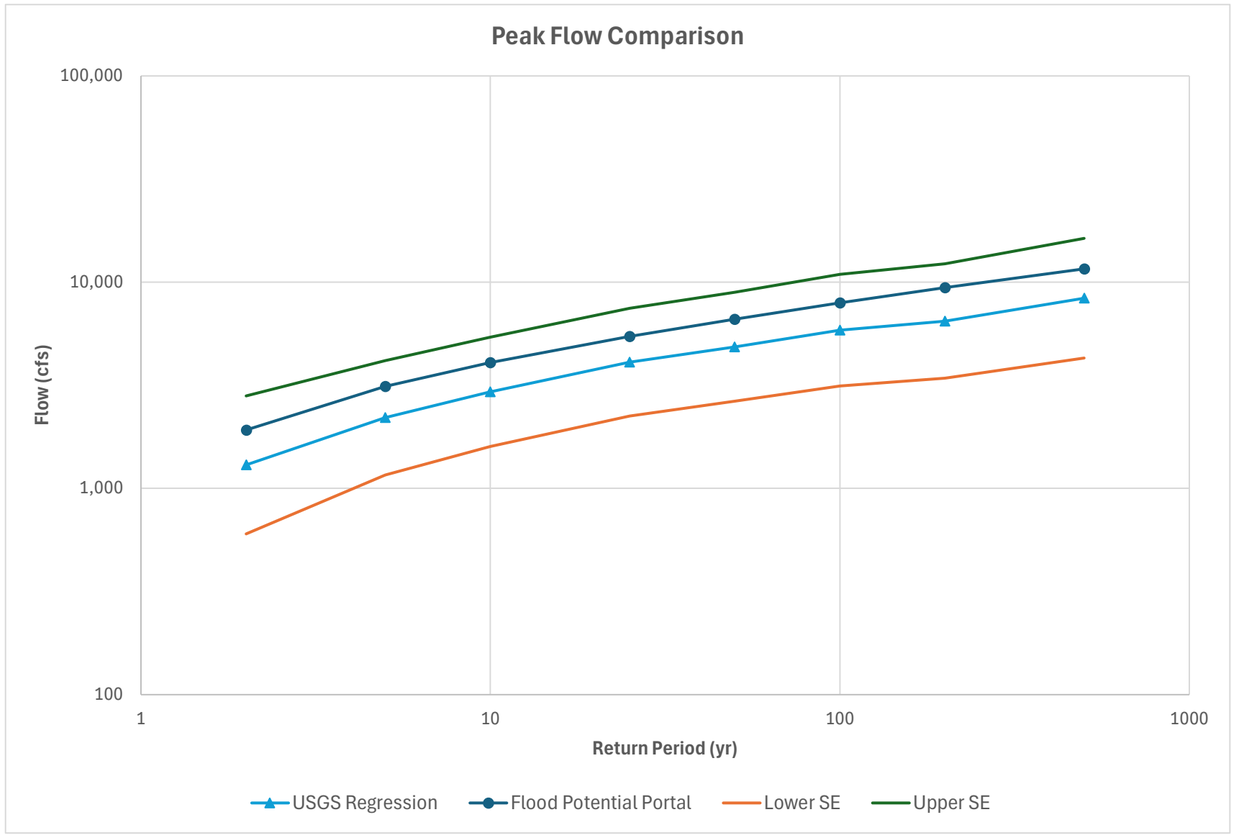
Citations
Capesius, J.P., and Stephens, V. C., 2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p.
Yochum, S.E., Scott, J.A., and Levinson, D.H., 2019, Methods for Assessing Expected Flood Potential and Variability: Southern Rocky Mountains Region. Water Resources Research, vol. 55, no. 8, pp. 6392-6416.
Yochum, S.E., Wible, T., Korsa, M., Ghanbari, M., Arabi, M. 2024, Flood Potential Portal: A web tool for understanding flood variability and predicting peak discharges. River Research and Applications. Wiley. https://doi.org/10.1002/rra.4354

Appendix B-4

621 Lower Piedra Road

621 Lower Piedra Road - Peak Flow Estimate Comparison

Exceedance Probability (%)	Return Period (yr)	USGS Regression Peak Flow (cfs)	SE (%)	SE(log)	SE (+%)	SE (-%)	Upper (cfs)	Lower (cfs)	FPP Peak Flow (cfs)	Adopted Flows (cfs)
50%	2	1,300	90	0.33	116	-54	2,808	602	1,920	1,920
20%	5	2,200	71	0.28	89	-47	4,167	1,161	3,130	3,130
10%	10	2,940	67	0.26	84	-46	5,405	1,599	4,080	4,080
4%	25	4,100	66	0.26	82	-45	7,480	2,247	5,450	5,450
2%	50	4,860	67	0.26	84	-46	8,935	2,644	6,620	6,620
1%	100	5,850	69	0.27	87	-46	10,918	3,134	7,930	7,930
0.5%	200	6,480	71	0.28	89	-47	12,275	3,421	9,400	9,400
0.2%	500	8,360	75	0.29	95	-49	16,305	4,286	11,600	11,600

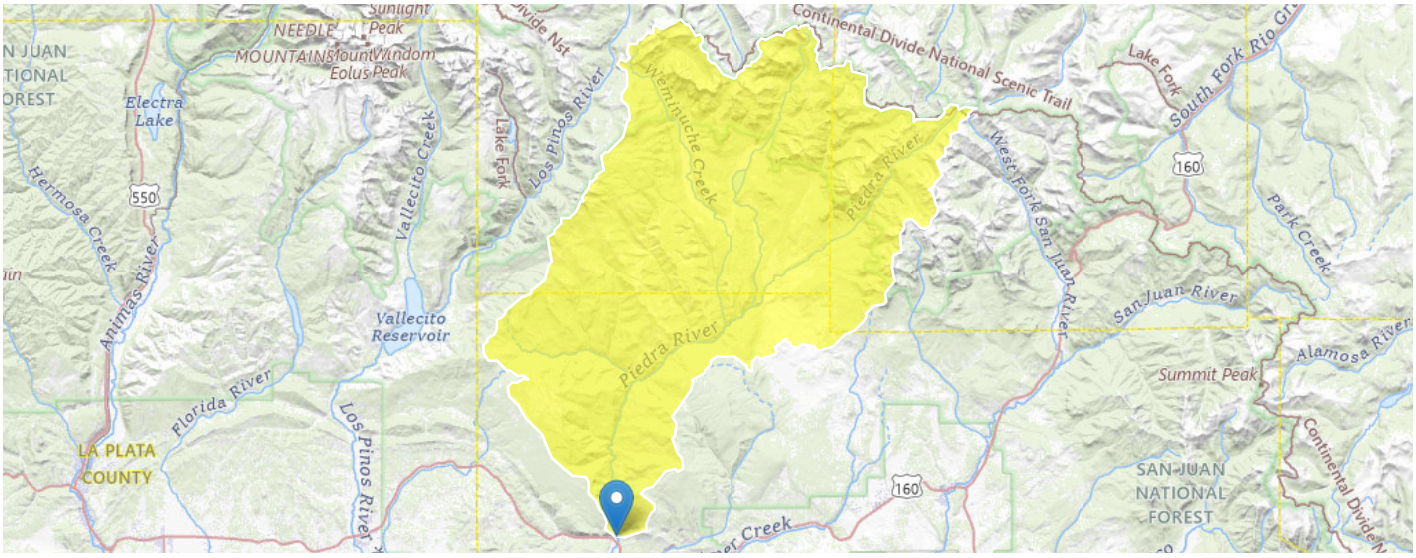


Comparisons:

Return Period (yr)	Difference USGS-FPP (cfs)	% Increase from USGS (%)	% Difference (%)
2	-620	48%	39%
5	-930	42%	35%
10	-1,140	39%	32%
25	-1,350	33%	28%
50	-1,760	36%	31%
100	-2,080	36%	30%
200	-2,920	45%	37%
500	-3,240	39%	32%
Average	-1,755	40%	33%
Minimum	-3,240	33%	28%
Maximum	-620	48%	39%

Piedra River at Lower Piedra Road StreamStats Report

Region ID: CO
Clicked Point (Latitude, Longitude): 37.23043, -107.34321
Time: 2026-02-20 08:00:10 -0700



StreamStats Update

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Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	369	square miles
EL7500	Percent of area above 7500 ft	97.1	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Southwest Region Peak Flow]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	369	square miles	1	4390
EL7500	Percent above 7500 ft	97.1	percent	0	99

Peak-Flow Statistics Flow Report [Southwest Region Peak Flow]

PIL: Lower 90% Prediction Interval, PIU: Upper 90% Prediction Interval, ASEp: Average Standard Error of Prediction, SE: Standard Error, PC: Percent Correct, RMSE: Root Mean Squared Error, PseudoR^2: Pseudo R Squared (other -- see report)

Statistic	Value	Unit	ASEp
50-percent AEP flood	1300	ft^3/s	90
20-percent AEP flood	2200	ft^3/s	71
10-percent AEP flood	2940	ft^3/s	67
4-percent AEP flood	4100	ft^3/s	66
2-percent AEP flood	4860	ft^3/s	67
1-percent AEP flood	5850	ft^3/s	69
0.5-percent AEP flood	6480	ft^3/s	71
0.2-percent AEP flood	8360	ft^3/s	75

Peak-Flow Statistics Citations

Capesius, J.P., and Stephens, V. C.,2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p. (http://pubs.usgs.gov/sir/2009/5136/)

Bankfull Statistics

Bankfull Statistics Parameters [44.0 Percent (161 square miles) Rocky Mountain System D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	369	square miles	0.15444	9730.1061

Bankfull Statistics Parameters [44.0 Percent (161 square miles) Southern Rocky Mountains P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	369	square miles	1.540539	9729.943938

Bankfull Statistics Parameters [56.0 Percent (207 square miles) Intermontane Plateau D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	369	square miles	3.62934	7579.9152

Bankfull Statistics Parameters [56.0 Percent (207 square miles) Colorado Plateau P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	369	square miles	3.621618	3649.980906

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	369	square miles	0.07722	59927.7393

Bankfull Statistics Flow Report [44.0 Percent (161 square miles) Rocky Mountain System D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	80.5	ft
Bieger_D_channel_depth	3.53	ft
Bieger_D_channel_cross_sectional_area	242	ft^2

Bankfull Statistics Flow Report [44.0 Percent (161 square miles) Southern Rocky Mountains P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	62.6	ft
Bieger_P_channel_depth	2.46	ft

Statistic	Value	Unit
Bieger_P_channel_cross_sectional_area	131	ft^2

Bankfull Statistics Flow Report [56.0 Percent (207 square miles) Intermontane Plateau D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	62.8	ft
Bieger_D_channel_depth	2.2	ft
Bieger_D_channel_cross_sectional_area	130	ft^2

Bankfull Statistics Flow Report [56.0 Percent (207 square miles) Colorado Plateau P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	31	ft
Bieger_P_channel_depth	1.43	ft
Bieger_P_channel_cross_sectional_area	45.2	ft^2

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	99.2	ft
Bieger_USA_channel_depth	4.25	ft
Bieger_USA_channel_cross_sectional_area	416	ft^2

Bankfull Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit
Bieger_D_channel_width	70.6	ft
Bieger_D_channel_depth	2.79	ft
Bieger_D_channel_cross_sectional_area	179	ft^2
Bieger_P_channel_width	44.9	ft
Bieger_P_channel_depth	1.88	ft
Bieger_P_channel_cross_sectional_area	83	ft^2
Bieger_USA_channel_width	99.2	ft
Bieger_USA_channel_depth	4.25	ft
Bieger_USA_channel_cross_sectional_area	416	ft^2

Bankfull Statistics Citations

Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_campaign=PDFCoverPages)

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Application Version: 4.31.0
SSHydro Services Version: 1.1.0
SSDelineate Services Version: 1.0.1
NSS Services Version: 2.2.1
GageStats Services Version: 1.2.1
Pourpoint Services Version: 1.2.0
Batch Processor Version: 1.6.1

Flood Potential Portal - Overview

Date Generated: 02/20/2026
Version: 2.6.2
Latitude: 37.23101054075592
Longitude: -107.34332123315707

Indices -- Watershed Flooding Characteristics	Values	Percentile [Range]
Flood Potential Index (Pf)	3	18.0th [0.25 - 164.7]
Watershed Scale Ratio (Rf)	1.43	79.0th [0 - 5.79]
Beard Flashiness Index (F)	0.61	35.0th [0.37 - 2.82]
Richards-Baker Flashiness Index (R-B)	0.109	12.0th [0.039 - 1.621]
Bimodality Index (Bi)	4.8	39.0th [2.1344 - 182.8173]
Flood Variability Index (Vf)	1.94	88.0th [1.15 - 2.86]
Flood Hazard Index (Hf)	1.84	12.0th [0.1 - 164.7]

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest (5%) of annual peak discharges (percent change = -1.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a significant decreasing trend in the magnitudes of largest quarter (Q4, >4 yr RI) of annual peak discharges (percent change = 0.0).
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of moderate quarter (Q3, 4 to 2 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of ~bankfull quarter (Q2, 2 to 1.33 yr RI) of annual peak discharges.

Trends	
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the magnitudes of < bankfull quarter (Q1, <1.33 yr RI) of annual peak discharges.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the annual frequency of floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing no trend in the event frequency of large floods.
Southern Rocky Mountains, South (3S)	Zone 3S is experiencing a possible decreasing trend in flood flashiness.

Flood Discharge Estimates (cfs)	Unadjusted	Trend-Adjusted
Expected Flood Potential (Qefp)	8920	8830
Maximum Likely Flood Potential (Qmlf)	16300	16200

Return Interval (yr)	Annual Exceedance Probability	Index Flood	USGS Equations (StreamStats)
500	0.2	11600	8360
200	0.5	9400	6480
100	1	7930	5850
50	2	6620	4860
25	4	5450	4100
10	10	4080	2940
5	20	3130	2200
2	50	1920	1300
1.5	66.7	1490	----

Flood Potential Portal - Calculations

Flood Potential

Zone Name (Zone ID)	Area (mi2)	Second Predictor	Predictor Value	Trends in Frequency	Trends in Magnitude	Qefp (cfs)	Trend-Adjusted Qefp (cfs)	Qmlf (cfs)	Trend-Adjusted Qmlf (cfs)
Southern Rocky Mountains, South (3S)	369	P9	3.3 (inches)	No trends	Significantly Decreasing	8920	8830	16300	16200
Total	369					8920	8830	16300	16200

Index Flood Frequency

Zone Name (Zone ID)	Area (mi2)	Second Predictor	Predictor Value	1.5 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	200 Year	500 Year
Southern Rocky Mountains, South (3S)	369	P1	2.67 (inches)	1490	1920	3130	4080	5450	6620	7930	9400	11600
Total	369			1490	1920	3130	4080	5450	6620	7930	9400	11600

USGS Regional Regression Flood Frequency (StreamStats)

USGS Regression Region	Area (mi2)	1.5 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	200 Year	500 Year
Southwest_Region_Peak_Flow	369	----	1300	2200	2940	4100	4860	5850	6480	8360
Total	369	----	1300	2200	2940	4100	4860	5850	6480	8360

Footnotes

P1 = mean average watershed monthly precipitation for January (in)

Footnotes
P9 = mean average watershed monthly precipitation for September (in)
Qefp = expected flood potential discharge
Qmlf> = maximum likely flood potential discharge

Citations
Capesius, J.P., and Stephens, V. C., 2009, Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado: U. S. Geological Survey Scientific Investigations Report 2009-5136, 32 p.
Yochum, S.E., Scott, J.A., and Levinson, D.H., 2019, Methods for Assessing Expected Flood Potential and Variability: Southern Rocky Mountains Region. Water Resources Research, vol. 55, no. 8, pp. 6392-6416.
Yochum, S.E., Wible, T., Korsa, M., Ghanbari, M., Arabi, M. 2024, Flood Potential Portal: A web tool for understanding flood variability and predicting peak discharges. River Research and Applications. Wiley. https://doi.org/10.1002/rra.4354

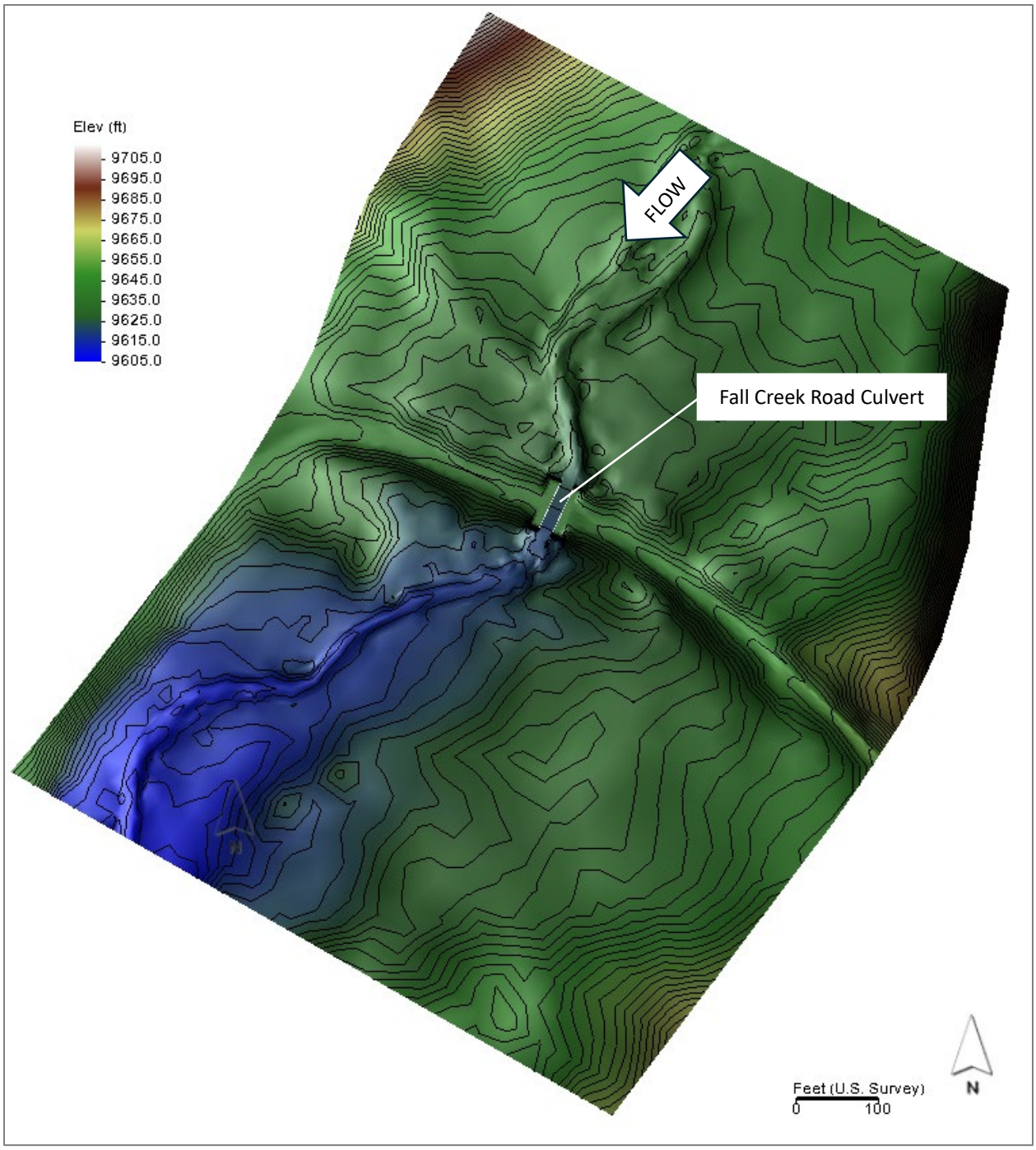
Appendix C

Hydraulic Analyses

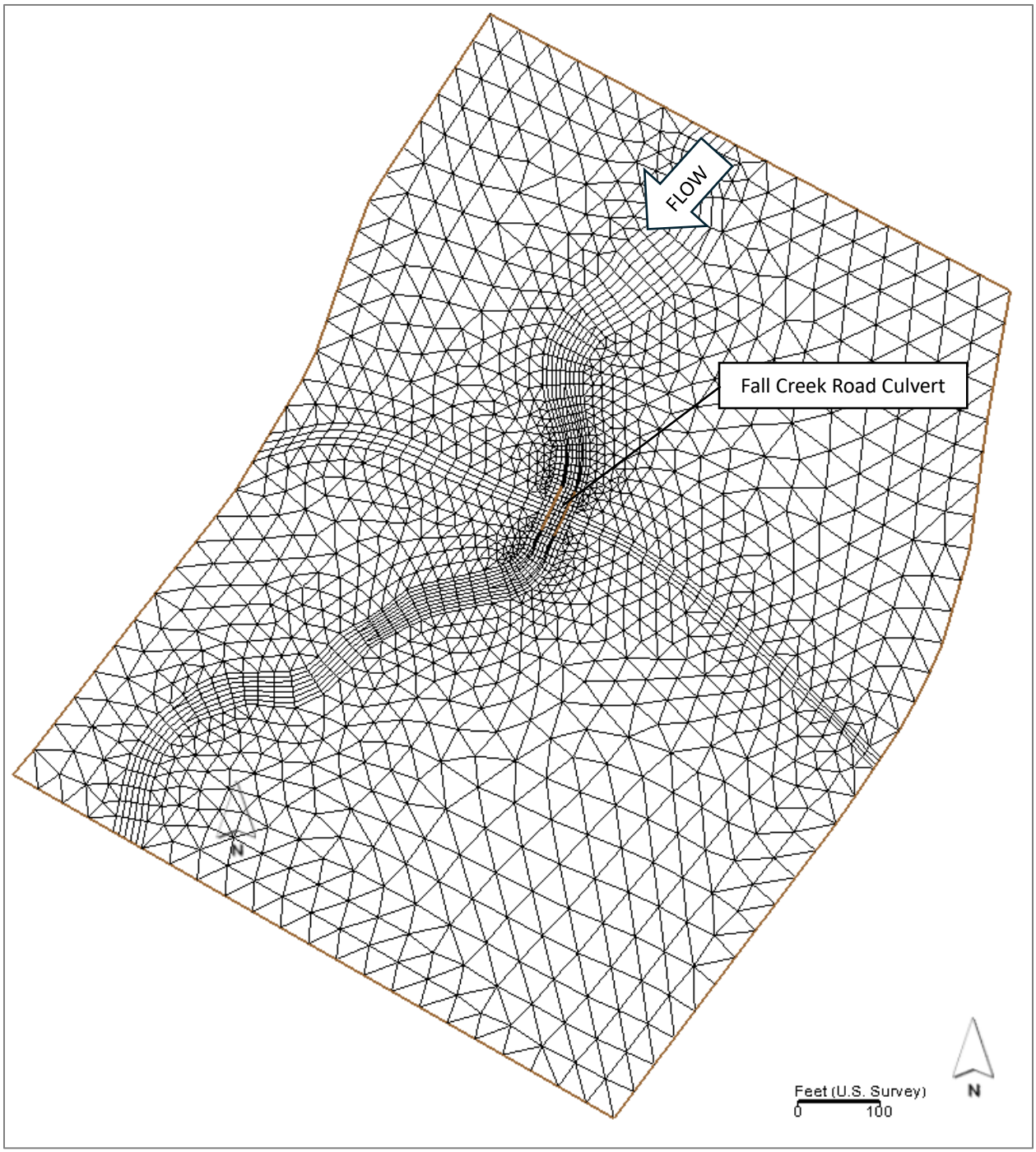
Appendix C-1

039 Fall Creek Road

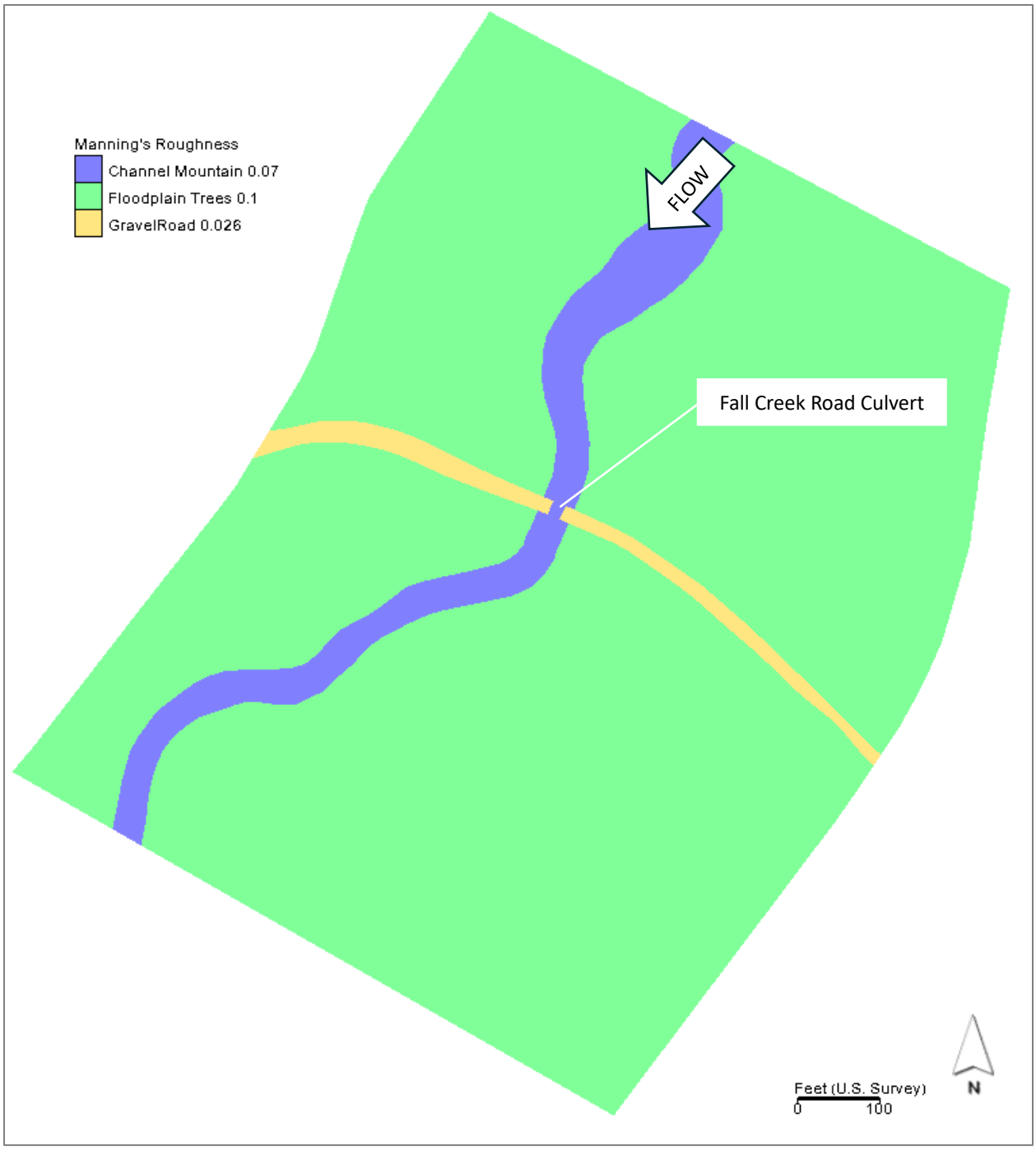
Topographic Surface:



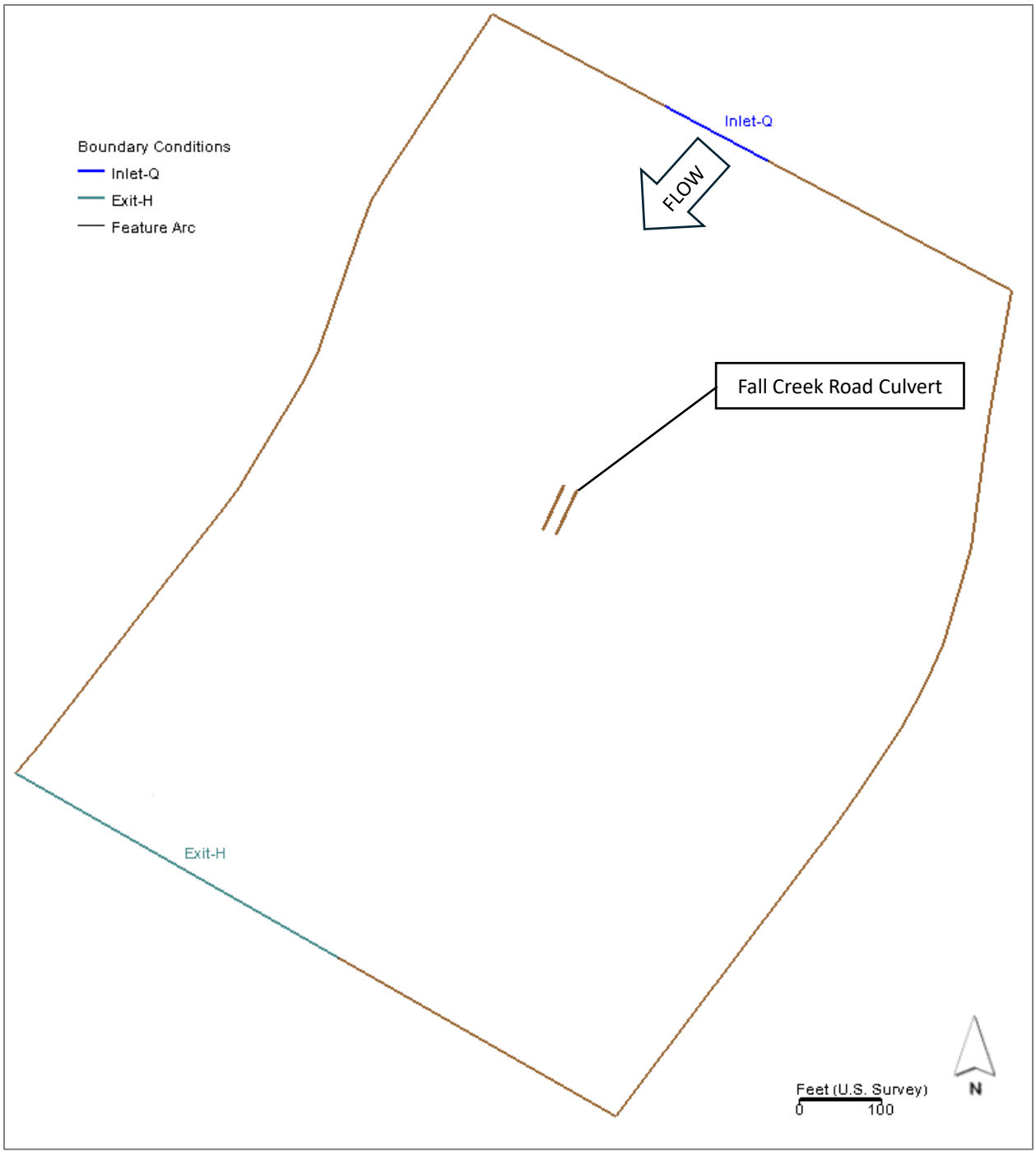
SRH-2D Mesh:



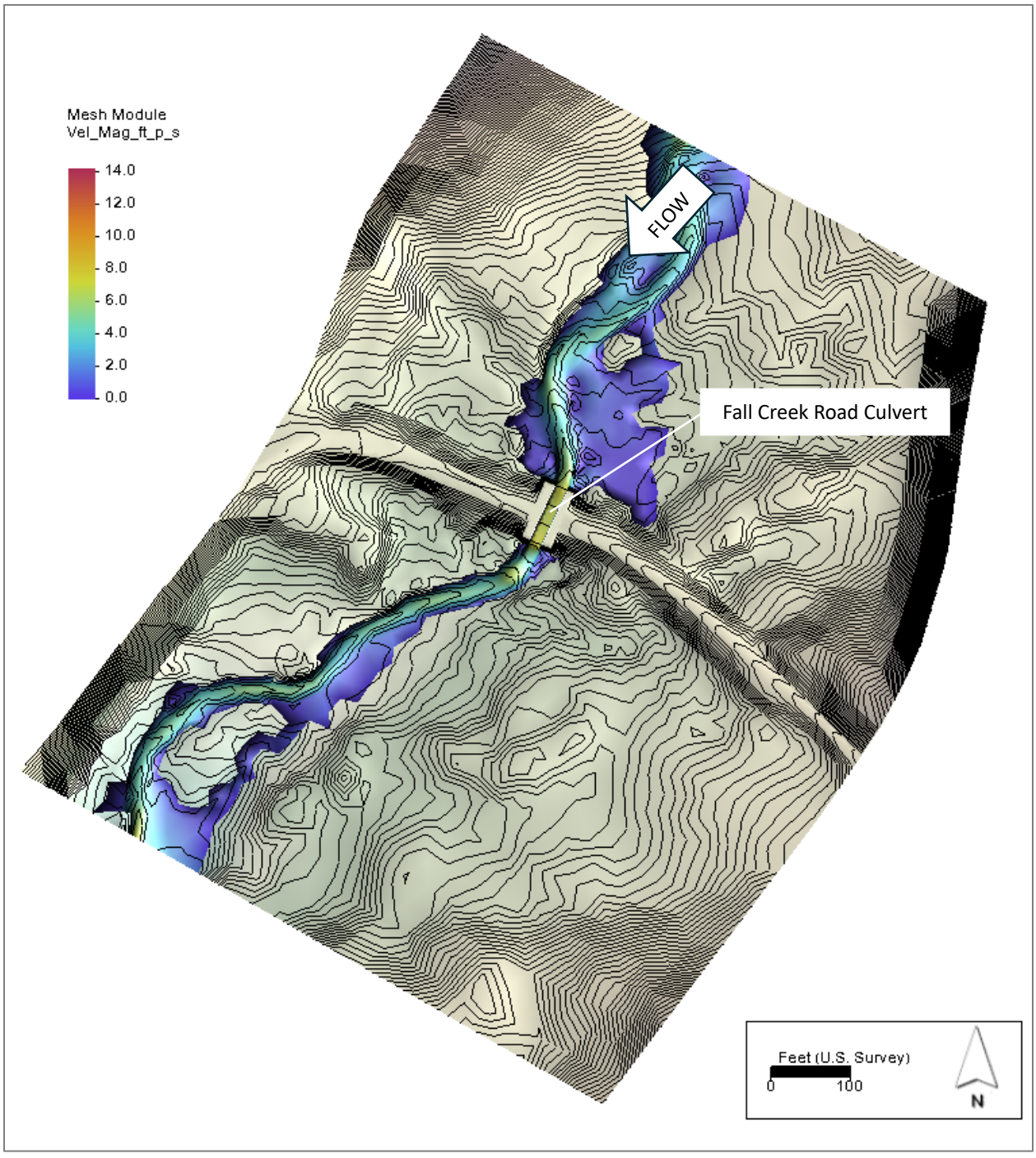
Materials (Manning's Roughness)



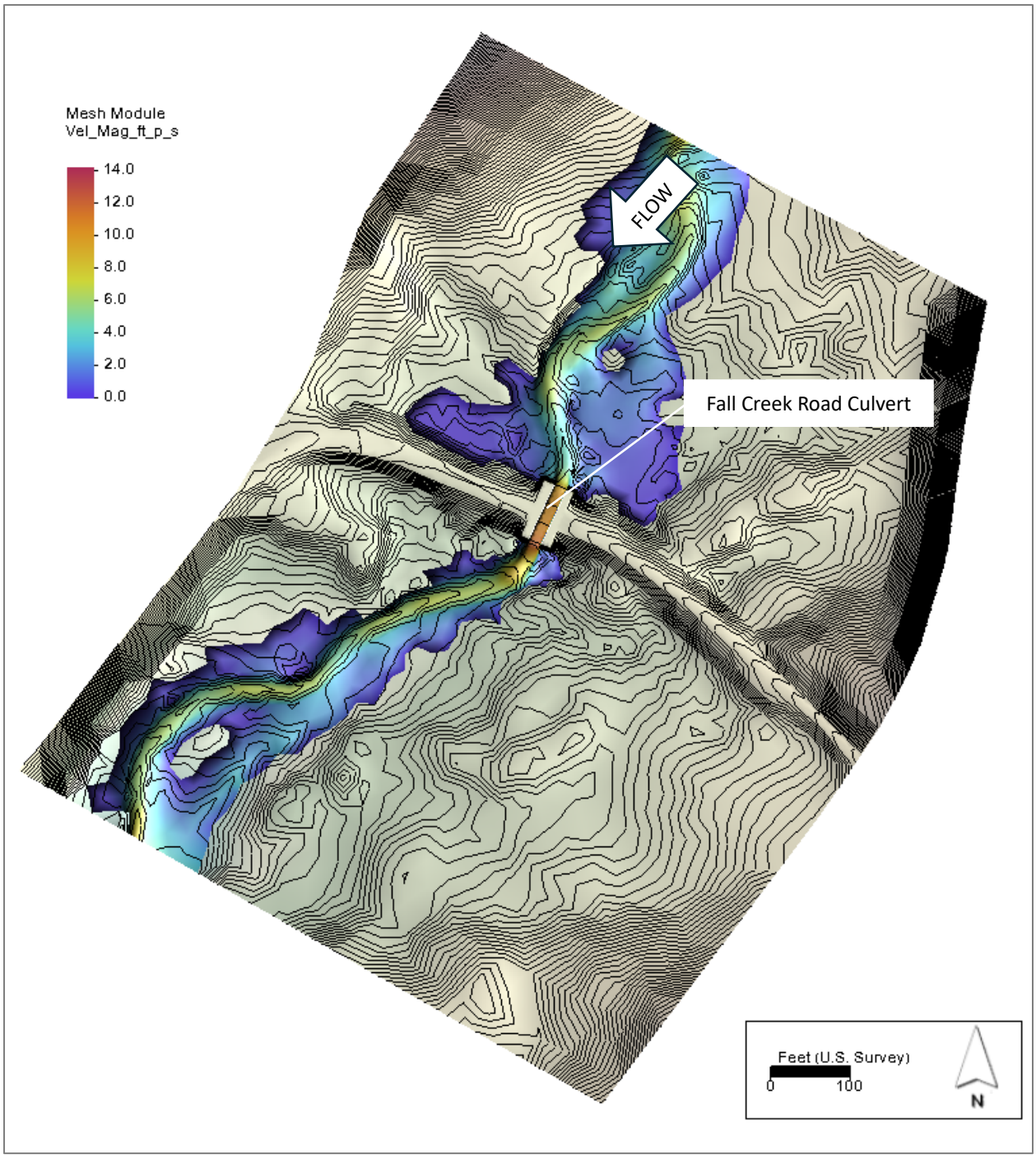
Boundary Conditions



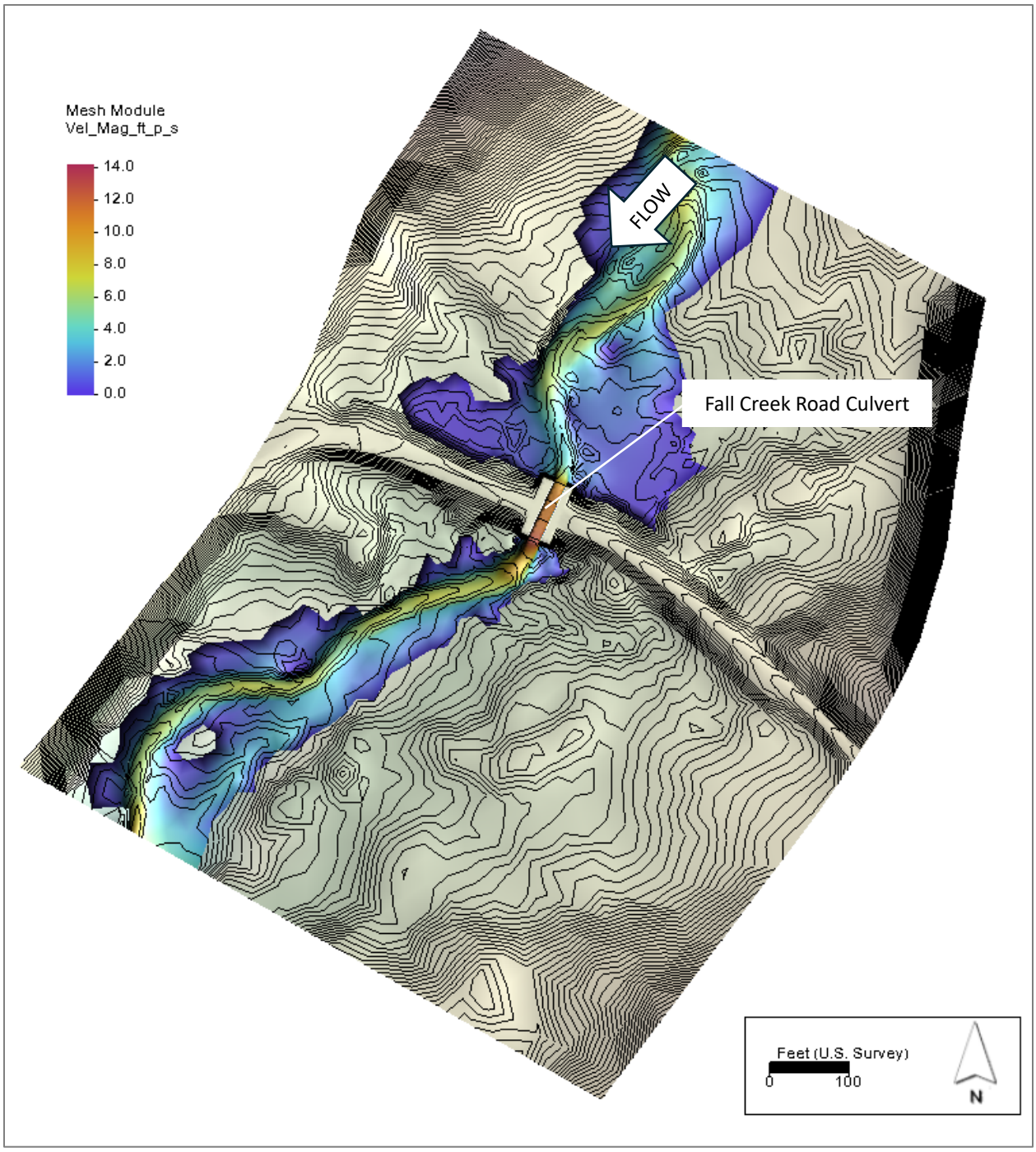
2-Year Velocity (ft/s) (16ft x 8ft CBC, embedded)



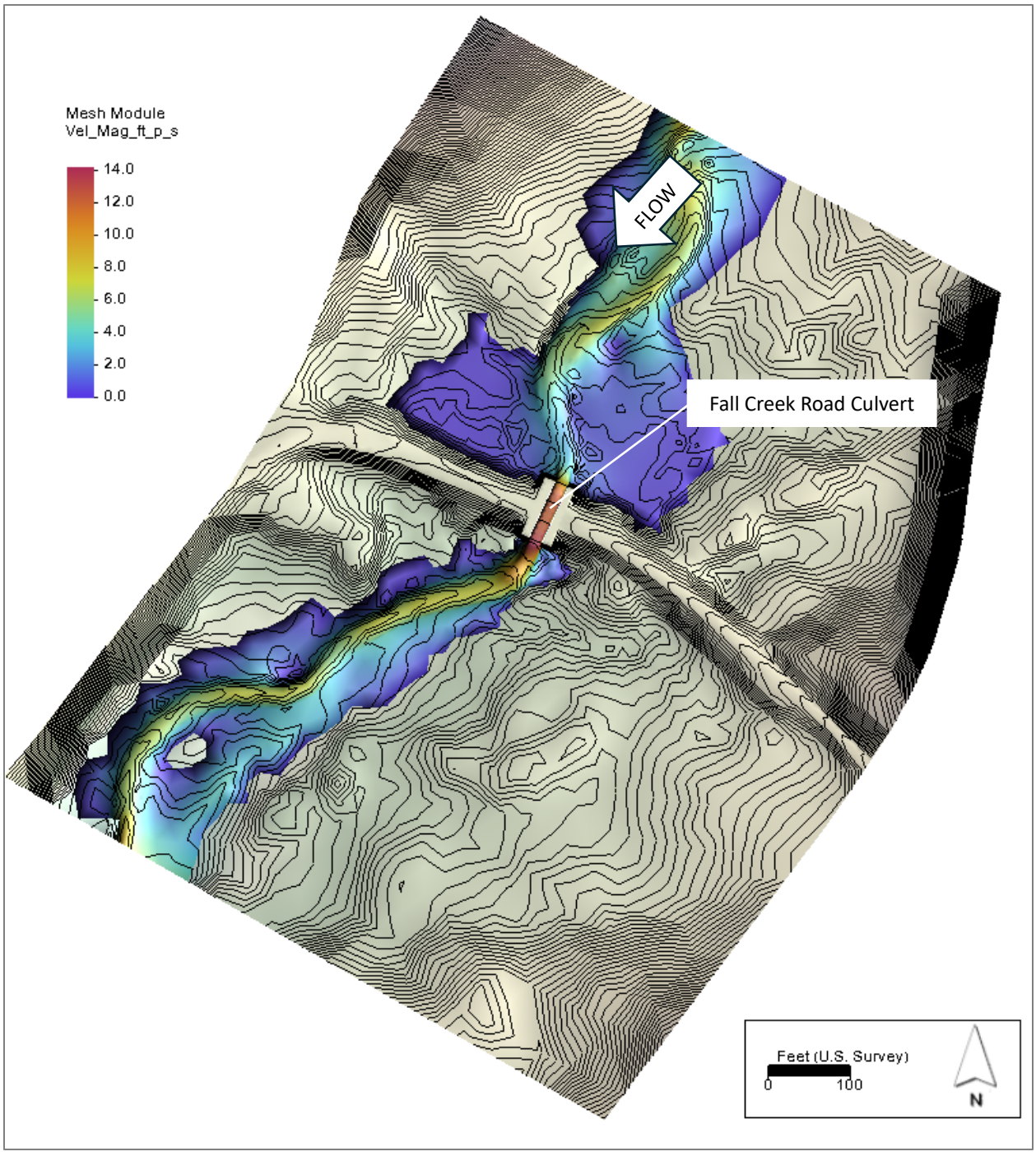
25-Year Velocity (ft/s) (16ft x 8ft CBC, embedded)



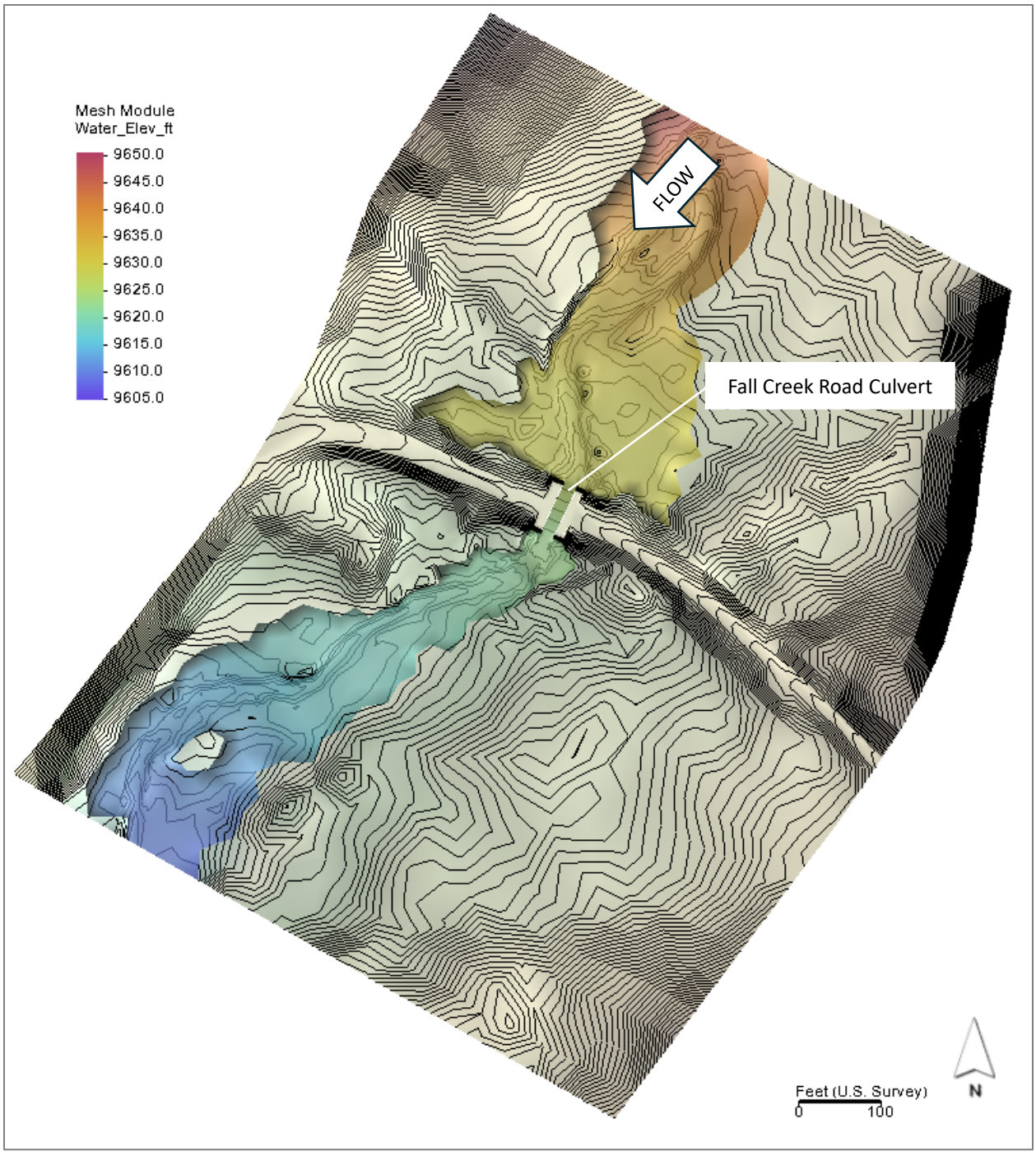
50-Year Velocity (ft/s) (16ft x 8ft CBC, embedded)



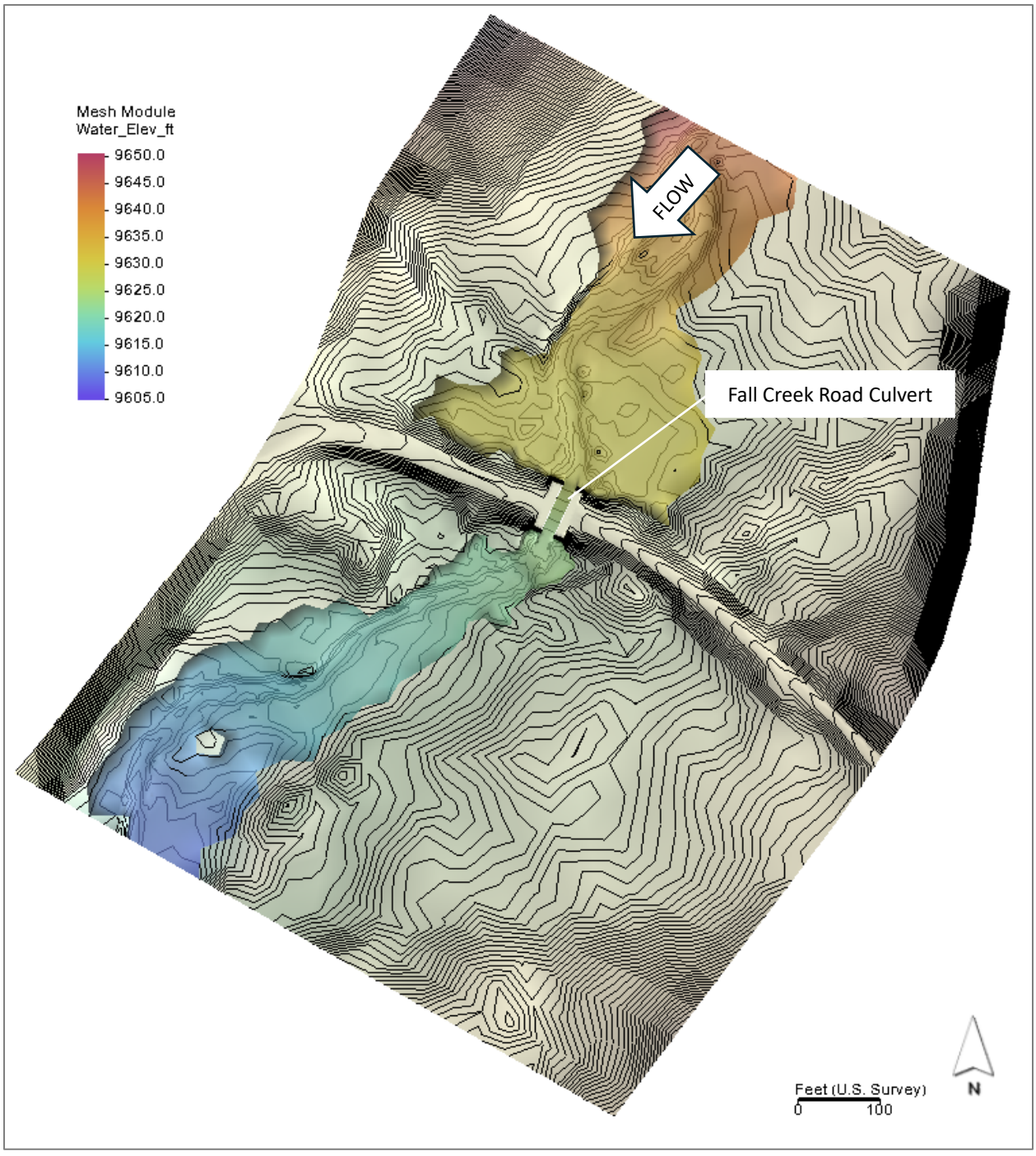
100-Year Velocity (ft/s) (16ft x 8ft CBC, embedded)



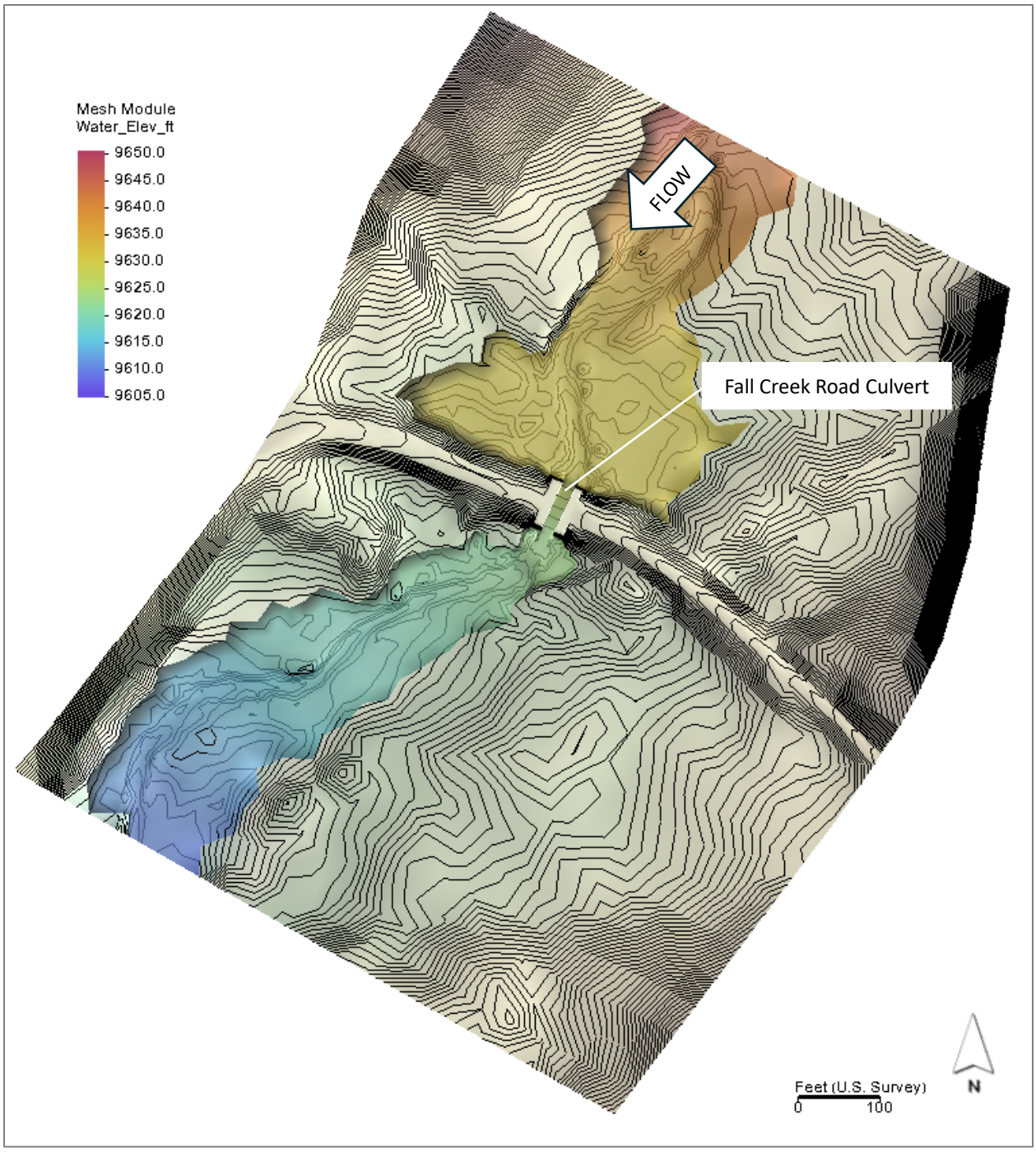
25-Year Water Surface Elevation (ft) (16ft x 8ft CBC, embedded)



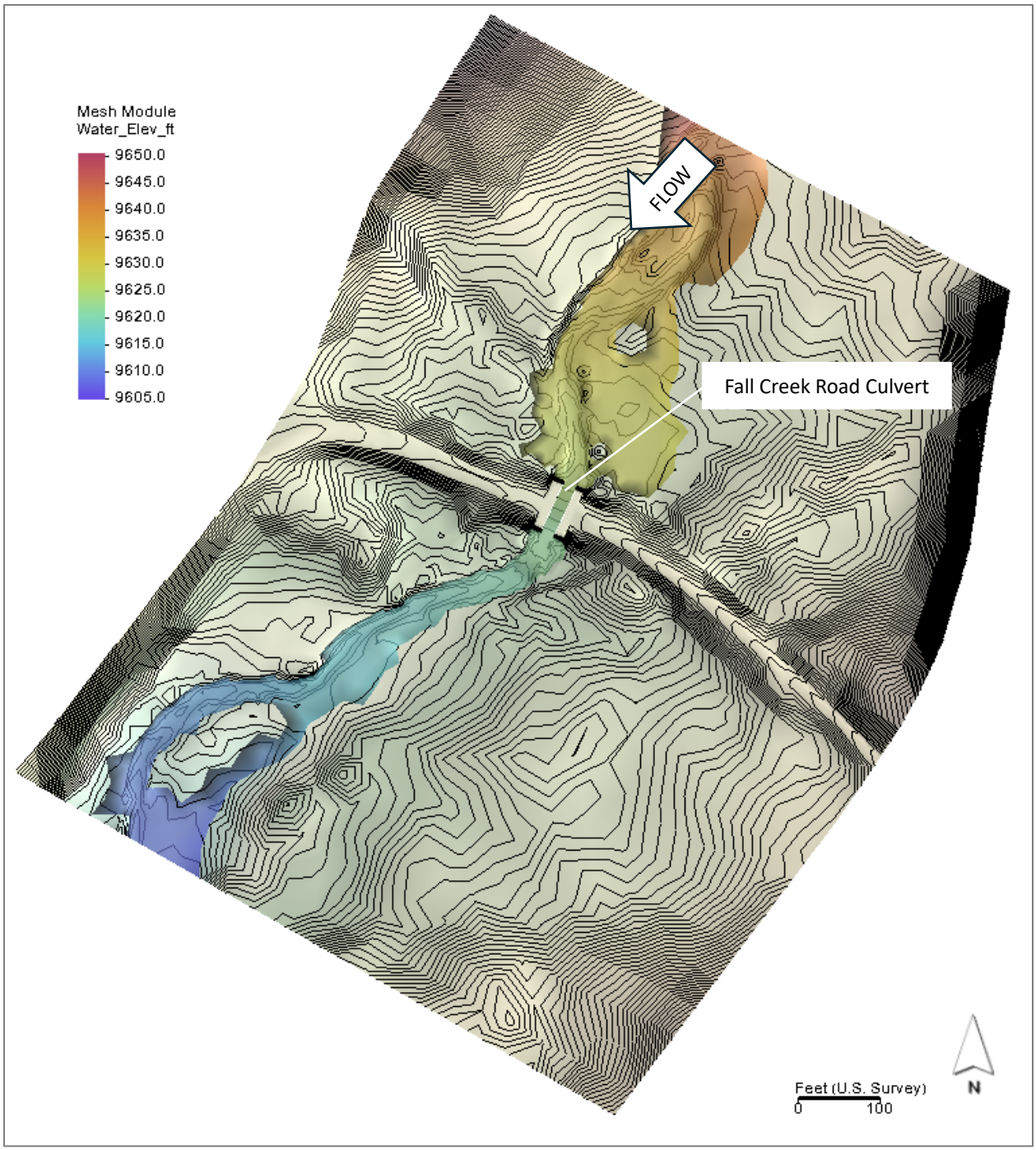
50-Year Water Surface Elevation (ft) (16ft x 8ft CBC, embedded)



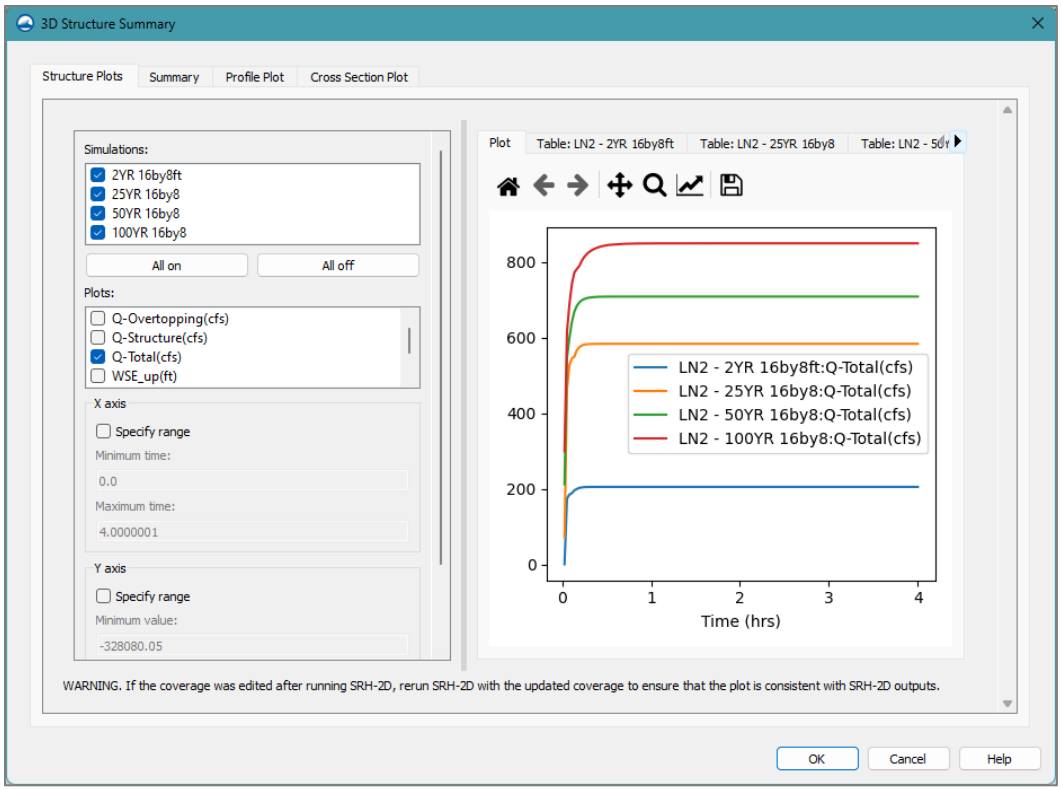
100-Year Water Surface Elevation (ft) (16ft x 8ft CBC, embedded)

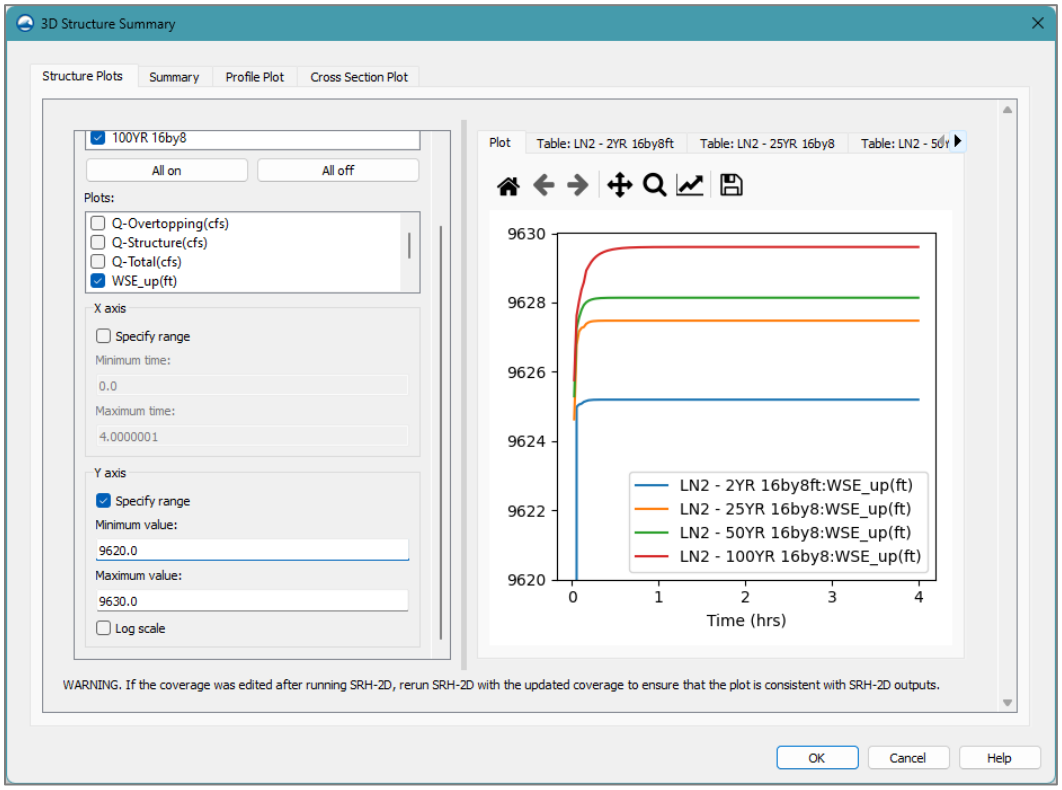


2-Year Water Surface Elevation (ft) (16ft x 8ft CBC, embedded)

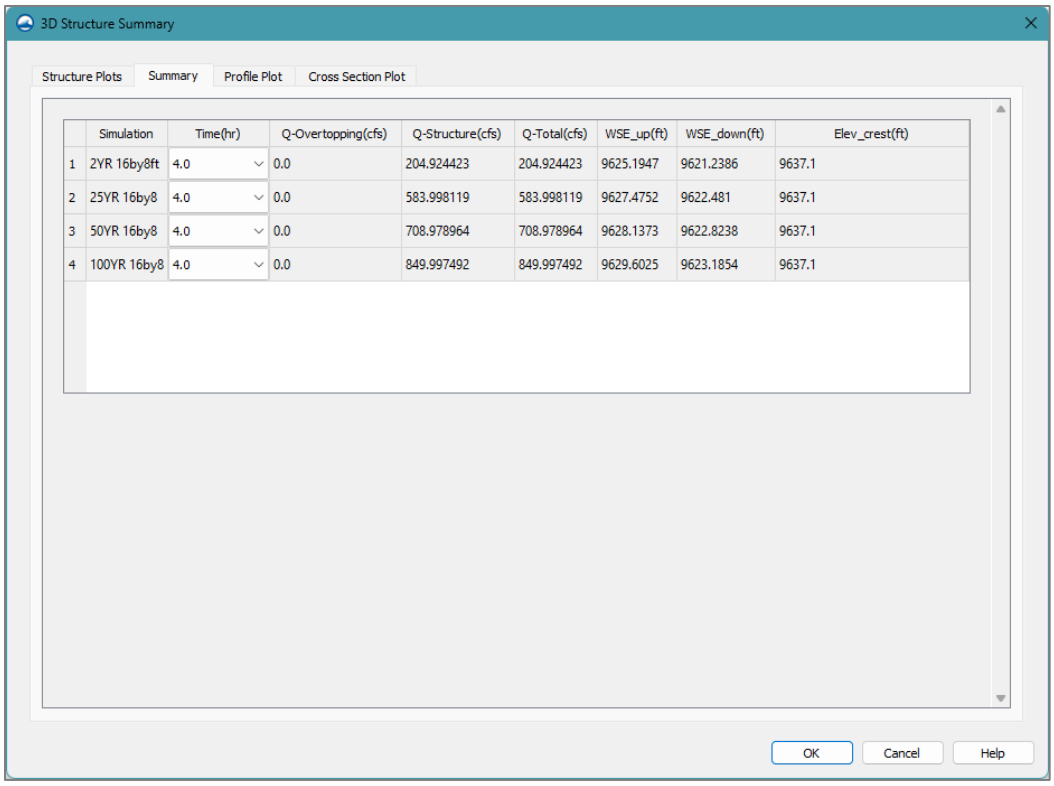


3D Structure Summary:

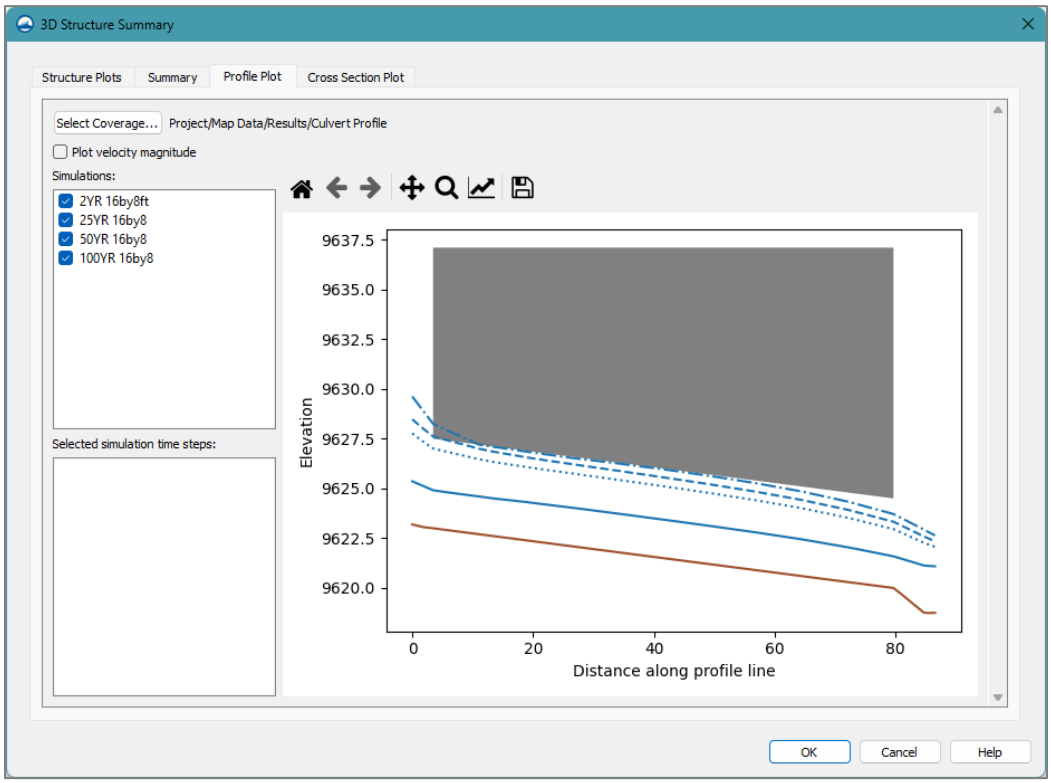




3D Structure Summary (cont.)



	Simulation	Time(hr)	Q-Overtopping(cfs)	Q-Structure(cfs)	Q-Total(cfs)	WSE_up(ft)	WSE_down(ft)	Elev_crest(ft)
1	2YR 16by8ft	4.0	0.0	204.924423	204.924423	9625.1947	9621.2386	9637.1
2	25YR 16by8	4.0	0.0	583.998119	583.998119	9627.4752	9622.481	9637.1
3	50YR 16by8	4.0	0.0	708.978964	708.978964	9628.1373	9622.8238	9637.1
4	100YR 16by8	4.0	0.0	849.997492	849.997492	9629.6025	9623.1854	9637.1



Riprap Sizing:

Riprap Analysis Sub d=9.6

Structure type: Culvert Outlet Protection — Geotextile/Granular Filter Design...

Parameter	Value	Units	Notes
Channel Parameters			
Select Channel	<Define Local Data>		
	Channel Calculator...		
Input Parameters			
	Transfer Values From Channel Calcu...		
Flow	425.000	cfs	
Culvert Diameter	9.600	ft	
Normal Depth in Culvert	3.800	ft	
Tailwater Depth	4.500	ft	If tailwater is unknown, use 0.4D
Flow Type	subcritical		
Results			
D50	209.726	mm	The sizing equation assumes a rock s.g.=2.65. If s.g. is not 2.65, rock size (D...
Riprap Shape	Riprap shape should be angular		
Riprap Class			
Riprap Class Name	CLASS II		
Riprap Class Order	2		
D15	177.80	mm	This value is an 'average' of the size fraction range for the selected riprap class
D50	241.30	mm	This value is an 'average' of the size fraction range for the selected riprap class
D85	330.20	mm	This value is an 'average' of the size fraction range for the selected riprap class
D100	457.20	mm	This value is an 'average' of the size fraction range for the selected riprap class
Layout			
Apron Length	38.400	ft	
Apron Thickness	2.612	ft	
Apron Width (at apron end)	54.400	ft	
Computation Variables			
Tailwater Depth Used in Computations	4.500	ft	This value may be adjusted according to the methods in HEC-14
Culvert Diameter Used in Calculations	9.600	ft	This value may be adjusted according to the methods in HEC-14

OK Cancel

Riprap Analysis Super d=9.6

Structure type: Culvert Outlet Protection — Geotextile/Granular Filter Design...

Parameter	Value	Units	Notes
Channel Parameters			
Select Channel	<Define Local Data>		
	Channel Calculator...		
Input Parameters			
	Transfer Values From Channel Calcu...		
Flow	425.000	cfs	
Culvert Diameter	9.600	ft	
Normal Depth in Culvert	3.800	ft	
Tailwater Depth	4.500	ft	If tailwater is unknown, use 0.4D
Flow Type	supercritical		
Results			
D50	338.778	mm	The sizing equation assumes a rock s.g.=2.65. If s.g. is not 2.65, rock size (D...
Riprap Shape	Riprap shape should be angular		
Riprap Class			
Riprap Class Name	CLASS IV		
Riprap Class Order	4		
D15	266.70	mm	This value is an 'average' of the size fraction range for the selected riprap class
D50	393.70	mm	This value is an 'average' of the size fraction range for the selected riprap class
D85	533.40	mm	This value is an 'average' of the size fraction range for the selected riprap class
D100	762.00	mm	This value is an 'average' of the size fraction range for the selected riprap class
Layout			
Apron Length	48.000	ft	
Apron Thickness	3.100	ft	
Apron Width (at apron end)	52.100	ft	
Computation Variables			
Tailwater Depth Used in Computations	4.500	ft	This value may be adjusted according to the methods in HEC-14
Culvert Diameter Used in Calculations	6.700	ft	This value may be adjusted according to the methods in HEC-14

OK Cancel

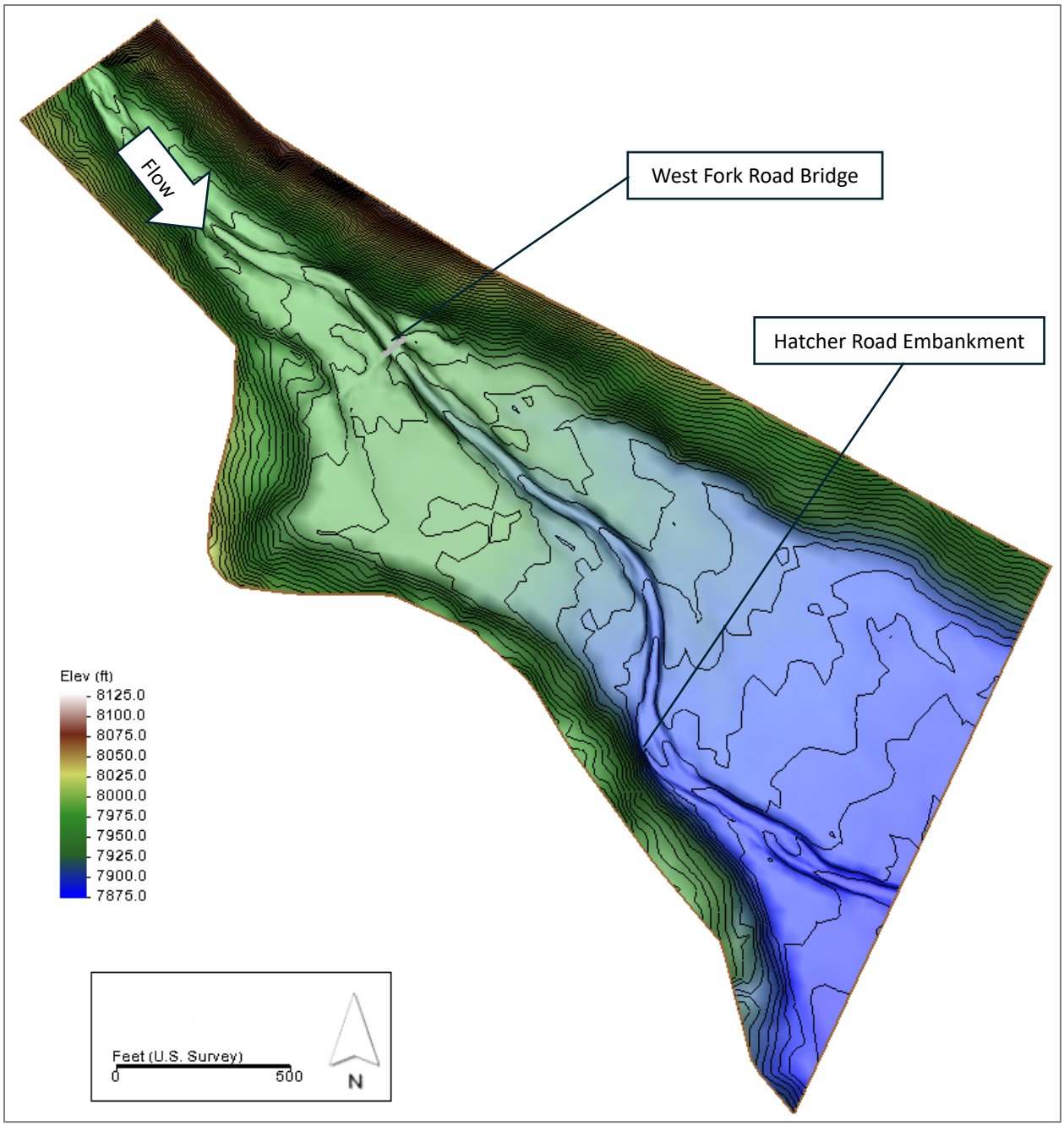
Riprap Sizing Methods		
25-Year Riprap sizing (Isbash)		
	Low Turbulence	**High Turbulence**
V (ft/s)	11.45	11.45
Sg	2.65	2.65
g (ft/s^2)	32.2	32.2
C	1.2	0.86
D50 (ft)	**0.86**	**1.67**
D50 (in)	**10**	**20**

25-Year Riprap sizing (EM 1110-2-1601 3-5 Steep Slope)	
S (ft/ft)	0.039
Q (cfs)	425
b (ft)	16
q (cfs/ft)	26.6
g (ft/s^2)	32.2
D30 (ft)	**0.90**
D30 (in)	**11**
D50 = 1.2 x D30 (ft)	**1.08**
D50 = 1.2 x D30 (in)	**13**

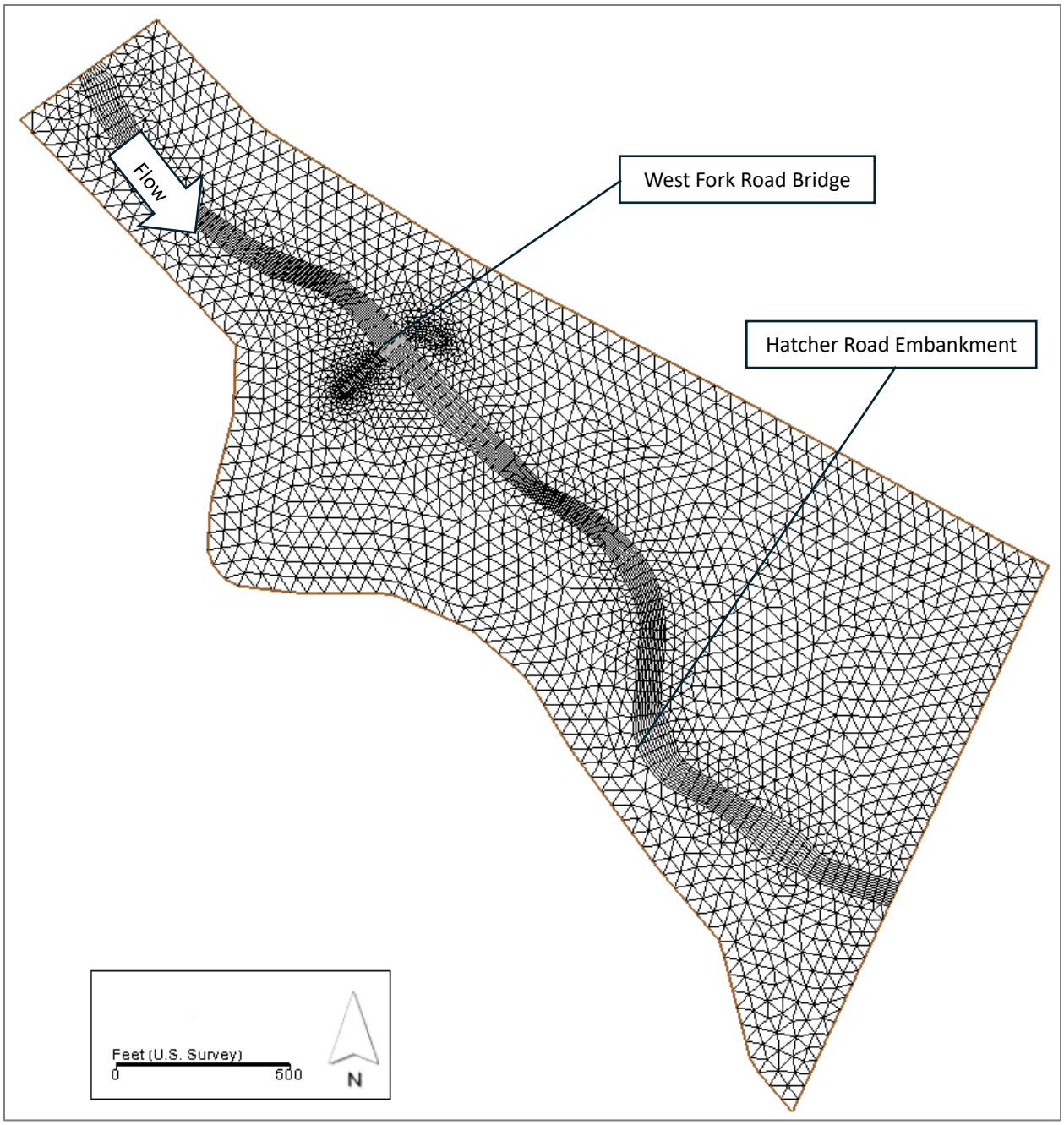
Appendix C-2

648 West Fork Road and 033 Hatcher Road

Topographic Surface:

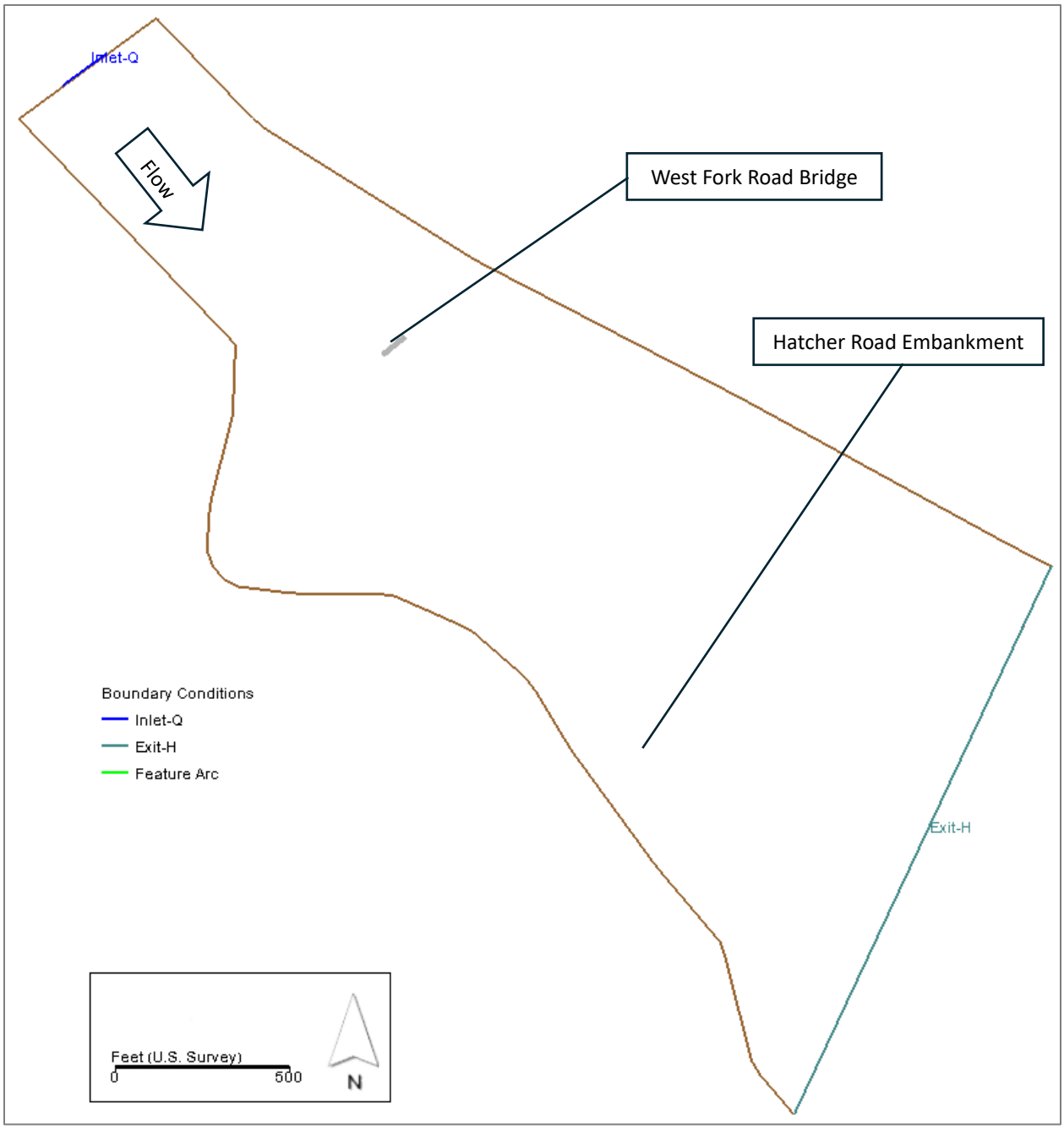


SRH-2D Mesh:

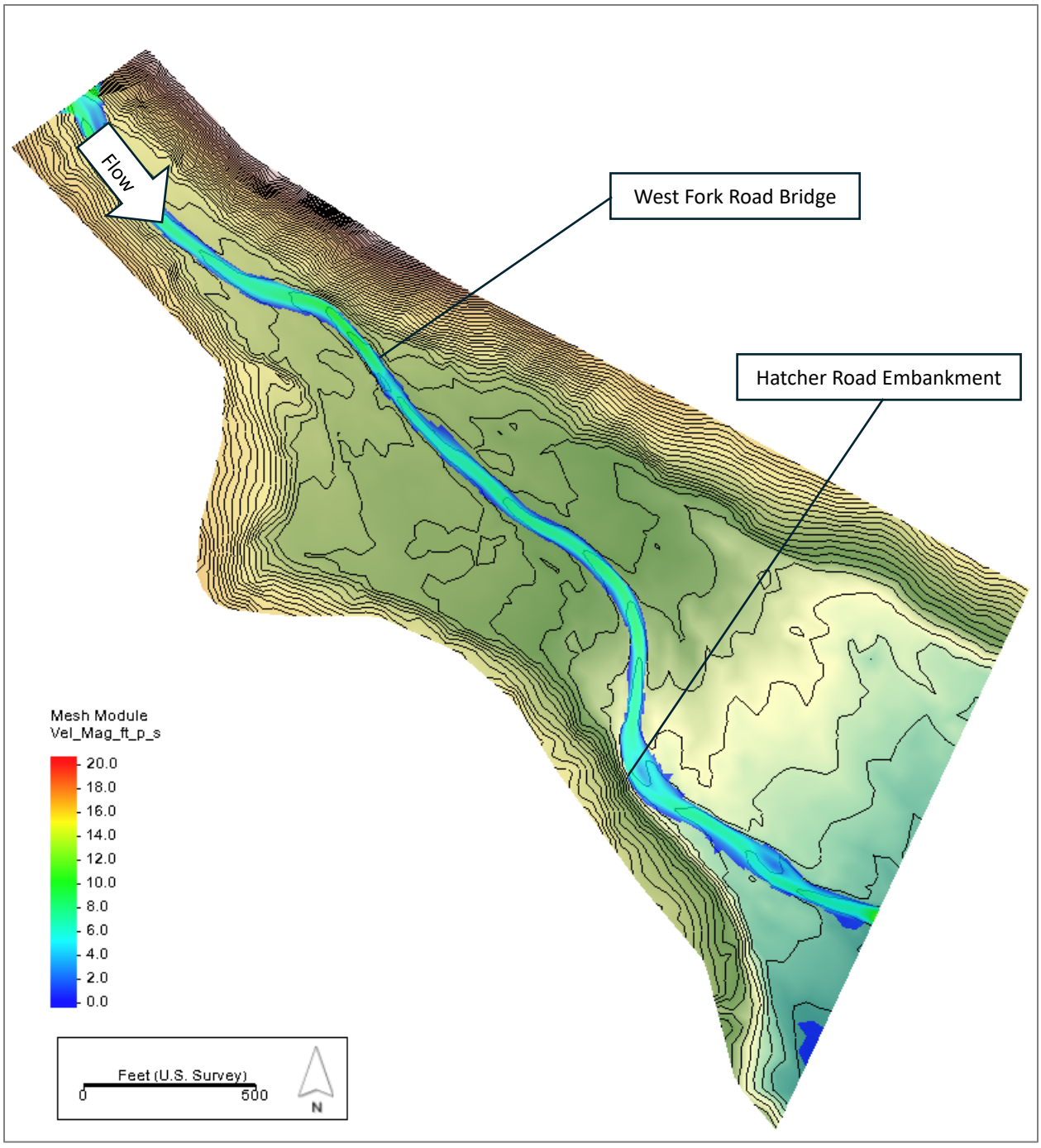

Flow
West Fork Road Bridge
Hatcher Road Embankment
Feet (U.S. Survey)
0
500
N

Materials (Manning's Roughness):

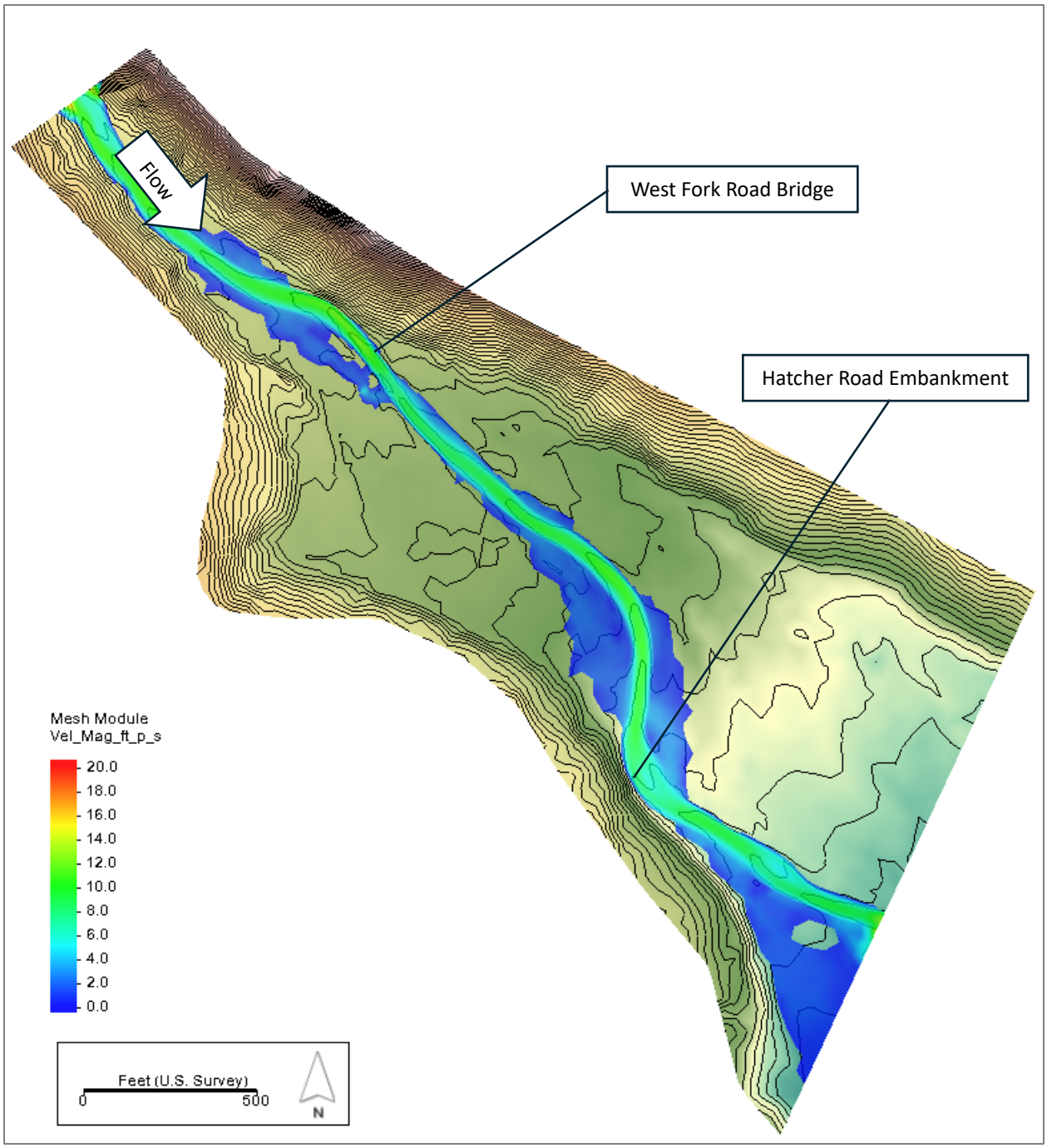
Boundary Conditions:



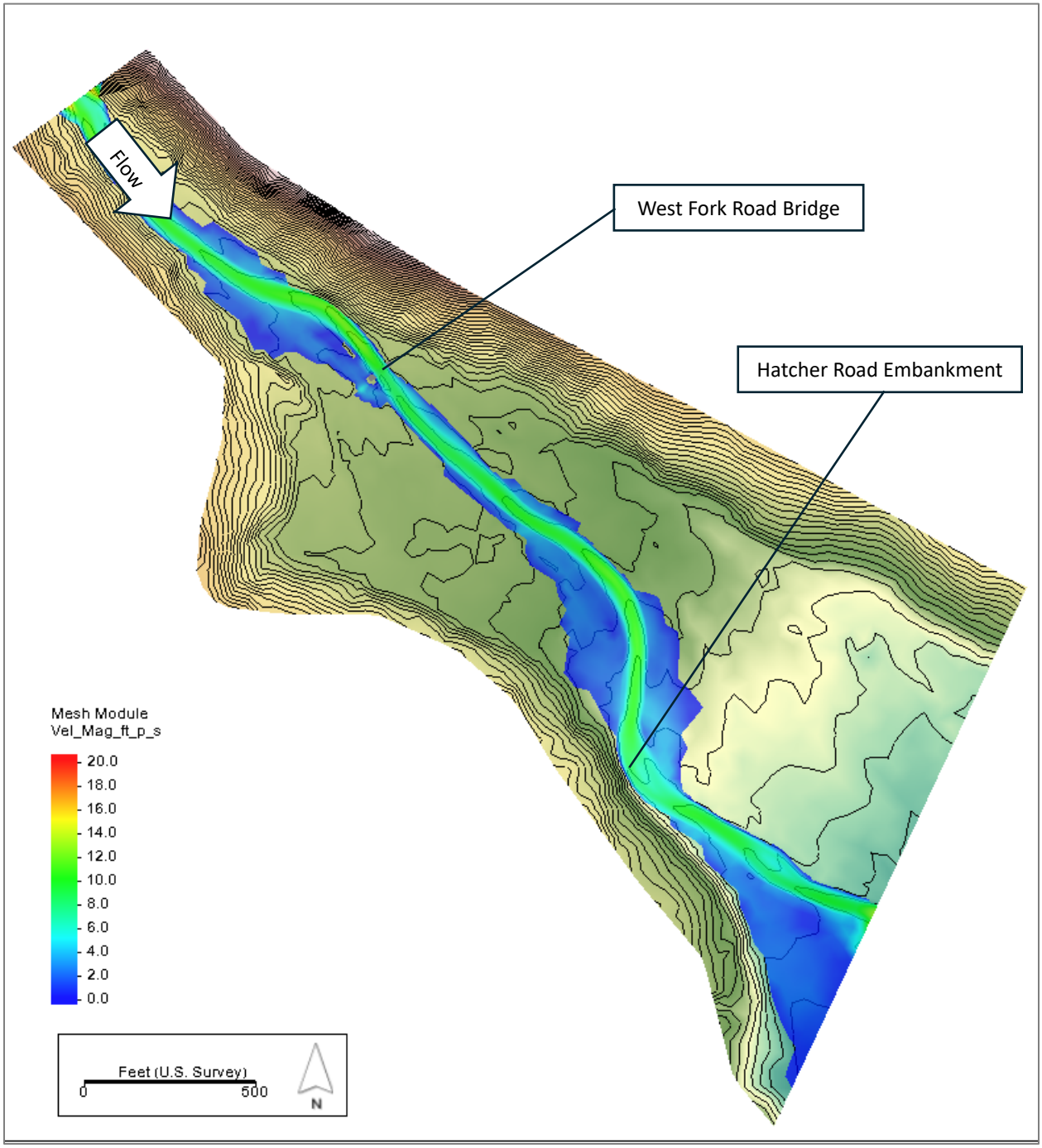
2-Year Velocity (ft/s):



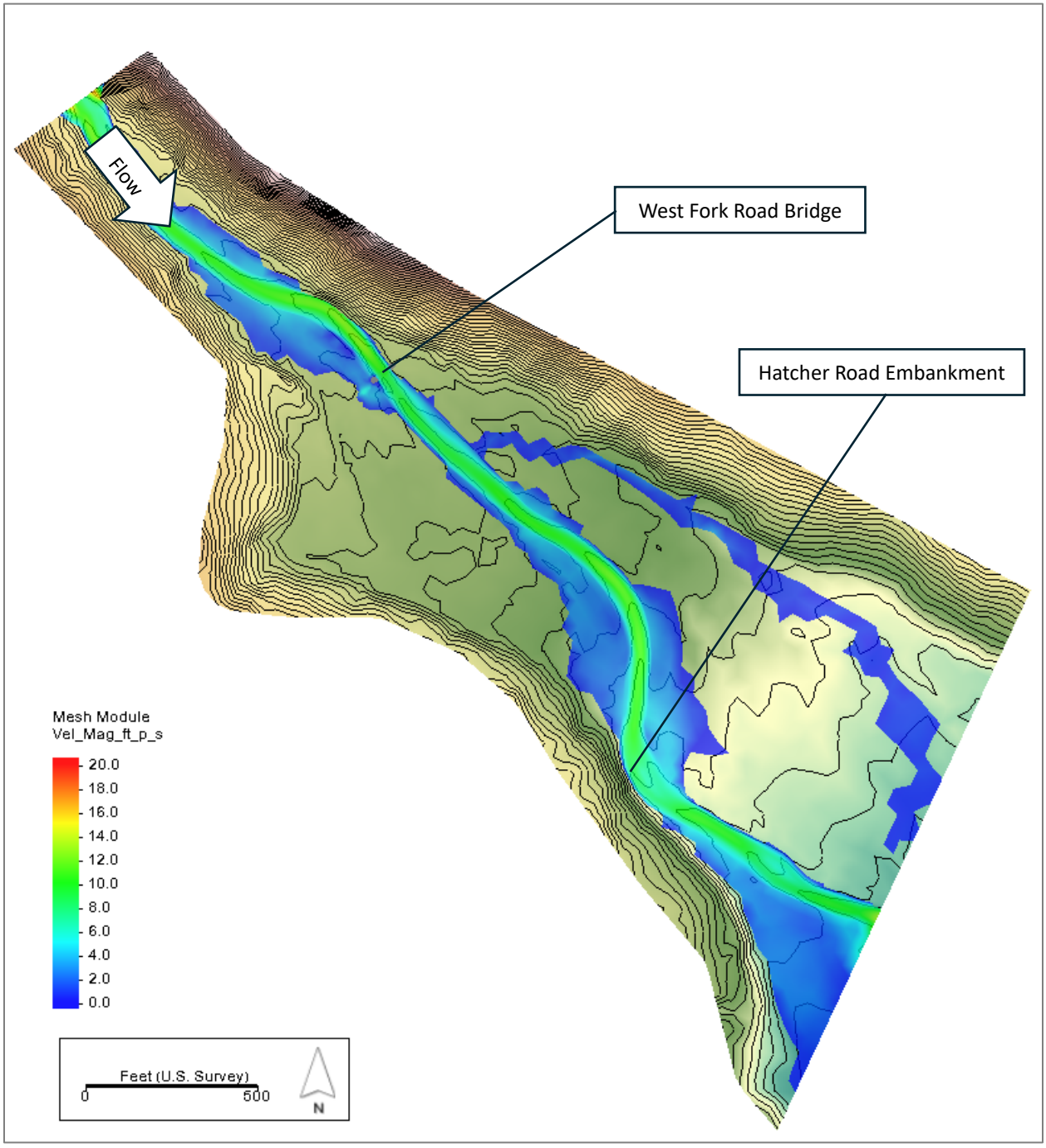
25-Year Velocity (ft/s):



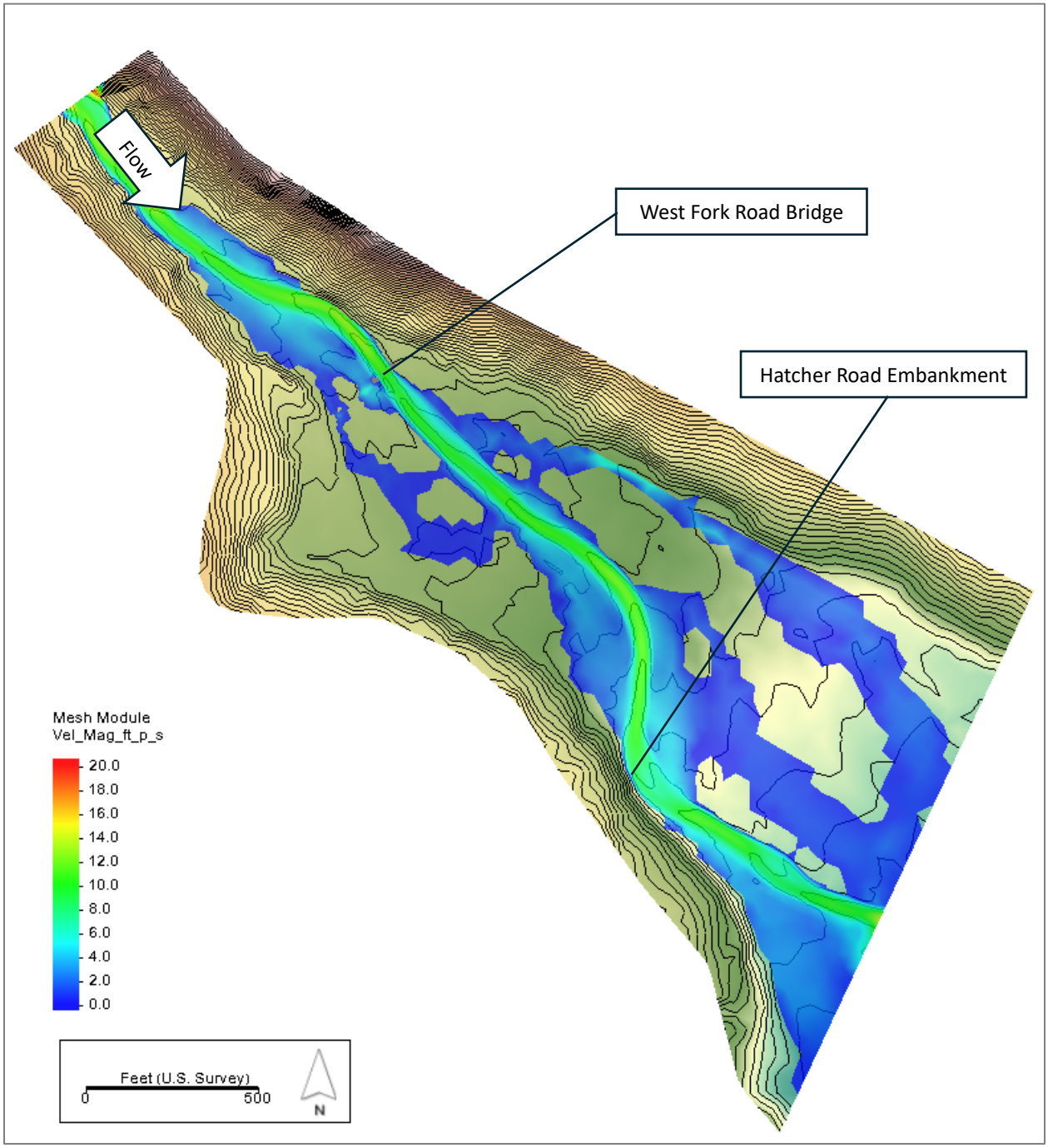
50-Year Velocity (ft/s):



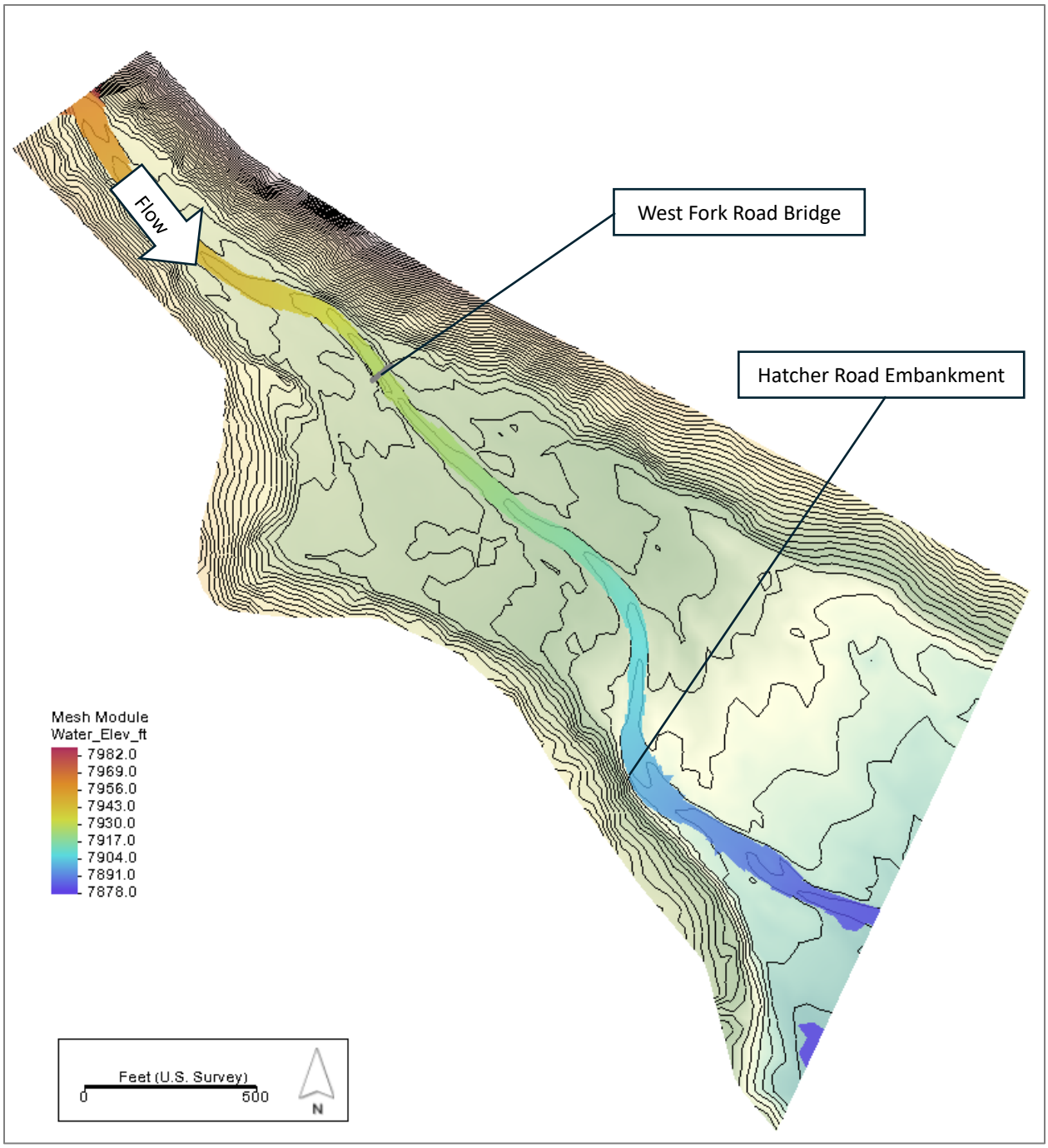
100-Year Velocity (ft/s):



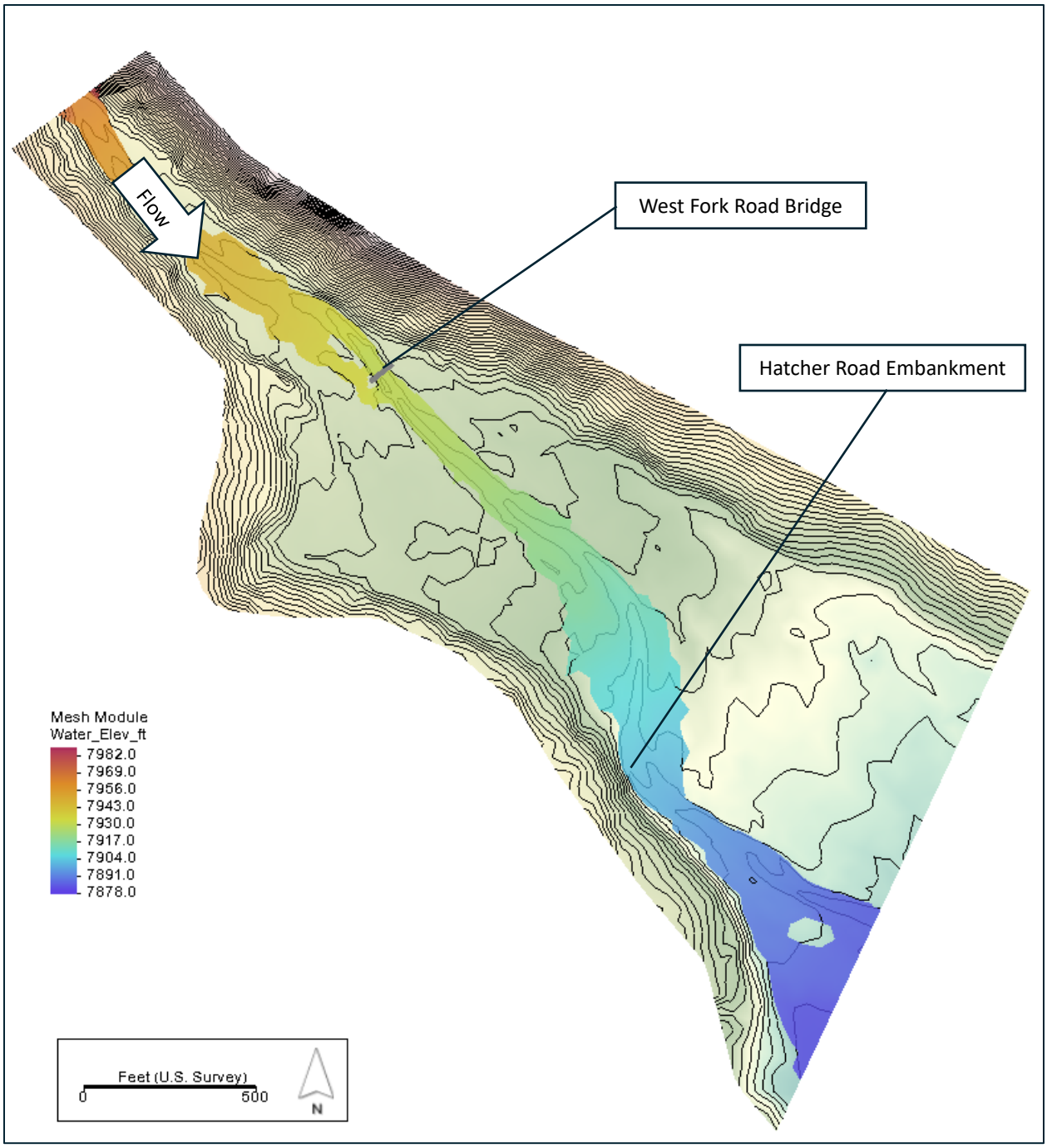
200-Year Velocity (ft/s):



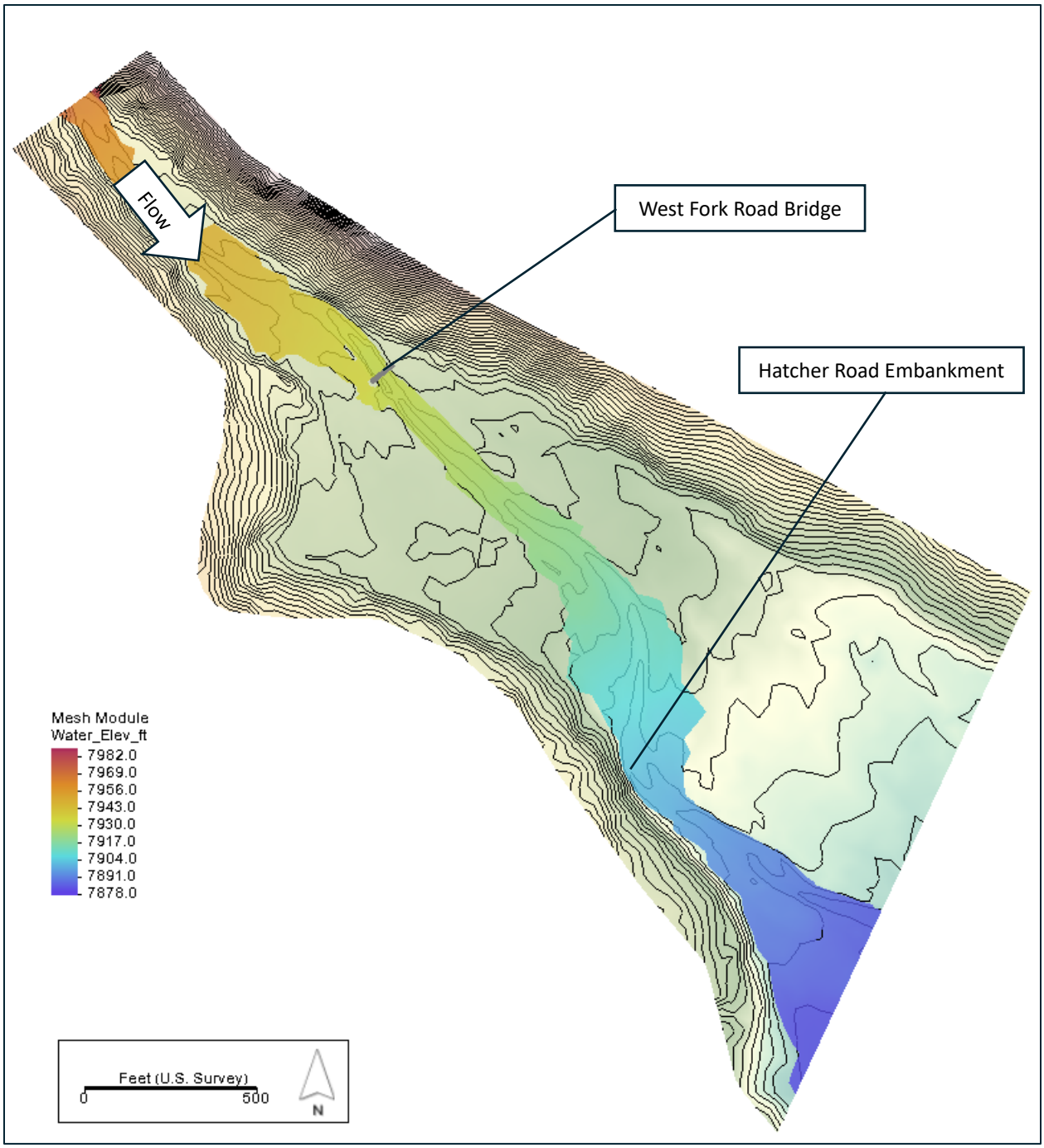
2-Year Water Surface Elevation (ft):



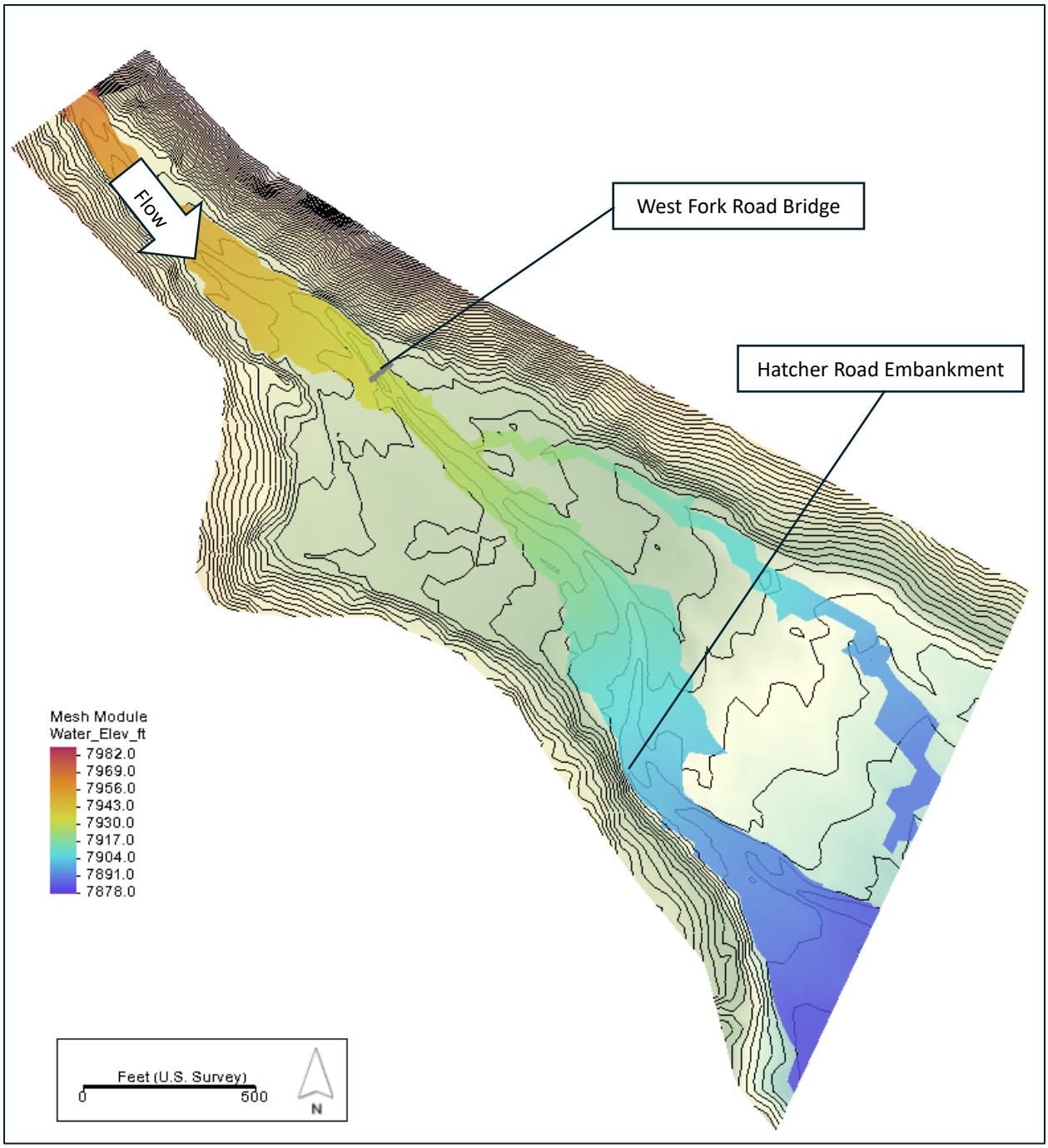
25-Year Water Surface Elevation (ft):



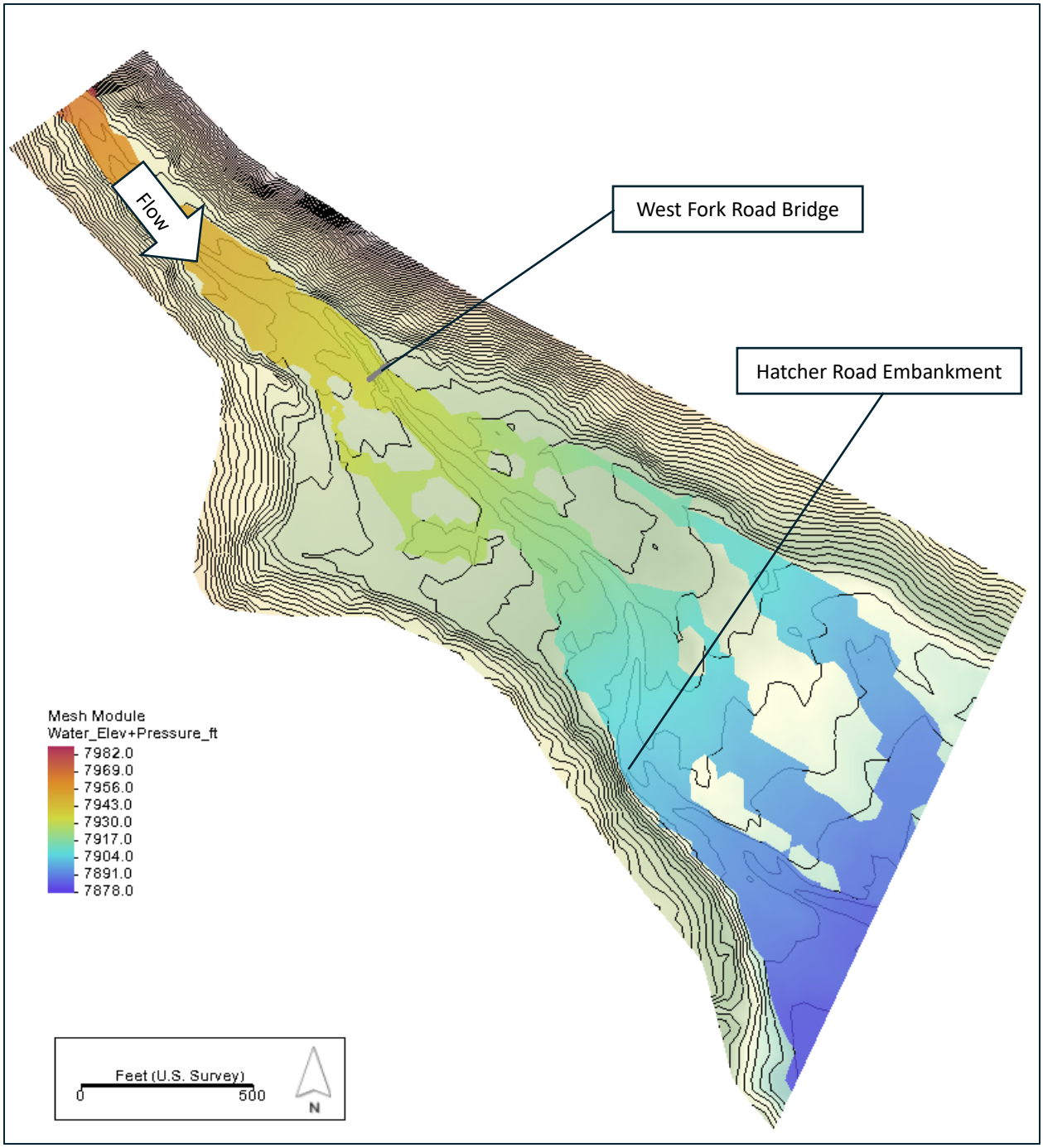
50-Year Water Surface Elevation (ft):



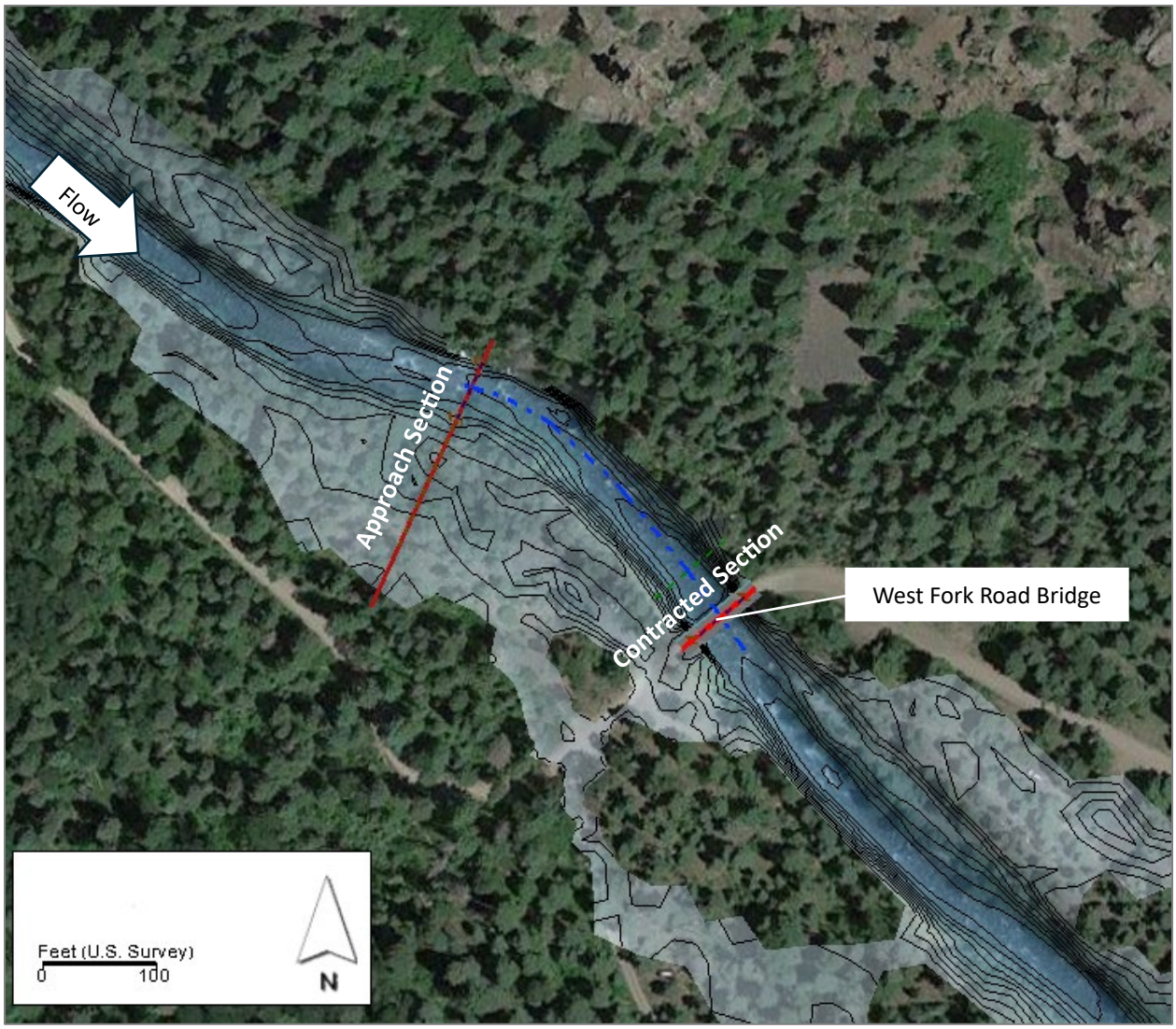
100-Year Water Surface Elevation (ft):



200-Year Water Surface Elevation (ft):



West Fork Scour Analysis Sections:



West Fork Contraction Scour (200-year):

Contraction Scour

Parameter	Value	Units	Notes
Pressure Scour Method			
Compute Pressure Scour (Vertical Contraction Scour)	☑		
Input Parameters			
Select Gradations			
Approach Gradation Set (D50 and/or tau c) (optional)	None		if provided, this will replace ...
Contracted Gradation Set (D50 and/or tau c)	New Gradation Set		Used for clear water scour d...
Input Parameters for Scour Condition			
Average Depth Upstream of Contraction (y1)	5.90	ft	
Average Velocity Upstream (V)	10.53	ft/s	
Input Parameters for Clear Water Method			
Depth Prior to Scour in Contracted Section (y0)	7.03	ft	
Input Parameters for Live Bed Method			
Temperature of Water	60.00	°F	Used to determine the fall v...
Slope of Energy Grade Line at Approach Section (S1)	0.044081	ft/ft	
Discharge in Contracted Section (Q2)	3942.40	cfs	
Discharge Upstream that is Transporting Sediment (Q1)	3389.79	cfs	
Bottom Width in Contracted Section (W2)	57.04	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment (W1)	54.53	ft	
Depth Prior to Scour in Contracted Section (y0)	7.03	ft	
Unit Weight of Water (gamma w)	62.40	lb/ft^3	
Unit Weight of Sediment (gamma s)	165.00	lb/ft^3	
Input Parameters for Pressure Scour			
Average Depth Approaching Bridge (hb + ht or hu)	7.16	ft	To be measured between W...
Average, Vertical Bridge Opening Prior to Scour (hb)	5.90	ft	To be measured between lo...
Deck Thickness (T)	3.90	ft	
Results			

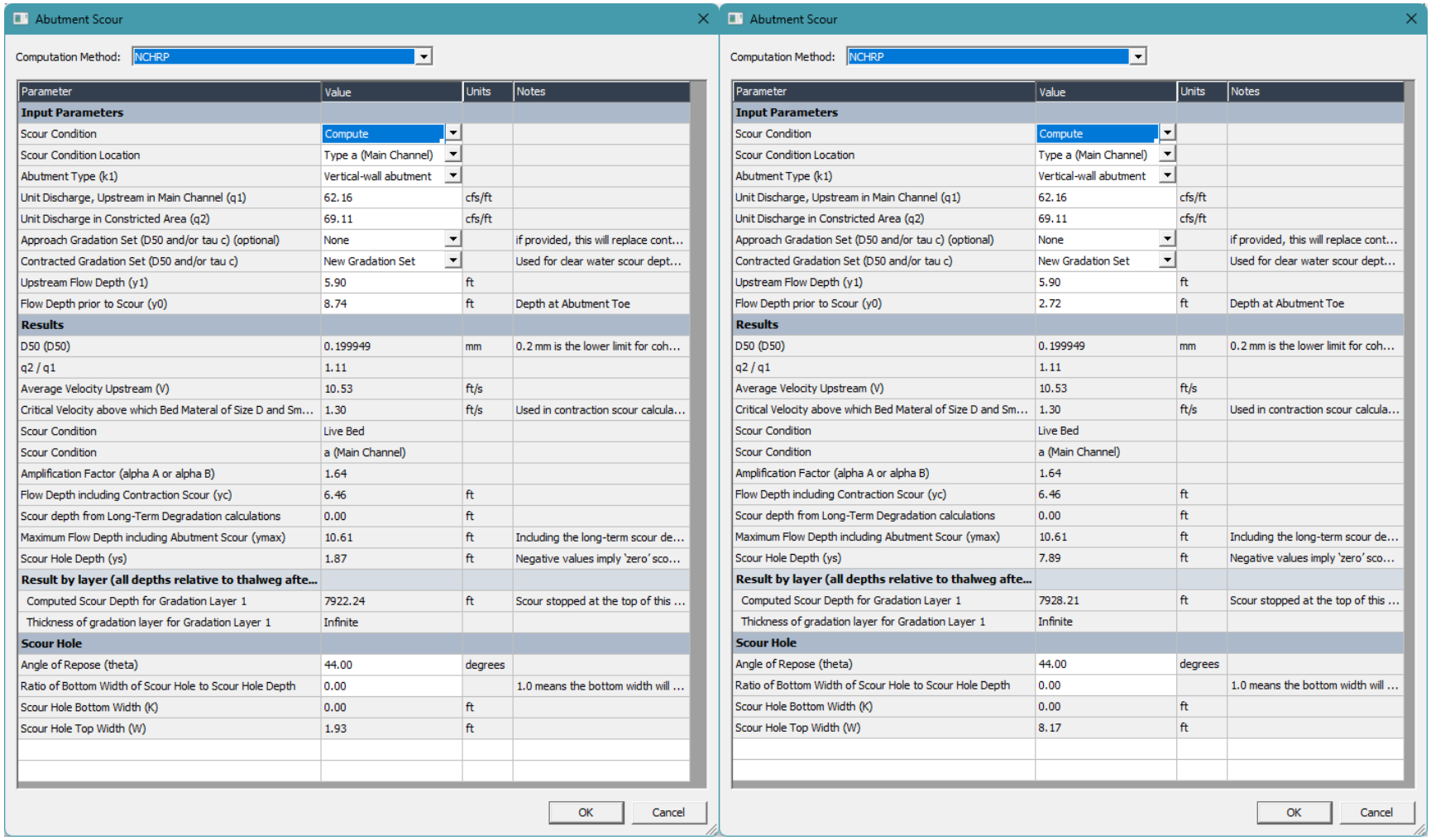
OK Cancel

Contraction Scour

Parameter	Value	Units	Notes
Results			
Results of Scour Condition			
D50 for Approach Location (D50)	0.199949	mm	0.2 mm is the lower limit for ...
Critical velocity above which bed material of size D and s...	1.30	ft/s	
Computed Contraction Scour Condition	Live Bed		Vc < V
Results of Clear Water Method			
Diameter of the smallest nontransportable particle in the ...	0.249936	mm	Dm based on Gradation Lay...
Average Depth in Contracted Section after Scour (y2)	35.71	ft	
Results of Live Bed Method			
k1 (k1)	0.690000		
Shear Velocity (V*)	2.89	ft/s	
Fall Velocity (T)	0.08	ft/s	
Average Depth in Contracted Section after Scour (y2)	6.51	ft	
Shear Applied to Bed by Live-Bed Scour (theta 0)	0.5971	lb/ft^2	
Shear Required for Movement of D50 Particle (Tau c)	0.0026	lb/ft^2	
Result by layer (all depths relative to thalweg prio...			
Computed Scour Condition for Gradation Layer 1	Pressure		
Computed Live-bed Scour Depth for Gradation Layer 1	-0.52	ft	
Clear-water Scour Equation for Gradation Layer 1	noncohesive		
Computed Clear-water Scour Depth for Gradation Layer 1	0.00	ft	
Depth to the bottom of Gradation Layer 1	Infinite		Clear Water Scour does not ...
Results of Pressure Scour			
k1 (k1)	0.69		
Weir Flow Height (hw)	0.000000	ft	
Diameter of Smallest Non-moving Particle (Dm)	0.000820	ft	
Average Depth In Contracted Section (y2)	6.51	ft	
Flow Separation Thickness (t)	2.00	ft	
Scour Depth (ys)	2.61	ft	
Summary			
Applied Scour Condition	Pressure		Determined by comparing sc...
Applied Scour Depth	2.61	ft	
Override Recommended Scour Condition	☐		

OK Cancel

West Fork Abutment Scour (200-year) Right and Left Looking Downstream – (Free-Surface Condition):



Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type (k1)	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	62.16	cfs/ft	
Unit Discharge in Constricted Area (q2)	69.11	cfs/ft	
Approach Gradation Set (D50 and/or tau c) (optional)	None		if provided, this will replace cont...
Contracted Gradation Set (D50 and/or tau c)	New Gradation Set		Used for clear water scour dept...
Upstream Flow Depth (y1)	5.90	ft	
Flow Depth prior to Scour (y0)	8.74	ft	Depth at Abutment Toe
Results			
D50 (D50)	0.199949	mm	0.2 mm is the lower limit for coh...
q2 / q1	1.11		
Average Velocity Upstream (V)	10.53	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	1.30	ft/s	Used in contraction scour calcula...
Scour Condition	Live Bed		
Scour Condition	a (Main Channel)		
Amplification Factor (alpha A or alpha B)	1.64		
Flow Depth including Contraction Scour (yc)	6.46	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour (ymax)	10.61	ft	Including the long-term scour de...
Scour Hole Depth (ys)	1.87	ft	Negative values imply 'zero' sco...
Result by layer (all depths relative to thalweg afte...			
Computed Scour Depth for Gradation Layer 1	7922.24	ft	Scour stopped at the top of this ...
Thickness of gradation layer for Gradation Layer 1	Infinite		
Scour Hole			
Angle of Repose (theta)	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width (K)	0.00	ft	
Scour Hole Top Width (W)	1.93	ft	

OK Cancel

Abutment Scour

Computation Method: NCHRP

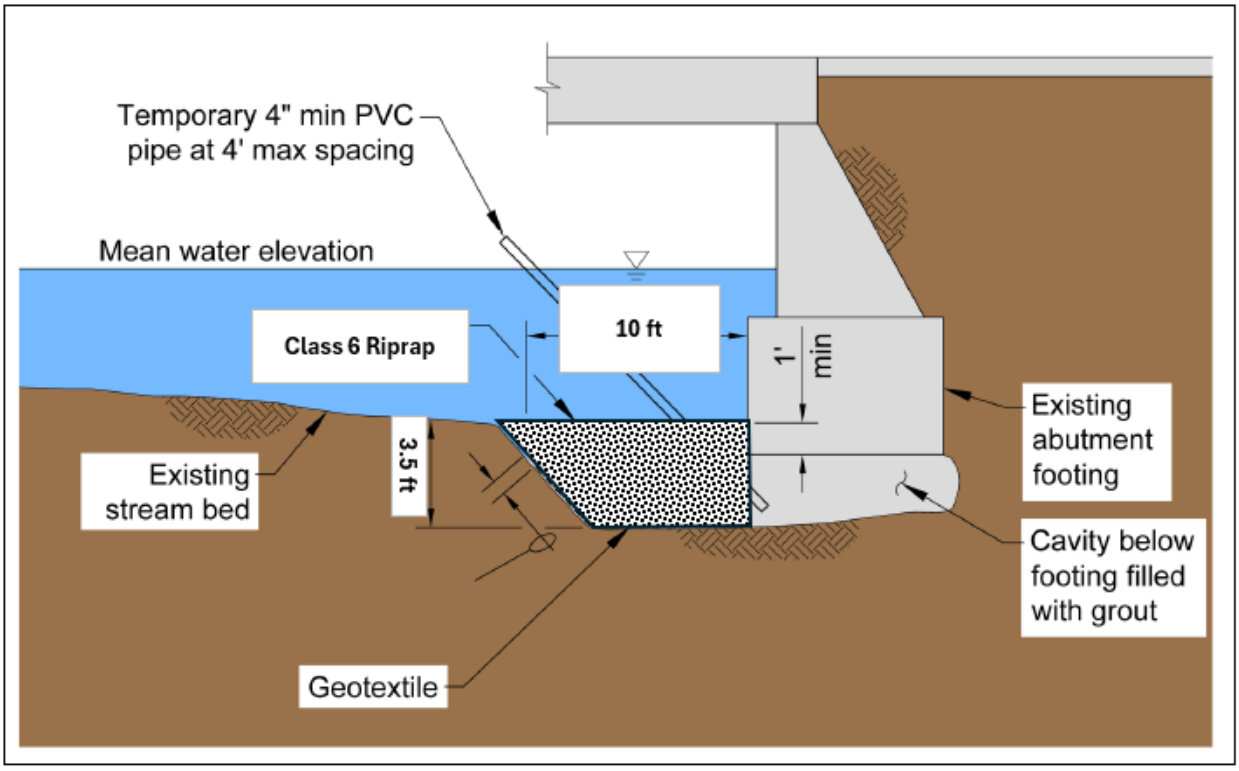
Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type (k1)	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	62.16	cfs/ft	
Unit Discharge in Constricted Area (q2)	69.11	cfs/ft	
Approach Gradation Set (D50 and/or tau c) (optional)	None		if provided, this will replace cont...
Contracted Gradation Set (D50 and/or tau c)	New Gradation Set		Used for clear water scour dept...
Upstream Flow Depth (y1)	5.90	ft	
Flow Depth prior to Scour (y0)	2.72	ft	Depth at Abutment Toe
Results			
D50 (D50)	0.199949	mm	0.2 mm is the lower limit for coh...
q2 / q1	1.11		
Average Velocity Upstream (V)	10.53	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	1.30	ft/s	Used in contraction scour calcula...
Scour Condition	Live Bed		
Scour Condition	a (Main Channel)		
Amplification Factor (alpha A or alpha B)	1.64		
Flow Depth including Contraction Scour (yc)	6.46	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour (ymax)	10.61	ft	Including the long-term scour de...
Scour Hole Depth (ys)	7.89	ft	Negative values imply 'zero' sco...
Result by layer (all depths relative to thalweg afte...			
Computed Scour Depth for Gradation Layer 1	7928.21	ft	Scour stopped at the top of this ...
Thickness of gradation layer for Gradation Layer 1	Infinite		
Scour Hole			
Angle of Repose (theta)	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width (K)	0.00	ft	
Scour Hole Top Width (W)	8.17	ft	

OK Cancel

West Fork Abutment Scour (200-year) (Pressure Condition):

Parameter	Value	Description
q_1	62.16	unit discharge in main channel, upstream (cfs)
q_2	69.11	unit discharge in contracted section, upstream (cfs)
y_1	5.90	flow depth at approach cross section (ft)
y_2	6.46	flow depth, including contraction scour depth (ft)
a	1.64	amplification factor for free-surface flow
y_{max}	10.60	maximum flow depth resulting from abutment scour (ft)
y_o	8.74	flow depth prior to scour (ft)
y_s	1.86	abutment scour depth (ft)
t	2.00	flow separation thickness (ft)
h_b	5.90	average vertical bridge opening prior to scour (ft)
y_s (pressure abutment)	6.70	**abutment scour depth accounting for pressure flow (ft)**

West Fork Abutment Repair Schematic:



West Fork HEC-23 (2009) Design Guideline 14 – Spill-Through Abutment Riprap:

Variable	Definition	Value	Units
y0	Pre-scour hydraulic depth of flow in the contracted opening (sub-section average value)	7.03	ft
y0(br)	Pre-scour hydraulic depth for the entire bridge opening	8.34	ft
W	Top Width of flow for entire bridge opening	48.39	ft
W/Yo	If greater than 6.2 does not require full apron.	5.80	
V	Characteristic average velocity in the contracted section	9.77	ft/s
CS	Depth of horizontal contraction scour from the scour reference datum	2.61	ft
LTD	Depth of the expected long-term degradation of the channel below the scour reference datum	0.00	ft
Bedform height	Height of bedform within sand-bed channels from top to trough	0.00	ft
Fr	Froude number	0.65	
K	Based on Fr and abutment type - spill through	0.89	
d50	Apply recommended equation based on Froude number	20.4	in
FP24 Riprap Class D50	Class 6, Nominal size 21 inch	21	in
FP24 Riprap Class D100	Class 6, Nominal d100 42 inch	42	in
Minimum Embedment	CS + LTD	2.61	ft
Apron	y0	7	ft
Thickness	1.5d50 or d100	42	in
Minimum riprap extent	2y0	14	ft
Minimum apron length	Y0	7	ft

West Fork HEC-23 (2009) Design Guideline 14 – Vertical Wall Abutment Riprap:

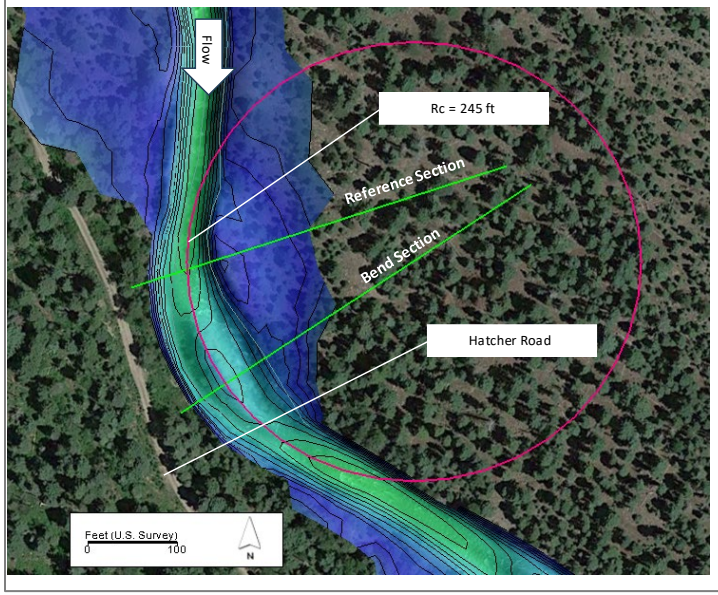
Variable	Definition	Value	Units
y0	Pre-scour hydraulic depth of flow in the contracted opening (sub-section average value)	8.60	ft
y0(br)	Pre-scour hydraulic depth for the entire bridge opening	8.34	ft
W	Top Width of flow for entire bridge opening	48.39	ft
W/Yo	If greater than 6.2 does not require full apron.	5.80	
V	Characteristic average velocity in the contracted section	9.77	ft/s
CS	Depth of horizontal contraction scour from the scour reference datum	2.61	ft
LTD	Depth of the expected long-term degradation of the channel below the scour reference datum	0.00	ft
Bedform height	Height of bedform within sand-bed channels from top to trough	0.00	ft
Fr	Froude number	0.59	
K	Based on Fr and abutment type – vertical wall	1.02	
d50	Apply recommended equation based on Froude number	23.4	in
FP24 Riprap Class D50	Class 7, Nominal size 24 inch	21	in
FP24 Riprap Class D100	Class 7, Nominal d100 48 inch	48	in
Minimum Embedment	CS + LTD	2.61	ft
Apron	y0	9	ft
Thickness	1.5d50 or d100	48	in
Minimum riprap extent	2y0	17	ft
Minimum apron length	Y0	9	ft

Hatcher Road Bend Scour:

Bend Scour Estimates - Hatcher Road

Parameters		25 Year	50 Year
Reference Hydraulic Depth	Dus (ft)	4.04	4.38
Bend Maximum Depth	Dmax (ft)	5.62	6.15
Bend Radius of Curvature	Rc (ft)	245	245
Reference Flow Width (within banks)	Wus (ft)	60.43	60.43
Rc/Wus	1.5 -10	4.05	4.05
Scour depth below reference section invert			
Maynord	Ys (ft)	2.9	3.1
USACE (Gravel)	Ys (ft)	4.0	4.3
Thorne	Ys (ft)	3.8	4.1
Scour depth below bend			
Maynord	Ys bend (ft)	1.3	1.5
USACE (Gravel)	Ys bend (ft)	2.5	2.7
Thorne	Ys bend(ft)	2.2	2.5
Maximum Scour		2.5	2.7
Average Scour		2.0	2.3

Note: 25-Year and higher events have significant overbank flow, equations applied within banks



Method	Equation	Assumptions and Conditions
Maynord*	$\Delta y = \bar{D}_{US}\left(1.8 - 0.051\left(\frac{Rc}{W_{US}}\right) + 0.0084\left(\frac{W_{US}}{\bar{D}_{US}}\right)\right) - \bar{D}_{US}$	Sand bed S ≤ 2%, $1.5 < \frac{Rc}{W_{US}} < 10$** Recommends a safety factor of 1.0 to 1.19
USACE EM 1110-2-1601	$\Delta y = \begin{cases} \bar{D}_{US}\left(-1.51\log_{10}\left(\frac{Rc}{W}\right) + 3.37\right) - D_{Max}\ for\ sand \\ \bar{D}_{US}\left(-1.62\log_{10}\left(\frac{Rc}{W}\right) + 3.375\right) - D_{Max}\ for\ gravel \end{cases}$	This method uses much of the same data as Thorne
Zeller†	$\Delta y = \frac{0.0685 \cdot D_{US_Max} V_{US}^{0.8}}{D_{h_US}^{0.4} S_{US}^{0.3}} + \left(2.1\left(\frac{W}{4Rc}\right)^{0.2} - 1\right)$	Sand bed channels.
Thorne	$\Delta y = \bar{D}_{US}\left(2.07 - 0.19\ln\left(\frac{Rc}{W_{US}} - 2\right)\right) - \bar{D}_{US}$	Includes data from large sand bed rivers and smaller gravel-cobble systems $\frac{Rc}{W_{US}} < 2$

* For a factor of safety of 1. The method recommends a factor of safety between 1.0 and 1.19 based on the percentage of "significantly unconservative data".

**The algorithm has alternate forms for $\frac{Rc}{W_{US}} < 10$ and $\frac{Rc}{W_{US}} < 1.5$.

†This form replaces $\frac{\sin^2\frac{\alpha}{2}}{\cos\alpha}$ with the equivalent $\frac{W}{4Rc}$.

Where:

Δy is the scour depth below the initial channel invert
W is the flow width (within the banks)
W_{US} is the flow width (within the banks) at the upstream, reference cross section
R_c is the radius of curvature
D is depth. Depth takes several forms in these equations including:
D_h, the hydraulic depth, which is the area divided by the top width
$\bar{D}_{US}$, the average cross section depth at the upstream, reference cross section, but is often approximated with D_h and
D_{Max}, the maximum cross section depth before scour at the evaluation cross section.

Reference:

HEC-RAS User's Manual https://www.hec.usace.army.mil/confluence/rasdocs/rasum/6.2/hydraulic-design-hd-calculators/riprap-and-scour-calculator/scour-calculator-computing-launchable-volume/step-4-select-the-appropriate-equations

Hatcher Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing:

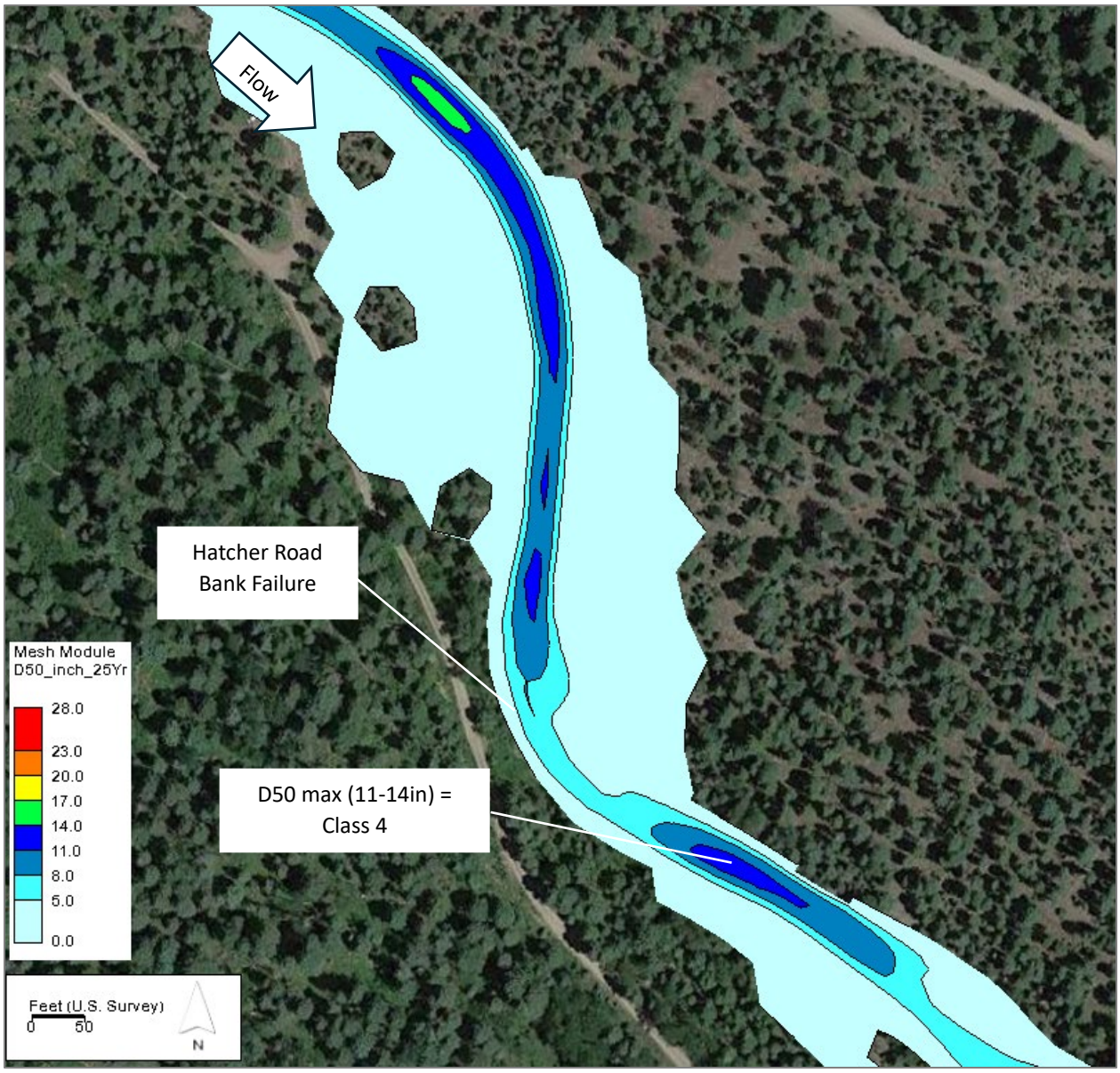
Bank Protection Sizing			
HEC-23 Eq 4.1 Parameters		**25 Year**	**50 Year**
Safety factor	S_f	1.2	1.2
Stability coefficient (Angular = 0.30, Rounded =0.375)	C_s	0.3	0.3
Radius of curvature	Rc (ft)	245	245
Width of water surface upstream	W(ft)	60.43	60.43
Rc/W		4.05	4.05
Velocity distribution coefficient	C_v	1.16	1.16
Bank slope (__:1V)	(__H:1V)	1.5	1.5
Bank Angle	t (deg)	33.69	33.69
Side slope correction factor	K_1	0.718	0.718
Specific gravity of riprap	Sg	2.65	2.65
Acceleration due to gravity	g (ft/s^2)	32.2	32.2

SMS Data Set Toolbox: Data Calculator Simplification	25 Year	50 Year
$A = 1.2S_fC_sC_v$	**0.502**	**0.502**
$B = K_1(S_g\text{-}1)g$	**38.145**	**38.145**

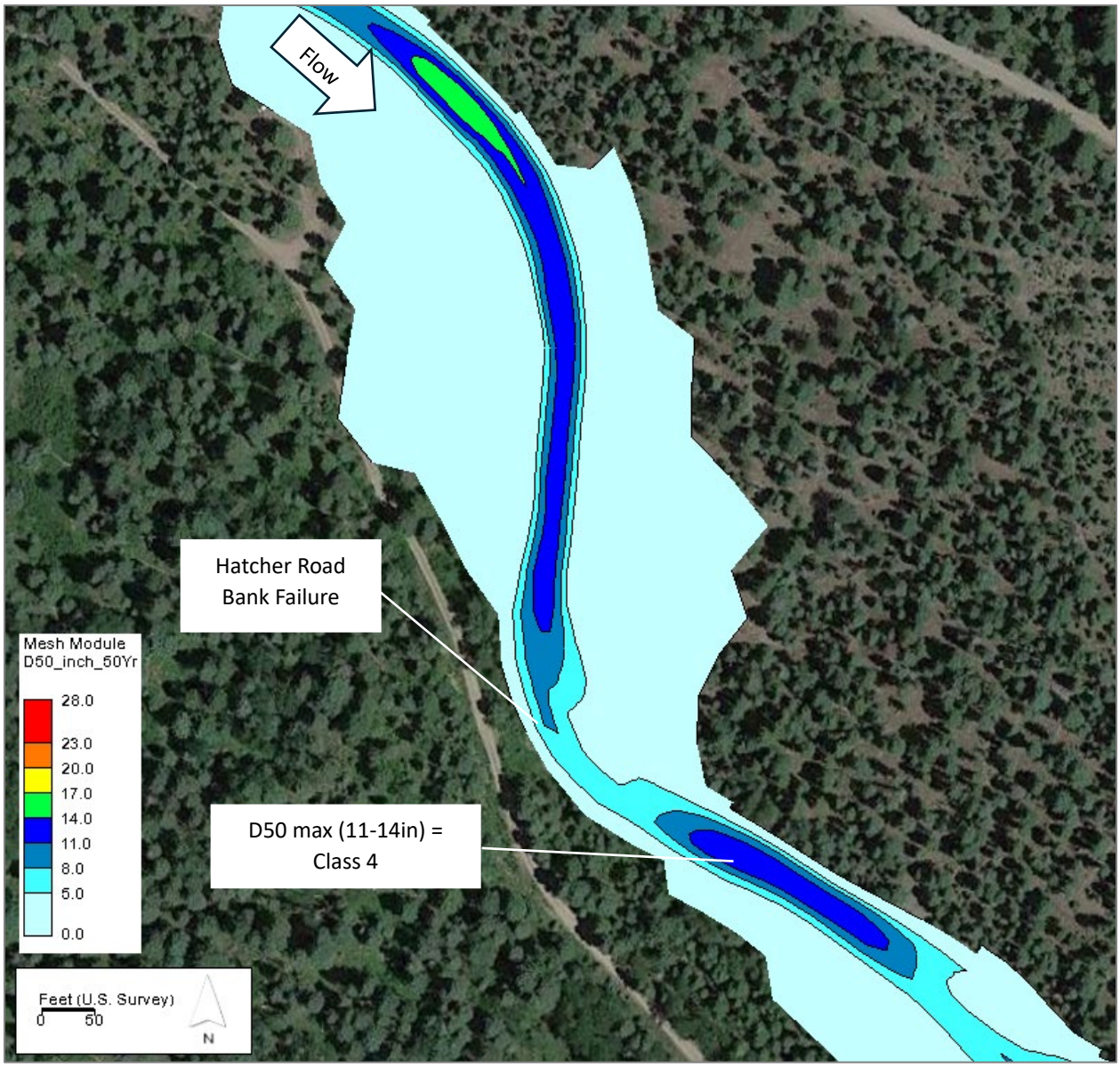
$$d_{50} = 1.2yS_fC_sC_v\left(\frac{V_{des}}{\sqrt{K_1(S_g-1)gy}}\right)^{2.5} \qquad d_{50} = Ay\left(\frac{V_{des}}{\sqrt{By}}\right)^{2.5}$$

SMS Data Calculator Equation:
12*0.502*d11*((d10/((38.145*d11)^0.5))^2.5)
Where:
d11 = SMS Water_Depth_ft dataset
d10 = SMS Vel_Mag_ft_p_s dataset

Hatcher Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing 25-Year:



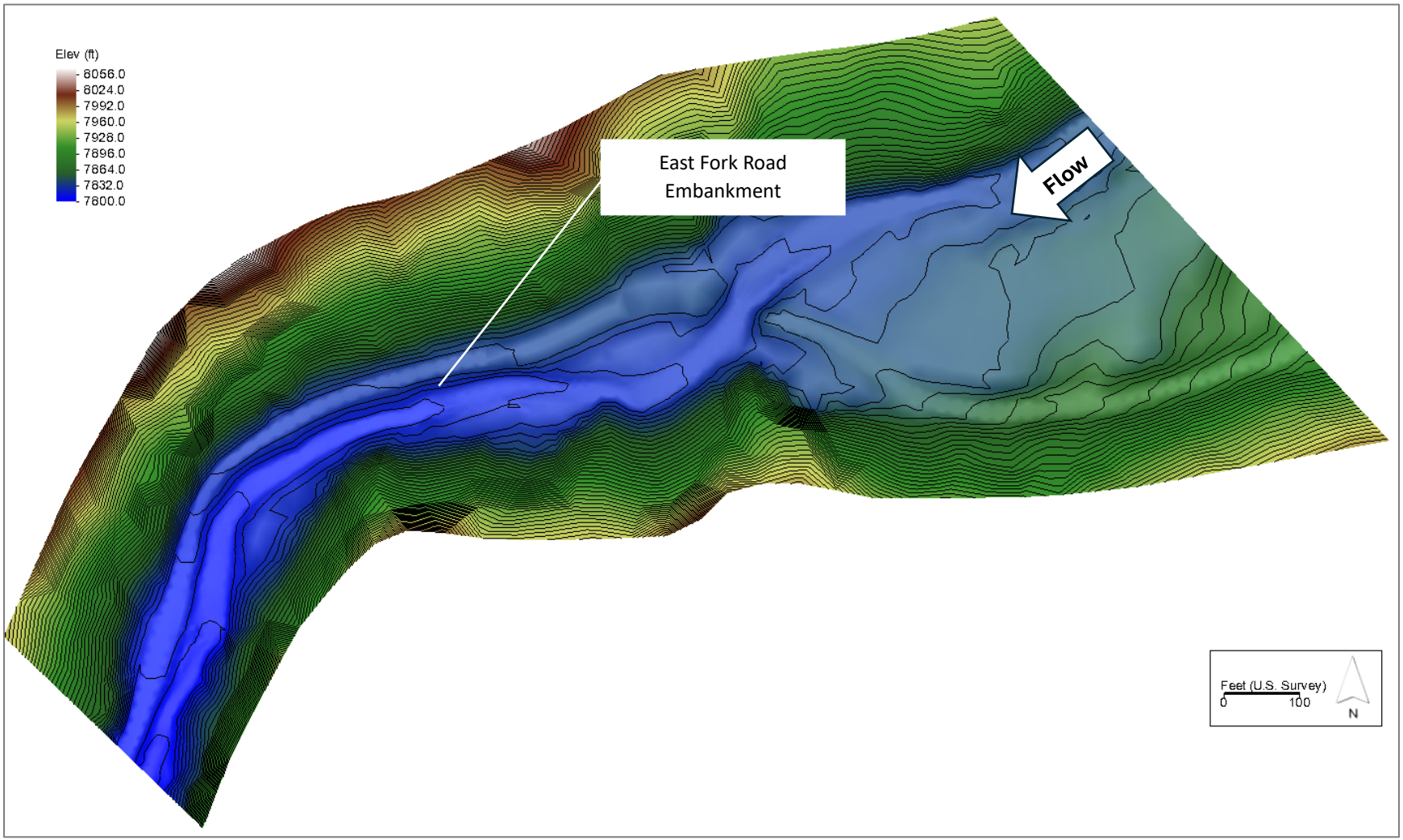
Hatcher Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing 50-Year:



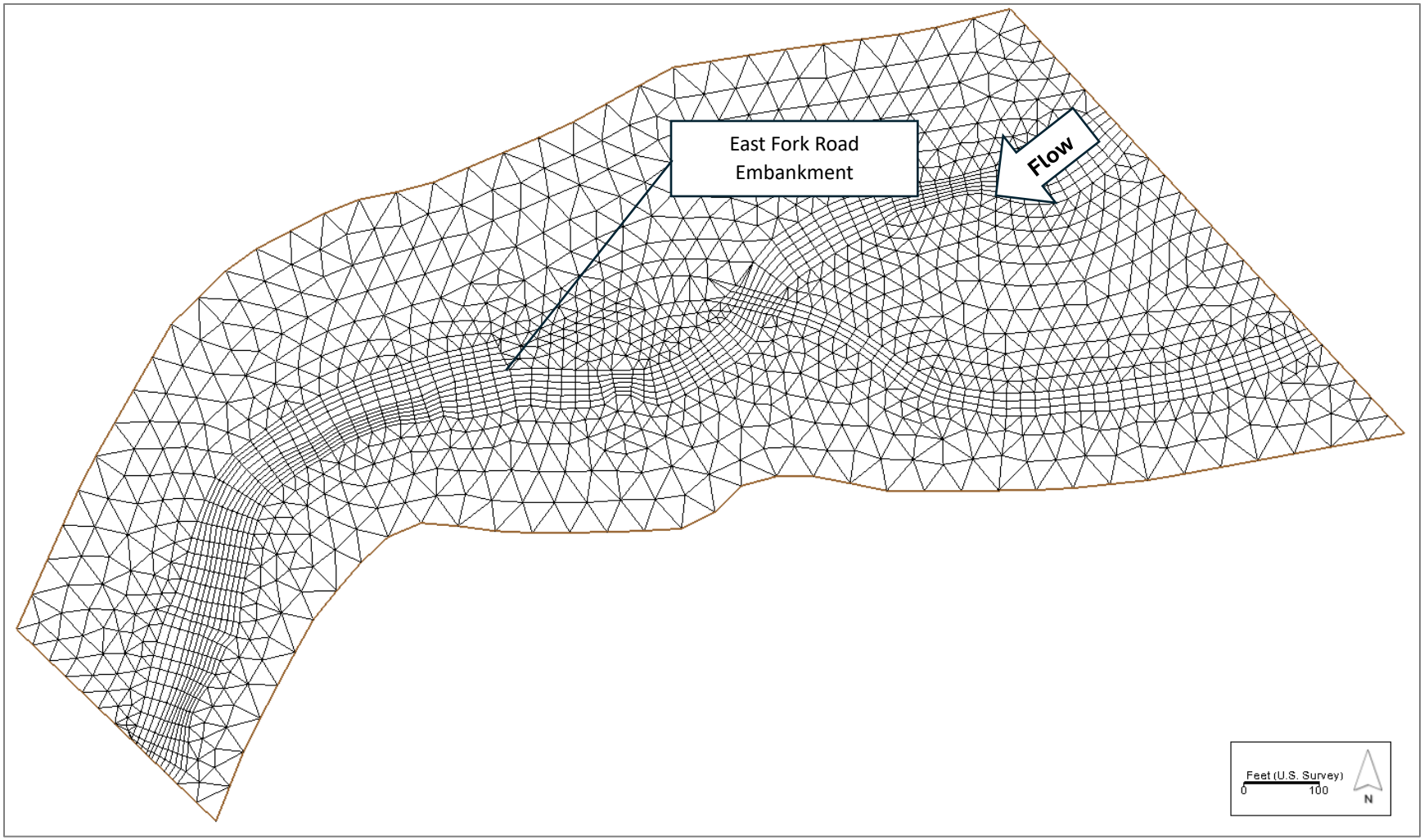
Appendix C-3

667 East Fork Road

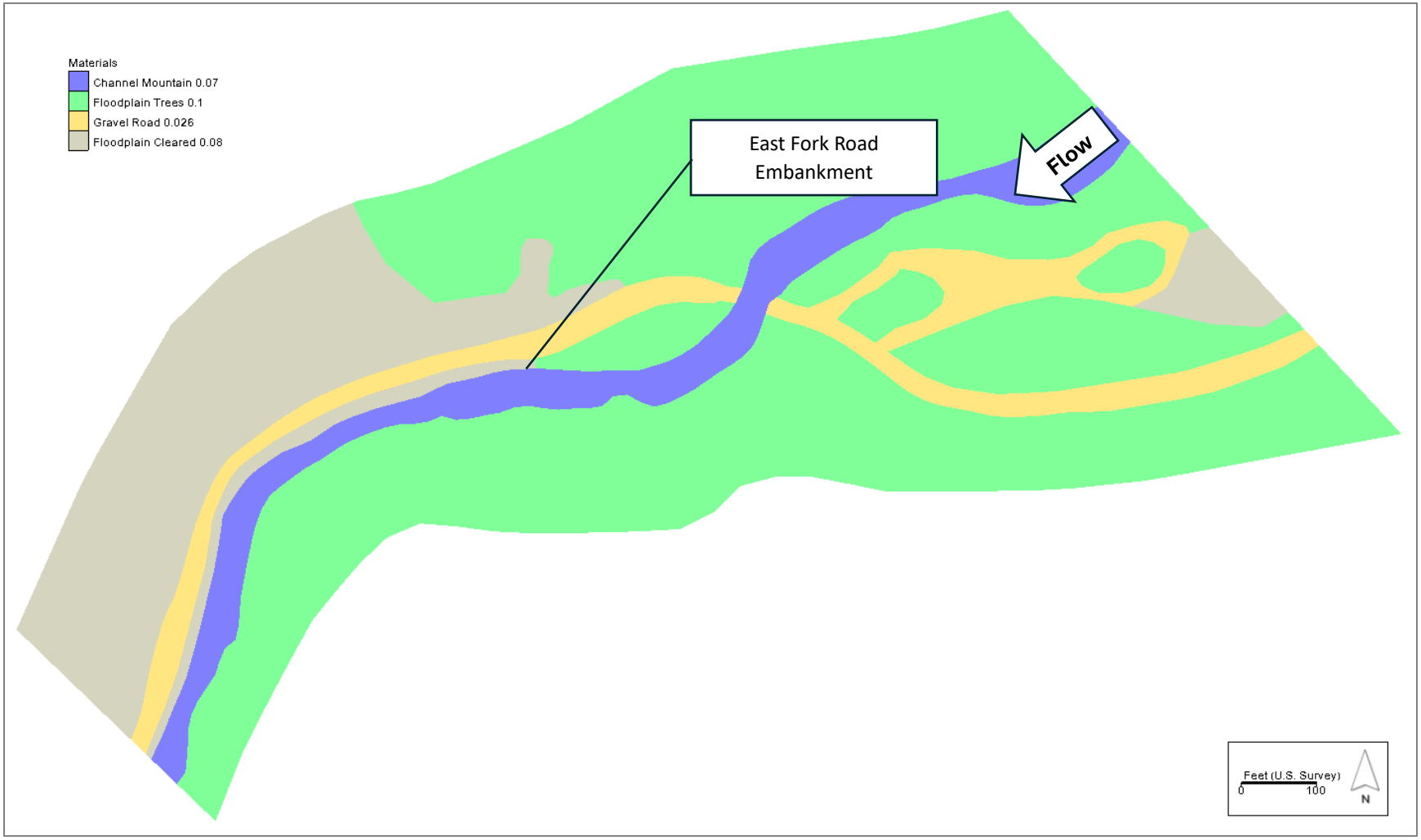
Topographic Surface:



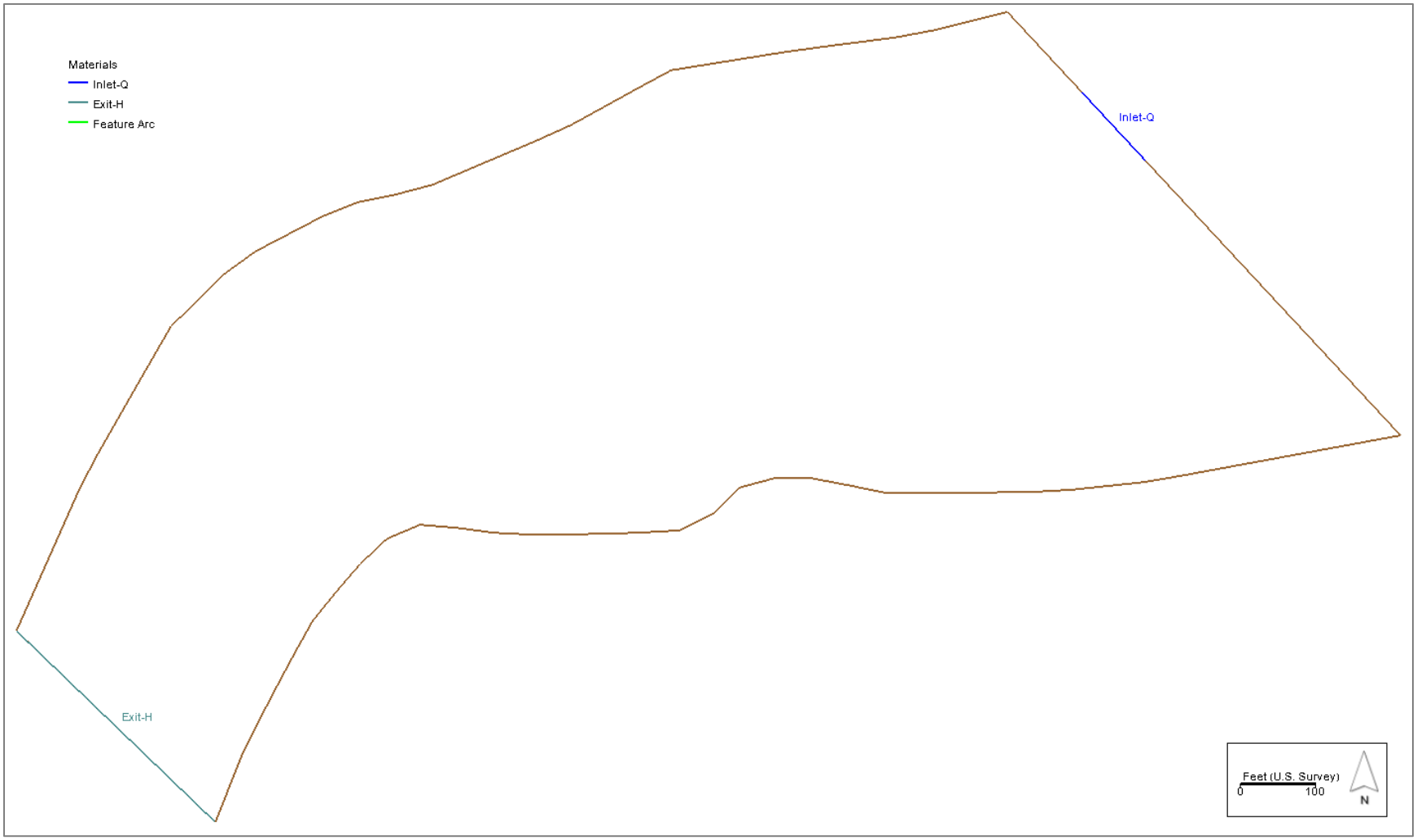
SRH-2D Mesh:



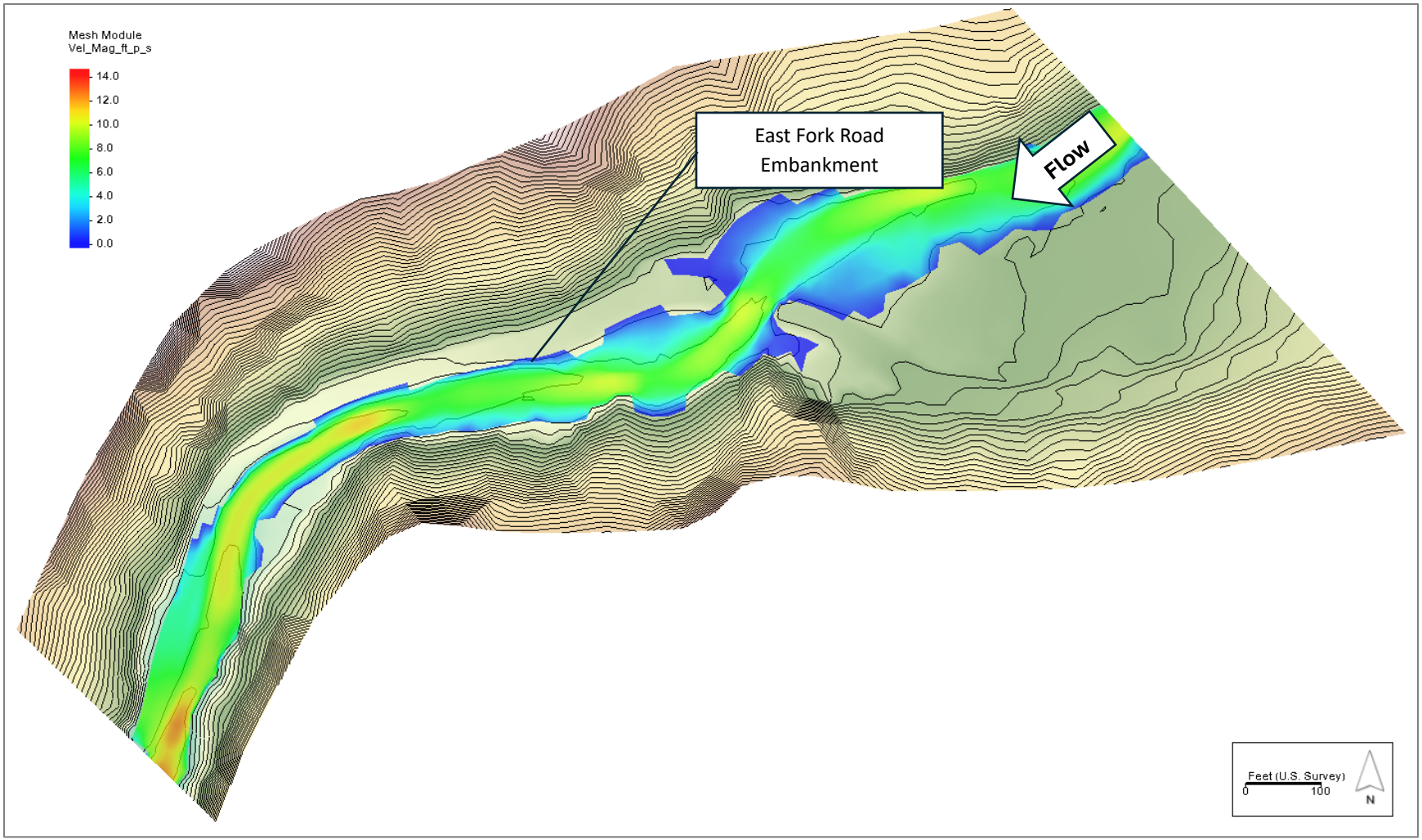
Materials (Manning's Roughness):



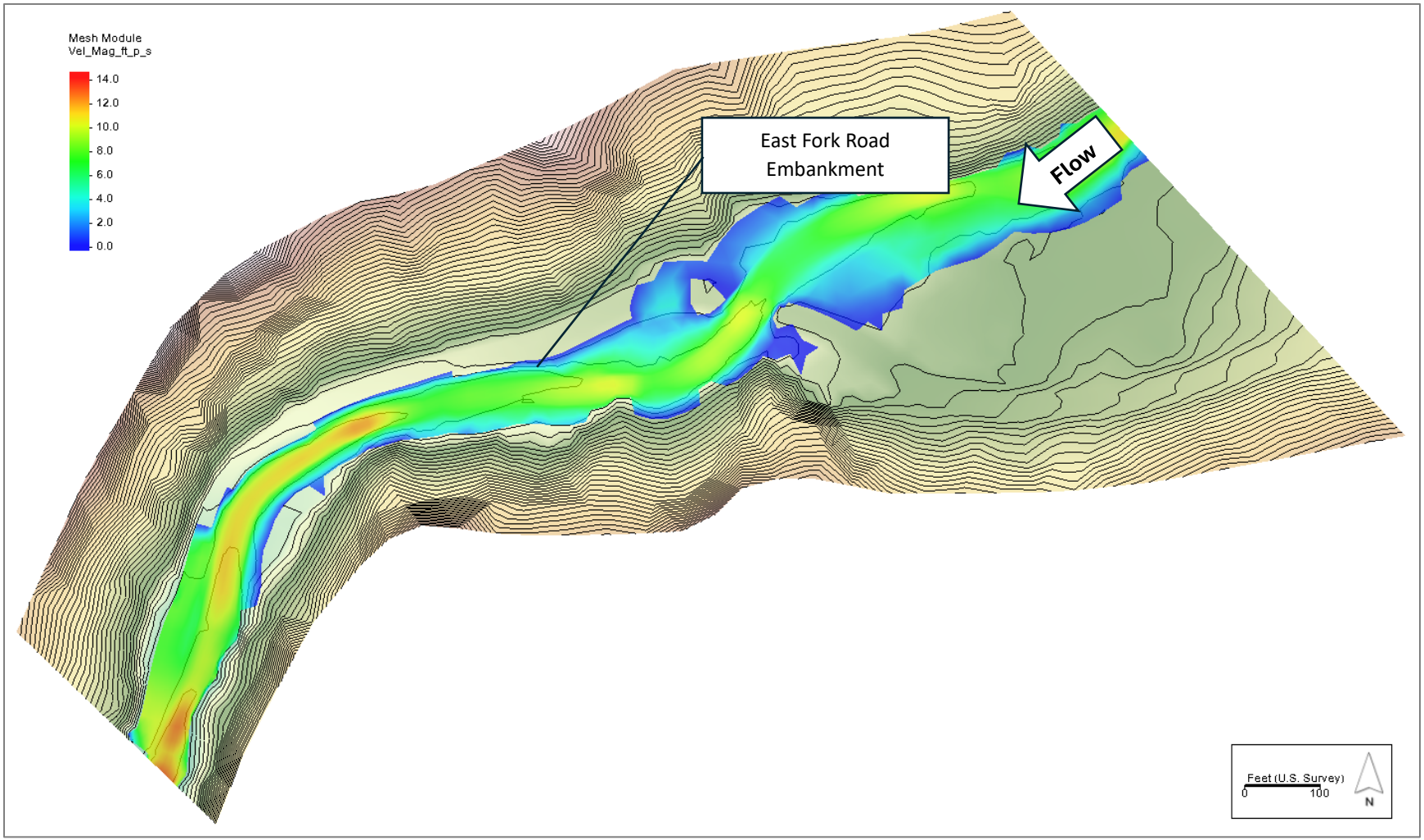
Boundary Conditions:



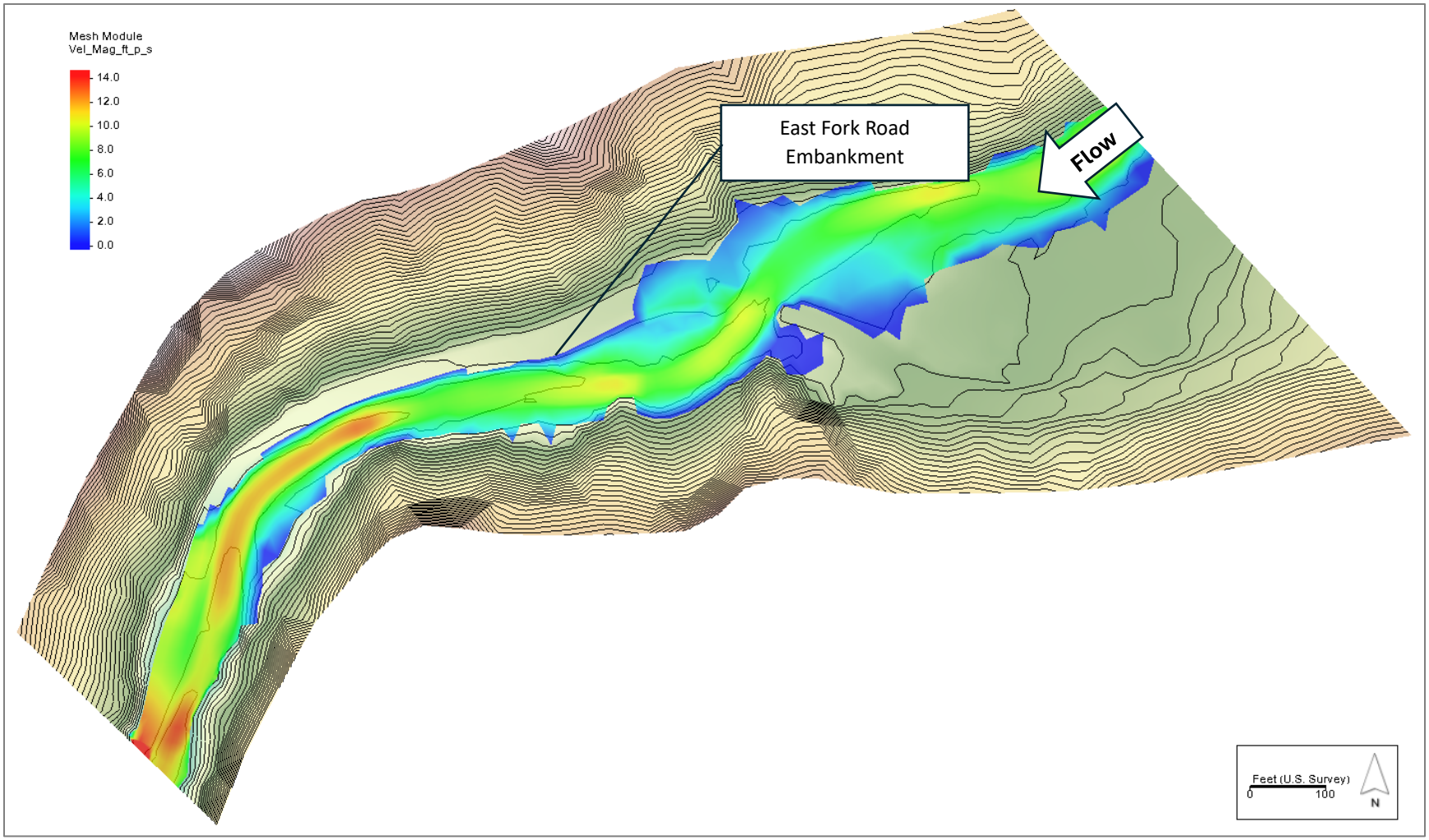
25-Year Velocity (ft/s):



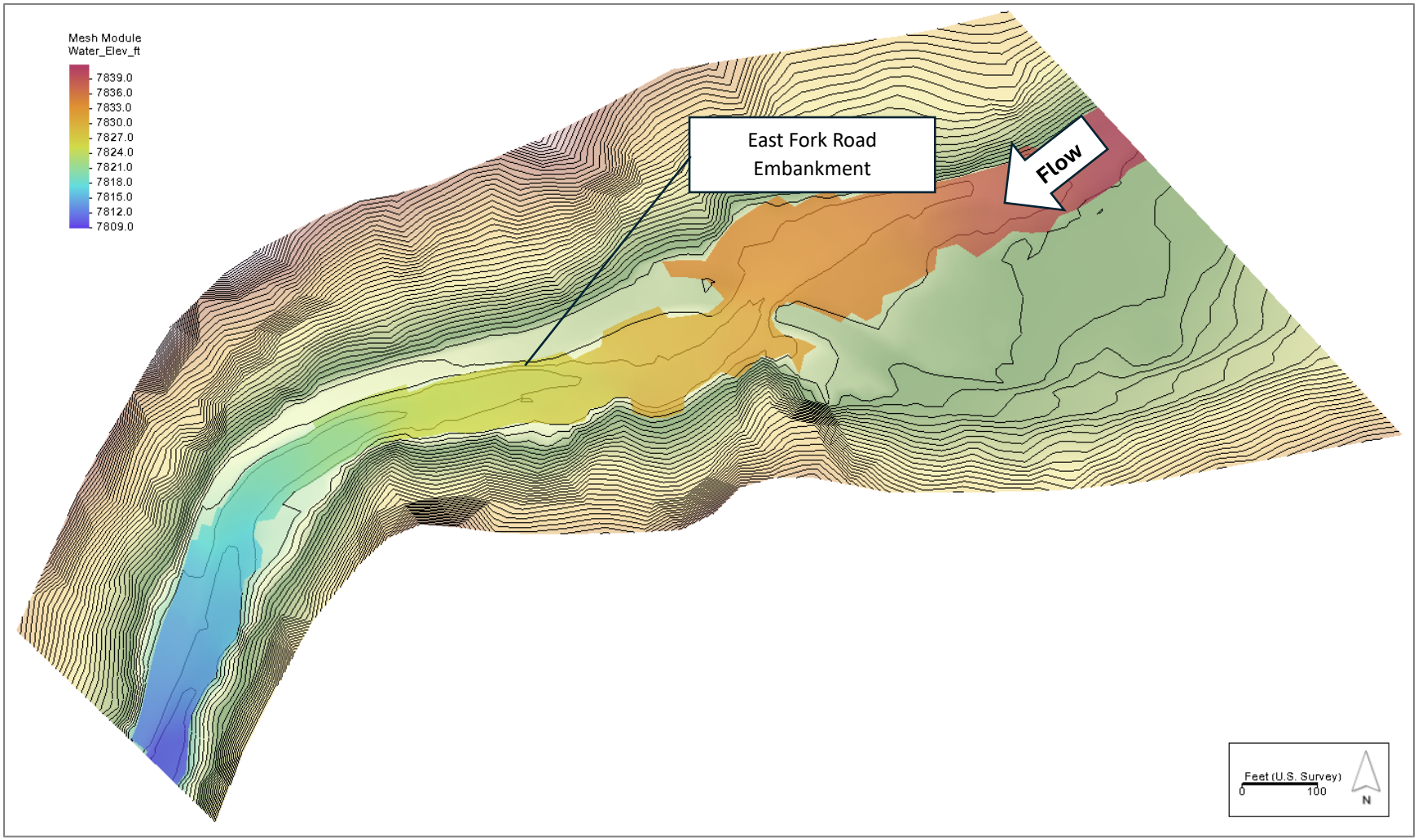
50-Year Velocity (ft/s):



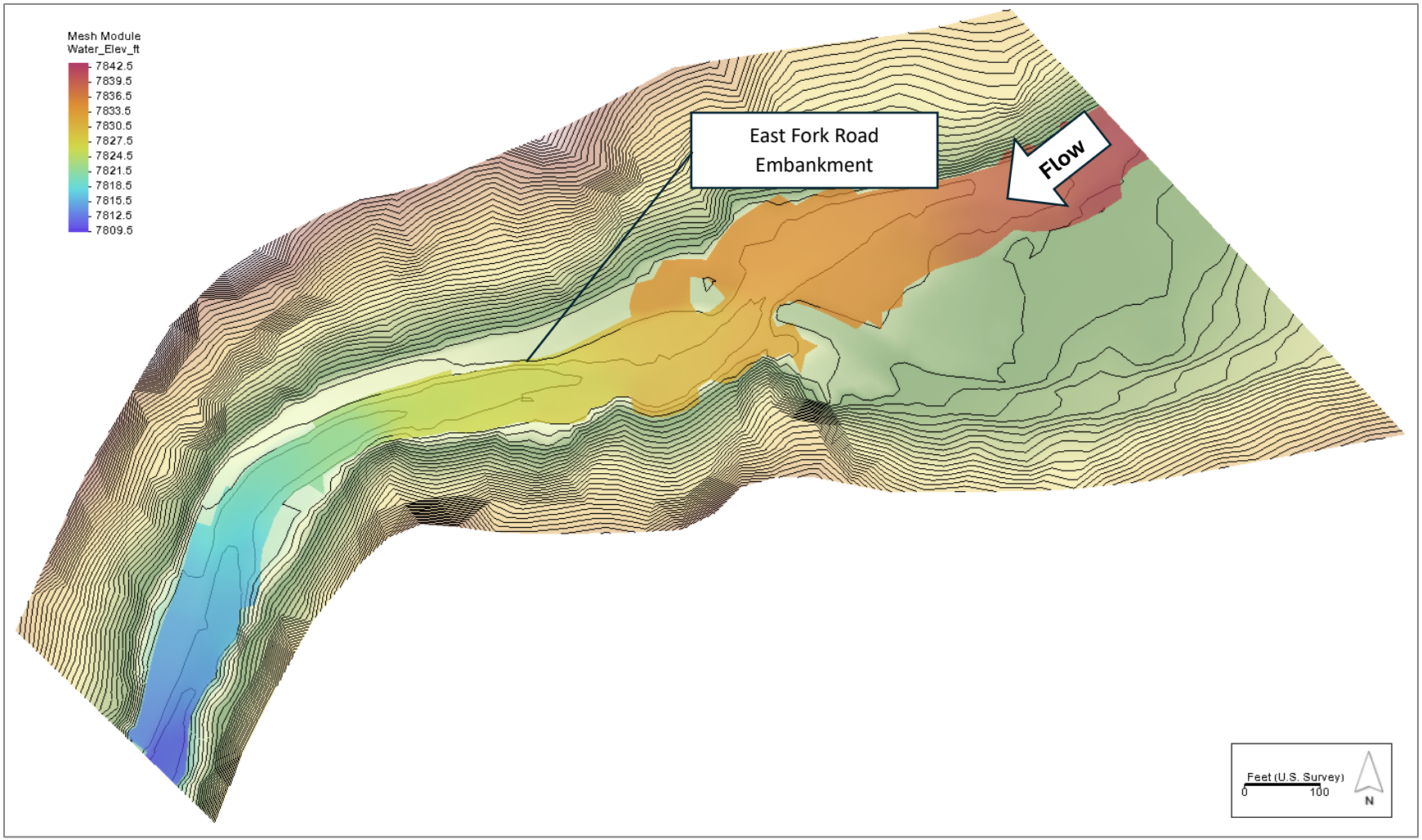
100-Year Velocity (ft/s):



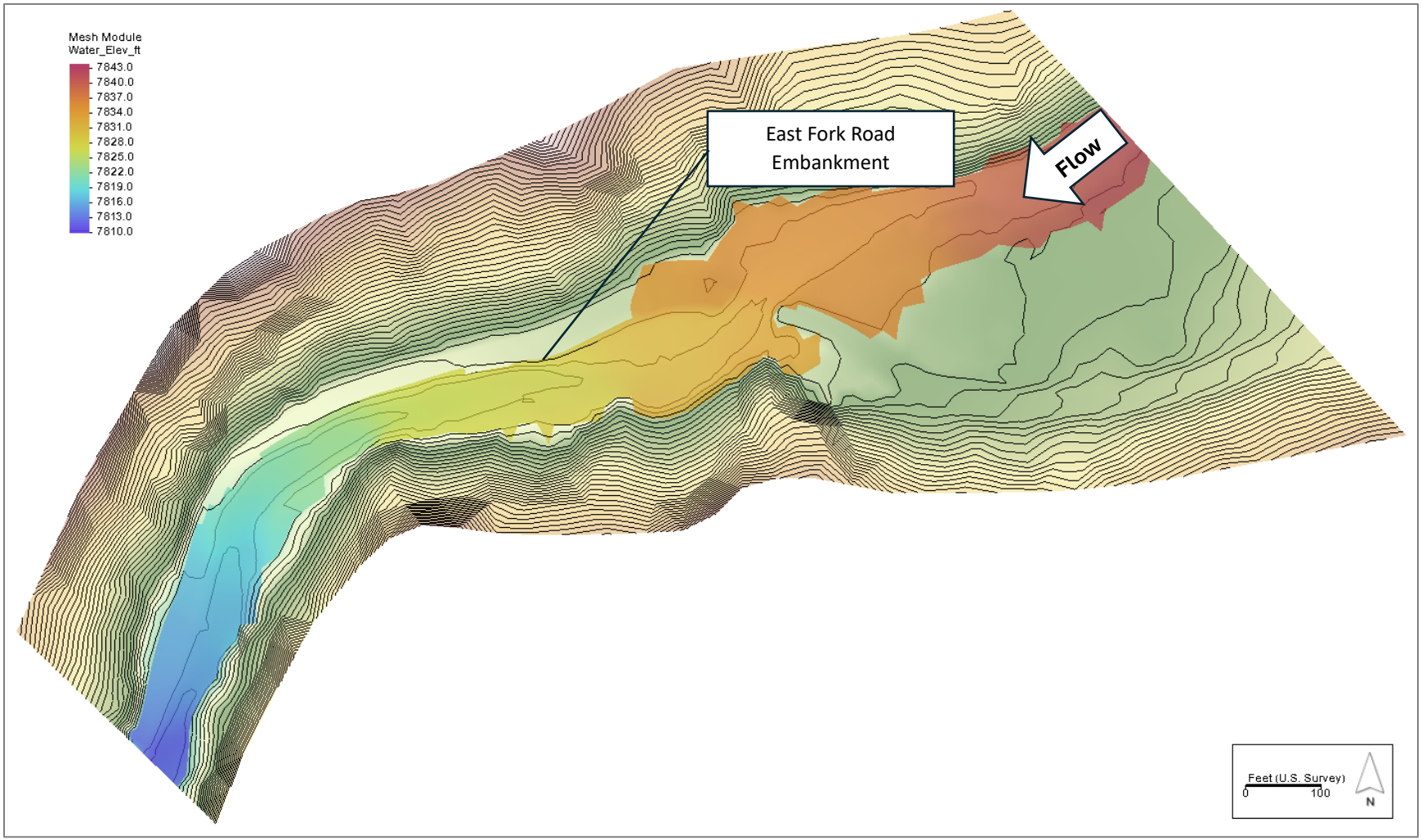
25-Year Water Surface Elevation (ft):



50-Year Water Surface Elevation (ft):



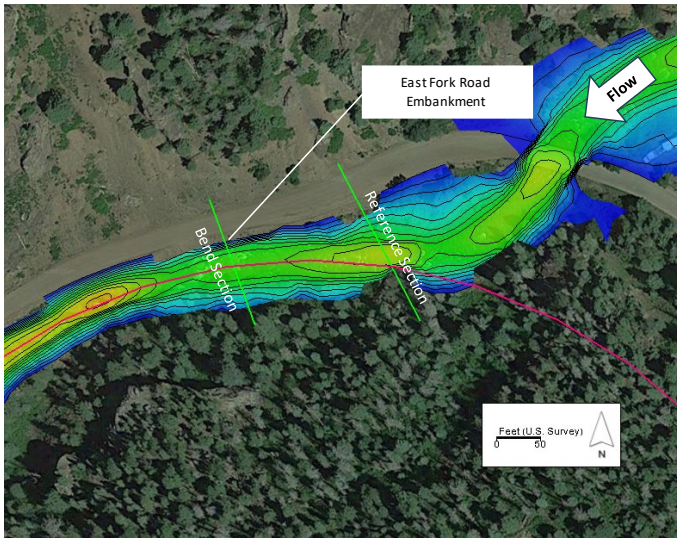
100-Year Water Surface Elevation (ft):



Bend Scour:

Bend Scour Estimates - East Fork Road

Parameters		25 Year	50 Year
Reference Hydraulic Depth	Dus (ft)	4.72	5.19
Bend Maximum Depth	Dmax (ft)	7.77	8.77
Bend Radius of Curvature	Rc (ft)	621.5	621.5
Reference Flow Width (within banks)	Wus (ft)	69.55	75.23
Rc/Wus	1.5 -10	8.94	8.26
Scour depth below reference section invert			
Maynord	Ys (ft)	2.2	2.6
USACE (Gravel)	Ys (ft)	0.9	1.0
Thorne	Ys (ft)	3.3	3.7
Scour depth below bend			
Maynord	Ys bend (ft)	-0.8	-0.5
USACE (Gravel)	Ys bend (ft)	-2.2	-2.0
Thorne	Ys bend(ft)	0.3	0.7
Maximum Scour		**0.3**	**0.7**
Average Scour		**-0.9**	**-0.6**



Method	Equation	Assumptions and Conditions
Maynord*	$\Delta y = \bar{D}_{US}\left(1.8 - 0.051\left(\frac{Rc}{W_{US}}\right) + 0.0084\left(\frac{W_{US}}{\bar{D}_{US}}\right)\right) - \bar{D}_{US}$	Sand bed S ≤ 2%, $1.5 < \frac{Rc}{W_{US}} < 10$** Recommends a safety factor of 1.0 to 1.19
USACE EM 1110-2-1601	$\Delta y = \begin{cases} \bar{D}_{US}\left(-1.51\log_{10}\left(\frac{Rc}{W}\right) + 3.37\right) - D_{Max}\ for\ sand \\ \bar{D}_{US}\left(-1.62\log_{10}\left(\frac{Rc}{W}\right) + 3.375\right) - D_{Max}\ for\ gravel \end{cases}$	This method uses much of the same data as Thorne
Zeller†	$\Delta y = \frac{0.0685 \cdot D_{US_Max} V_{US}^{0.8}}{D_{h_US}^{0.4} S_{US}^{0.3}} + \left(2.1\left(\frac{W}{4Rc}\right)^{0.2} - 1\right)$	Sand bed channels.
Thorne	$\Delta y = \bar{D}_{US}\left(2.07 - 0.19\ln\left(\frac{Rc}{W_{US}} - 2\right)\right) - \bar{D}_{US}$	Includes data from large sand bed rivers and smaller gravel-cobble systems $\frac{Rc}{W_{US}} < 2$

* For a factor of safety of 1. The method recommends a factor of safety between 1.0 and 1.19 based on the percentage of "significantly unconservative data".

**The algorithm has alternate forms for $\frac{Rc}{W_{US}} < 10$ and $\frac{Rc}{W_{US}} < 1.5$.

†This form replaces $\frac{\sin^2\frac{\alpha}{2}}{\cos\alpha}$ with the equivalent $\frac{W}{4Rc}$.

Where:

Δy is the scour depth below the initial channel invert
W is the flow width (within the banks)
W_{US} is the flow width (within the banks) at the upstream, reference cross section
R_c is the radius of curvature
D is depth. Depth takes several forms in these equations including:
D_h, the hydraulic depth, which is the area divided by the top width
$\bar{D}_{US}$, the average cross section depth at the upstream, reference cross section, but is often approximated with D_h and
D_{Max}, the maximum cross section depth before scour at the evaluation cross section.

East Fork Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing:

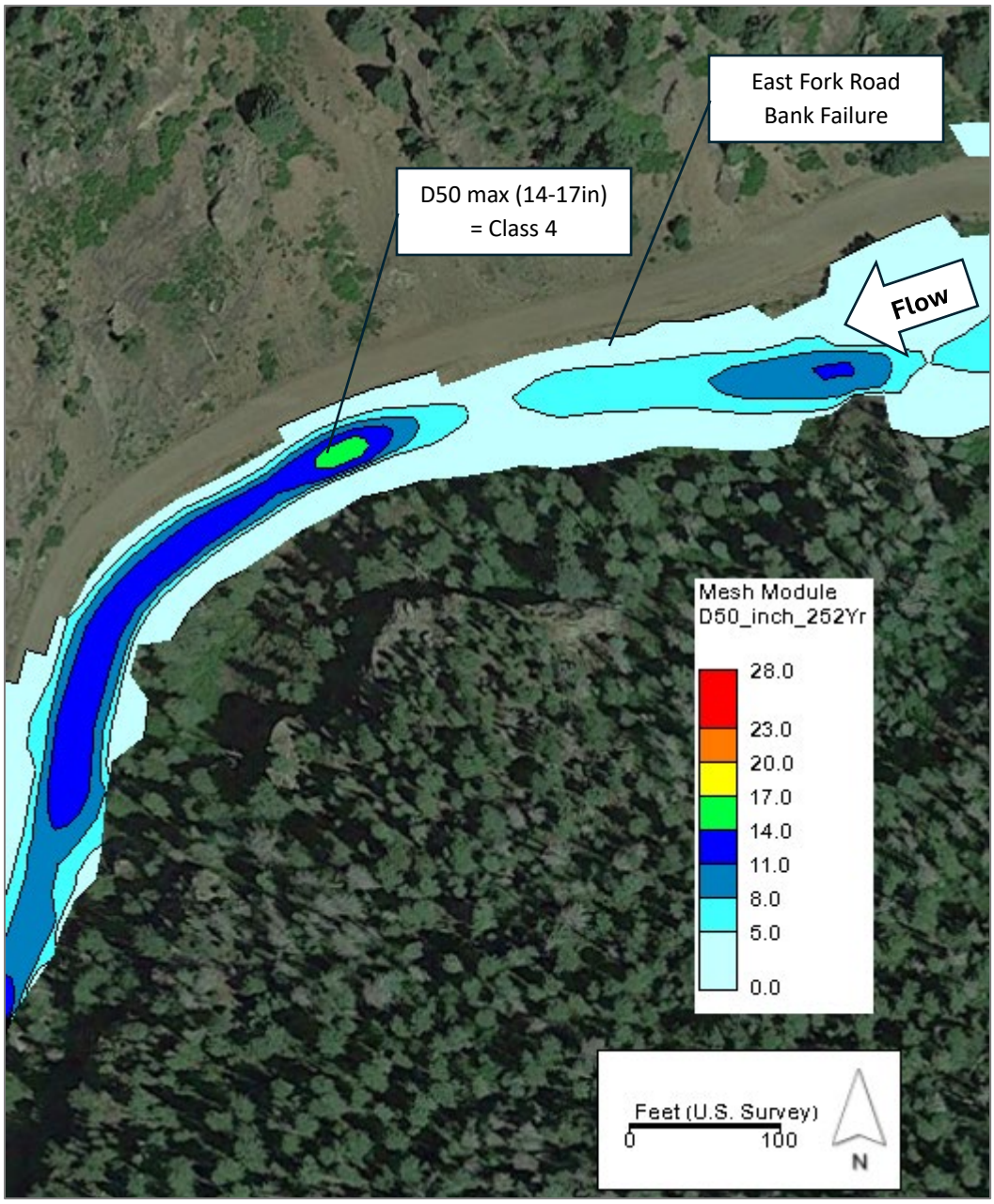
Bank Protection Sizing			
HEC-23 Eq 4.1 Parameters		**25 Year**	**50 Year**
Safety factor	S_f	1.2	1.2
Stability coefficient (Angular = 0.30, Rounded =0.375)	C_s	0.3	0.3
Radius of curvature	Rc (ft)	621.5	621.5
Width of water surface upstream	W(ft)	69.55	75.23
Rc/W		8.94	8.26
Velocity distribution coefficient	C_v	1.09	1.10
Bank slope (__:1V)	(__H:1V)	1.5	1.5
Bank Angle	t (deg)	33.69	33.69
Side slope correction factor	K_1	0.718	0.718
Specific gravity of riprap	Sg	2.65	2.65
Acceleration due to gravity	g (ft/s^2)	32.2	32.2

SMS Data Set Toolbox: Data Calculator Simplification	25 Year	50 Year
$A = 1.2S_fC_sC_v$	**0.472**	**0.475**
$B = K_1(S_g\text{-}1)g$	**38.145**	**38.145**

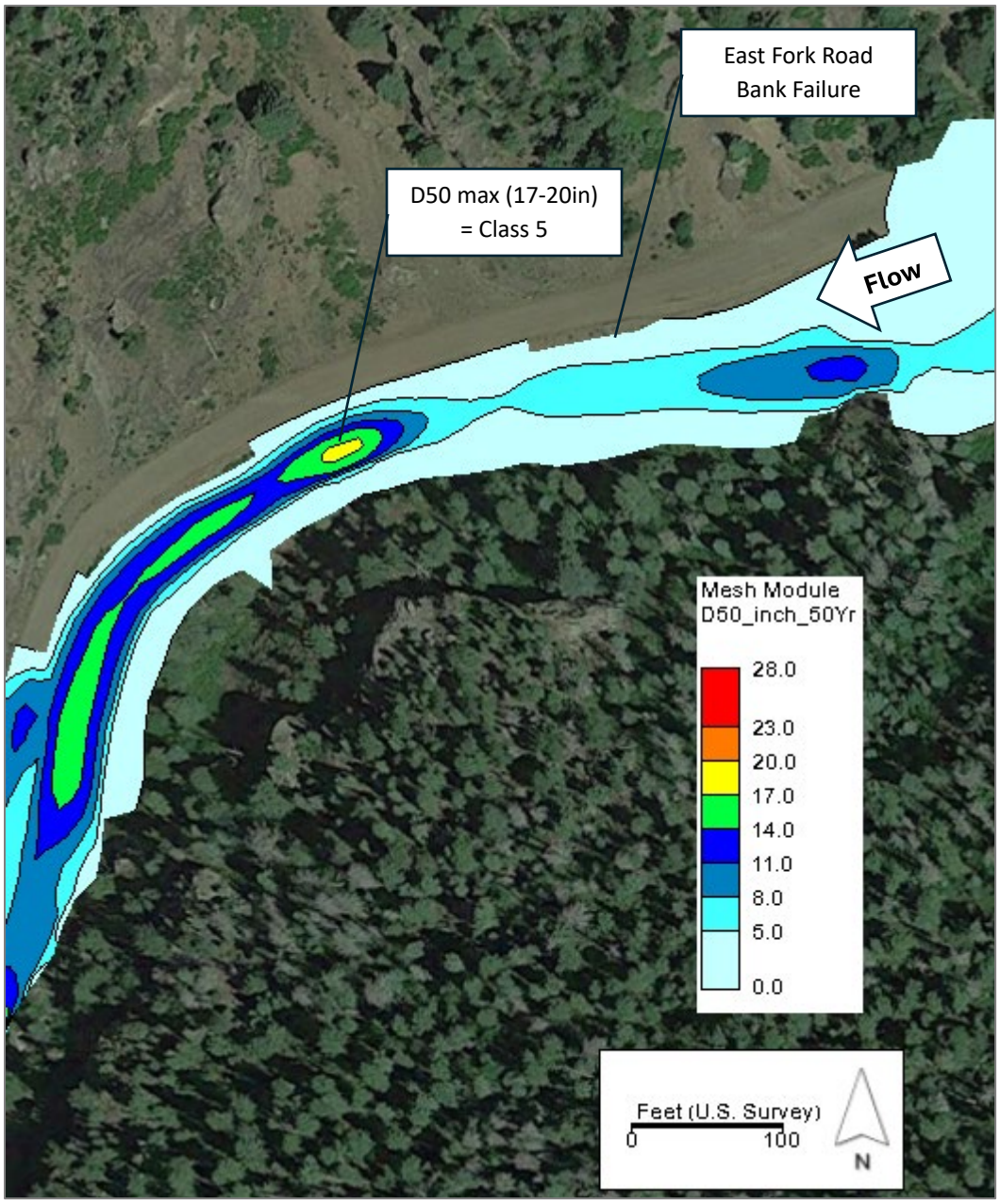
$$d_{50} = 1.2yS_fC_sC_v\left(\frac{V_{des}}{\sqrt{K_1(S_g-1)gy}}\right)^{2.5} \qquad d_{50} = Ay\left(\frac{V_{des}}{\sqrt{By}}\right)^{2.5}$$

SMS Data Calculator Equation:
12*0.475*d11*((d10/((38.145*d11)^0.5))^2.5)
Where:
d11 = SMS Water_Depth_ft dataset
d10 = SMS Vel_Mag_ft_p_s dataset

East Fork Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing 25-Year:



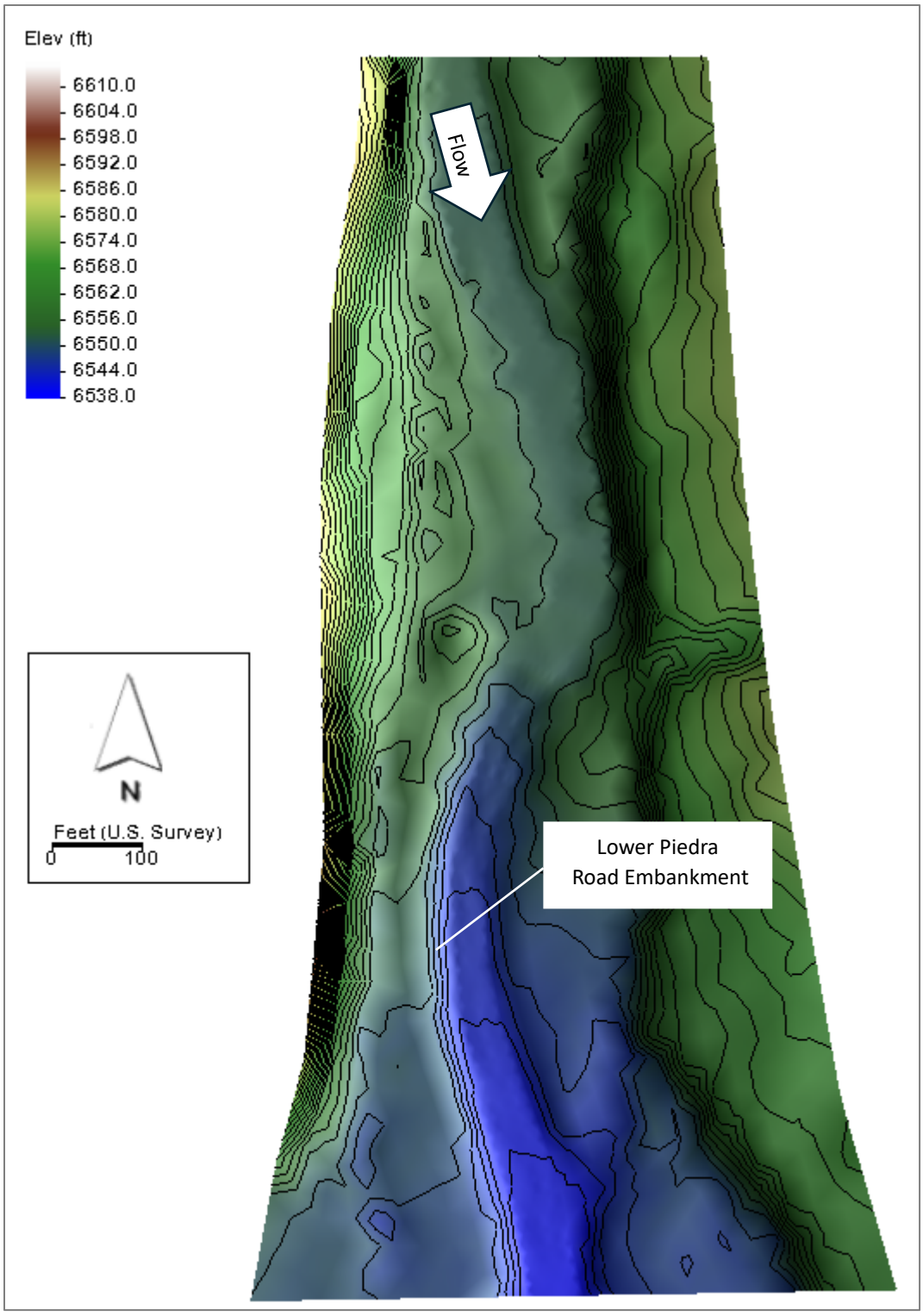
East Fork Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing 50-Year:



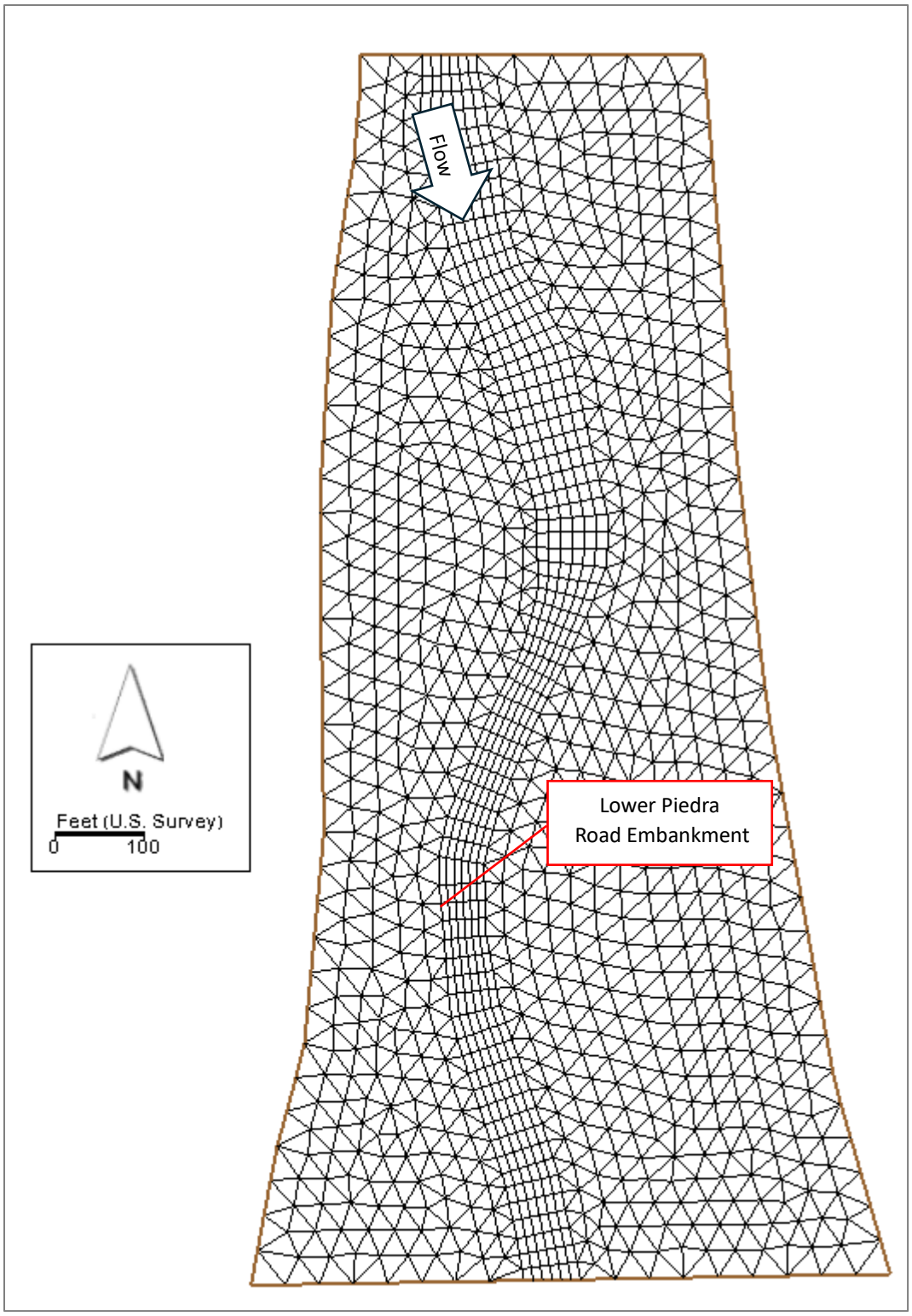
Appendix C-4

621 Lower Piedra Road

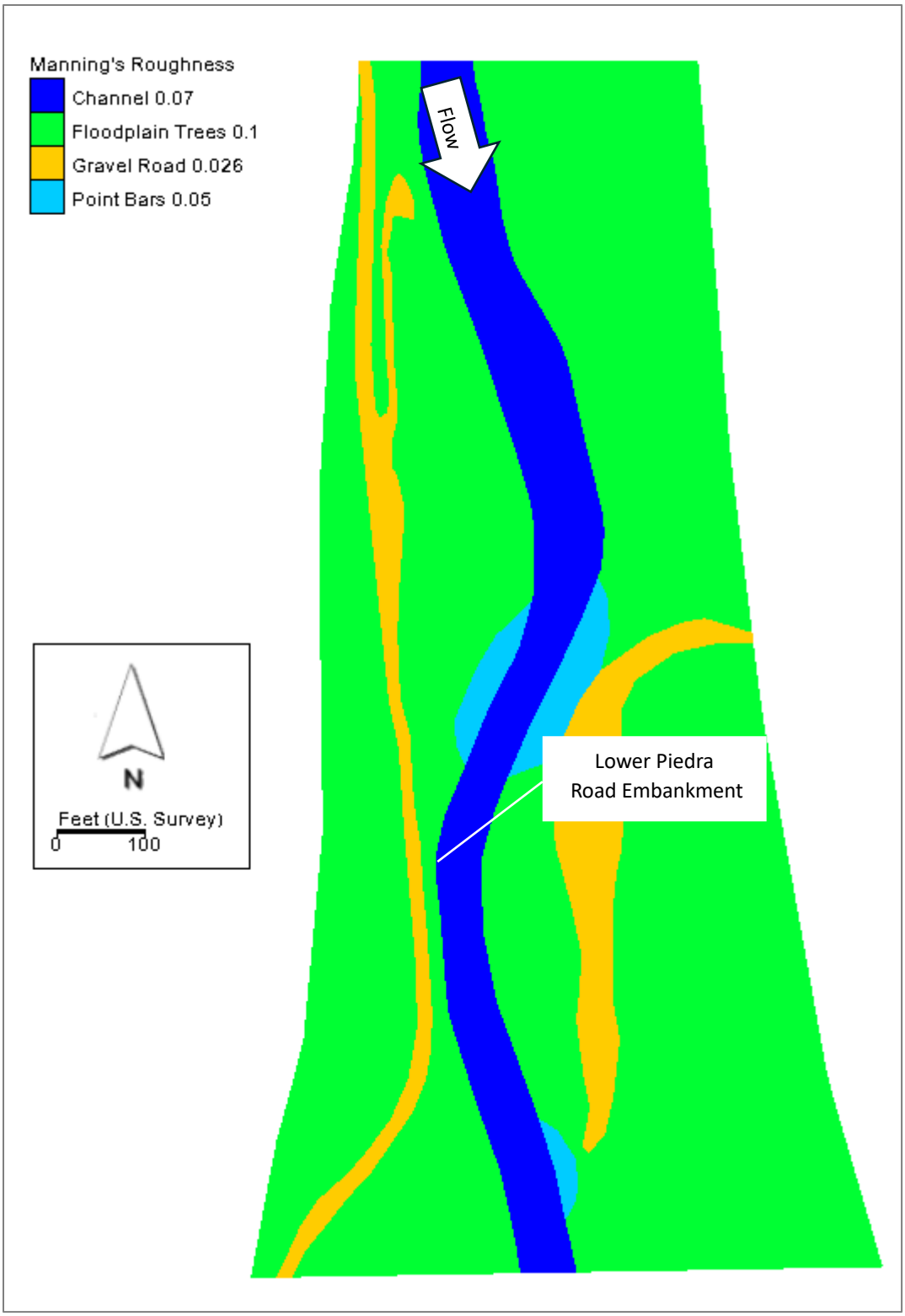
Topographic Surface (LIDAR-Only):



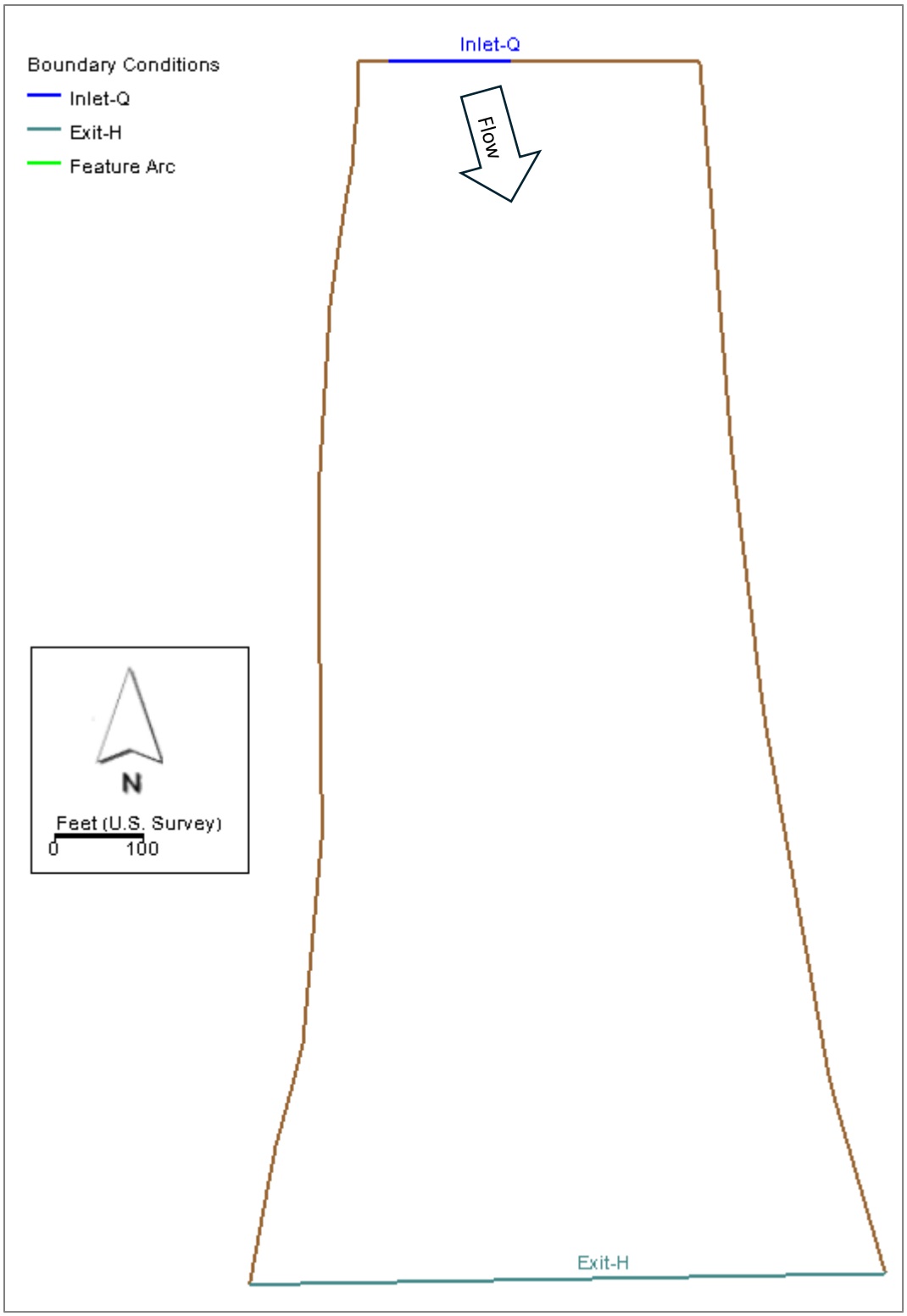
SRH-2D Mesh:



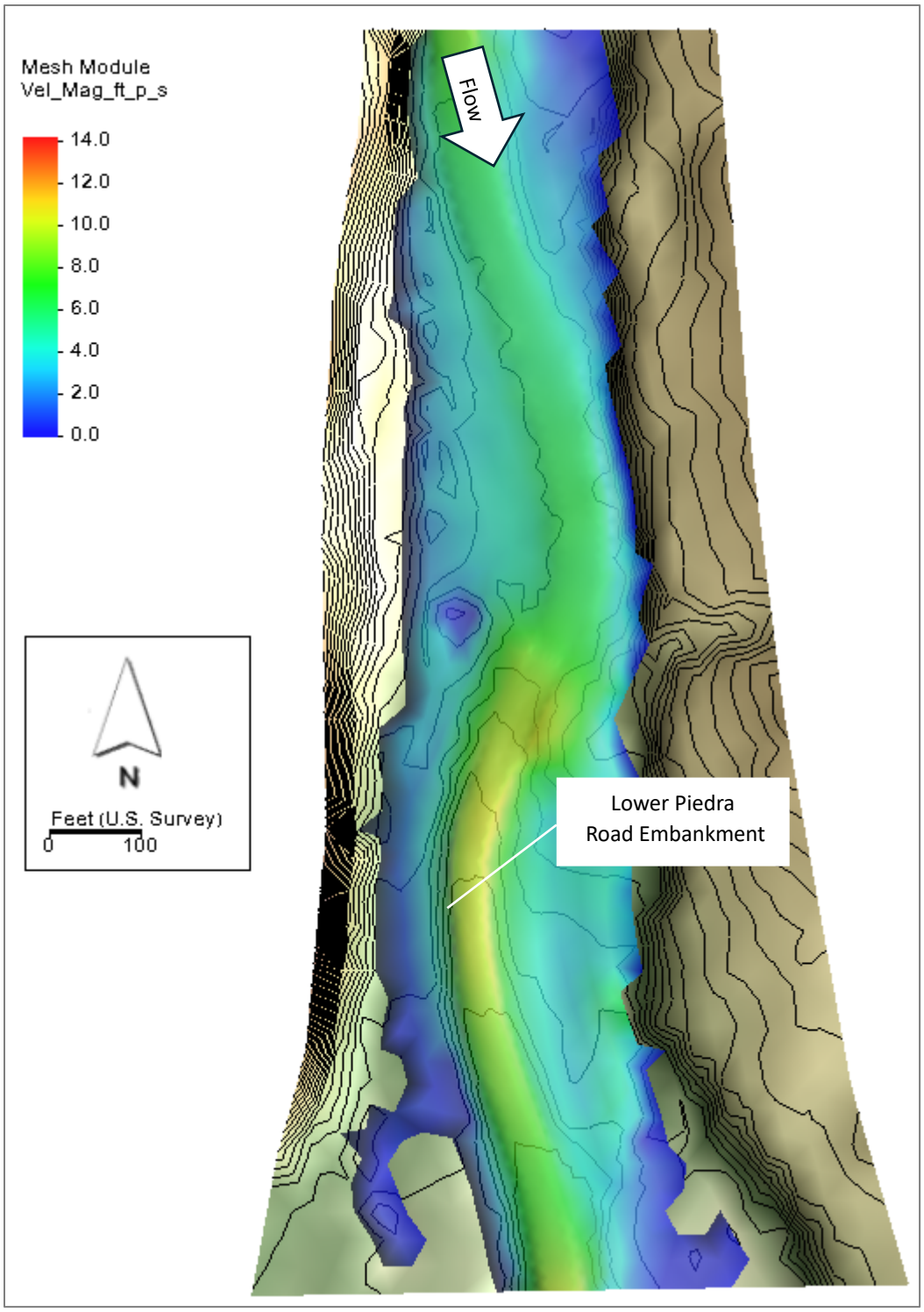
Materials (Manning's Roughness):



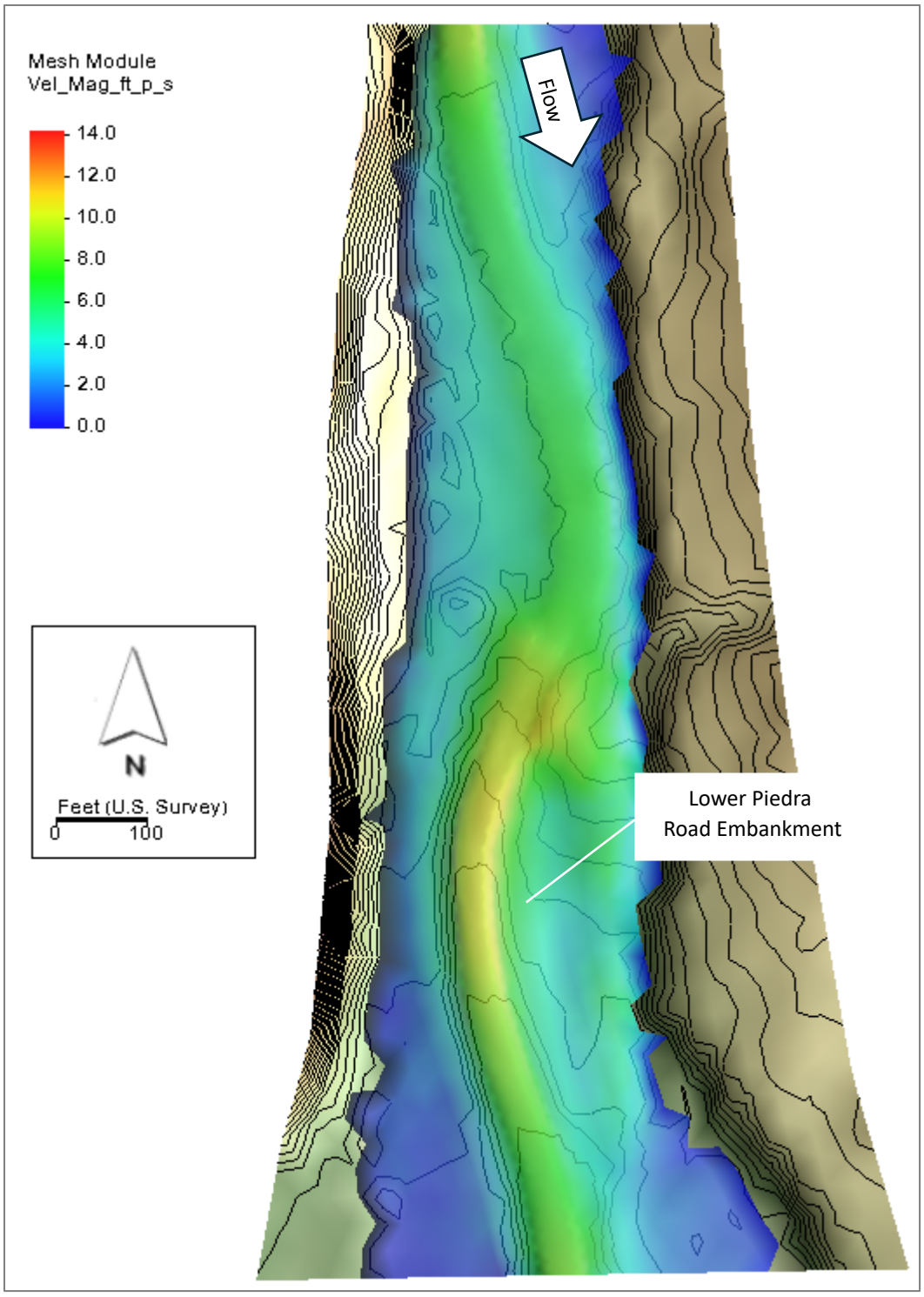
Boundary Conditions:



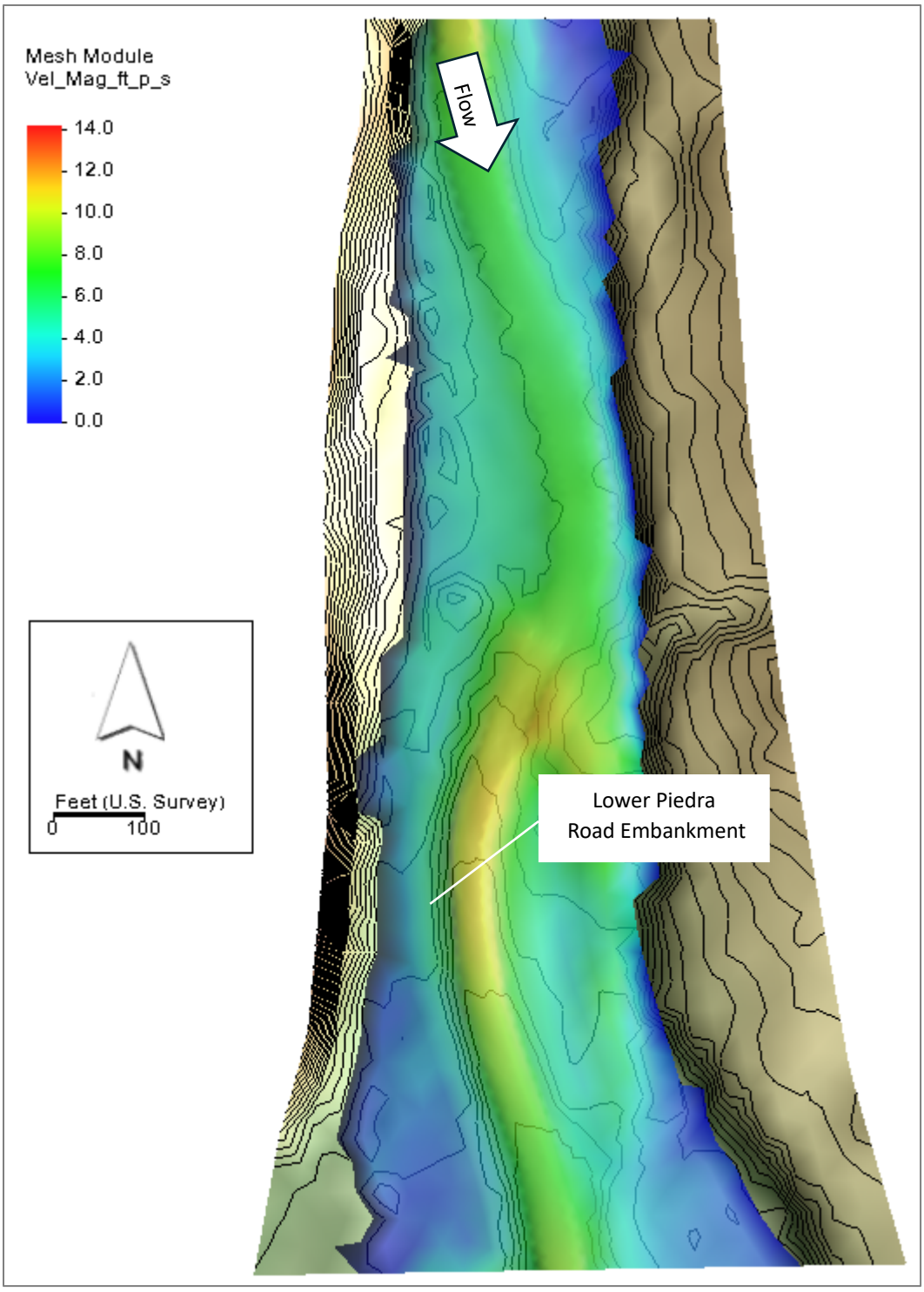
25-Year Velocity (ft/s) (LIDAR-Only):



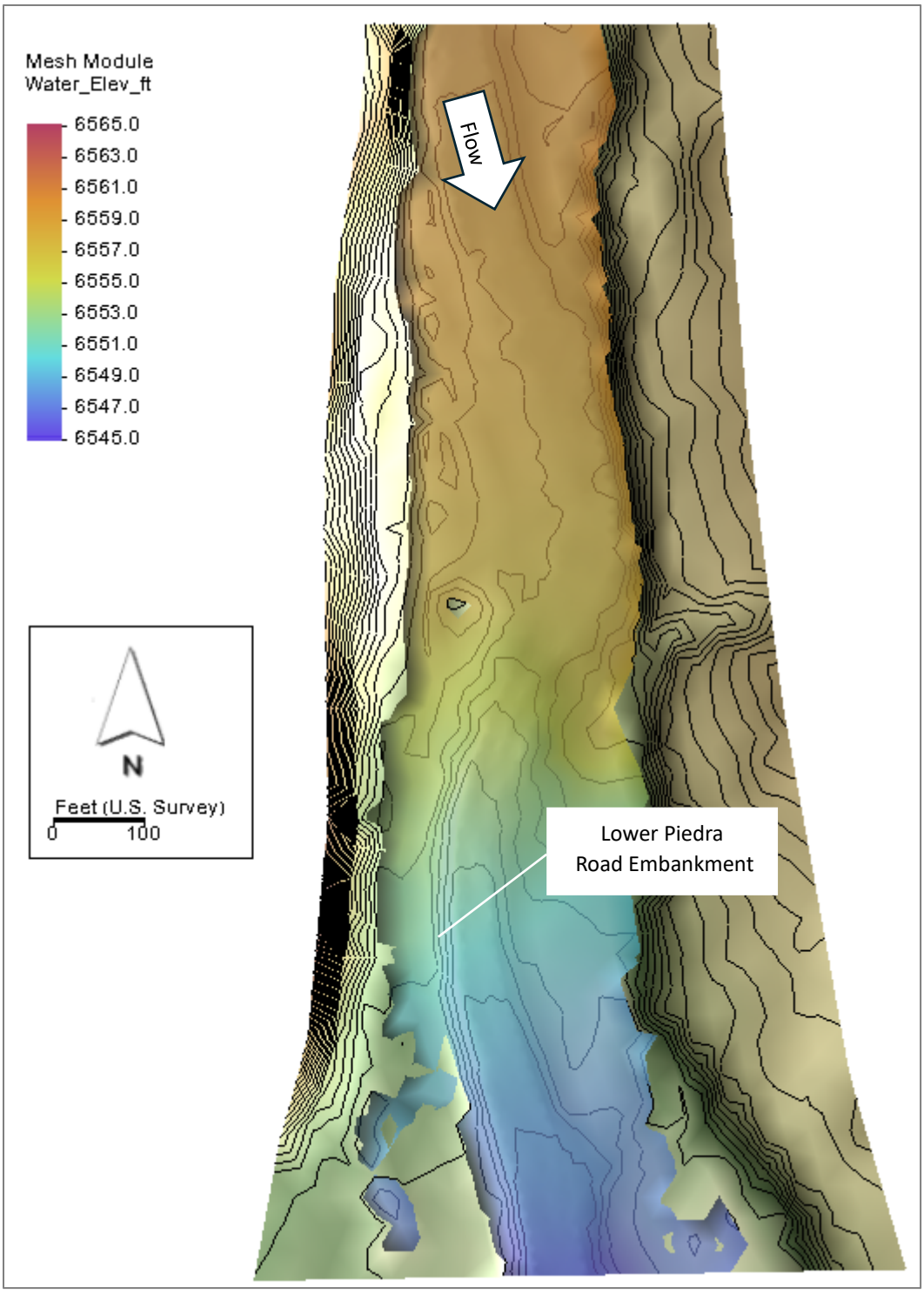
50-Year Velocity (ft/s) (LIDAR-Only):



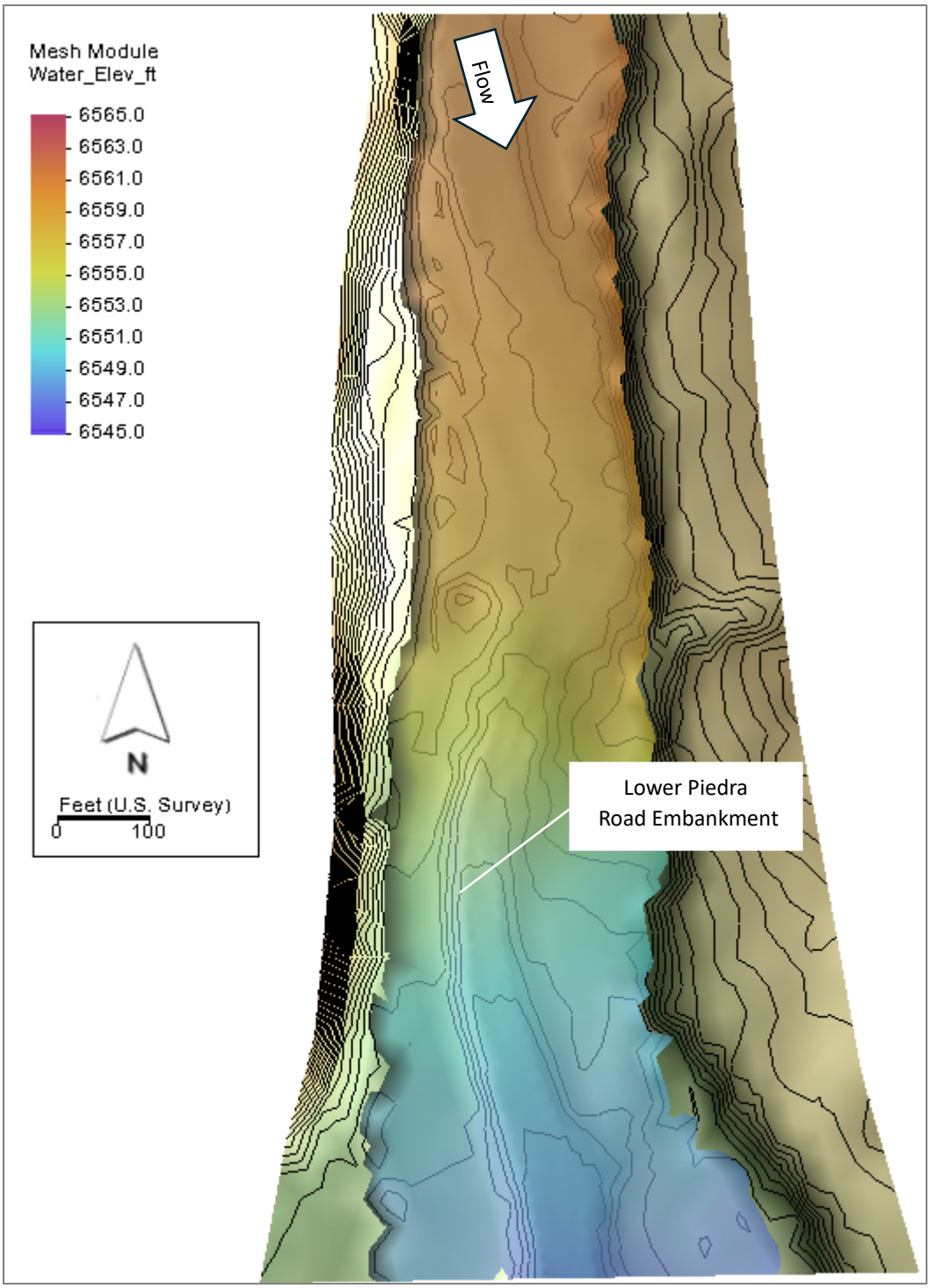
100-Year Velocity (ft/s) (LIDAR-Only):



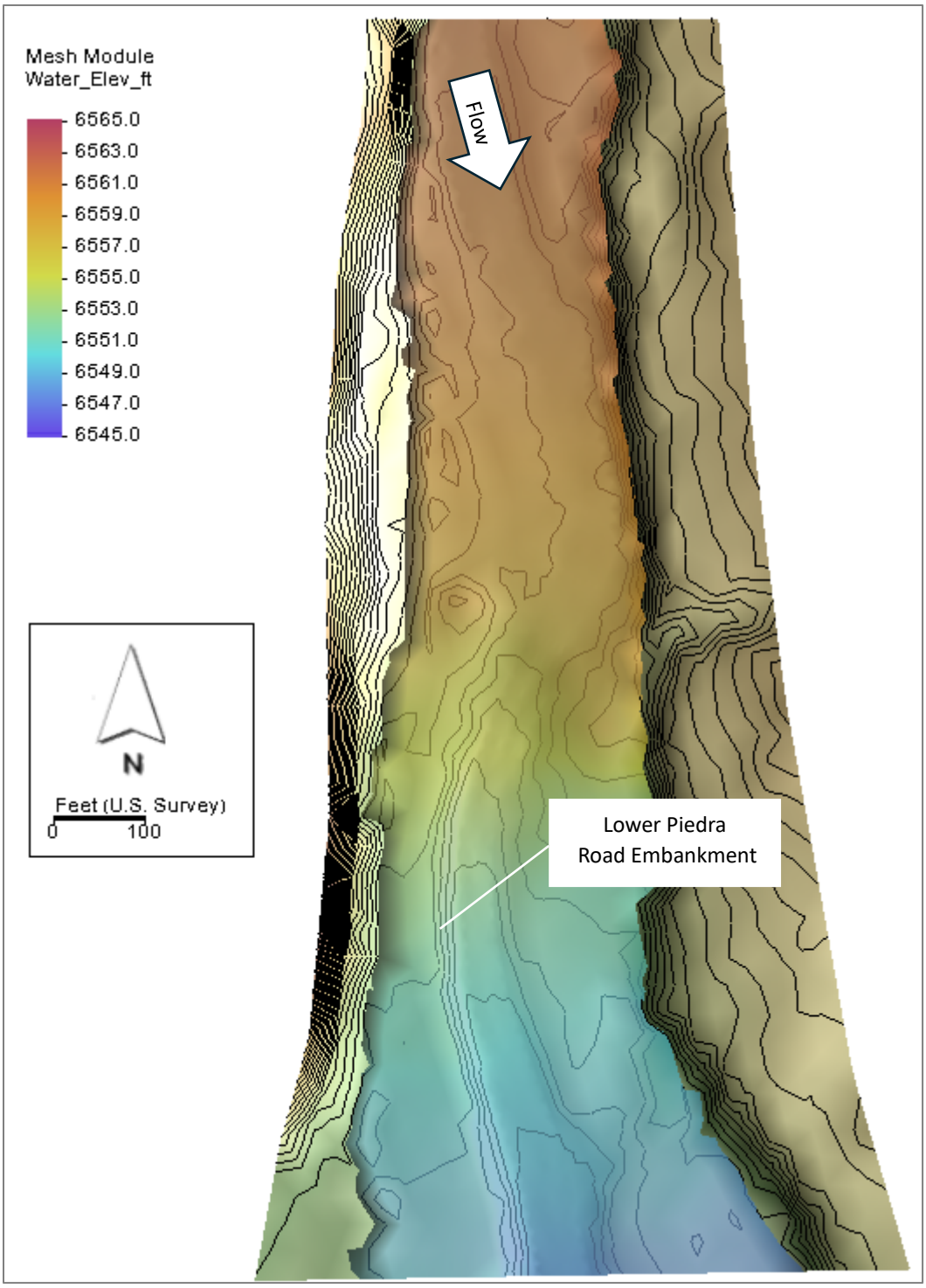
25-Year Water Surface Elevation (ft) (LIDAR-Only):



50-Year Water Surface Elevation (ft) (LIDAR-Only):



100-Year Water Surface Elevation (ft) (LIDAR-Only):

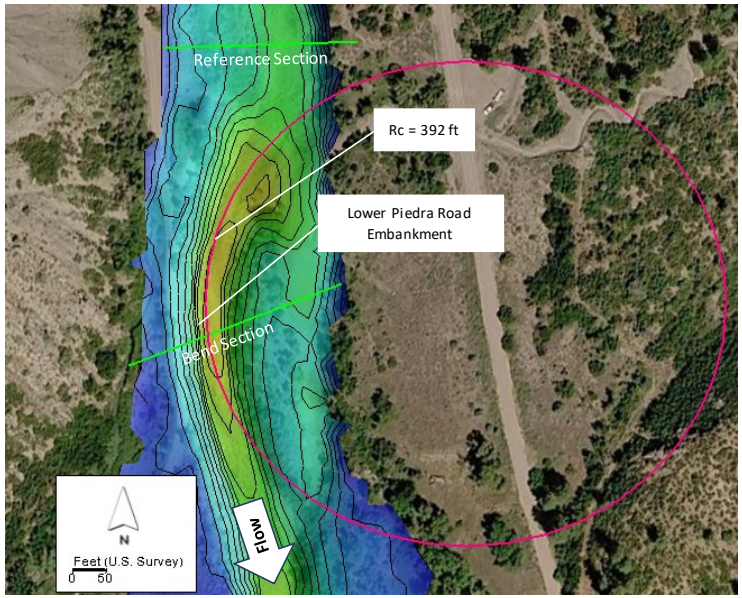


Bend Scour:

Bend Scour Estimates - Lower Piedra Road

Parameters		25 Year	50 Year
Reference Hydraulic Depth	Dus (ft)	6.67	7.23
Bend Maximum Depth	Dmax (ft)	7.59	8.22
Bend Radius of Curvature	Rc (ft)	392	392
Reference Flow Width (within banks)	Wus (ft)	78.02	78.02
Rc/Wus	1.5 -10	5.02	5.02
Scour depth below reference section invert			
Maynord	Ys (ft)	4.3	4.6
USACE (Gravel)	Ys (ft)	7.3	8.0
Thorne	Ys (ft)	5.7	6.2
Scour depth below bend			
Maynord	Ys bend (ft)	3.4	3.7
USACE (Gravel)	Ys bend (ft)	6.4	7.0
Thorne	Ys bend(ft)	4.8	5.3
Maximum Scour		**6.4**	**7.0**
Average Scour		**4.9**	**5.3**

Note: 25-Year and higher events have overbank flow, equations applied within banks



Method	Equation	Assumptions and Conditions
Maynord*	$\Delta y = \bar{D}_{US}\left(1.8 - 0.051\left(\frac{Rc}{W_{US}}\right) + 0.0084\left(\frac{W_{US}}{\bar{D}_{US}}\right)\right) - \bar{D}_{US}$	Sand bed S ≤ 2%, $1.5 < \frac{Rc}{W_{US}} < 10$** Recommends a safety factor of 1.0 to 1.19
USACE EM 1110-2-1601	$\Delta y = \begin{cases} \bar{D}_{US}\left(-1.51\log_{10}\left(\frac{Rc}{W}\right) + 3.37\right) - D_{Max}\ for\ sand \\ \bar{D}_{US}\left(-1.62\log_{10}\left(\frac{Rc}{W}\right) + 3.375\right) - D_{Max}\ for\ gravel \end{cases}$	This method uses much of the same data as Thorne
Zeller†	$\Delta y = \frac{0.0685 \cdot D_{US_Max} V_{US}^{0.8}}{D_{h_US}^{0.4} S_{US}^{0.3}} + \left(2.1\left(\frac{W}{4Rc}\right)^{0.2} - 1\right)$	Sand bed channels.
Thorne	$\Delta y = \bar{D}_{US}\left(2.07 - 0.19\ln\left(\frac{Rc}{W_{US}} - 2\right)\right) - \bar{D}_{US}$	Includes data from large sand bed rivers and smaller gravel-cobble systems $\frac{Rc}{W_{US}} < 2$

* For a factor of safety of 1. The method recommends a factor of safety between 1.0 and 1.19 based on the percentage of "significantly unconservative data".

**The algorithm has alternate forms for $\frac{Rc}{W_{US}} < 10$ and $\frac{Rc}{W_{US}} < 1.5$.

†This form replaces $\frac{\sin^2\frac{\alpha}{2}}{\cos\alpha}$ with the equivalent $\frac{W}{4Rc}$.

Where:

Δy is the scour depth below the initial channel invert
W is the flow width (within the banks)
W_{US} is the flow width (within the banks) at the upstream, reference cross section
R_c is the radius of curvature
D is depth. Depth takes several forms in these equations including:
D_h, the hydraulic depth, which is the area divided by the top width
$\bar{D}_{US}$, the average cross section depth at the upstream, reference cross section, but is often approximated with D_h and
D_{Max}, the maximum cross section depth before scour at the evaluation cross section.

Lower Piedra Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing:

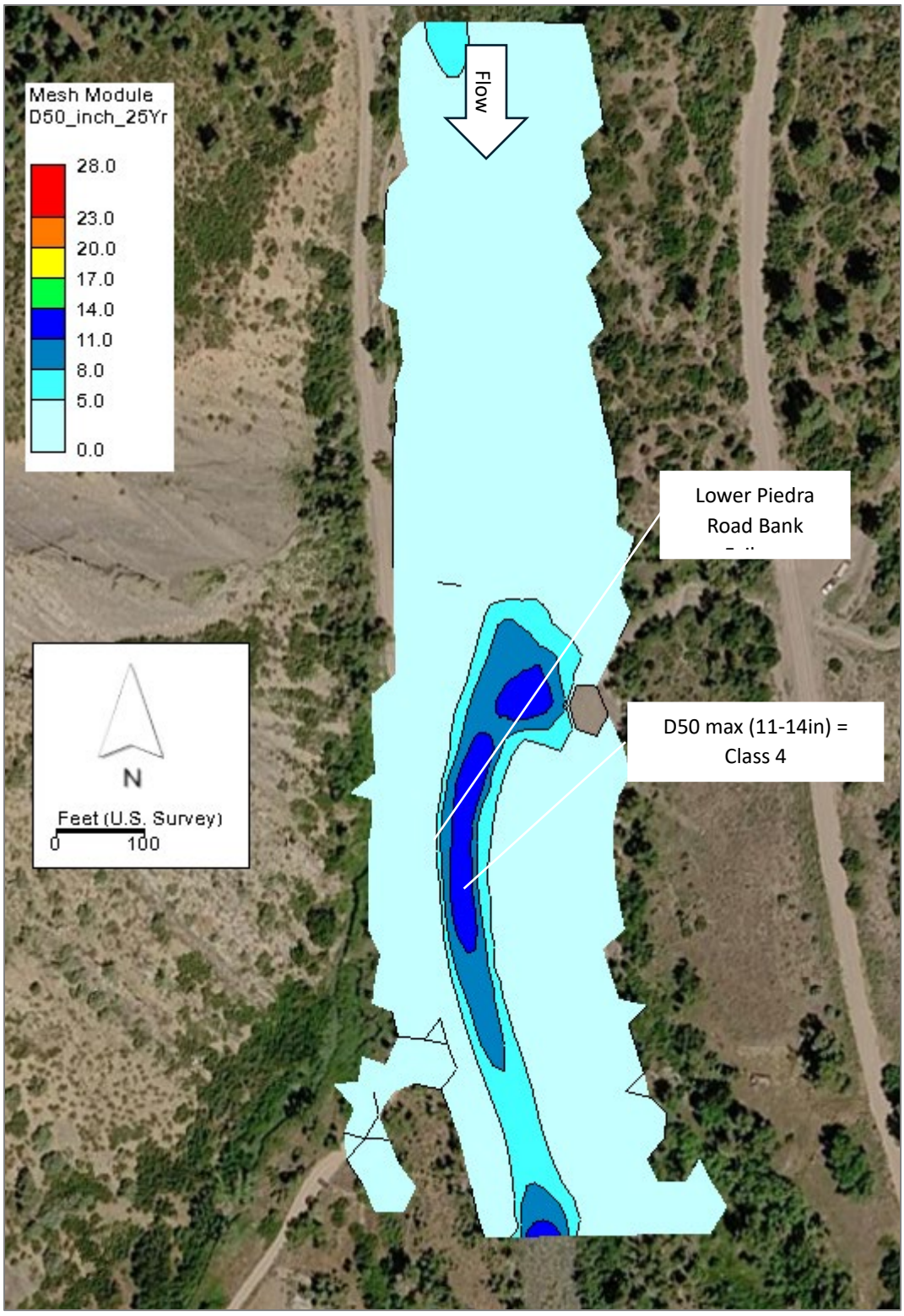
Bank Protection Sizing			
HEC-23 Eq 4.1 Parameters		**25 Year**	**50 Year**
Safety factor	S_f	1.2	1.2
Stability coefficient (Angular = 0.30, Rounded =0.375)	C_s	0.3	0.3
Radius of curvature	Rc (ft)	392	392
Width of water surface upstream	W(ft)	78.02	78.02
Rc/W		5.02	5.02
Velocity distribution coefficient	C_v	1.14	1.14
Bank slope (__:1V)	(__H:1V)	1.5	1.5
Bank Angle	t (deg)	33.69	33.69
Side slope correction factor	K_1	0.718	0.718
Specific gravity of riprap	Sg	2.65	2.65
Acceleration due to gravity	g (ft/s^2)	32.2	32.2

SMS Data Set Toolbox: Data Calculator Simplification	25 Year	50 Year
$A = 1.2S_fC_sC_v$	**0.494**	**0.494**
$B = K_1(S_g\text{-}1)g$	**38.145**	**38.145**

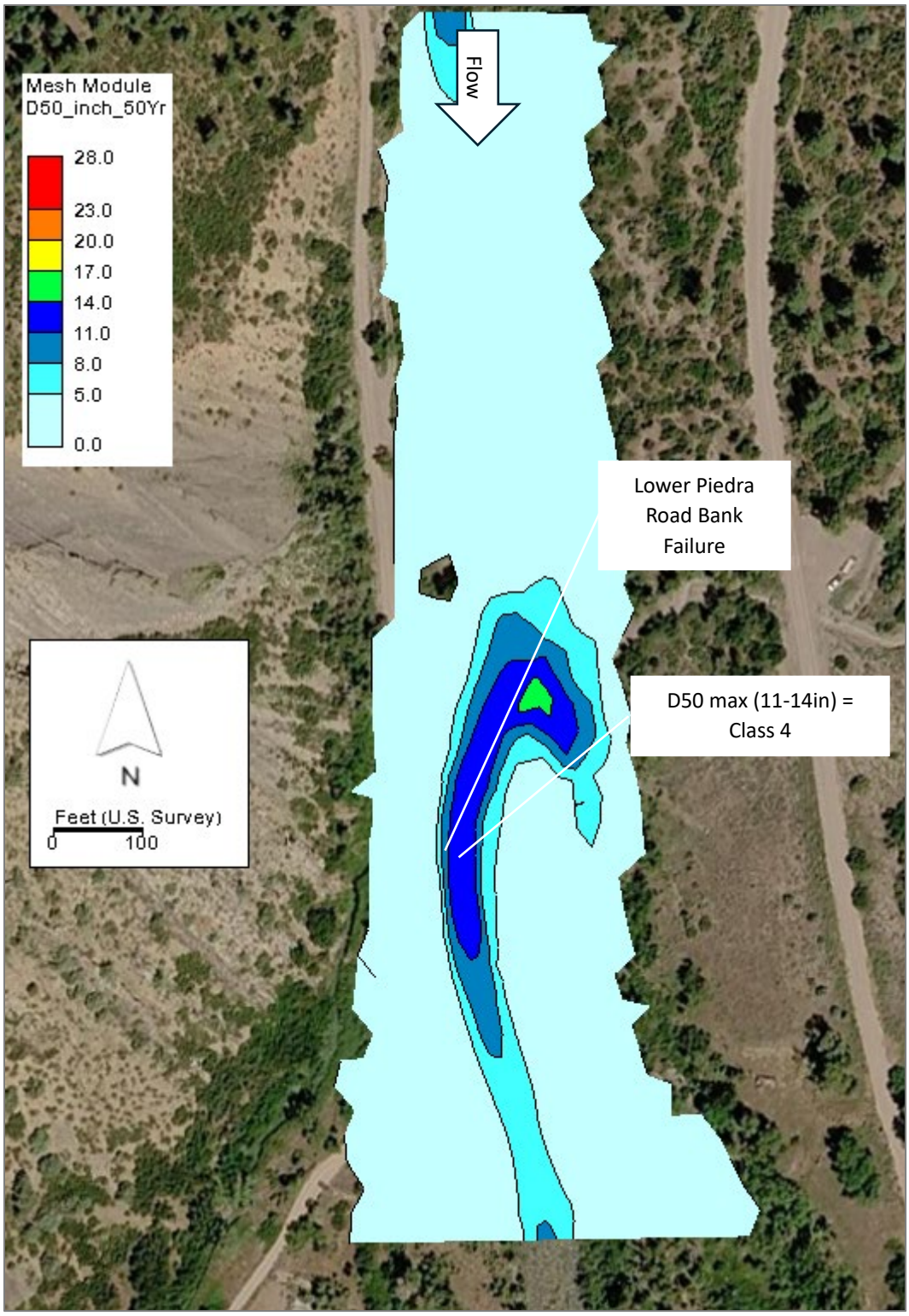
$$d_{50} = 1.2yS_fC_sC_v\left(\frac{V_{des}}{\sqrt{K_1(S_g-1)gy}}\right)^{2.5} \qquad d_{50} = Ay\left(\frac{V_{des}}{\sqrt{By}}\right)^{2.5}$$

SMS Data Calculator Equation:
12*0.494*d11*((d10/((38.145*d11)^0.5))^2.5)
Where:
d11 = SMS Water_Depth_ft dataset
d10 = SMS Vel_Mag_ft_p_s dataset

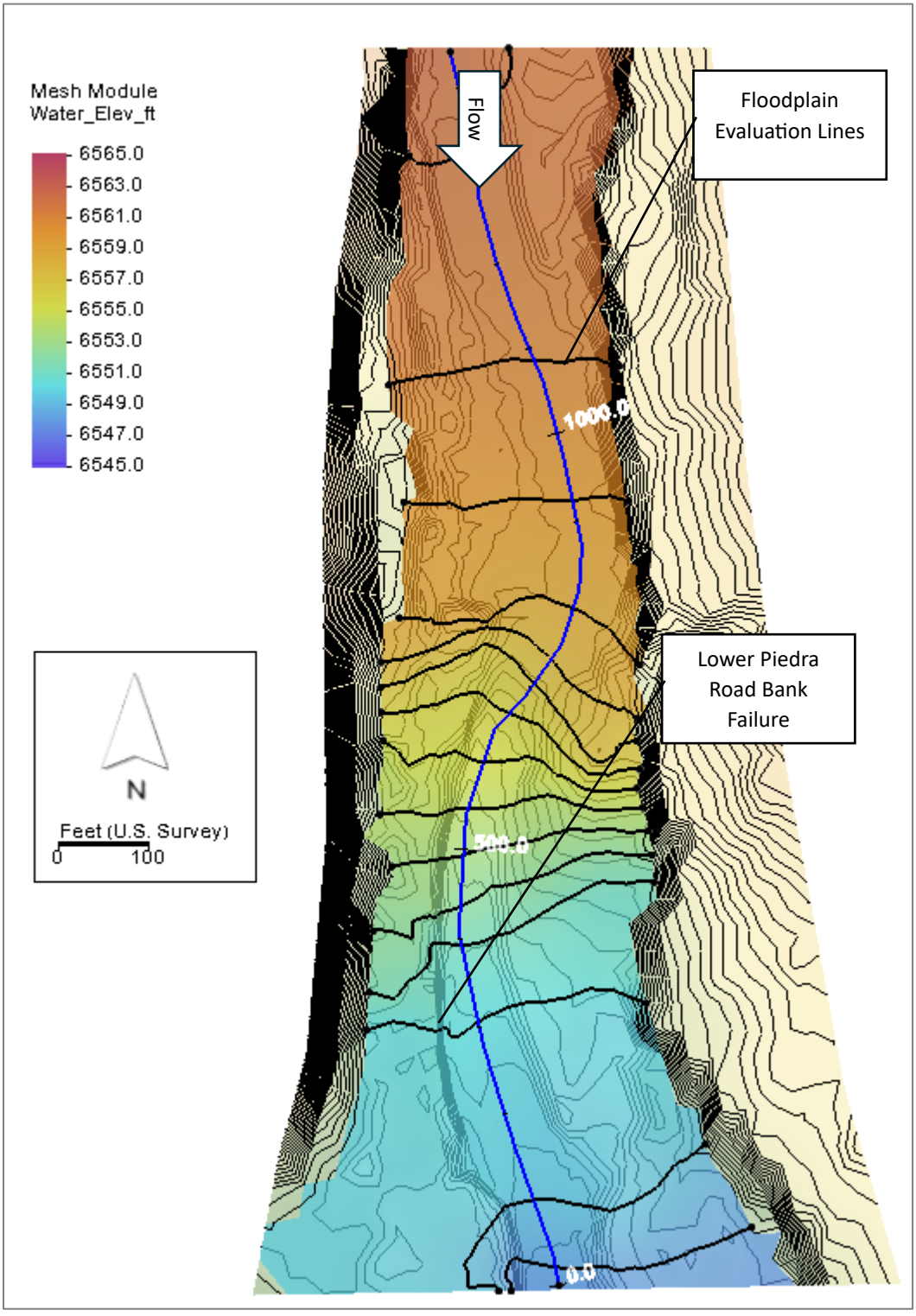
Lower Piedra Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing 25-Year:



Lower Piedra Road Bank Protection Estimate – SMS Data Calculator Riprap Sizing 50-Year:



Lower Piedra Road 100-Year Existing Conditions Floodplain (Using Post-Flood Survey) and Evaluation Lines



Lower Piedra Road 100-Year Existing and Proposed Conditions WSEL Comparison:

Evaluation Line Station	Existing Condition (Post Flood Event Failure)		Proposed Conditions (Post Project Repair)		Difference (Post Project - Existing Condition)	
	100-Year Water Surface Elevation (ft)		100-Year Water Surface Elevation (ft)		100-Year Water Surface Elevation (ft)	
	Average	Maximum	Average	Maximum	Average	Maximum
20.5	6548.0	6548.0	6548.0	6548.3	-0.02	0.31
98.8	6549.0	6549.0	6548.9	6549.0	-0.14	-0.02
306.2	6550.0	6550.0	6550.6	6550.8	0.55	0.81
393.6	6551.0	6551.0	6551.4	6552.0	0.42	0.96
437.2	6552.0	6552.0	6552.3	6552.6	0.32	0.55
494.0	6553.0	6553.0	6553.3	6553.6	0.26	0.63
546.0	6554.0	6554.0	6554.2	6554.5	0.24	0.52
601.2	6555.0	6555.0	6555.2	6555.4	0.18	0.41
663.1	6556.0	6556.0	6556.2	6556.4	0.18	0.40
706.4	6557.0	6557.0	6557.2	6557.8	0.20	0.80
738.7	6558.0	6558.0	6558.1	6558.7	0.09	0.69
801.4	6559.0	6559.0	6558.9	6559.1	-0.14	0.14
923.5	6560.0	6560.0	6559.8	6559.9	-0.17	-0.08
1084.8	6561.0	6561.0	6560.9	6560.9	-0.11	-0.09
1350.3	6562.0	6562.0	6561.9	6562.0	-0.12	-0.04

Average:	**0.12**	**0.40**
Maximum:	**0.55**	**0.96**