PRELIMINARY HYDRAULICS REPORT
STRUCTURE J-14-C REPLACEMENT

As a part of the
REGION TWO BRIDGE BUNDLE PACKAGE
PARK COUNTY, COLORADO

A Part of Section 25, Township 15 South, Range 73 West of the 6^{th} P.M.,
County of Park, Colorado

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Prepared for:

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1. INTRODUCTION

1.1 Background and Purpose

The objective of Colorado Department of Transportation (CDOT) Region 2 Bridge Bundle Design Build project is to replace nineteen (19) rural structures spread across highway corridors in southern and western Colorado. The structures are located on US 350, US 24, CO 9, and CO 239. The role of Stanley Consultants is to assist CDOT in the design build procurement, geotechnical engineering, environmental clearances, survey, utility location and coordination, hydrology and hydraulics, preliminary structural design and roadway design.

This design build project is partially funded by the USDOT FHWA Competitive Highway Bridge Program grant (14 structures, project number 23558) and funds from the Colorado Bridge Enterprise (5 additional structures, project number 23559). These projects are combined to form one design-build project.

The nineteen bridges identified to be included in the 'Region 2 Bridge Bundle' were selected based on similarities in the bridge conditions, risk factors, site characteristics, and probable replacement type, with the goal of achieving economy of scale. Seventeen of the bridges being replaced are at least 80 years old. Five of the bridges are Load Restricted limiting trucking routes through major sections of the US 24 and US 350 corridors. The bundle is comprised of nine timber bridges, four concrete box culverts, one corrugated metal pipe (CMP), four concrete I-beam bridges, and one I-beam bridge with corrugated metal deck.

1.2 Site Description

The purpose of this report is to document the preliminary hydraulic analysis and design for the replacement of Structure J-14-C as a part of the CDOT Region 2 Bridge Bundle Design Build. The project is located within Park County at Mile Post 20.107 along SH 9 between Hartsel and US 50 junction. Structure J-14-C crosses over the Louis Gulch. Figure 1 below illustrates the project location. The project is located in Section 25, Township 15 South, Range 73 West of the 6^{th} P.M., County of Park, Colorado. Figure 1 shows the project limits.

The report will document preliminary hydrology, hydraulic, and scour analysis to support the proposed structure replacement design.

The Federal Emergency Management Agency (FEMA) has designated the project site as a FEMA Zone A, as determined by the Flood Insurance Rate Maps (FIRM) 08093C1300C effective date December 18, 2009, as shown in Appendix A. FEMA Zone A is a special flood hazard area inundated by the 100-year flood; however, base flood elevations are not determined in a Zone A designation. 44 Code of Federal Regulations (CFR) 60.3 (b) state that for Zone A floodplains, all cumulative impacts to the system from the time of the original study cannot result in a water surface elevation (WSE) increase of more than one foot.

This report also reviews changes to the WSE due to the proposed alternatives. The goal for this preliminary analysis is to provide viable options for the design build contractor to achieve a no-rise condition for replacement structures within Zone A floodplains. The Park County floodplain administrator has indicated that a no-rise certification will be necessary to obtain a floodplain development permit from the county. If a no-rise condition is not met, the contractor will be required to complete the Letter of Map Change (LOMC) process through FEMA.

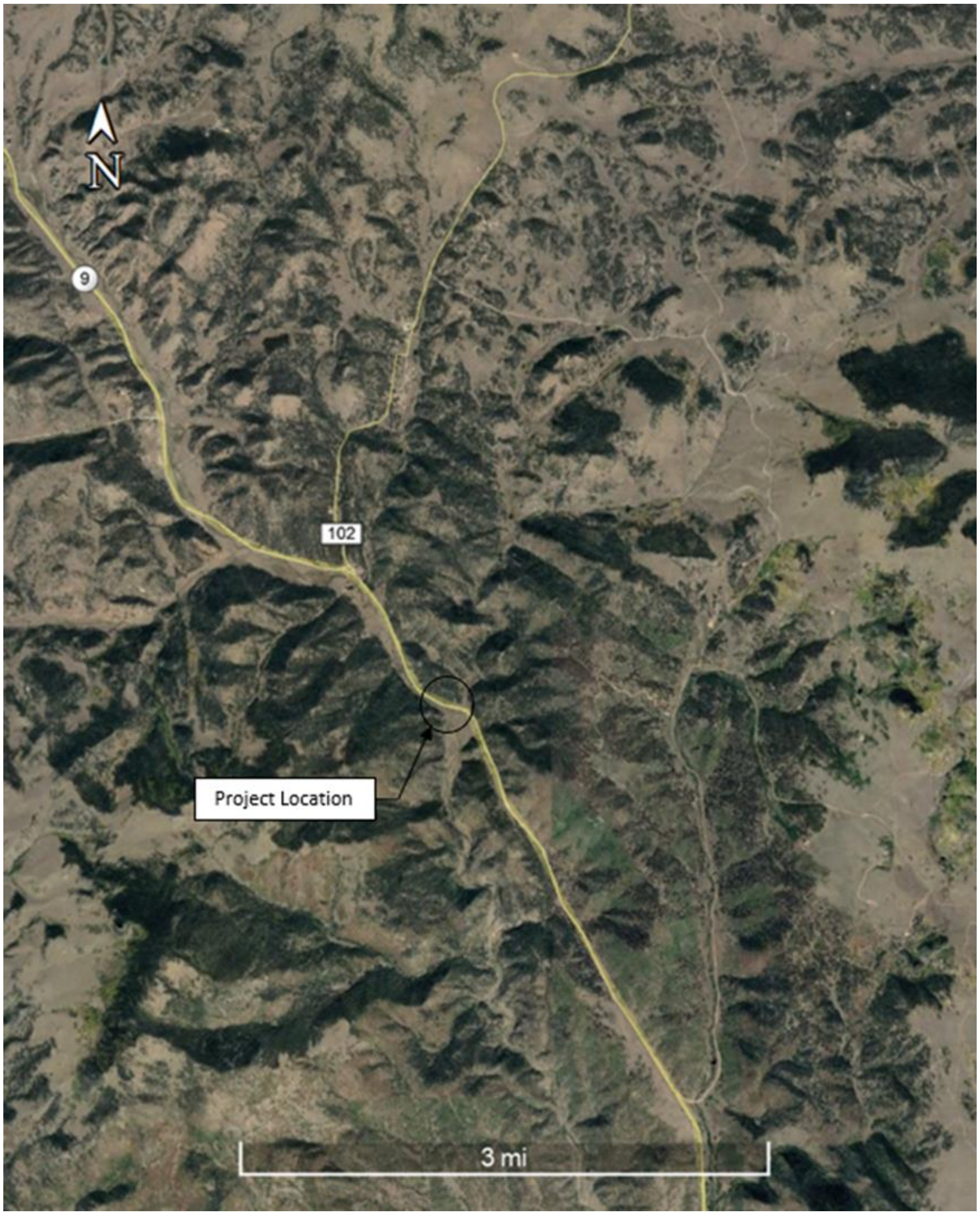


Figure 1: Vicinity Map

2. HYDROLOGY

Preliminary hydrology for the watershed tributary to this structure was provided by CDOT. A memorandum provided by CDOT summarizes basin areas, runoff methodology and approximate flowrates determined by the preliminary analysis. Table 1 is a summary of the approximate flowrates provided by CDOT of structure J-14-C.

Table 1: Summary of Peak Discharge for Bridge J-14-C

River Location	Design Storm	100-year (cfs)	200-year (cfs)	500-year (cfs)
Upstream of Bridge	100-year	1,288	1,685.4	2,290.8

3. EXISTING CONDITIONS

3.1 Existing Structure

Existing structure is a two-span treated timber stringer bridge built in 1934 to span a Louis Gulch. The bridge does not have skew and was based on a CDOT Standard P-117-B-H. The existing bridge consist of two 23.0 ft spans, has a curb-to-curb width of 24.0 ft, and out -to-out deck width of 25.0 ft. The existing vertical clearance varies from 7.0 ft to 8.0 ft. The existing bridge framing consists of 18 rows of 6 in x 20 in wood stringers in span 1 and 17 rows in span 2. The spacing of the stringers varies from 13.0 in to 19.5 in. The bridge deck consists of 3 in x 6 in wood planks.

The center piers consist of 1.0 ft square wood beam pier caps supported by (5) 1.0 ft diameter concrete-filled steel piles and diagonal steel braces. The pier piles are spaced at approximately 6.0 ft. The abutments consist of 1.0 ft square wood beam abutment caps supported by (5) 1.0 ft diameter concrete-filled steel piles and diagonal steel braces. The abutment piles are spaced at approximately 6.0 ft. There are 4 wood wingwalls at the existing bridge. The wingwalls are 20’-0” feet long and vary in height. Each wingwall is supported by (3) 10.5 in diameter steel piles.

The bridge is located on SH 9, 2.2 miles south of Guffey, Colorado, at milepost 20.107. The bridge is located 18 miles north of junction of SH 9 and US 50.

3.2 Watershed Overview

Louis Gulch is a valley in Park County, Colorado that flows from the northeast to the southwest and curves south as it combines with Currant Creek. The watershed tributary to Louis Gulch is approximately 5.5 square miles in area. The watershed generally slopes to the south. The stream bed does not have a base flow. The existing bridge crosses Louis Gulch perpendicularly. The area surrounding the bridge is rural with undeveloped land to both upstream and downstream sides of the bridge.

3.3 Site Investigation

A site investigation by Stanley Consultants in August 2020 was performed to gain an understanding of the key hydraulic and geomorphic features of the stream at the project site and of the overall watershed. This investigation found obvious scour damage at the base of the center pier columns. This is evident by the exposed columns and high soil marks. Site photos are included in Appendix C.

4. HYDRAULIC ANALYSIS

A two-dimensional (2D) hydraulic model was developed using the Sediment and River Hydraulics 2D model (SRH-2D) software developed by the United States Bureau of Reclamation in 2008. A 2D model was chosen to represent this area due to the complexity of the stream and for the preliminary scour countermeasure design. The Surface Water Modeling System (SMS) was used to develop the inputs for the SRH-2D Version 13.0 model, as well as post-process the results. For this analysis, four models were developed:

- Existing Conditions
- Proposed Conditions: RCBC Replacement
- Proposed Conditions: Bridge Replacement
- Proposed Conditions: ALBC Replacement

4.1 Debris Potential

The potential for debris production and delivery is estimated to be low (minimal) based on guidance from Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 20. The flowchart for potential debris production is presented in Figure 2. The channel banks near the bridge are vegetated with tall grasses and shrubs, and no trees present, as confirmed with the site visit in August 2020. Aerial imagery of the watershed near the bridge is shown in Appendix B.

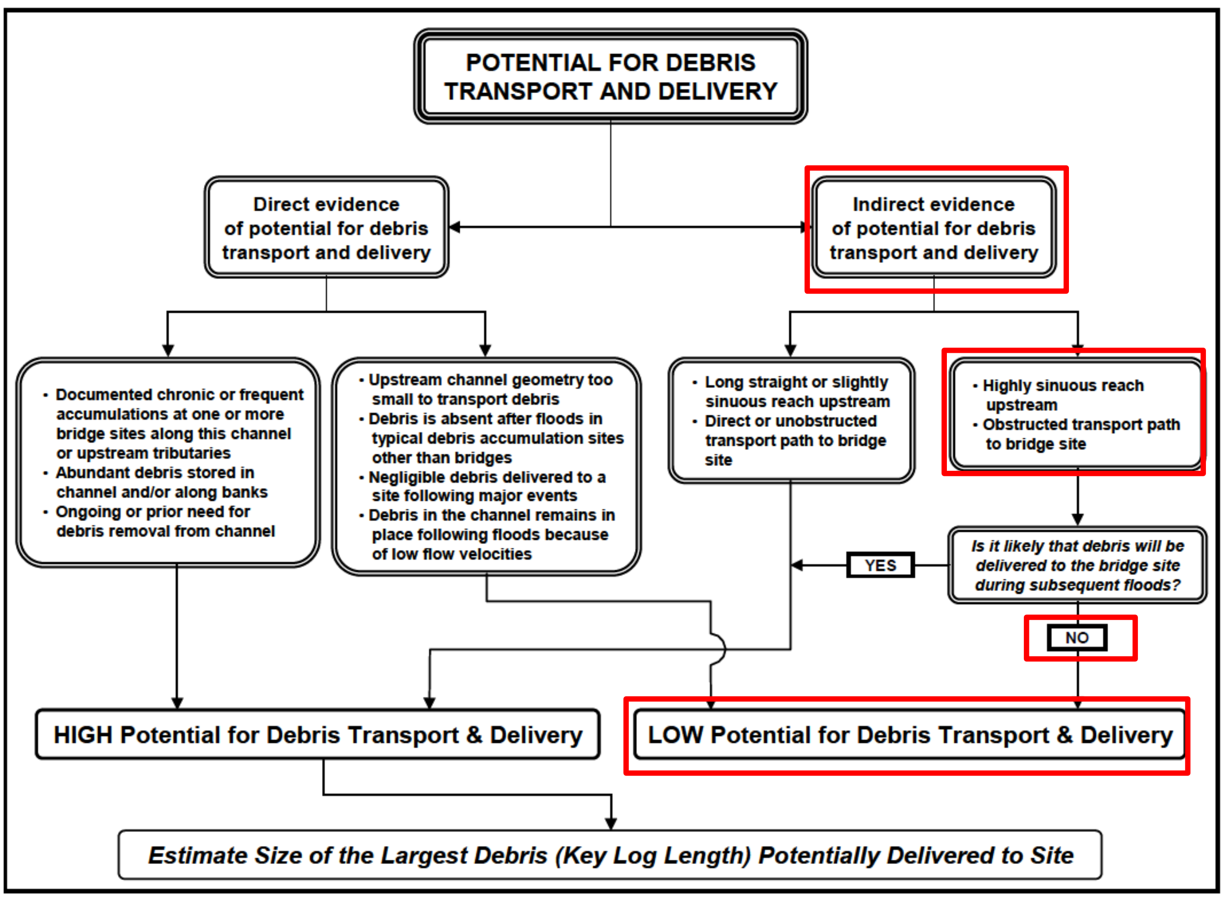


Figure 2: Flow Chart for Potential Debris Production (FHWA, HEC 20)

4.2 Freeboard

The CDOT Drainage Design Manual (2019) specifies freeboard requirements for all bridges. Freeboard is the minimum clearance between the design approach WSE and the low chord of the bridge. It is a factor of safety that acts as a buffer to account for unknown factors that could increase the height of the calculated WSE. Streams classified as high debris streams shall have a minimum of 4 feet of freeboard. Low-to-moderate streams CDOT highly encourages 2 feet be provided, where practical. The elevation of the water surface 50 to 100 feet upstream of the face of the bridge shall be the elevation to which the freeboard is added to get the bottom or low-girder elevation of the bridge.

The channel was not identified as having a high potential for debris production. Therefore, 2 feet of freeboard is required, if a bridge is selected for the proposed conveyance structure.

4.3 Modeling Parameters

4.3.1 Elevation Data

Existing conditions survey for the bridge and channel cross sections was performed by CDOT in June 2020. LiDAR was acquired by CDOT in June 2020. These two data sources were combined for the modeling elevation surface.

A local, custom projection was used for the data collection in the existing conditions survey. The survey was converted into NAD 1983 Colorado State Plane Central US Survey Feet for the hydraulic modeling. All elevations are referenced to NAVD 88 (feet).

4.3.2 Computational Mesh

The computational mesh is an unstructured mesh, which allows for the use of triangles and quadrilaterals, with variable element sizes. Roadways and the channel were modelled with a patch mesh, which uses quadrilaterals. The faces of the quadrilaterals are lined up perpendicular to flow and allow for a more precise modelling of the conveyance structure. Triangles were typically used in the floodplain and the areas upstream and downstream of the highway crossing. The total number of mesh elements is 10,394 and the mesh extends approximately 1,500 feet upstream of the bridge and 1,275 feet downstream of the bridge. These extents were chosen due to it encompassing the limits of the survey from CDOT, and to account for the nearby confluence of Louis Gulch and Currant Creek downstream of J-14-C.

4.3.3 Surface Roughness

Surface roughness, represented by the Manning's roughness coefficient, is presented in Table 2. A Manning's n-value was assigned to each land use based on aerial imagery, topography, a site visit in August 2020 and engineering judgment. Photos from the site visit used to confirm the n-values selected are shown in Appendix B. A map showing existing conditions materials coverages is shown in Appendix C.

Table 2: Manning's n-values

Land Use	n-value
Channel	0.035
Overbank	0.050
Open Space	0.040
Mountain – High Vegetation	0.100
Mountain – Low Vegetation	0.060
Paved Road	0.016

4.3.4 Boundary Conditions

The boundary conditions include a steady state inflow and a normal depth calculated outflow.

The peak flows developed in Table 1 were used to develop a steady-state inflow boundary condition. The inflow boundary condition extends the full length of the inundation boundary in the upstream portion of the project location. The model was set to a dry initial condition.

For the downstream boundary condition, the subcritical outflow option was selected. This outflow condition uses the inputs of anticipated flow, Manning's n-value, channel slope, and terrain data to determine the outflow constant water surface elevation. Table 3 presents the boundary condition values.

Table 3: Model Boundary Condition Inputs

Frequency Storm	Inflow (cfs)	Outflow Constant WSE (ft)
100-Year	1,288	8249.77
500-Year	2,291	8250.98

4.3.5 Hydraulic Structures

The modeled existing bridge geometry is based on the survey completed in August 2020. The survey data included shots detailing the bridge, including the existing pier locations. The high chord of the bridge is 8291.8 feet, at the grade center, while the low chord is 8289.3 feet. The bridge was modeled as overtopping which allows flow to overtop the bridge if the water surface elevation reaches an elevation greater than the high chord of the bridge.

The existing bridge piers were modeled as holes, across the width of the bridge in the computational mesh, allowing flow to run around the piers, which replicates true hydraulic conditions.

Additionally, a small 24" culvert is modelled. The flow splits from the main channel due to a manmade berm just upstream of structure J-14-C. This flow ponds and is drained by the culvert. The discharge then combines with the main channel 250 feet downstream.

4.3.6 Simulation Control

The hydraulic simulations are run with a 1.0 second time step for 2 hours until a steady state solution is met. The parabolic turbulence method is used with a coefficient of 0.7.

4.4 Model Results

4.4.1 Existing Conditions

The range of depths experienced in the channel at the bridge during the 100-year event is from 1.8 feet to 4.0 feet. Figure 5 presents the depth for the entire floodplain and the bridge. The results demonstrate that the existing bridge does not overtop during the 100-year event. The results show that flows pond behind the embankment. The 100-year depth for the existing conditions are shown in Appendix C.

4.4.2 Alternatives Analysis

An alternatives analysis was completed in the preliminary design process to determine the most feasible options for the hydraulic conveyance structure. A reinforced concrete box culvert (RCBC), bridge and aluminum box culvert option were analyzed. Many factors were taken into consideration when determining the preferred alternative for this preliminary analysis. These factors include cost, constructability, effects on the stream hydraulics, environmental impacts, etc.

<u>Proposed RCBC</u>

This option was modeled using the same SRH-2D model as was used for the existing conditions. Modifications to the model included adjusting the mesh for the culvert and minor grading upstream and downstream to allow for the conveyance of flow. To model the culvert, HY-8 was used. This was deemed acceptable due to the perpendicular approach of Louis Gulch to structure J-14-C. HY-8 is a 1D program that works within the SRH 2D model. An internal boundary condition at the beginning of the structure receives the modelling results and populates the needed data into HY-8. Then, with an internal boundary condition at the end of the structure, the model results are inputted back into SRH 2D. The culverts can be modelled completely in 2D but is only done if HY-8 is not suitable.

The total head, elevation and velocity head, was utilized in the calculations due to the lack of upstream ponding. The default setting only considers the elevation head and assumes that the velocity is zero, which is not the case for the existing model. The proposed model has 10,382 mesh elements.

Due to the bridge existing in a floodplain, a similar opening size was used for the box culvert to keep the WSEs the same or lower than existing conditions. The preliminary model shows the roadway embankment sloping at 2:1, and the proposed culvert being 47 feet in length. The RCBC option for this structure required a 2 cell 18-foot wide by 7-foot tall structure. This structure size was determined to allow zero rise in the WSEs of the channel.

Depths and velocity grids for the proposed RCBC show depths from 2.6 to 4.2 feet and velocities from 6.6 to 13.1 ft/s. See Appendix D for 100-year depths and velocities graphics for this option.

Proposed Bridge

This option was modeled using the same SRH-2D model as was used for the existing conditions. Modifications to the model included adjusting the mesh for a one-span bridge and lengthening the span of the proposed bridge length. The proposed model has 10,459 mesh elements. The bridge will match the existing skew and lay on the same grade. The span is 55 feet long from centerline to centerline of the abutments. The low chord of the bridge is at 8288.76 feet in elevation, and the high chord didn't change from the existing condition. Roadway embankments were graded at 2:1.

Depths and velocity grids for the proposed bridge show depths from 1.6 to 3.3 feet and velocities from 8 to 12.4 ft/s. See Appendix E for 100-year depths and velocities graphics for this option.

Proposed ALBC

This option was modeled using the same SRH-2D model as was used for the existing conditions. Modifications to the model included adjusting the mesh for an ALBC and minor grading upstream and downstream. The proposed model has 10,422 mesh elements. An ALBC can be modelled as 1D culvert in HY-8 or as a 2D culvert. The 2D methodology was chosen because scour can be calculated in SRH 2D.

To model the ALBC in SRH 2D, holes in the mesh were used to model the outer walls. This allows for it to be modelled as a 2D culvert, since the boundary conditions and materials coverage are unaffected. ALBCs have angled walls and a parabolic top, which resembles an arch. The outer walls were modelled as vertical and were assumed to begin within the ALBC where the angled wall ends. Even though this conservative approach reduces the opening of the ALBC, the flow would be considered ineffective. A footing foundation of 2.5 feet was assumed to space the ALBCs and was modelled as a hole in the mesh combined with the outer walls.

To model the arch ceiling, the parabolic option was selected on the internal boundary condition. For this option, SRH 2D determines a parabolic polynomial based on the provided elevations and boundary condition length. The elevations required are the edges of the arch, which would be the top of the vertical walls, and the height of the arch. The edges of the arch are at 8285.24 feet in elevation, and the top of the arch is at 8288.46 feet in elevation. Since each boundary condition represents one ALBC, two pressure zones were required side by side.

Due to the bridge existing in a floodplain, a similar opening size was used for the culvert to keep the WSEs the same or lower than existing conditions. The preliminary model shows the roadway embankment sloping at 2:1, and the proposed culvert being 35 feet in length. The ALBC option for this structure required a 2-cell size 45, 19.81-foot wide by 7.68-foot tall, structure. This structure size was determined to allow zero rise in the WSEs of the channel.

Depths and velocity grids for the proposed bridge show depths from 3.0 to 4.1 feet and velocities from 10.7 to 13.1 ft/s. See Appendix E for 100-year depths and velocities graphics for this option.

5. FEMA FLOODPLAIN ANALYSIS

FEMA has designated the project site as a Zone A, as determined by the FIRM 08093C1300C effective date December 18, 2009, as shown in Appendix A.

FEMA Zone A is a special flood hazard area inundated by the 100-year flood; however, base flood elevations are not determined in a Zone A designation. 44 CFR 60.3 (b) states that for Zone A floodplains, all cumulative impacts to the system from the time of the original study cannot result in a WSE increase of more than one foot. A Floodplain Development Permit will be submitted to Park County during the next phase of design. For this preliminary design, the goal is to demonstrate a no-rise condition, so that a CLOMR is not needed.

Proposed RCBC

Based on modeling results, the proposed bridge will not increase the WSE by more than 1 foot. Even though the opening of the proposed culvert is slightly smaller than the existing opening, no change in WSE is expected, with a decrease seen immediately upstream and downstream of the bridge opening.

To perform a comparison between the existing and proposed WSE, eight cross sections were cut across the 2D hydraulic model results upstream and downstream of the proposed bridge. The average WSE was determined for both existing and the proposed bridge option, as shown in Appendix G.

For the proposed culvert option, upstream of Bridge J-14-C (Cross Sections 1-3), the WSE increases between 0.04 and 0.06 feet between existing and proposed. At the structure and downstream of Bridge J-14-C (Cross Sections 4-8), the WSE decreases between 0.02 and 0.42 feet between existing and proposed. The WSE comparison at these sections is shown below.

Table 4: WSE Comparison for RCBC Option

Cross Section	Location Relative to Proposed Bridge	Existing WSE (ft)	Proposed WSE (ft)	Proposed vs Existing
1	Upstream	8292.13	8292.17	0.04
2	Upstream	8290.39	8290.45	0.06
3	Upstream	8287.89	8287.93	0.04
4	Upstream	8284.66	8284.25	-0.42
5	Downstream	8283.20	8283.10	-0.10
6	Downstream	8279.83	8279.80	-0.03
7	Downstream	8276.95	8276.93	-0.02
8	Downstream	8273.37	8273.35	-0.02

Proposed Bridge

Based on modeling results, the proposed bridge will not increase the WSE by more than 1 foot. Because the opening of the proposed bridge is larger than the existing opening, no change in WSE is expected, with a decrease seen immediately upstream and downstream of the bridge opening.

For the proposed bridge option, upstream of Bridge J-14-C (Cross Sections 1-2), the WSE increases a maximum of 0.02 feet between existing and proposed. Upstream and immediately downstream of Bridge J-14-C (Cross Sections 3-5), the WSE decreases between 0.01 and 0.89 feet between existing and proposed. Further downstream of Bridge J-14-C (Cross Sections 6-8), the WSE increases between 0.00 and 0.03 feet between existing and proposed.

Appendix G shows the cross sections used for the proposed bridge option as well as the floodplain limit changes between existing and proposed for this scenario. Table 5 shows a WSE comparison at each section for the proposed bridge option.

Table 5: WSE Comparison for Bridge Option

Cross Section	Location Relative to Proposed Bridge	Existing WSE (ft)	Proposed WSE (ft)	Proposed vs Existing
1	Upstream	8292.13	8292.15	0.02
2	Upstream	8290.39	8290.41	0.02
3	Upstream	8287.89	8287.88	-0.01
4	Upstream	8284.66	8283.77	-0.89
5	Downstream	8283.20	8283.15	-0.05
6	Downstream	8279.83	8279.86	0.03
7	Downstream	8276.95	8276.97	0.02
8	Downstream	8273.37	8273.37	0.00

<u>Proposed ALBC</u>

Based on modeling results, the proposed ALBC will not increase the WSE by more than 1 foot. Even though the proposed arch structure is smaller than the existing opening, no change in WSE is expected, with a decrease seen immediately upstream and downstream of the bridge opening.

For the proposed ALBC option, upstream of Bridge J-14-C (Cross Sections 1-3), the WSE increases between 0.03 and 0.06 feet between existing and proposed. At the structure and downstream of Bridge J-14-C (Cross Sections 4-8), the WSE decreases between 0.00 and 0.40 feet between existing and proposed.

Appendix G shows the cross sections used for the proposed bridge option as well as the floodplain limit changes between existing and proposed for this scenario. Table 6 shows a WSE comparison at each section for the proposed bridge option.

Table 6: WSE Comparison for ALBC Option

Cross Section	Location Relative to Proposed Bridge	Existing WSE (ft)	Proposed WSE (ft)	Proposed vs Existing
1	Upstream	8292.13	8292.16	0.03
2	Upstream	8290.39	8290.45	0.06
3	Upstream	8287.89	8287.95	0.06
4	Upstream	8284.66	8284.50	-0.16
5	Downstream	8283.20	8282.80	-0.40
6	Downstream	8279.84	8279.84	0.00
7	Downstream	8276.95	8276.92	-0.03
8	Downstream	8273.37	8273.37	0.00

6. BRIDGE SCOUR ANALYSIS

6.1 Scour Overview

For the proposed bridge and ALBC option, as determined in the alternatives analysis, a scour analysis was performed for Louis Gulch at the structure. The scour analysis is intended to inform the structural design of the crossing and countermeasure design. The FHWA recommends that bridges with complex flow characteristics use a 2D model to represent hydraulic conditions.

For the scour analysis, the FHWA Hydraulic Toolbox Version 5.0 software program was used. The Hydraulic Toolbox program uses equations presented in the FHWA Hydraulic Engineering Circular No. 18 Evaluation of Scour at Bridges (HEC-18) and the National Cooperative Highway Research Program (NCHRP) 24-20. SRH-2D was used as the hydraulic model platform and it has the capability to extract the data needed for these calculations directly from the model.

Based on Table 2.1 from HEC-18 and the conditions of the bridge, the 100-year event is used as the hydraulic design flood frequency, the 200-year event results are used as the scour design flood frequency, and the 500-year results are used as the scour design check flood frequency. Scour was calculated for the 100- and 500-year event for this preliminary analysis. 200-year scour analysis and design will be completed in a later phase of the design.

At the project site, the following scour components were calculated:

- Contraction Scour
- Pier Scour
- Abutment Scour
- Long-Term Degradation

All scour calculations can be found in Appendix H.

6.2 Site Geology/Geotechnical Information and Impact to Scour Depths

A geotechnical analysis was completed by Yeh and Associates for the project. Gradation of the stream bed was provided in this investigation and used for this preliminary scour analysis. Only one sample was taken from the channel, therefore this sample will be applied to contraction, pier (local), abutment (local) and long-term degradation scour. Results from the geotechnical investigation are provided in Appendix I.

Borings at each abutment and one at each bridge approach, were also conducted as part of the field exploration. These were used to better understand subsurface conditions at the bridge crossing. Soils information from borings were not used in the scour analysis because boring samples at the abutments were assumed to not be as representative of channel bed conditions as the channel sample discussed above.

Because exact bedrock elevations are not known, no adjustment was made to the scour depths shown below.

6.3 Scour Results

Below, Table 7 summarizes the preliminary results for scour at the bridge over Louis Gulch.

Table 7: Scour Analysis Results for Bridge

Scour Type (ft)				
Storm Event	**Contraction**	**Long-Term Degradation**	**Abutment (Local)**	**Total Abutment Scour***
100-Year	**0.9**	**3.9**	**1.1**	**5.0**
500-Year	**1.3**	**5.0**	**1.7**	**6.7**

*Contraction Scour is not included in the Total Scour when computing the NCHRP methodology.

Below, Table 8 summarizes the preliminary results for scour at the ALBC over Louis Gulch.

Table 8: Scour Analysis Results for ALBC

Scour Type (ft)						
Storm Event	**Contraction**	**Long-Term Degradation**	**Abutment (Local)**	**Pier (Local)**	**Total Abutment Scour***	**Total Pier Scour****
100-Year	**2.0**	**0.9**	**0.8**	**17.2**	**1.6**	**18.1**
500-Year	**3.0**	**1.1**	**1.6**	**17.9**	**2.7**	**19.0**

*Minimum toe down depth of 5' was used.
**Contraction Scour is not included in the Total Scour when computing the NCHRP methodology.

6.4 Scour Countermeasures

The proposed bridge foundations will be designed to withstand the effects of scour up to and including the 500-year Scour Design Check Flood Frequency. Scour countermeasures will be designed to protect the approach roadway and bridge embankments from the effects of scour for the 100-year Hydraulic Design Flood Frequency.

This reach of the river is characterized with a slight sinuosity, defined low flow channel and highly erosive soils. These conditions indicate a significant scour potential at this bridge crossing. Vertical wall abutments with wing walls and riprap are recommended as scour countermeasures. The abutment and wing walls shall be designed with a toe wall extending down to the 100-yr scour depth.

The FHWA Hydraulic Toolbox Version 5.0 (FHWA, 2018) was used to size riprap at the ends of the proposed wing walls and along the roadway embankment. The riprap was sized for the 100-year hydraulic design event. The Hydraulic Toolbox applies methodology outlined in the FHWA Hydraulic Engineering Circular No. 23 Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance (HEC-23) for sizing riprap at abutments based on abutment type, set-back ratio, Froude number, specific gravity of rock riprap, and a characteristic maximum velocity in the channel.

Results of the Hydraulic Toolbox analysis are provided in Appendix H, and final design values for the bridge are summarized in Table 9. A riprap with D50 of 18-inches (in) (Class 5 per HEC-

23) is recommended with a thickness of 2.0 D50 or D100. The resulting recommended thickness is 36-in based on HEC-23 D50 for Class 5. For the ALBC, a riprap with D100 of 24-inches (in) (Class 7 per HEC-23) is recommended with a thickness of 2.0 D50 or D100. The resulting recommended thickness is 48-in based on HEC-23 D50 for Class 7. Refer to Table 10 for the final design values for the ALBC. Please refer to Table 506-2 of CDOT's Division 500 Structures Specifications for the recommended gradation of an 18-in and 24-in riprap.

Riprap should also be placed over a Class 1, non-woven geotextile filter material. According to CDOT's Division 700 Materials Details, geotextile materials should be selected from the New York Department of Transportation's Approved Products List of Geosynthetic materials that meet the National Transportation Product Evaluation Program (NTPEP) and AASHTO M-288 testing requirements. Class 1 geotextiles is the only class approved for applications related to slope protection.

The riprap slope protection at each wing wall should extend 25' from the end of the wing walls along the roadway embankment and configured with the data shown in Table 9. Riprap placed below existing grade shall be constructed with a maximum 2:1 side slope. Riprap above grade will be placed at the roadway embankment slope and no steeper than 2:1. All riprap countermeasure calculations can be found in Appendix H.

Table 9: Riprap Apron Countermeasure Summary for Bridge

Countermeasure	D50 (in)	Recommended Thickness	Side Slopes (Max)	Toe Down Depth (ft)	Bottom Ref. Elevation (ft)	Top Ref. Elevation (ft)
Riprap	18	36	2:1	5.0	8275.3	8287.5
Wing Walls	N/A	N/A	N/A	5.0	8275.3	8287.5

Refer to Table 10 for the final design values for the ALBC.

Table 10: Riprap Apron Countermeasure Summary for ALBC

Countermeasure	D50 (in)	Recommended Thickness	Side Slopes (Max)	Toe Down Depth (ft)	Bottom Ref. Elevation (ft)	Top Ref. Elevation (ft)
Riprap	24	48	2:1	5.0	8275.3	8287.5
Wing Walls	N/A	N/A	N/A	5.0	8275.3	8287.5

7. RCBC OUTLET ENERGY DISSIPATION

The design procedure recommended in section 11.4 of the DDM was followed for outlet protection and energy dissipation at the outlet of the box culvert. All hydraulic data from the proposed culvert was gathered including height, width, length, slope, etc. The culvert control was determined to be outlet controlled, and outlet depth, velocity and Froude number was determined. To determine tailwater data, the downstream channel information was gathered from the survey data, field inspection, and the SRH-2D model.

Allowable scour estimation was completed using HY-8. Soil parameters of the downstream channel were extracted from the soil reports and geotechnical investigation. The estimated scour hole was then determined using HY-8. Due to large scour hole estimates, energy dissipation was then considered.

The energy dissipation alternative selected for this RCBC outlet is a riprap apron based on the Froude number of 1.49 which is less than 3. The riprap apron has a D50 of 6 inches and thickness of 12 inches. See results from HY-8 energy dissipation analysis in Appendix H.

8. CONCLUSIONS

This report presents preliminary analysis and results from the hydrologic and hydraulic study for the Region 2 Bridge Bundle Design Build – Bridge J-14-C. This report documents preliminary analysis in determining costs for proposed structure replacement at this location. It also includes preliminary FEMA floodplain analysis and scour analysis.

A two-dimensional model was developed to analyze the flows through the existing bridge and compare the WSEs and velocities to the proposed design. This model was utilized to optimize the proposed solution to replacement of the existing bridge.

Based on the hydraulic and cost analysis, the proposed replacement for this bridge is a double-cell, size 45 (19.81' x 7.68'), aluminum arch culvert. Floodplain analysis demonstrates that the proposed ALBC opening will not cause a cumulative rise in flood levels during the 100-year design event. This meets guidelines in CFR Sections 60.3 (b). A floodplain development permit is required to be approved through the Park County floodplain administrator during the final design phase of this Design Build project.

Total design scour for the ALBC was determined to be 5.0 feet at the 100-year design event. A riprap apron was designed in order to protect the proposed abutments.

9. REFERENCES

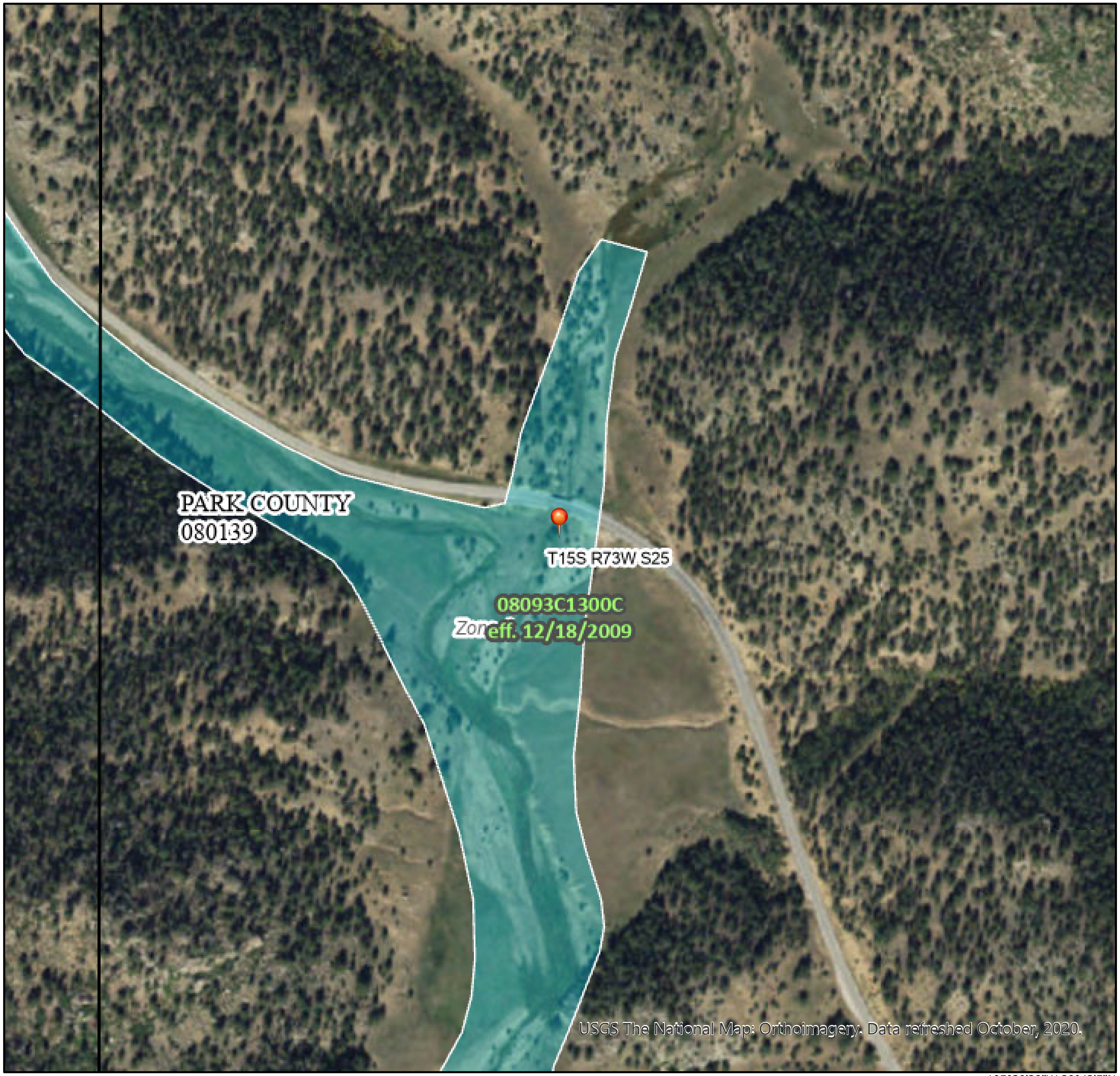
1. "Colorado Department of Transportation Drainage Design Manual", Colorado Department of Transportation, 2019.
2. Mile High Flood District, Urban Storm Drainage Criteria Manual (USDCM), Volumes I, II, and III, August 2018.
3. "Hydraulic Engineering Circular No. 18 – Evaluating Scour At Bridges Fifth Edition". U.S. Department of Transportation Federal Highway Administration, April 2012.
4. "Hydraulic Engineering Circular No. 20 – Stream Stability at Highway Structures". U.S. Department of Transportation Federal Highway Administration, April 2012.
5. "Hydraulic Engineering Circular No. 23 – Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance – Third Edition," U.S. Department of Transportation, Federal Highway Administration, September 2009.
6. CDOT Region 2 2D Quick Check Hydrology Summary Report and Matrix, Colorado Department of Transportation, 2020.

APPENDIX A FEMA FIRM

National Flood Hazard Layer FIRMette

FEMA

105°31'15"W 38°43'33"N



Feet

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

1:6,000

105°30'38"W 38°43'5"N

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
- 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

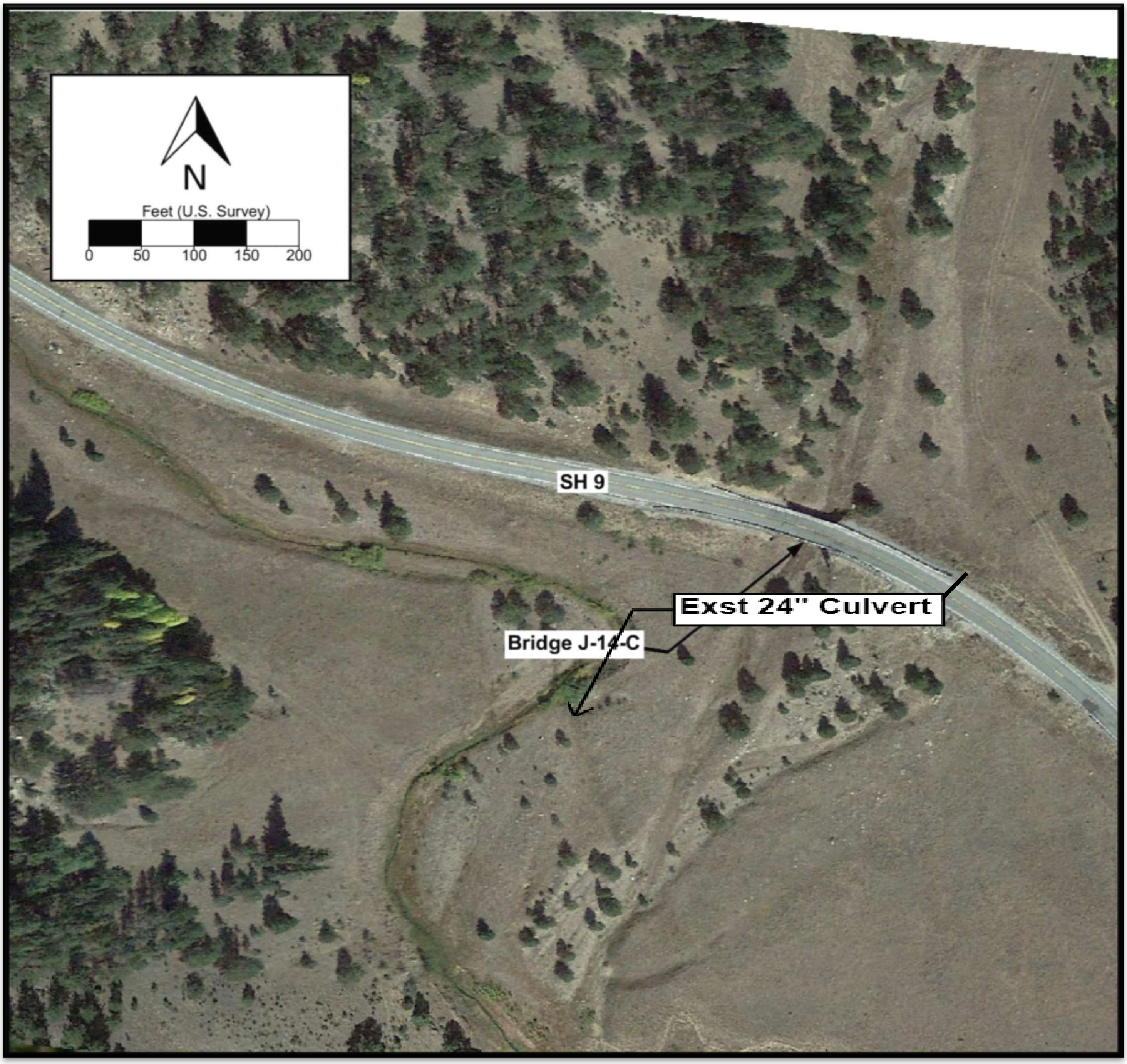
The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

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

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 12/10/2020 at 9:22 AM 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 AERIAL IMAGERY AND PHOTOS



AERIAL IMAGERY
STRUCTURE J-14-C
FIGURE 3

PHOTO 1: BRIDGE STRUCTURE SIGN

STRUCTURE J-14-C

APPENDIX B

PHOTO 2: BRIDGE J-14-C EXISTING STRUCTURE

STRUCTURE J-14C

APPENDIX B

PHOTO 3: LOOKING NORTH UPSTREAM OF BRIDGE

STRUCTURE J-14-C

APPENDIX B

PHOTO 4: DITCH UNDER THE BRIDGE

STRUCTURE J-14-C

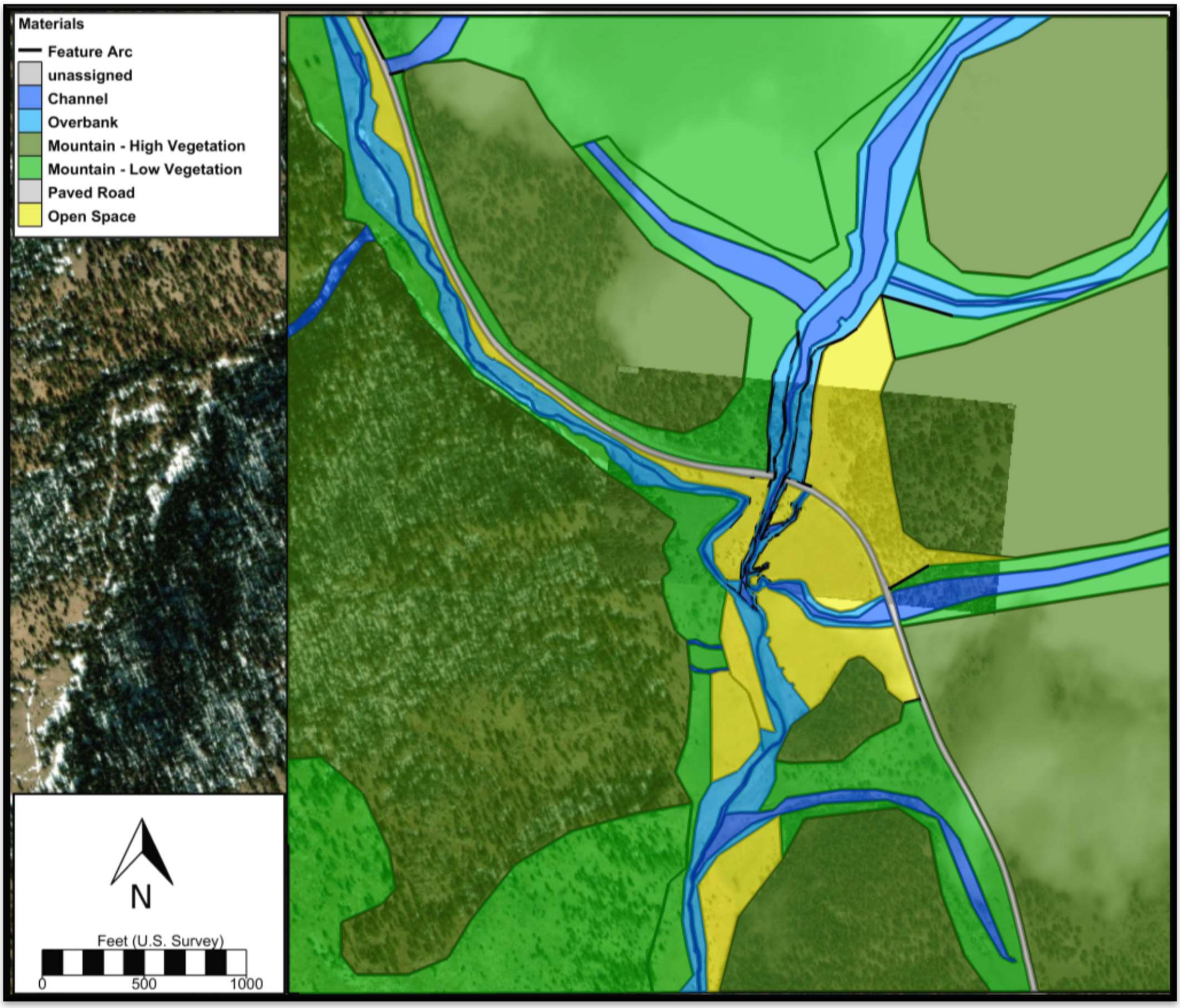
APPENDIX B

PHOTO 5: DOWNSTREAM OF BRIDGE LOOKING SOUTH

STRUCTURE J-14-C

APPENDIX B

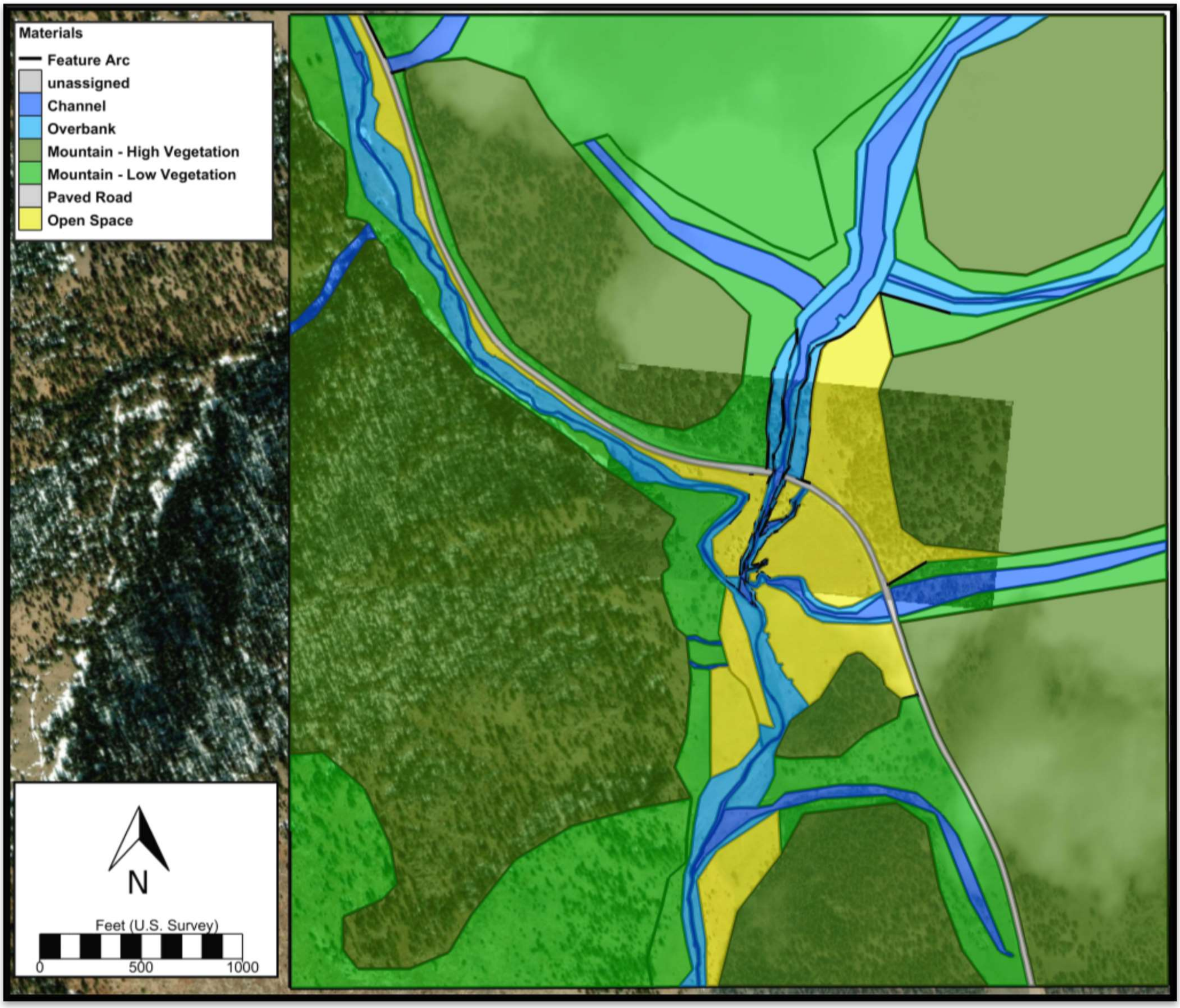
APPENDIX C EXISTING CONDITIONS MODEL GRAPHICS



MATERIALS COVERAGE - EXISTING

STRUCTURE J-14-C

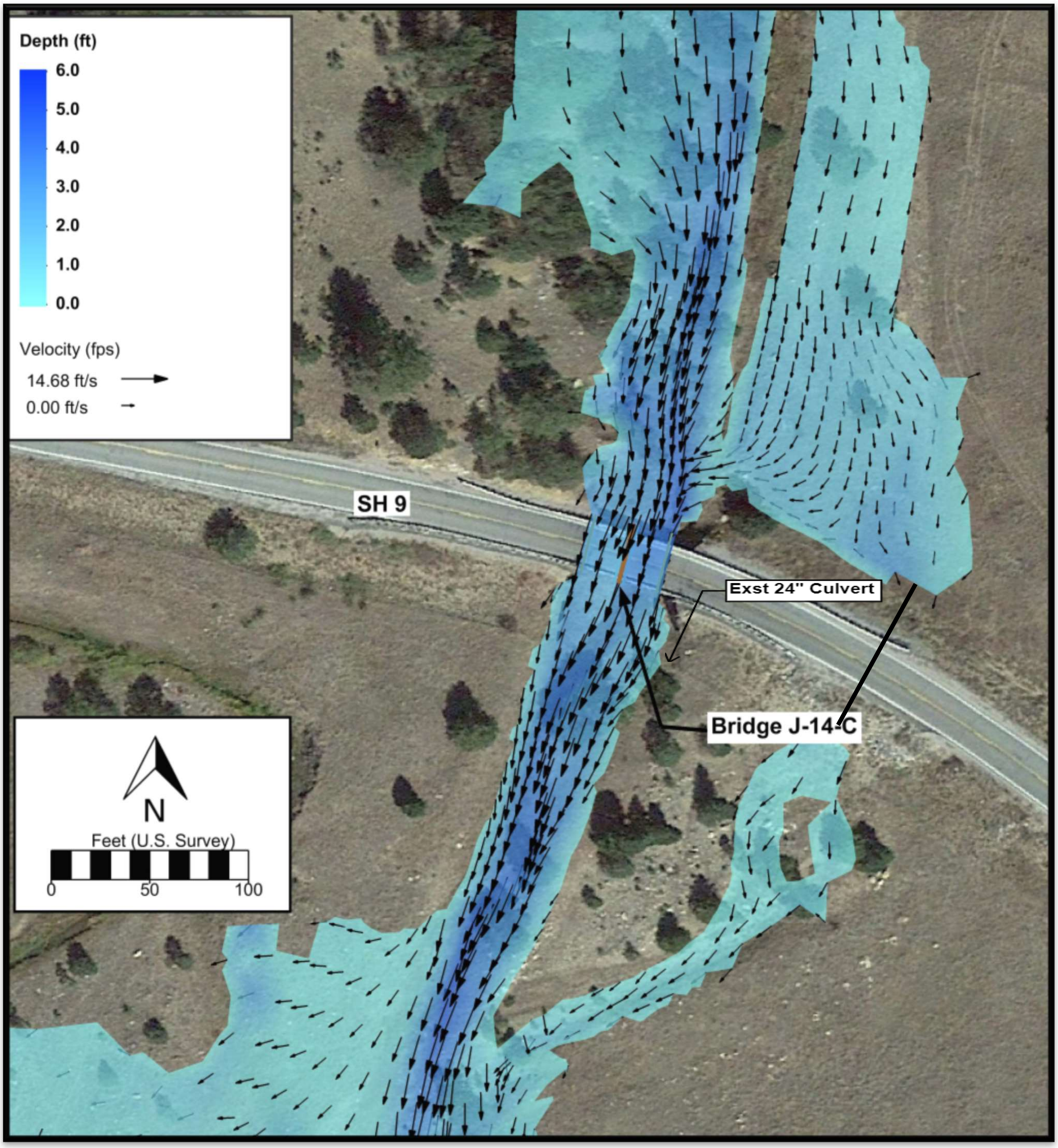
FIGURE 4



MATERIALS COVERAGE - PROPOSED

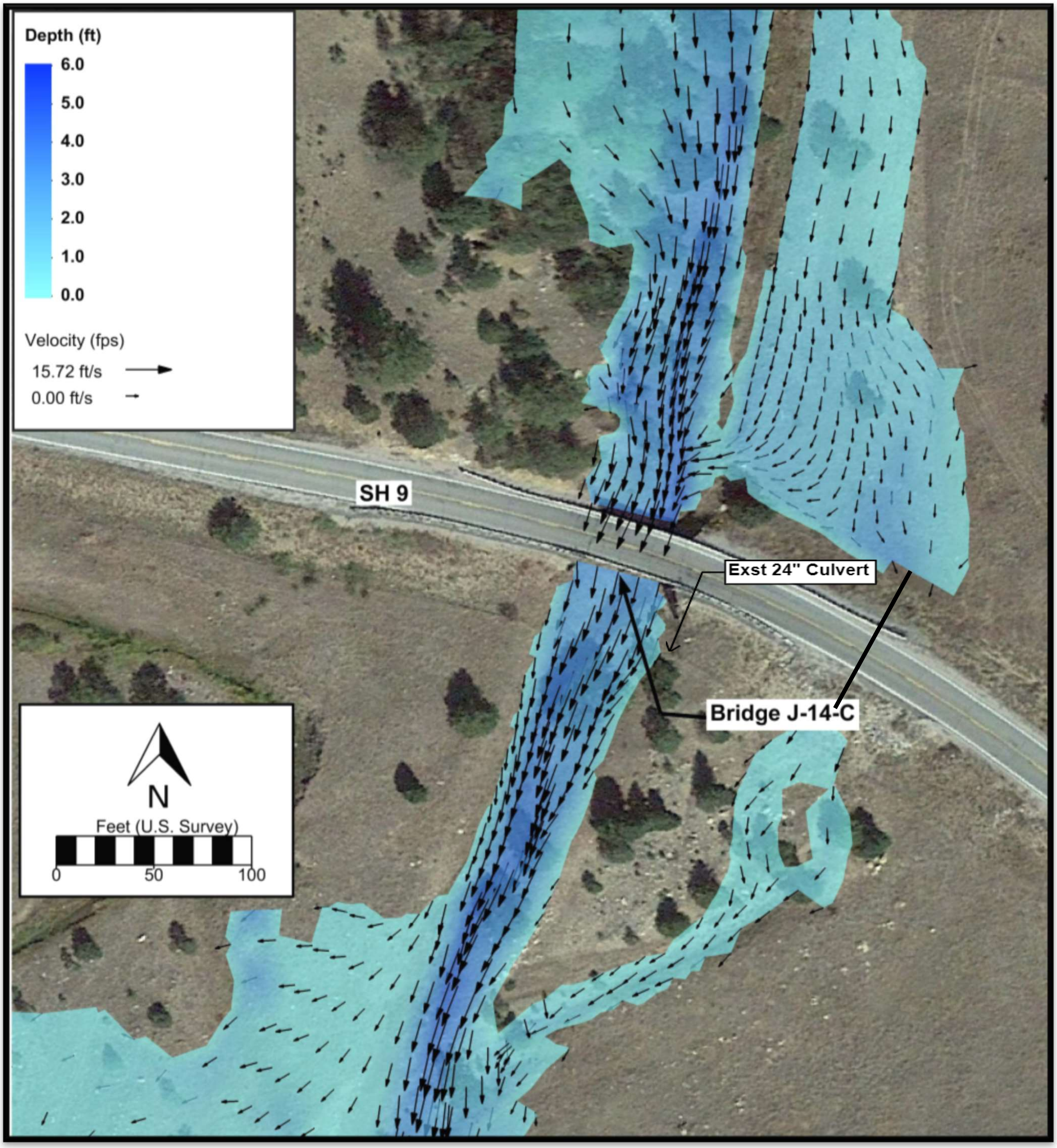
STRUCTURE J-14-C

FIGURE 5



EXISTING CONDITIONS 100-YEAR DEPTH RESULTS
STRUCTURE J-14-C
FIGURE 6

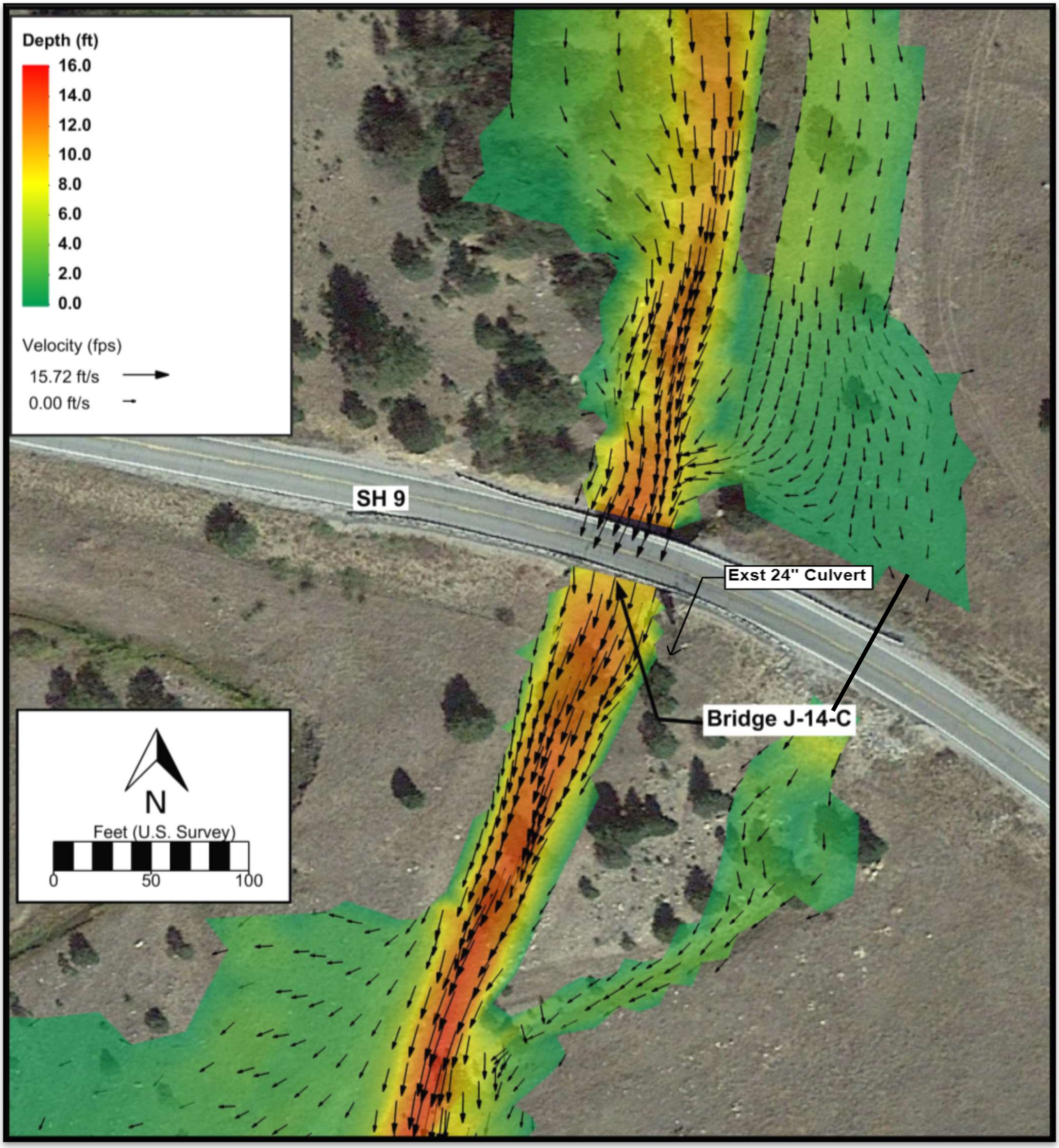
APPENDIX D PROPOSED RCBC ALTERNATIVE MODEL GRAPHICS



PROPOSED 100-YEAR DEPTH RESULTS – RCBC OPTION

STRUCTURE J-14-C

FIGURE 7

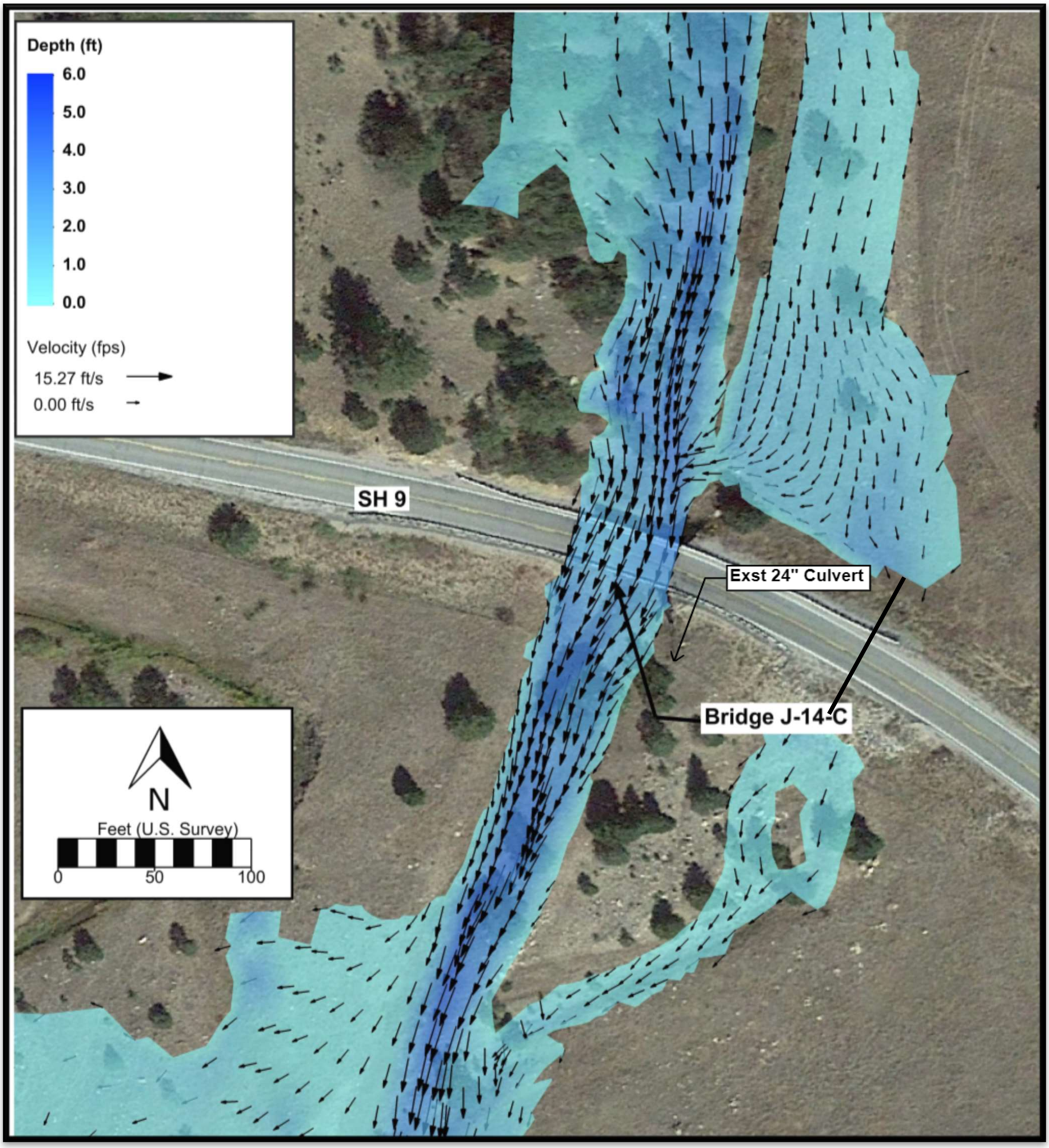


PROPOSED 100-YEAR VELOCITY RESULTS – RCBC OPTION

STRUCTURE J-14-C

FIGURE 8

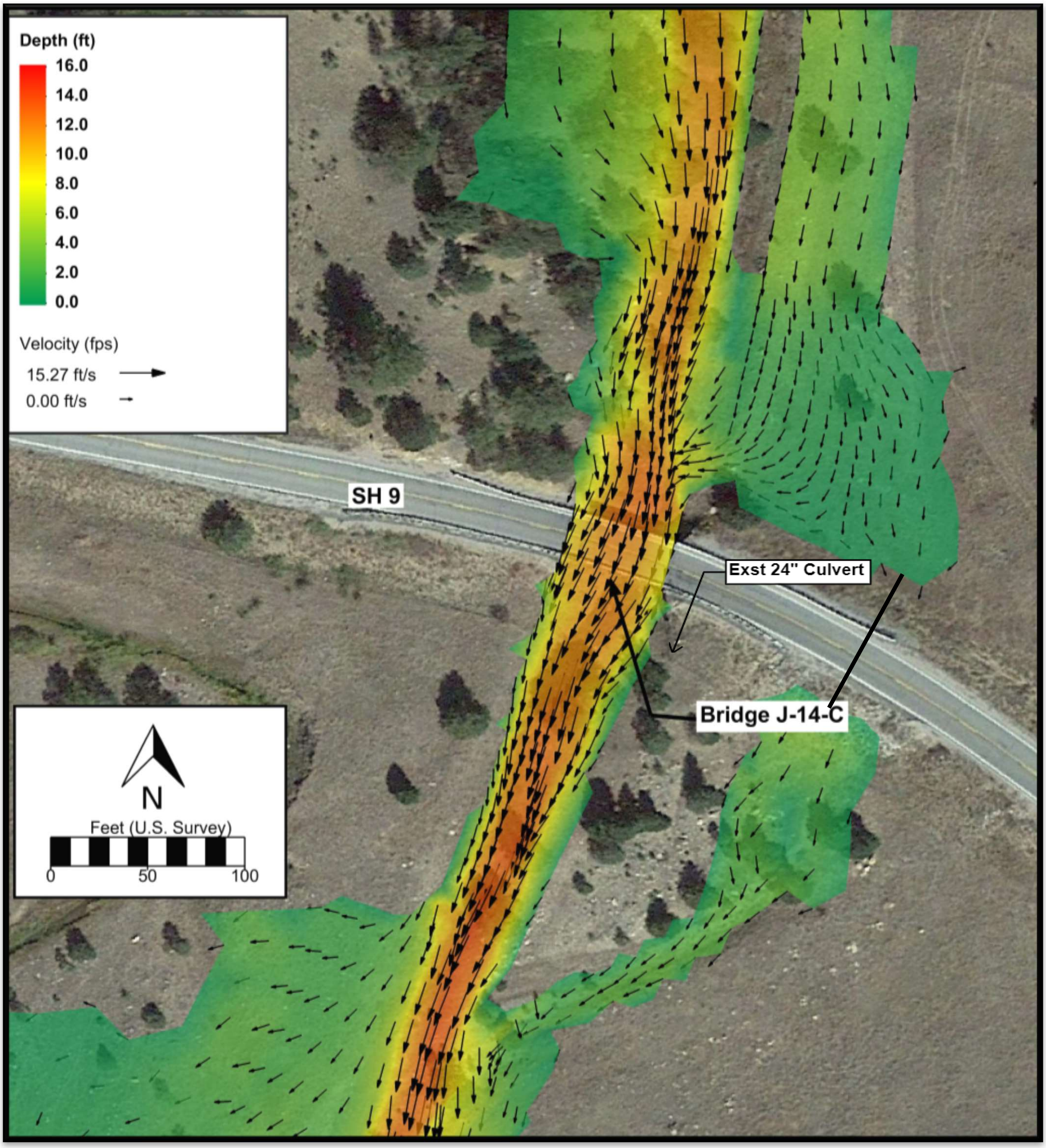
APPENDIX E PROPOSED BRIDGE ALTERNATIVE MODEL GRAPHICS



PROPOSED 100-YEAR DEPTH RESULTS – BRIDGE OPTION

STRUCTURE J-14-C

FIGURE 9

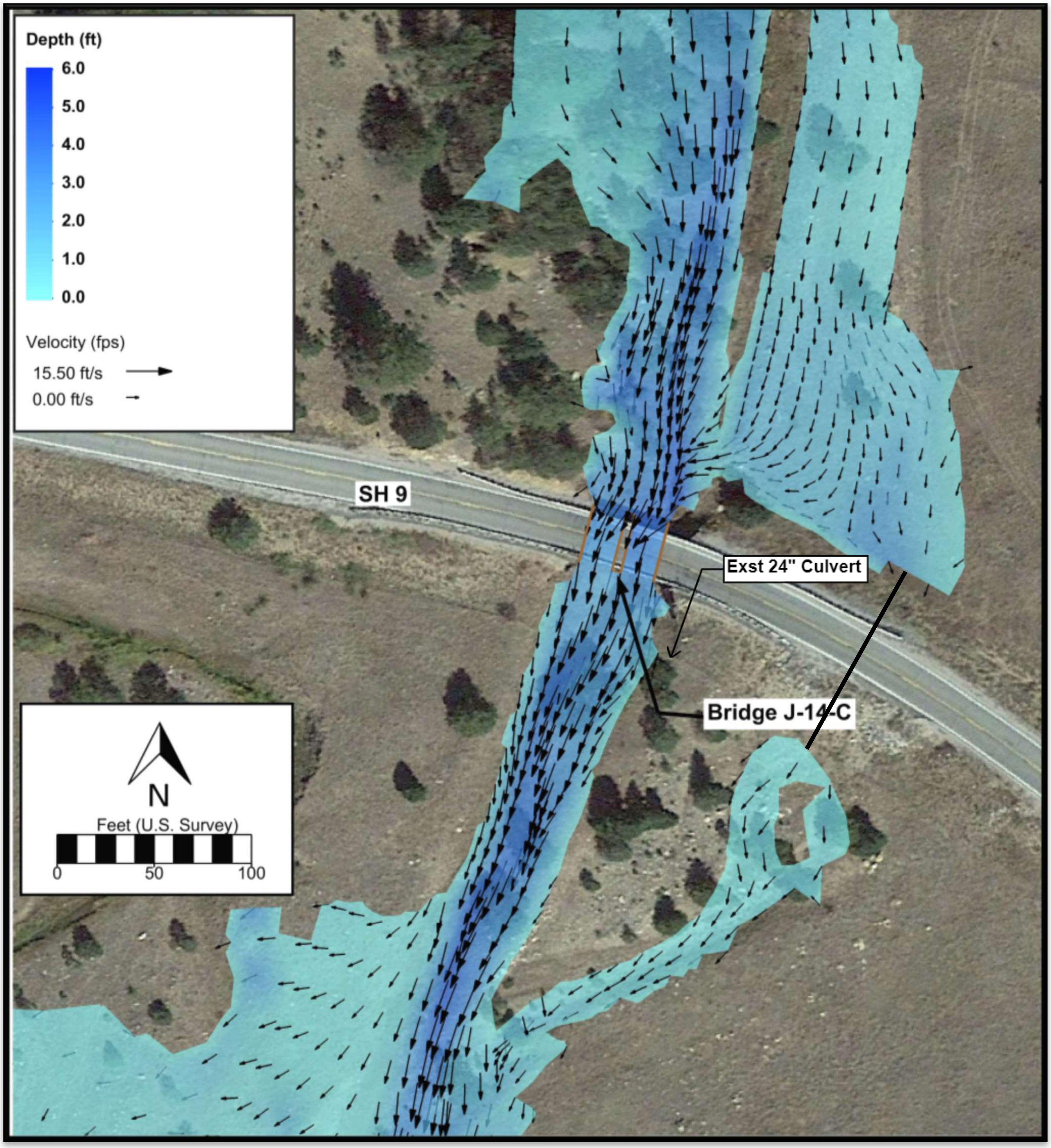


PROPOSED 100-YEAR VELOCITY RESULTS – BRIDGE OPTION

STRUCTURE J-14-C

FIGURE 10

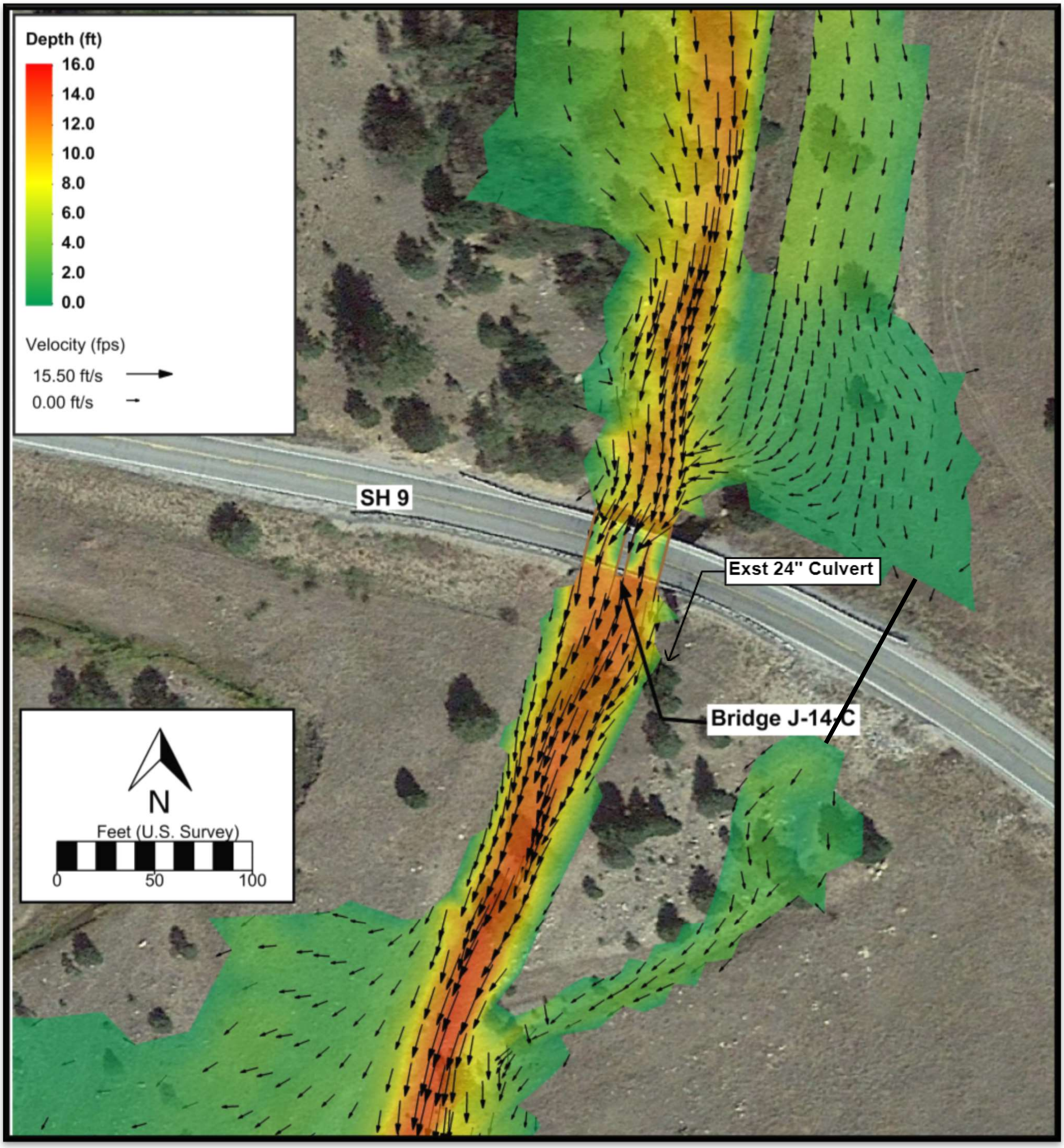
APPENDIX F PROPOSED ALBC ALTERNATIVE MODEL GRAPHICS



PROPOSED 100-YEAR DEPTH RESULTS – ALBC OPTION

STRUCTURE J-14-C

FIGURE 11

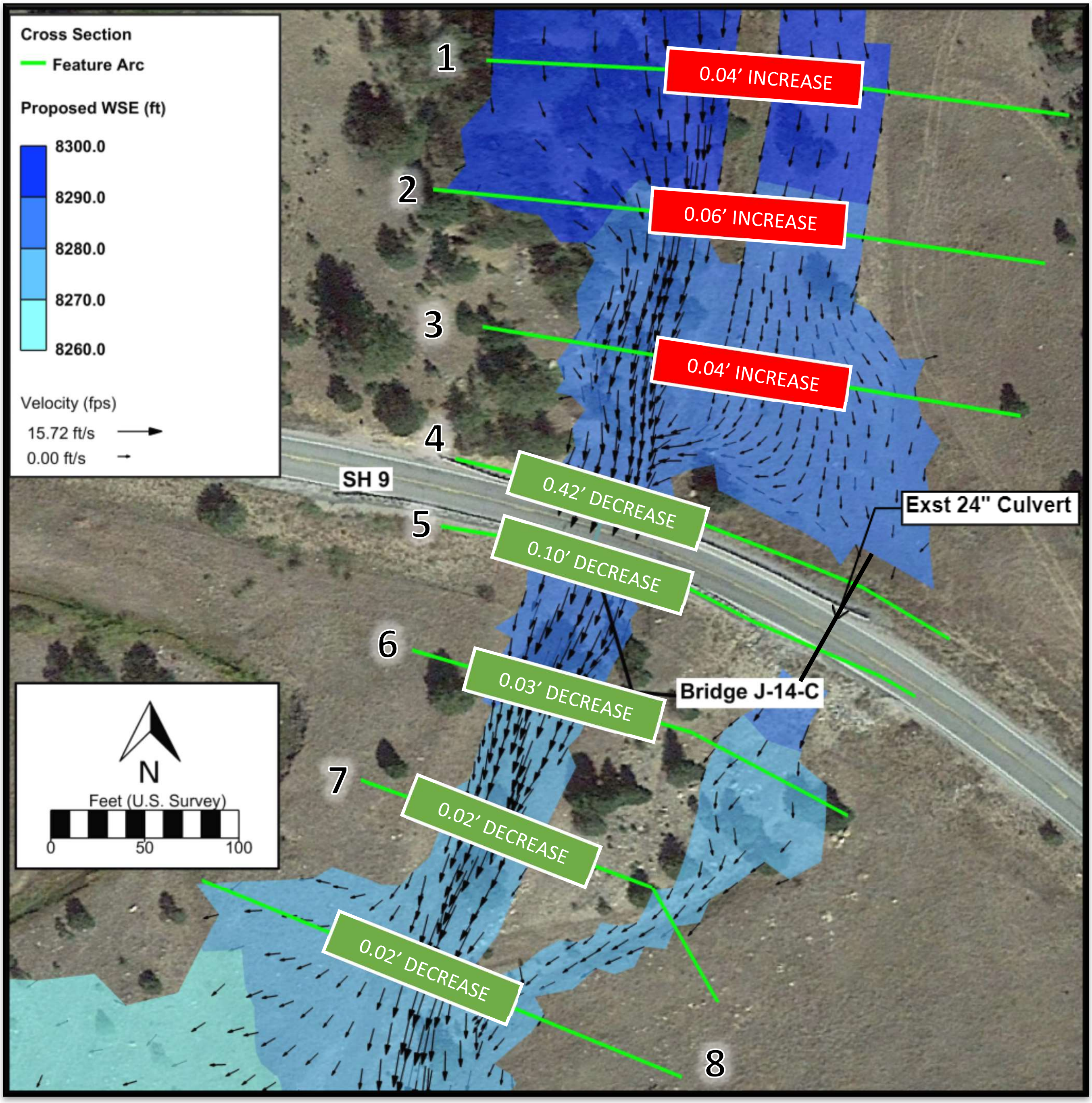


PROPOSED 100-YEAR VELOCITY RESULTS – ALBC OPTION

STRUCTURE J-14-C

FIGURE 12

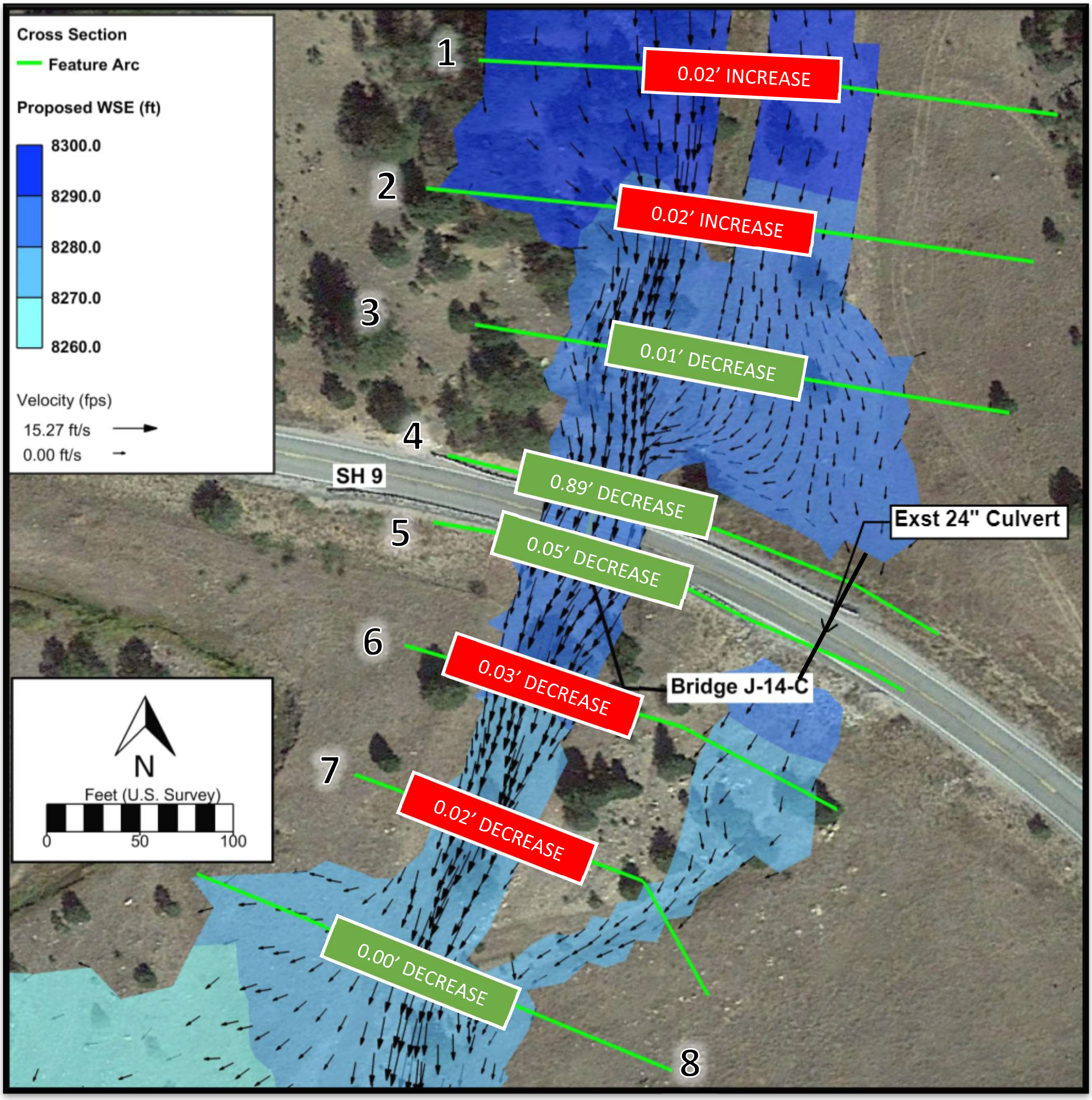
APPENDIX G WATER SURFACE ELEVATION COMPARISON GRAPHICS



FLOODPLAIN CROSS SECTIONS – RCBC OPTION

STRUCTURE J-14-C

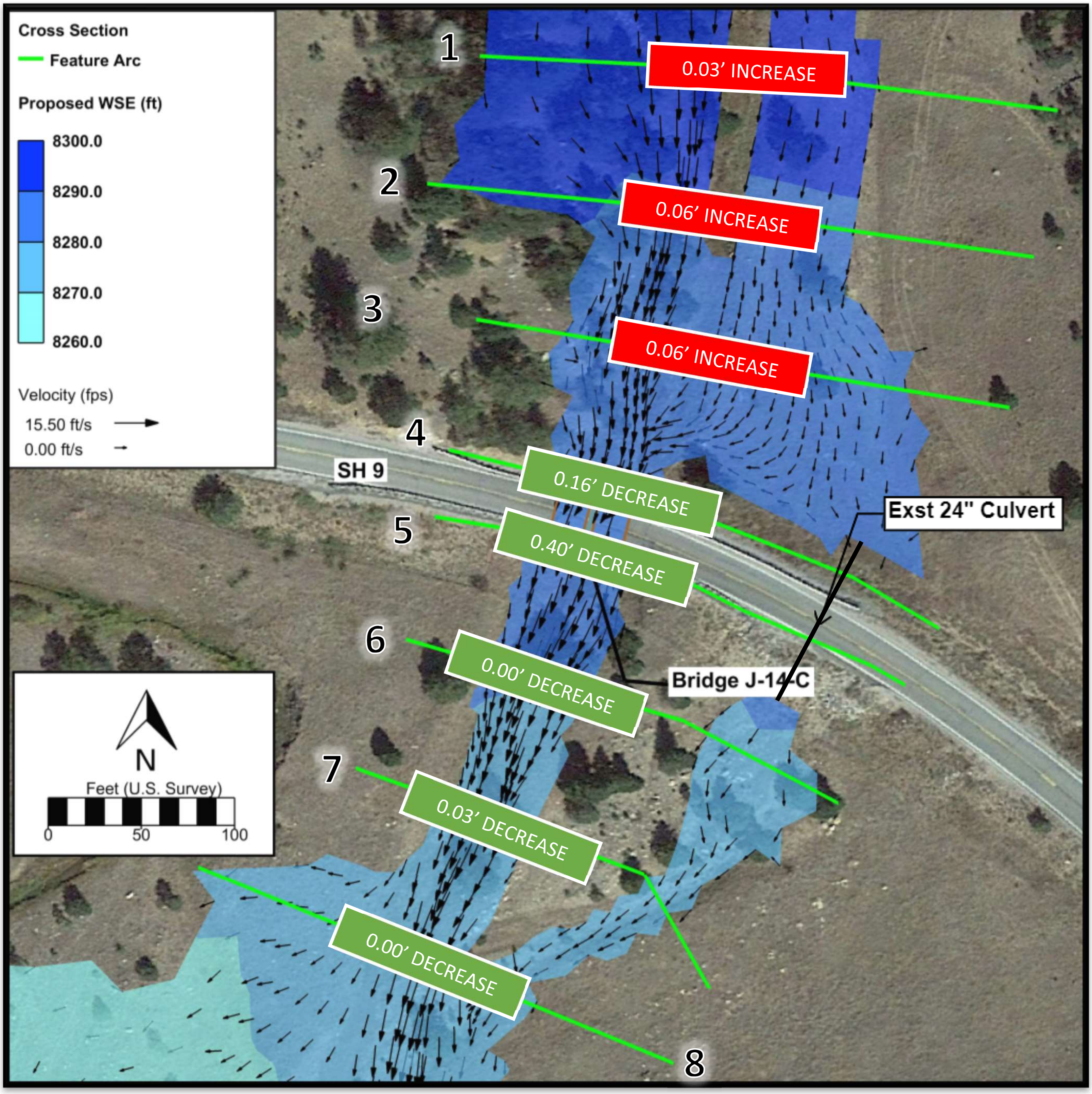
FIGURE 13



FLOODPLAIN CROSS SECTIONS – BRIDGE OPTION

STRUCTURE J-14-C

FIGURE 14



FLOODPLAIN CROSS SECTIONS – ALBC OPTION

STRUCTURE J-14-C

FIGURE 15

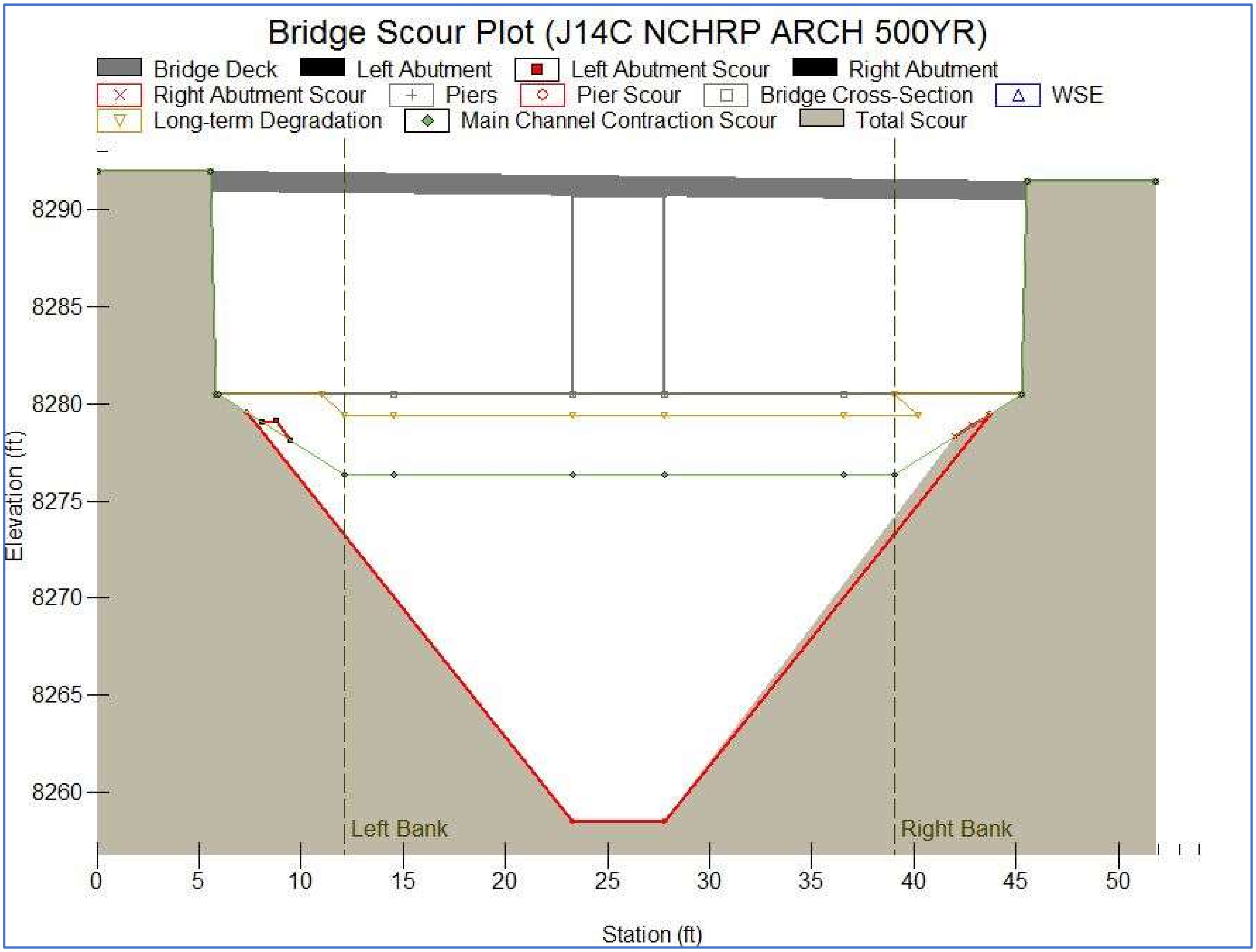
APPENDIX H ENERGY DISSIPATION AND SCOUR ANALYSIS

HY-8 Energy Dissipation Report

External Energy Dissipator

Parameter	Value	Units
Select Culvert and Flow		
Crossing	2-18'x7'	
Culvert	Culvert 1	
Flow	1288.00	cfs
Culvert Data		
Culvert Width (including multiple barrels)	36.0	ft
Culvert Height	7.0	ft
Outlet Depth	2.62	ft
Outlet Velocity	13.68	ft/s
Froude Number	1.49	
Tailwater Depth	1.99	ft
Tailwater Velocity	16.15	ft/s
Tailwater Slope (SO)	0.0123	
External Dissipator Data		
External Dissipator Category	Streambed Level Structures	
External Dissipator Type	Riprap Basin	
Restrictions		
Froude Number	<3	
Input Data		
Condition to be used to Compute Basin Outlet Velocity	Best Fit Curve	
D50 of the Riprap Mixture		
Note:	Minimum HS/D50 = 2 is Obtained if D50 = 0.722 ft	
D50 of the Riprap Mixture	0.500	ft
DMax of the Riprap Mixture	1.000	ft
Results		
Brink Depth	2.616	ft
Brink Velocity	13.677	ft/s
Depth (YE)	2.616	ft
Riprap Thickness	1.500	ft
Riprap Foreslope	2.0000	ft
Check HS/D50		
Note:	OK if HS/D50 > 2.0	
HS/D50	5.945	
HS/D50 Check	HS/D50 is OK	
Check D50/YE		
Note:	OK if 0.1 < D50/YE < 0.7	
Check D50/YE	0.191	
D50/YE Check	D50/YE is OK	
Basin Length (LB)	144.000	ft
Basin Width	132.000	ft
Apron Length	36.000	ft
Pool Length	108.000	ft
Pool Depth (HS)	2.972	ft
TW/YE	0.762	
Tailwater Depth (TW)	1.993	ft
Average Velocity with TW	4.752	ft/s
Critical Depth (Yc)	1.425	ft
Average Velocity with Yc	6.701	ft/s
Downstream Riprap for High TW		
Distance: 1 LB		
Velocity	6.310	ft/s
Size	0.260	ft
Distance: 2 LB		
Velocity	3.139	ft/s
Size	0.064	ft

Distance: 3 LB		
Velocity	2.087	ft/s
Size	0.028	ft
Distance: 4 LB		
Velocity	1.562	ft/s
Size	0.016	ft


Bridge Scour Plot (J14C NCHRP ARCH 500YR)
Bridge Deck
Left Abutment
Left Abutment Scour
Right Abutment
Right Abutment Scour
Piers
Pier Scour
Bridge Cross-Section
WSE
Long-term Degradation
Main Channel Contraction Scour
Total Scour
Elevation (ft)
8290
8285
8280
8275
8270
8265
8260
Left Bank
Right Bank
0
5
10
15
20
25
30
35
40
45
50
Station (ft)

Hydraulic Analysis Report

Project Data

Project Title: J-14-C 100YR

Designer: Stanley Consultants

Project Date: Tuesday, December 22, 2020

Project Units: U.S. Customary Units

Riprap Analysis: Bridge - Left Abutment

Notes: The Total Bridge Area was adjusted until the characteristic velocity matched the maximum channel velocity. This allows for a more conservative calculation at the abutment. Based on engineering judgement, the D50 is rounded to the next highest class. When results are considered liberal, the maximum channel velocity is used in lieu of the average to achieve more practical results. When results are considered conservative, the average channel velocity is used in lieu of the maximum to achieve more practical results. For this calculation, the average velocity is used.

Input Parameters

Riprap Type: Abutment/Guide Bank

The structure is a guidebank

Set-back Length: 7 ft

The set-back length is the distance from the near edge of the main channel to the toe of abutment

Main Channel Average Flow Depth: 2.055 ft

Flow Depth at Toe of Abutment: 3.42 ft

Calculations will use either total or overbank discharges.

Total Discharge: 1288 cfs

Overbank Discharge: 239.4 cfs

Total Bridge Area: 128.8 ft^2

Setback Area: 23.94 ft^2

Maximum Channel Velocity: 10 ft/s

Specific Gravity of Riprap: 2.65

Result Parameters

Set-back ratio: 3.40633

Characteristic Velocity: 10 ft/s

Froude Number at the Abutment Toe: 0.953311

Abutment Coefficient: 0.69

Computed D50: 16.9339 in

Design D50 = 18 in

Thickness = 36 in

Design D50 > Computed D50

18 in > 16.9339 in

Riprap Class

Riprap shape should be angular

Riprap Class Name: CLASS V

Riprap Class Order: 5

The following values are an 'average' of the size fraction range for the selected riprap class.

d100: 36 in

d85: 25.5 in

d50: 18.5 in

d15: 13 in

Layout Recommendations

Minimum Riprap Thickness: 36 in

Minimum Horizontal Extent of the Toe Apron from the Abutment Toe: 6.84 ft

Minimum Extent of "Wrap Around" beyond the Abutment Radius, along the Approach Embankment: 25 ft

See HEC 23, Figure 14.7

No channel used in calculations

Riprap Analysis: Bridge - Right Abutment

Notes: The Total Bridge Area was adjusted until the characteristic velocity matched the maximum channel velocity. This allows for a more conservative calculation at the abutment. Based on engineering judgement, the D50 is rounded to the next highest class. When results are considered liberal, the maximum channel velocity is used in lieu of the average to achieve more practical results. When results are considered conservative, the average channel velocity is used in lieu of the maximum to achieve more practical results. For this calculation, the average velocity is used.

Input Parameters

Riprap Type: Abutment/Guide Bank

The structure is a guidebank

Set-back Length: 2.5 ft

The set-back length is the distance from the near edge of the main channel to the toe of abutment

Main Channel Average Flow Depth: 2.055 ft

Flow Depth at Toe of Abutment: 1.85 ft

Calculations will use either total or overbank discharges.

Total Discharge: 1288 cfs

Overbank Discharge: 45 cfs

Total Bridge Area: 128.8 ft^2

Setback Area: 4.5 ft^2

Maximum Channel Velocity: 10 ft/s

Specific Gravity of Riprap: 2.65

Result Parameters

Set-back ratio: 1.21655

Characteristic Velocity: 10 ft/s

Froude Number at the Abutment Toe: 1.29617

Abutment Coefficient: 0.69

Computed D50: 9.98305 in

Design D50 = 18 in

Thickness = 36 in

Design D50 > Computed D50

18 in > 9.98305 in

Riprap Class

Riprap shape should be angular

Riprap Class Name: CLASS V

Riprap Class Order: 5

The following values are an 'average' of the size fraction range for the selected riprap class.

d100: 36 in

d85: 25.5 in

d50: 18.5 in

d15: 13 in

Layout Recommendations

Minimum Riprap Thickness: 36 in

Minimum Horizontal Extent of the Toe Apron from the Abutment Toe: 3.7 ft

Minimum Extent of "Wrap Around" beyond the Abutment Radius, along the Approach Embankment: 25 ft

See HEC 23, Figure 14.7

No channel used in calculations

Riprap Analysis: Arch Culvert - Left Abutment

Notes: The Total Bridge Area was adjusted until the characteristic velocity matched the maximum channel velocity. This allows for a more conservative calculation at the abutment. Based on engineering judgement, the D50 is rounded to the next highest class. When results are considered liberal, the maximum channel velocity is used in lieu of the average to achieve more practical results. When results are considered conservative, the average channel velocity is used in lieu of the maximum to achieve more practical results. For this calculation, the average velocity is used.

Input Parameters

Riprap Type: Abutment/Guide Bank

The structure is a guidebank

Set-back Length: 5 ft

The set-back length is the distance from the near edge of the main channel to the toe of abutment

Main Channel Average Flow Depth: 3.54 ft

Flow Depth at Toe of Abutment: 3.64 ft

Calculations will use either total or overbank discharges.

Total Discharge: 1288 cfs

Overbank Discharge: 209 cfs

Total Bridge Area: 112 ft^2

Setback Area: 18.2 ft^2

Maximum Channel Velocity: 11.5 ft/s

Specific Gravity of Riprap: 2.65

Result Parameters

Set-back ratio: 1.41243

Characteristic Velocity: 11.5 ft/s

Froude Number at the Abutment Toe: 1.06266

Abutment Coefficient: 0.69

Computed D50: 18.5797 in

Design D50 = 24 in

Thickness = 48 in

Design D50 > Computed D50

24 in > 18.5797 in

Riprap Class

Riprap shape should be angular

Riprap Class Name: CLASS VII

Riprap Class Order: 7

The following values are an **'average'** of the size fraction range for the selected riprap class.

d100: 49.5 in

d85: 35 in

d50: 25.5 in

d15: 17.5 in

Layout Recommendations

Minimum Riprap Thickness: 48 in

Minimum Horizontal Extent of the Toe Apron from the Abutment Toe: 7.28 ft

Minimum Extent of "Wrap Around" beyond the Abutment Radius, along the Approach Embankment: 25 ft

See HEC 23, Figure 14.7

No channel used in calculations

Riprap Analysis: Arch Culvert - Right Abutment

Notes: The Total Bridge Area was adjusted until the characteristic velocity matched the maximum channel velocity. This allows for a more conservative calculation at the abutment. Based on engineering judgement, the D50 is rounded to the next highest class. When results are considered liberal, the maximum channel velocity is used in lieu of the average to achieve more practical results. When results are considered conservative, the average channel velocity is used in lieu of the maximum to achieve more practical results. For this calculation, the average velocity is used.

Input Parameters

Riprap Type: Abutment/Guide Bank

The structure is a guidebank

Set-back Length: 5 ft

The set-back length is the distance from the near edge of the main channel to the toe of abutment

Main Channel Average Flow Depth: 3.12 ft

Flow Depth at Toe of Abutment: 2.95 ft

Calculations will use either total or overbank discharges.

Total Discharge: 1288 cfs

Overbank Discharge: 147.8 cfs

Total Bridge Area: 128.8 ft^2

Setback Area: 14.75 ft^2

Maximum Channel Velocity: 10.02 ft/s

Specific Gravity of Riprap: 2.65

Result Parameters

Set-back ratio: 1.60256

Characteristic Velocity: 10 ft/s

Froude Number at the Abutment Toe: 1.02645

Abutment Coefficient: 0.69

Computed D50: 14.9122 in

Design D50 = 24 in

Thickness = 48 in

Design D50 > Computed D50

24 in > 14.9122 in

Riprap Class

Riprap shape should be angular

Riprap Class Name: CLASS VII

Riprap Class Order: 7

The following values are an **'average'** of the size fraction range for the selected riprap class.

d100: 49.5 in

d85: 35 in

d50: 25.5 in

d15: 17.5 in

Layout Recommendations

Minimum Riprap Thickness: 48 in

Minimum Horizontal Extent of the Toe Apron from the Abutment Toe: 5.9 ft

Minimum Extent of "Wrap Around" beyond the Abutment Radius, along the Approach Embankment: 25 ft

See HEC 23, Figure 14.7

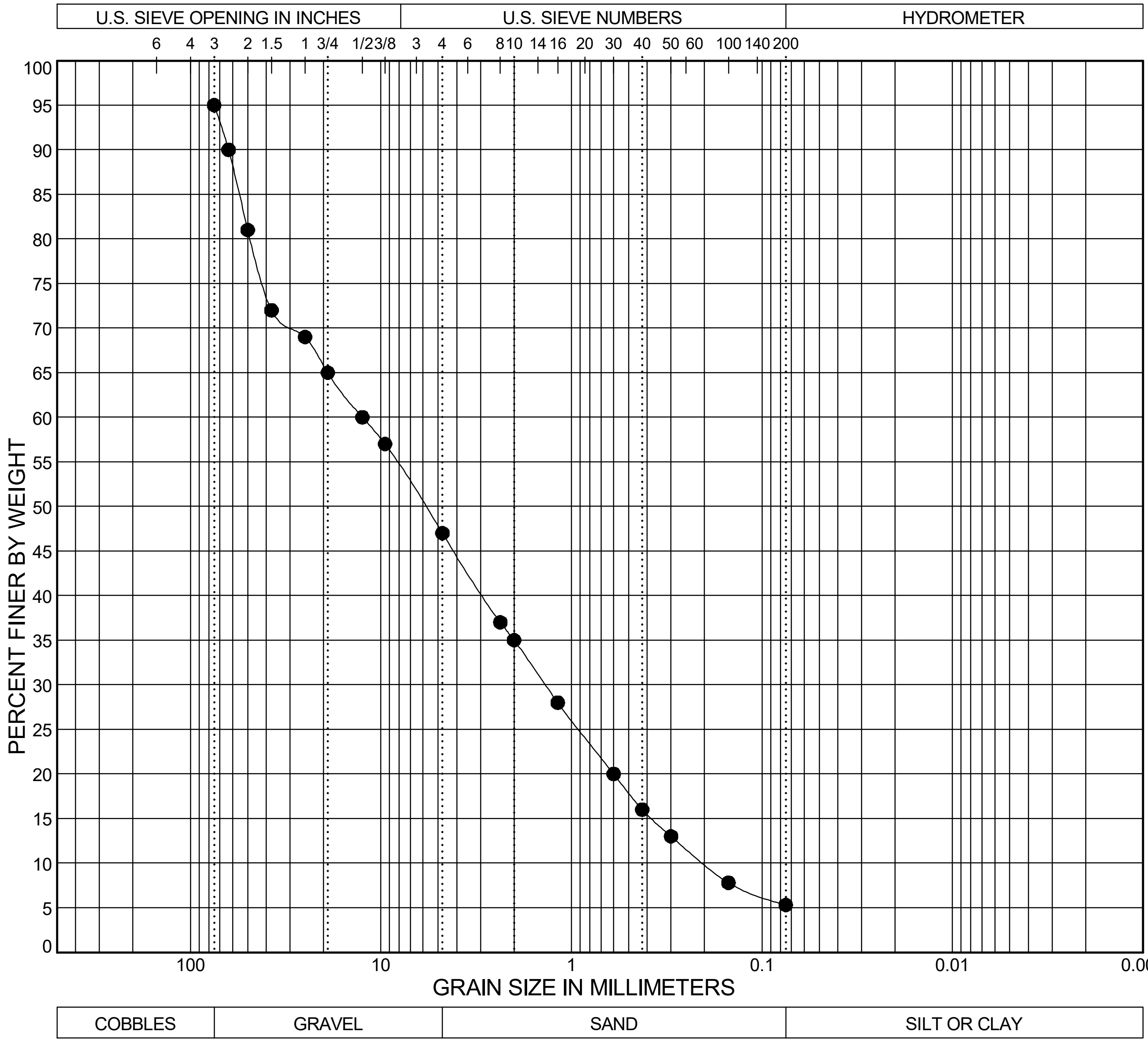
No channel used in calculations

APPENDIX I GEOTECHNICAL INFORMATION

Summary of Laboratory Test Results

Project No: 220-063 Project Name: CDOT Region 2 Bridge Bundle Date: 11-24-2020

Sample Location			Natural Moisture Content (%)	Natural Dry Density (pcf)	Gradation			Atterberg			pH	Water Soluble Sulfate (%)	Water Soluble Chloride (%)	Resistivity (ohm-cm)	Swell (+) / Collapse (-) (% at Load in psf)	Unconf. Comp. Strength (psi)	R-Value	Classification	
Boring No.	Depth (ft)	Sample Type			Gravel > #4 (%)	Sand (%)	Fines < #200 (%)	LL	PL	PI								AASHTO	USCS
G-12-C Scour	0	BULK	0.4		83.0	16.6	0.4	NV	NP	NP								A-1-a (0)	GP
H-13-N Scour	0	BULK	5		0.0	60.0	40.0	NV	NP	NP								A-4 (0)	SM
I-13-G Scour	0	BULK	1.3		45.0	44.1	10.9	27	18	9								A-2-4 (0)	GW-GC
I-13-H Scour	0	BULK	12		9.0	24.1	66.9	46	31	15								A-7-5 (10)	ML
I-15-AO Scour	0	BULK	1.2		53.0	41.2	5.8	NV	NP	NP								A-1-a (0)	GW-GM
I-15-T Scour	0	BULK	1.4		41.0	55.2	3.8	NV	NP	NP								A-1-a (0)	SW
I-17-X Scour	0	BULK	0.4		55.0	44.3	0.7	NV	NP	NP								A-1-a (0)	GW
J-14-C Scour	0	BULK	1.9		48.0	46.7	5.3	NV	NP	NP								A-1-a (0)	GP-GM
J-15-G Scour	0	BULK	5.4		13.0	79.7	7.3	NV	NP	NP								A-1-b (0)	SP-SM



	BOREHOLE	DEPTH (ft)	AASHTO Classification	USCS Classification	LL	PL	PI	%Gravel	%Sand	%Fines %Silt	%Fines %Clay
●	**J-14-C Scour**	**0.0**	**A-1-a (0)**	**GP-GM**	**NV**	**NP**	**NP**	**48.0**	**41.7**	**5.3**	

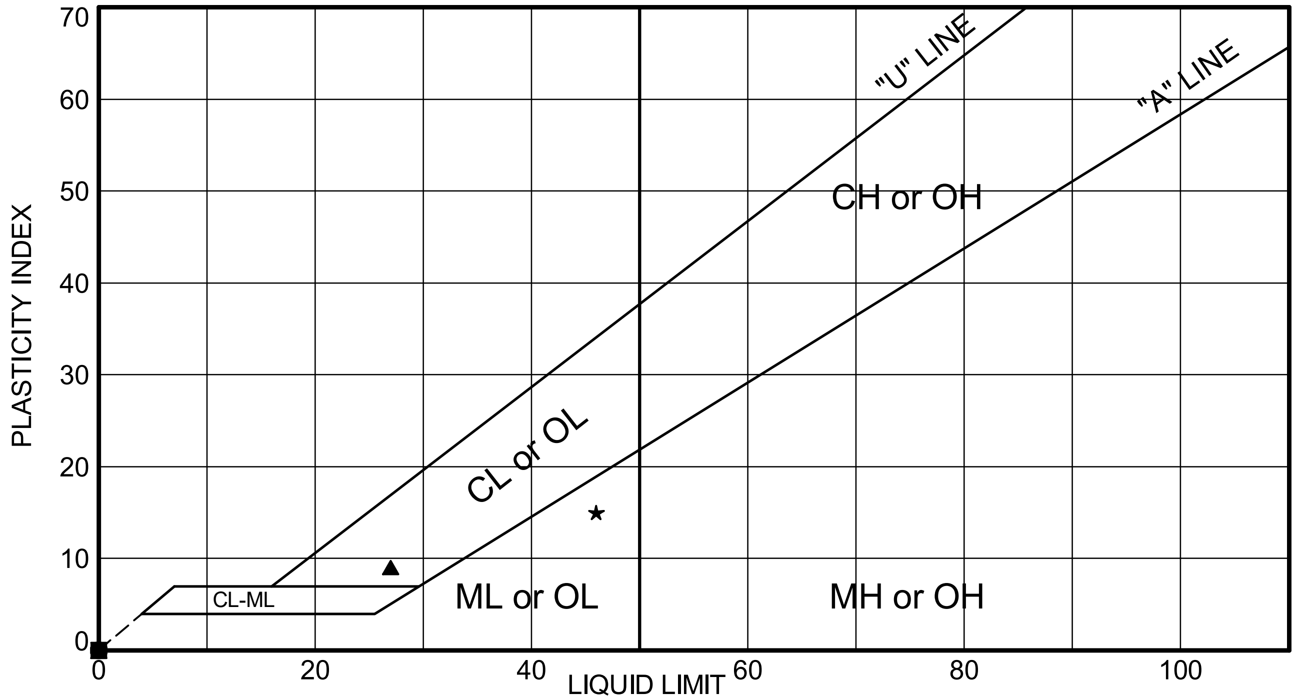
Yeh and Associates, Inc.
Geotechnical • Geological • Construction Services

SIEVE ANALYSIS

FIGURE S- 8

Project No.	220-063	Date:	11-24-2020
Report By:	D. Gruenwald	Yeh Lab:	Colorado Springs
Checked By:	J. McCall		

CDOT Region 2 Bridge Bundle
Scour Test Results
Structure J-14-C



	BOREHOLE	DEPTH (ft)	LL	PL	PI	Passing #200	USCS Sample Description and Symbol	AASHTO Class.
●	**G-12-C Scour**	**0.0**	**NV**	**NP**	**NP**	**0.4**	**POORLY GRADED GRAVEL (GP)**	**A-1-a (0)**
⧗	**H-13-N Scour**	**0.0**	**NV**	**NP**	**NP**	**40.0**	**SILTY SAND (SM)**	**A-4 (0)**
▲	**I-13-G Scour**	**0.0**	**27**	**18**	**9**	**10.9**	**WELL-GRADED GRAVEL with CLAY and SAND (GW-GC)**	**A-2-4 (0)**
★	**I-13-H Scour**	**0.0**	**46**	**31**	**15**	**66.9**	**SANDY SILT (ML)**	**A-7-5 (10)**
⊙	**I-15-AO Scour**	**0.0**	**NV**	**NP**	**NP**	**5.8**	**WELL-GRADED GRAVEL with SILT and SAND (GW-GM)**	**A-1-a (0)**
✿	**I-15-T Scour**	**0.0**	**NV**	**NP**	**NP**	**3.8**	**WELL-GRADED SAND with GRAVEL (SW)**	**A-1-a (0)**
○	**I-17-X Scour**	**0.0**	**NV**	**NP**	**NP**	**0.7**	**WELL-GRADED GRAVEL with SAND (GW)**	**A-1-a (0)**
△	**J-14-C Scour**	**0.0**	**NV**	**NP**	**NP**	**5.3**	**POORLY GRADED GRAVEL with SILT and SAND (GP-GM)**	**A-1-a (0)**
⊗	**J-15-G Scour**	**0.0**	**NV**	**NP**	**NP**	**7.3**	**POORLY GRADED SAND with SILT (SP-SM)**	**A-1-b (0)**

Yeh and Associates, Inc.
Geotechnical • Geological • Construction Services

ATTERBERG LIMITS

CDOT Region 2 Bridge Bundle
West Bridges

FIGURE

S - 10

Project No. 220-063 Date: 11-24-2020
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