Appendix D – Hydrologic and Hydraulic Assessment

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Memorandum

Date: **April 23, 2021**

To: **Chris Hodge and Dean Zurcher – Wood Rodgers, Inc.**

From: **Chris Sewell – WRECO**

Project: **Arroyo Road at Dry Creek Bridge Replacement Project**

Subject: **Hydrologic and Hydraulic Assessment**

INTRODUCTION

Project Location

The Arroyo Road at Dry Creek Bridge Replacement Project (Project) is located in the City of Livermore within the County of Alameda (County) (see Figure 1, which shows the location of the Project site). The Project is located along Arroyo Road over Dry Creek (see Figure 2, which shows the aerial image of the Project vicinity). The Project site is located southeast of Sycamore Grove Park and northwest of The Course at Wente Vineyards. The existing bridge is shown in Photo 1 and Photo 2, which were taken during the WRECO's field review on April 10, 2020.

Purpose

The purpose of this *Memorandum* is to present the evaluation of the hydrologic and hydraulic conditions of Dry Creek at Arroyo Road for the replacement bridge structure.

Project Description

Alameda County Public Works Agency is proposing to replace the structurally deficient Arroyo Road over Dry Creek Bridge (33C0448) with a new bridge that meets current applicable County, American Association of State Highway and Transportation Officials (AASHTO), and California Department of Transportation (Caltrans) design criteria and standards. In addition to the new bridge, the proposed Project will ensure the roadway within the Project limits meets current County and AASHTO standards and will provide a Class I bike path over the bridge. The Project is funded primarily through the State set-aside of Federal funds for the Highway Bridge Program (HBP), as administered through Caltrans Local Assistance. The Class I bike path will be funded using local dollars.

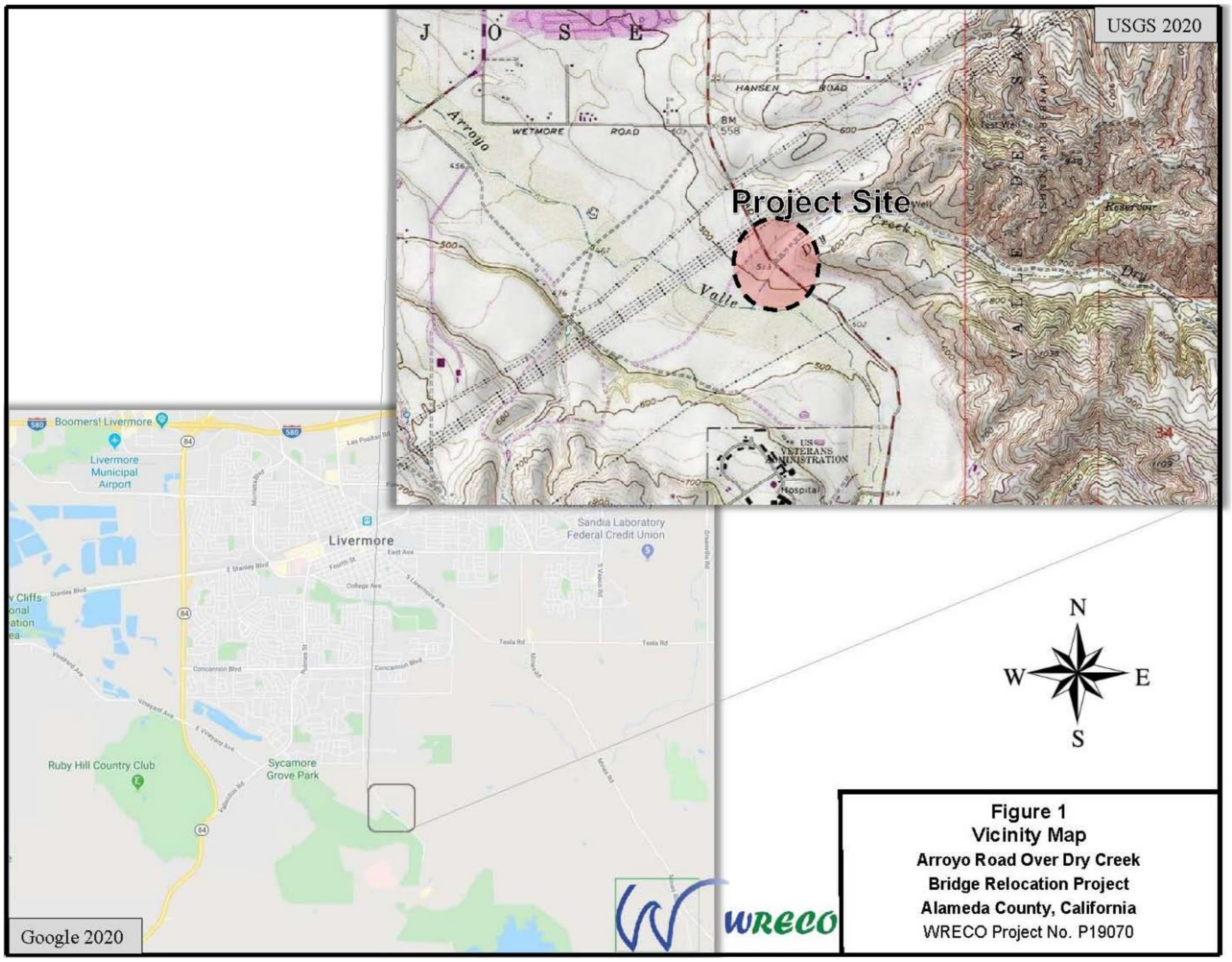

Figure 1. Project Vicinity Map

Sources: Google and United States Geological Survey (USGS)

Figure 2. Project Aerial Map

Source: Environmental Systems Research Institute (ESRI)

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Photo 1. Upstream Face of Existing Bridge (April 10, 2020)

Source: WRECO

Photo 2. Downstream Face of Existing Bridge (April 10, 2020)

Source: WRECO

Existing Facilities

The Project area is in a rural area of the County and includes agricultural, residential, and commercial land uses. Arroyo Road in the vicinity of the Project follows an approximate northwest-southeast alignment, and is classified as a Local Rural Road. The future average daily traffic (ADT) estimate for the year 2037 is 6,206. The road serves as the single point of access across the creek for all points south, including large commercial agricultural/ranching parcels, a golf course, Department of Veteran Affairs health care services complex, a camp, a recreational park, and reservoir facilities. Specific land use conditions are noted for the following parcels:

- Wente Bros, northwest (APN 099-0500-001-03): CLC (Williamson) Act contract, and South Livermore Valley Agricultural Land Trust
- Wente Land & Cattle Co, northeast (APN 099-0625-002-01): CLC (Williamson) Act contract
- Cresta Blanca Golf, LLC, southeast (APN 099-0625-002-03): CLC (Williamson) Act contract

The existing concrete-encased steel girder bridge is a 25-foot (ft)-long single-span structure consisting of two, 10-ft-wide traffic lanes and narrow 1-ft-wide shoulders, one lane traveling in each direction. A separate timber pedestrian walkway is present along the east side of the bridge. The existing geometry of the road has limited sight distance at the bridge due to profile and alignment constraints. Safety features of the structure, such as railing and guardrail, do not meet current standards.

Within the Project area, Dry Creek is a natural watercourse with uncontrolled flows. The creek does not contain water for the majority of the year. During peak rainfall events, the bridge constricts the flow at the crossing, the creek overtops the south channel bank, and the water flows across the south approach roadway.

A private gated access driveway connects into Arroyo Road immediately northeast of the bridge. Additional private frontage roads north of the bridge parallel Arroyo Road on each side.

Proposed Improvements

The County proposes to replace the existing bridge with a cast-in-place reinforced concrete single-span slab bridge that will accommodate two travel lanes plus shoulders and traffic rated vehicular barriers to meet AASHTO standards (see Figure 3). The bridge will also accommodate a 12-ft-wide Class I bike path separated from traffic by an interior vehicular traffic rated barrier. The replacement structure will be 34-ft-long and supported by integral diaphragm type abutments on deep foundations.

The roadway profile will be raised approximately 2 ft to meet hydraulic and geometric requirements. To accommodate the raised profile, wider bridge structure, and longer span, the roadway centerline at the bridge will be shifted to the southwest to maintain traffic throughout construction while balancing impacts from slopes encroaching upon agricultural land (winery) to the northwest, a park to the southwest, grazing land to the northeast, and a recreational facility to the southeast.

The access driveway will be reconstructed to connect into the raised roadway.

Project Watershed

The contributing watershed at the Project site is approximately 2.8 square miles (mi) (see Figure 4). USGS's California StreamStats is a web-based geographic information system that provides information on streamflow statistics and drainage-basin characteristics. According to USGS StreamStats (2020), approximately 4.3% of the watershed is covered by forest and 2.5% of the watershed is developed. The mean annual precipitation of the watershed is 19.4 inches (see Appendix for the watershed characteristics).

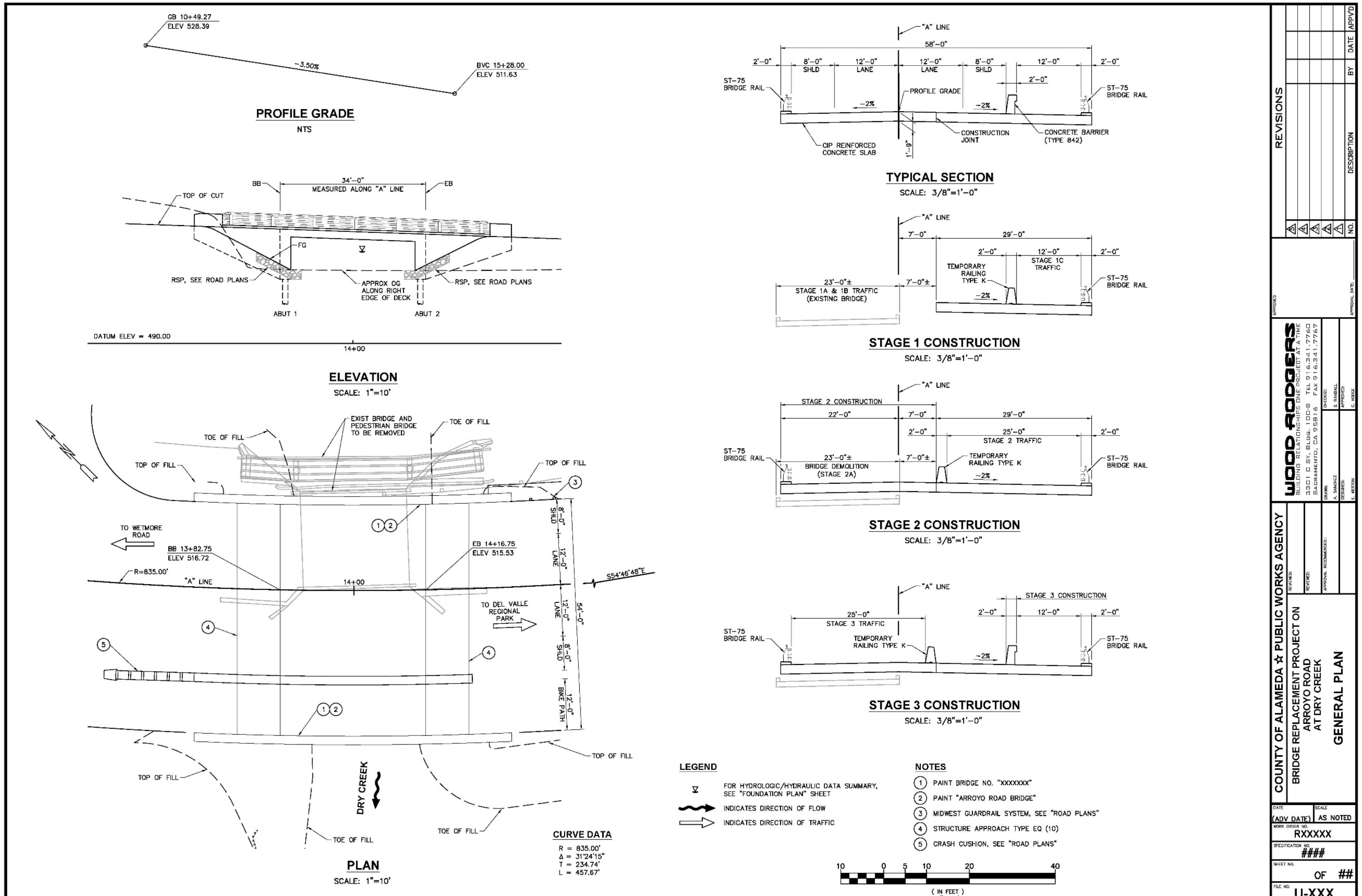

Figure 3. Proposed Bridge General Plan

Source: Wood Rodgers 2020a

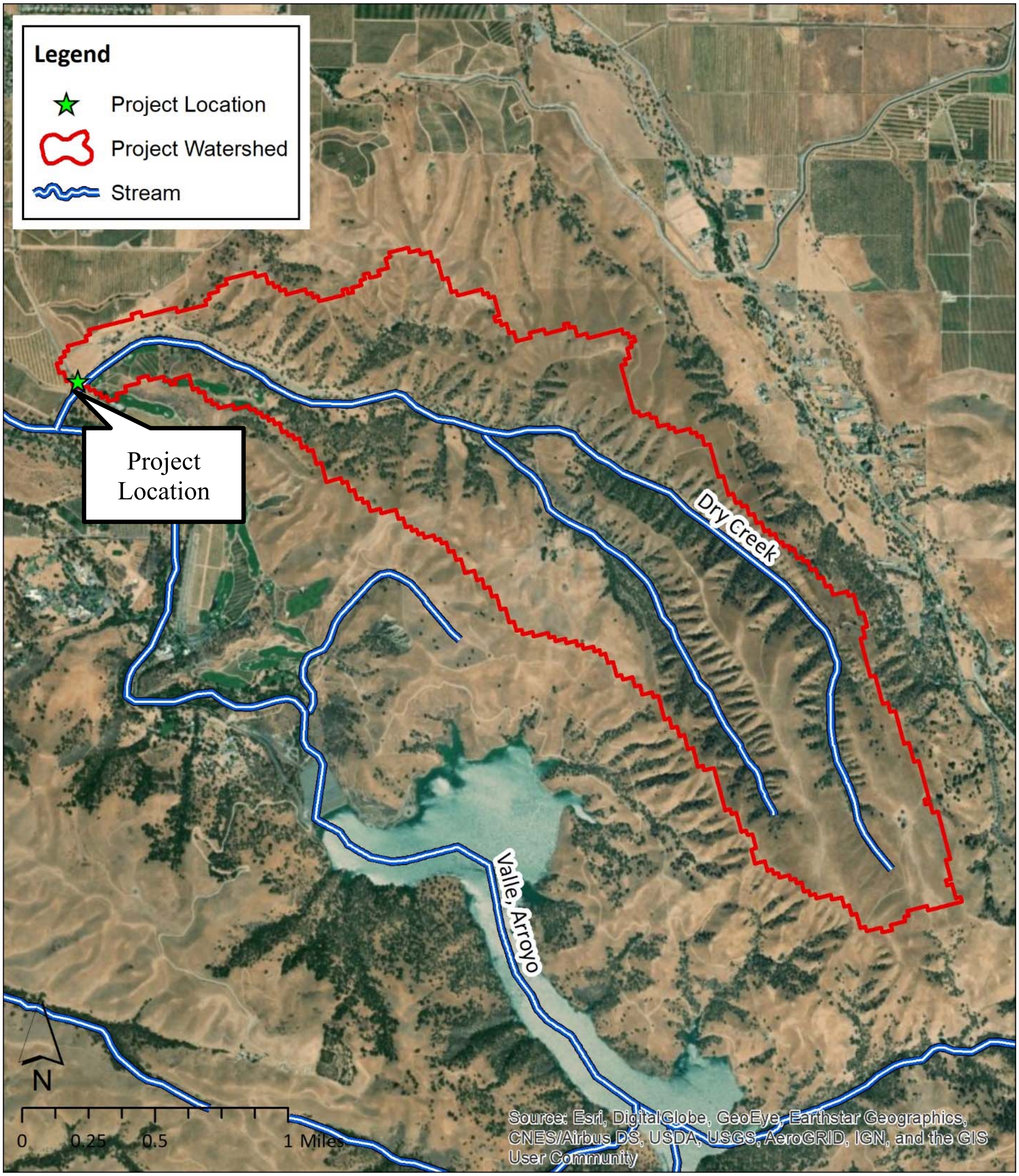

Figure 4. Project Watershed Map

Sources: ESRI and USGS

HYDROLOGIC ANALYSIS

The following sub-sections describe the hydrologic data sources and methodologies that were used to estimate the peak flows for the Project site, and the design flows selected for the Project.

WRECO evaluated the hydrology at the Project site using the following hydrologic design methods:

1. USGS Regional Flood-Frequency Equations
2. Soil Conservation Service (SCS) Unit-Hydrograph Method.

There are no known USGS peak streamflow gages along Dry Creek within the Project vicinity. No additional stream flow information for Dry Creek was found in the effective Federal Emergency Management Agency Flood Insurance Study (FIS) for Alameda County (2018).

Design Discharge Summary

USGS Regional Flood-Frequency Equations

Flood-frequency equations were developed by the USGS and are based on an analysis of data from gage stations. The USGS has divided California into six hydrologic regions; the Project site is within the Central Coast region. These flood frequency equations are generally used to estimate stream flow for ungaged sites that are not affected by substantial urban development and that are natural (unregulated) streams.

On July 18, 2012, the USGS issued *Methods for Determining Magnitude and Frequency of Floods in California, Based on Data through Water Year 2006* (Gotvald et al., 2012), which contains updated regional flood-frequency equations, and revised the boundaries of the six unique regions within California. These equations are based on annual peak-flow data through water year 2006 for 771 streamflow-gaging stations in California with 10 or more years of data.

With a watershed area of 2.8 square mi and mean annual precipitation of 19.4 inches, the estimated 100- and 50-year peak discharges are provided in Table 1 (see Appendix for the watershed characteristics and peak discharge calculations).

Table 1. Peak Discharges Estimated Using USGS Regional Flood-Frequency Equation

Return Period (year)	Peak Discharge (cubic feet per second [cfs])
100	500
50	380

SCS Unit Hydrograph Method

WRECO developed a hydrologic model of the Dry Creek watershed at the Project site to estimate the 100- and 50-year recurrence interval peak discharges using United States Army Corps of Engineers' (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software, and following the SCS' Unit Hydrograph Method. The hydrologic model simulates the rainfall/runoff process and generates discharge hydrographs. The input parameters were estimated by following the procedures in Technical Release 55 (TR-55), the *Urban Hydrology for Small Watersheds* manual (Natural Resources Conservation Service [NRCS] 1986), *A Guide to Hydrologic Analysis Using SCS Methods* (McCuen 1982), and Chapter 810 from the Caltrans *Highway Design Manual* (HDM) (2020). Some of the factors that affect the runoff at the Project site include the watershed area, slope and elevations of the watershed, land uses, and soils. The following discussions describes the characteristics of the watershed that were applied in the hydrologic model of HEC-HMS to estimate the peak discharges.

The meteorological data used in the model to estimate the peak discharges of the watershed was calculated by subtracting losses and transforming excess precipitation. The losses were estimated using the SCS Curve Number (CN) loss method, and the excess precipitation was calculated using the SCS Unit Hydrograph transform method in HEC-HMS.

The SCS Type 1A method was defined using precipitation depths from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 website for California Precipitation Frequency Data using the longitude and latitude of the approximate centroid of the watershed. Per the NRCS TR-55, the 24-hour synthetic rainfall distribution is appropriate to use for modeling because it nests the rainfall intensities from the shorter-duration storms. A 24-hour storm duration is commonly used for design calculations per industry standards and was used to estimate the peak flows for the Project site. The 24-hour frequency storm depth was estimated to be 4.68 inches for the 100-year storm event and 4.11 inches for the 50-year storm event.

The losses for the watershed were calculated using a CN. In the hydrologic model, the rainfall is converted to runoff by using a CN, which was based on the watershed's soils, plant cover type and treatment, amount of impervious areas, interception, and surface storage. The CN was estimated using Table 2-2 from TR-55. The CN selected to represent the Project watershed was 83, which is associated with a brush, weed, grass cover type with poor hydrologic condition based on hydrologic soil group (HSG) D.

The transformation of the effective rainfall was accomplished using the SCS unit hydrograph transform method, which is dependent on lag time. Lag time is defined as the time in hours from the center of mass of rainfall excess to the peak discharge. The lag time was estimated to be 2.1 hours (see Appendix for the lag time calculation).

The HEC-HMS model was developed by applying the parameters discussed in the previous paragraphs. The estimated peak discharge values from the model are summarized in Table 2.

Table 2. Peak Discharges Estimated Using SCS Unit Hydrograph

Return Period (year)	Peak Discharge (cfs)
100	530
50	430

Selected Design Discharge

The peak discharges estimated using the SCS Unit Hydrograph method were selected for use in the hydraulic analysis because the SCS Unit hydrograph method provided a more detailed analysis of the watershed characteristics. In addition, the peak discharges using this method were more conservative than those calculated using the USGS regional regression method. The selected design discharges are 530 cfs and 430 cfs for 100-year and 50-year storm events, respectively (see Table 2).

HYDRAULIC ANALYSIS

The following sections discuss the development of the hydraulic models and summarize the results for the existing and proposed conditions. The water surface profile plots, hydraulic summary tables, and channel cross sections are included in the appendices.

Design Tools

The hydraulic analyses were performed for the existing and proposed conditions using the USACE's HEC-RAS modeling software, Version 5.0.7.

Hydraulic Model Development

Cross Section and Bridge Data

The geometry of the hydraulic model was developed using topographic data provided by Wood Rodgers, Inc. in March 2020 (2020b). The elevations of the topographic data reference the North American Vertical Datum of 1988 (NAVD 88). The cross sections in the model encompass a stream reach length of approximately 1,100 ft. The locations of the cross sections are depicted in Figure 5.

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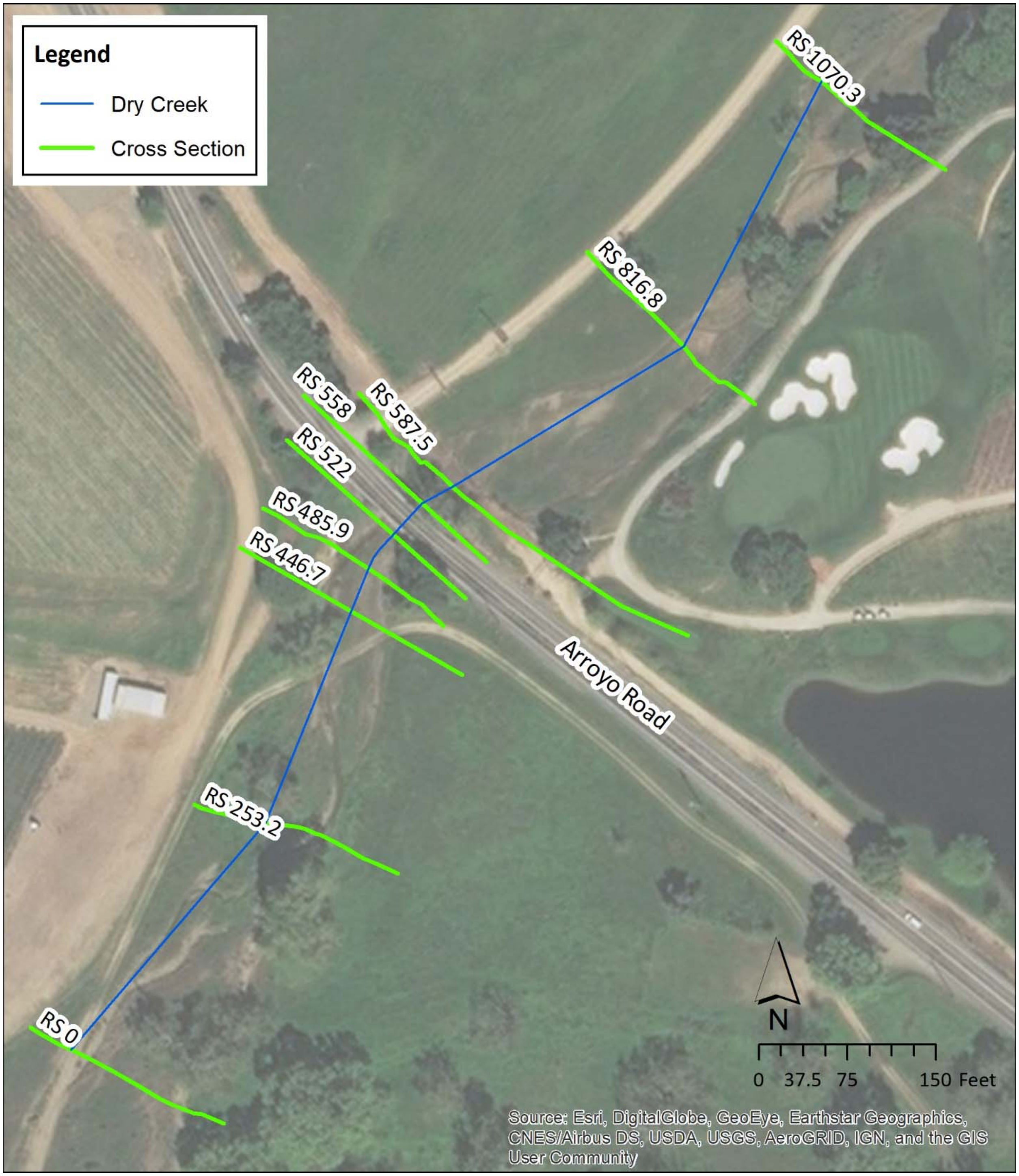

Figure 5. Cross Section Locations

Source: ESRI

The cross sections are labeled by river station (RS), which increase numerically in the upstream direction. In the vicinity of the Project site, upstream is in the northeast direction and downstream is in the southwest direction. The cross sections were cut facing the downstream direction.

The existing bridge is modeled at RS 539.8. The single-span bridge has a clear opening of 25 ft and a width of 23 ft. Based on the survey data, the minimum soffit elevation of the existing bridge is 510.4 ft NAVD 88.

The proposed bridge will be longer and wider than the existing bridge. The proposed bridge is modeled at RS 520.5. The proposed bridge was modeled based on plan and profile information provided by Wood Rodgers, Inc. July 2020 (2020a). The single-span bridge will have a clear opening of 30 ft and a width of 58 ft. The Project will incorporate localized grading at the embankment slopes of the proposed bridge. The minimum soffit elevation of the proposed bridge is 513.1 ft NAVD 88 at the downstream side of the bridge and 513.4 ft NAVD 88 at the upstream side of the bridge.

Model Boundary Condition

A normal depth slope of 0.016 ft/ft was used as the downstream reach boundary condition. The slope was estimated based on the thalweg elevations from the Project's survey of Dry Creek in the Project vicinity.

Manning's Roughness Coefficients

Manning's roughness coefficients were used in the hydraulic model to estimate energy losses in the flow due to friction. A roughness coefficient of 0.03 was used to describe the channel, which corresponds to main channels that are clean and straight. A roughness coefficient of 0.045 was used to describe the banks at the proposed bridge to account for the increased roughness from proposed rock slope protection (RSP).

Expansion and Contraction Coefficients

Expansion and contraction coefficients were used in the hydraulic model to represent energy losses in the channel. An expansion coefficient of 0.3 and a contraction coefficient of 0.1 were used to represent the channel. These values represent a channel with gradual transitions between cross sections. An expansion coefficient of 0.5 and a contraction coefficient of 0.3 were used to represent the channel in the vicinity of the Arroyo Road bridge. These values represent the flow interference caused by the bridge structure.

Hydraulic Model Results

The model was computed using the steady flow analysis and a subcritical flow regime using a downstream normal depth boundary condition. This section summarizes the results of the hydraulic model analysis.

Water Surface Elevations

The water surface elevations in the vicinity of the Arroyo Road bridge are presented in Table 3 and Table 4 for the 100-year and 50-year storms, as evaluated in the hydraulic model. The cross section of the existing structure is depicted in Figure 6. The cross section of the proposed structure is depicted in Figure 7. The cross sections face the downstream or southwest direction. The water surface profiles for the two evaluated storm events are presented in Figure 8 and Figure 9. Additional model output for the existing and proposed conditions are included in the Appendix.

The results of the hydraulic modeling indicated the proposed condition would lessen the backwater effect upstream of the bridge compared to the existing condition for both the 100-year and 50-year storm events. The decreases in water surface elevation upstream of the bridge are a result of the larger opening of the proposed bridge. The proposed condition would result in a localized increase in water surface elevation of 1.0 ft for the 100-year storm and 0.9 ft for the 50-year storm just downstream of the bridge at RS 485.9. At RS 485.9, the grading of the embankment slopes for the proposed condition would reduce the area of the cross section in comparison to the same location in the existing condition. Although the water surface elevation would increase at this location, the flow for the proposed condition would be contained within the channel. The 100-year and 50-year proposed water surfaces would converge to the existing water surface profiles approximately 90 ft downstream of the existing bridge centerline, which is the area just beyond the proposed embankment fill slope.

Table 3. Dry Creek 100-Year Water Surface Elevations

River Station	Description/Distance from Existing Bridge Centerline (ft)	Water Surface Elevation (ft NAVD 88)	
		Existing	Proposed
1070.3	531 feet upstream	518.0	518.0
816.8	277 feet upstream	513.6	513.6
587.5	48 feet upstream	512.8	511.4
558	18 feet upstream	512.7	510.7
539.8 BR U	Upstream face of existing bridge	512.7	--
520.5 BR U	Upstream face of proposed bridge	--	510.1
539.8 BR D	Downstream face of existing bridge	512.4	--
520.5 BR D	Downstream face of proposed bridge	--	509.4
522	18 feet downstream	509.7	--
485.9	54 feet downstream	507.9	508.9
446.7	93 feet downstream	507.1	507.1
253.2	287 feet downstream	503.4	503.4
0	540 feet downstream	499.3	499.3

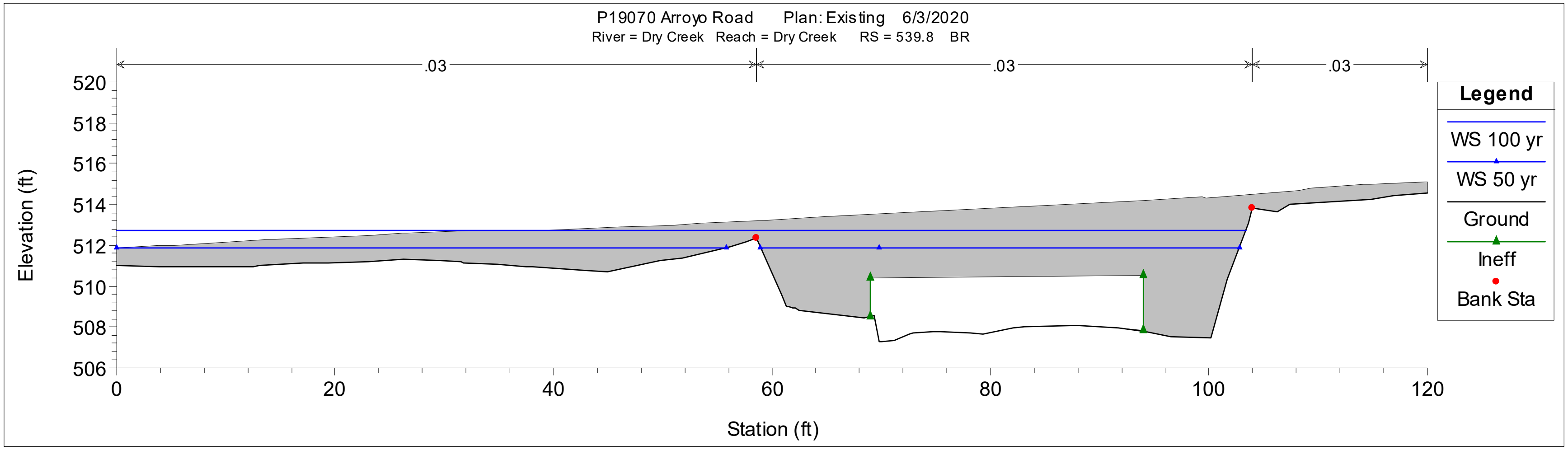

Figure 6. Existing Bridge Upstream Cross Section

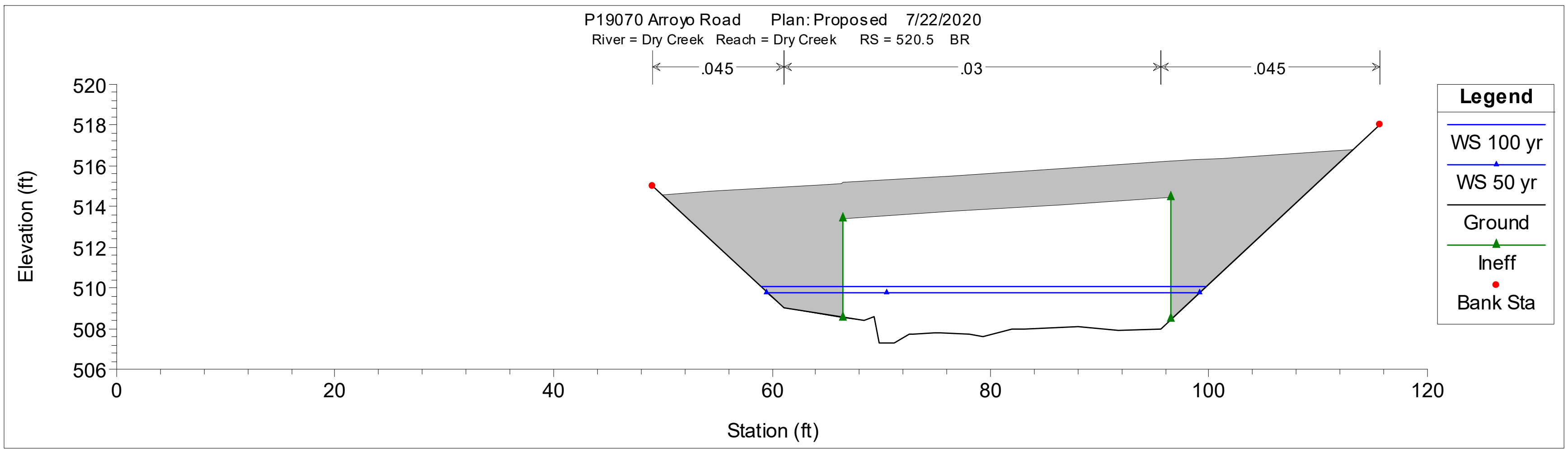

Figure 7. Proposed Bridge Upstream Cross Section

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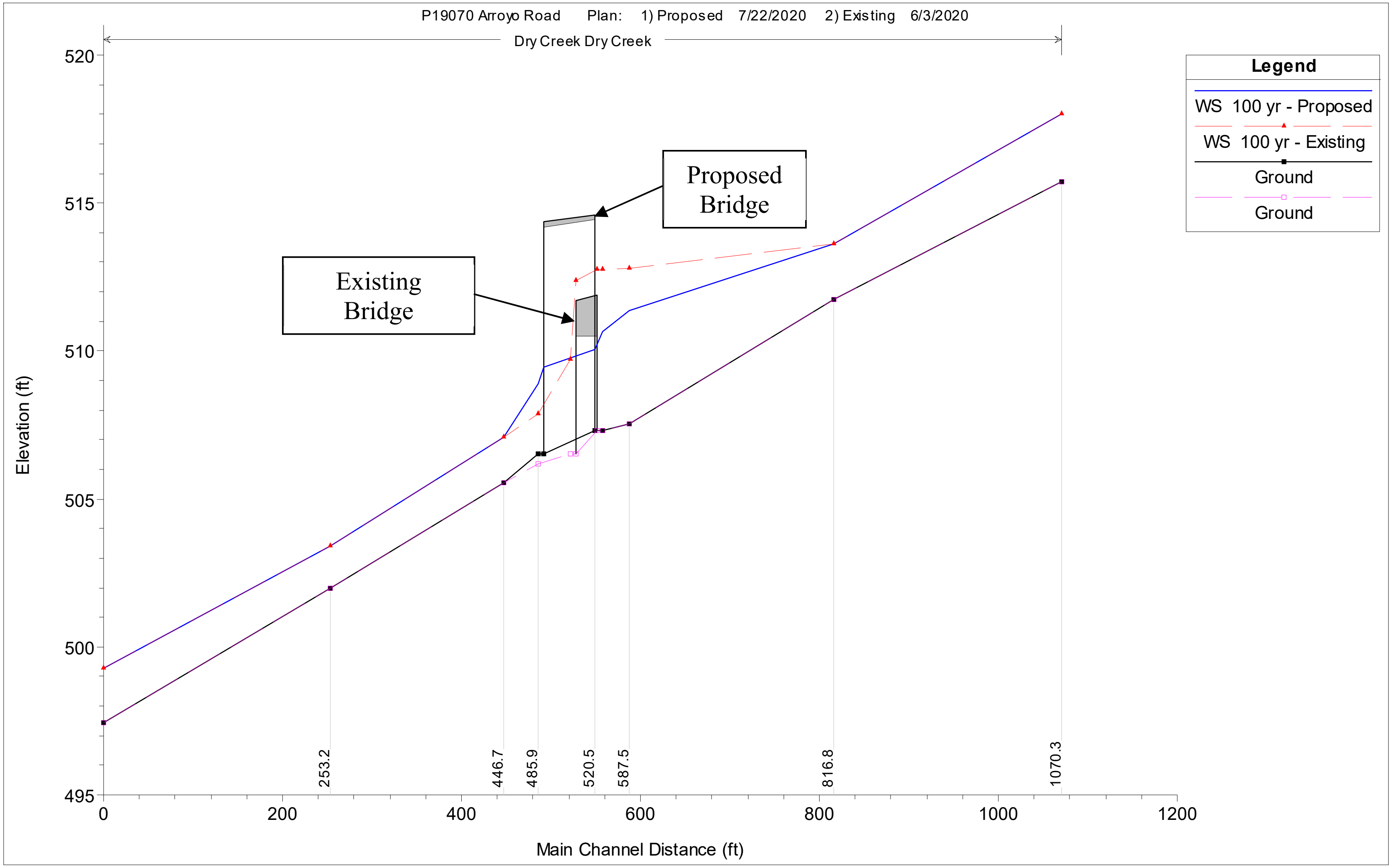

Figure 8. 100-Year Water Surface Profiles

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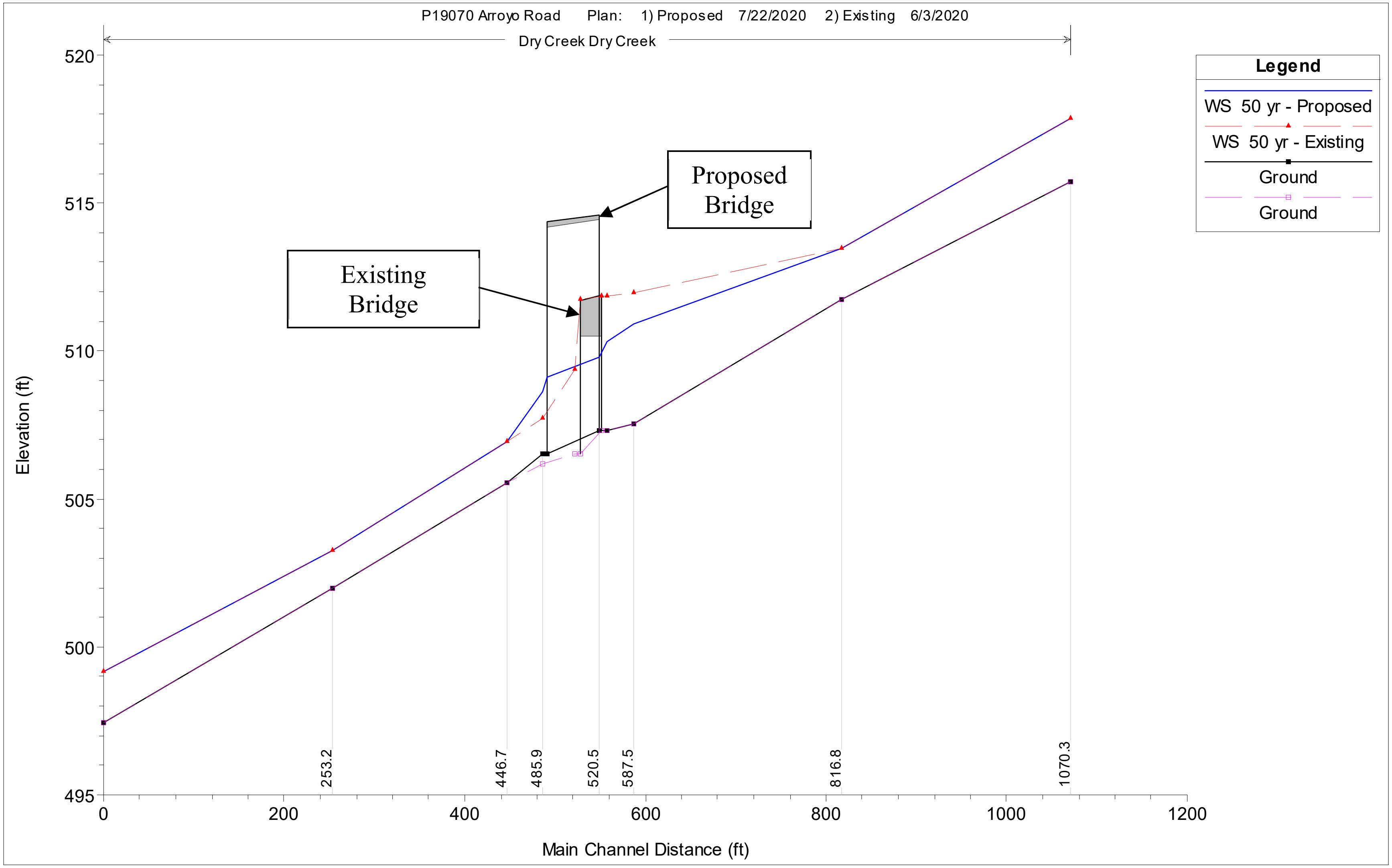

Figure 9. 50-Year Water Surface Profiles

Table 4. Dry Creek 50-Year Water Surface Elevations

River Station	Description/Distance from Existing Bridge Centerline (ft)	Water Surface Elevation (ft NAVD 88)	
		Existing	Proposed
1070.3	531 feet upstream	517.9	517.9
816.8	277 feet upstream	513.5	513.5
587.5	48 feet upstream	512.0	510.9
558	18 feet upstream	511.9	510.3
539.8 BR U	Upstream face of existing bridge	511.9	--
520.5 BR U	Upstream face of proposed bridge	--	509.8
539.8 BR D	Downstream face of existing bridge	511.7	--
520.5 BR D	Downstream face of proposed bridge	--	509.1
522	18 feet downstream	509.4	--
485.9	54 feet downstream	507.7	508.6
446.7	93 feet downstream	506.9	506.9
253.2	287 feet downstream	503.3	503.3
0	540 feet downstream	499.2	499.2

As depicted in the figures, the existing structure does not have the capacity to convey the 100-year and 50-year design storms. The proposed bridge has been designed to convey the 100-year and 50-year design storms with freeboard. The freeboard for the existing and proposed structures is presented in Table 5. The freeboard is presented at the upstream face of the bridges. Although the soffit elevation for the proposed bridge is lower at the downstream side of the bridge, the water surface elevations are also lower, and the freeboard at the downstream side of the bridge is greater than the freeboard at the upstream side of the bridge.

Table 5. Arroyo Road Bridge Freeboard at Dry Creek

Alternative	Return Period	Soffit Elevation (ft NAVD 88)*	Water Surface Elevation (ft NAVD 88)*	Freeboard (ft)**
Existing	100-Year	510.4	512.7	-2.3
	50-Year	510.4	511.9	-1.5
Proposed	100-Year	513.4	510.7	2.8
	50-Year	513.4	510.3	3.1

Note:
* Soffit and water surface elevations are reported at the upstream face of the bridge.
** Freeboard is rounded to the nearest tenth of a foot.

The proposed bridge has over 2 ft of freeboard from the 100-year and 50-year water surface elevations and the existing bridge is overtopped during both storm events.

The Federal Highway Administration (FHWA) criterion refers to the *California Amendments to AASHTO Load and Resistance Factor Design* (LRFD) *Bridge Design Specifications* (2014), which indicates that the proposed bridge profile should provide adequate freeboard to pass anticipated drift for the 50-year design flood, to pass the 100-year base flood without freeboard, or the flood of record without freeboard, whichever is greater.

From Chapter 820 of the Caltrans' HDM, the criteria for the hydraulic design of bridges is that they be designed to pass the 2% probability of annual exceedance flow (50-year design discharge) with adequate freeboard to pass anticipated drift (2020). Two (2) ft of freeboard is commonly used in bridge designs. The bridge should also be designed to pass the 1% probability of annual exceedance flow (100-year design discharge) without freeboard.

The existing bridge does not meet applicable freeboard criteria and the proposed bridge would have sufficient freeboard to meet the criteria of FHWA and Caltrans.

The hydrologic and hydraulic summary for the proposed bridge is presented in Table 6. This table shall be placed on the Foundation Plan, and will also be available on the as-built plans.

Table 6. Hydrologic Summary Table

Hydrologic Summary for			
Bridge No. 33C0448			
Drainage Area: 2.8 mi^2			
Frequency	**Design Flood**	**Base Flood**	**Flood of Record**
	50-year	100-year	N/A
Discharge	430 cfs	530 cfs	N/A
Water Surface Elevation at Bridge	510.3 ft	510.7 ft	N/A

Flow Velocities

The average channel flow velocities were estimated for the existing and proposed conditions from the developed hydraulic models, which are summarized in Table 7 for the locations in the vicinity of the bridge. Based on the results of the analysis, the proposed bridge would result in a maximum increase in average velocity of 4.4 feet per second (ft/sec) at RS 558 for the 100-year storm. The increases in average channel velocities are a result of the reduced backwater effects in the proposed condition. In general, the average channel velocities in the vicinity of the bridge in the existing condition were approximately 8 ft/s, and will be approximately 8 ft/s in the proposed condition for the 100-year storm. Bank protection measures or other scour countermeasures, can be provided at the embankment slopes of the new bridge to limit the effects of erosion.

Table 7. Dry Creek 100-Year Average Channel Velocities

River Station	Description/Distance from Existing Bridge Centerline (ft)	Velocity (ft/s)	
		Existing	Proposed
558	18 feet upstream	2.1	6.5
539.8 BR U	Upstream face of existing bridge	7.7	--
520.5 BR U	Upstream face of proposed bridge	--	8.3
539.8 BR D	Downstream face of existing bridge	6.3	--
520.5 BR D	Downstream face of proposed bridge	--	6.6
522	18 feet downstream	8.8	--
485.9	54 feet downstream	6.0	8.3

SCOUR ASSESSMENT

The evaluation of potential scour at the proposed bridge followed the criteria described in the FHWA's *Hydraulic Engineering Circular No. 18* (HEC-18), "Evaluating Scour at Bridges" (2012). The evaluation of potential scour is typically based on the hydraulic characteristics of the 100-year design discharge. The total scour was estimated based upon the cumulative effects of the long-term bed elevation change, general (contraction) scour, and local scour. WRECO evaluated the scour potential and scour countermeasure analysis using the results of the steady-state flow analysis from HEC-RAS for the proposed bridge. The following sub-sections summarize the results of the analysis.

Existing Channel Bed

The Bridge Inspection Report (BIR) describes the channel material as sandy silt and gravel. According to the Particle Size Distribution report of the soil sample taken for the Project (Blackburn Consulting 2020) collected at the channel, the median particle size diameter (D_{50}) (Sample Number HA-20-003, S1) collected at a depth of 0 to 2 ft is 5.2 mm. The material of the sample is described as a well-graded gravel with sand. Based on this information, the bed material is considered cohesionless for the purposes of calculating potential scour.

Long-Term Bed Elevation Change

Long-term bed elevation changes can be due to either aggradation or degradation. Aggradation at the bridge site is a result of the deposition of material eroded from the channel. Degradation at the bridge site is a result of scouring of the channel due to sediment deficit. Only degradation is accounted for in scour calculations. The long-term bed elevation changes are typically based on historical data at the bridge site.

Caltrans BIRs were reviewed for scour-relevant information. The March 2013 BIR was a hydraulic inspection and notes the bridge was added to the State Inventory in 2012. As-built plans were unavailable. A stream measurement was taken at the time of the last investigation in

February 2012, but there were not historical stream measurements for comparison. At the time of the 2013 investigation, the cross section from 2012 was verified, and no changes were noted.

The National Bridge Inventory (NBI) Item 113 Scour Critical Bridges rating is 5, which indicates the bridge foundations have been determined to be stable for the assessed scour conditions, or that scour is determined to be within the limits of the footing or piles by assessment.

The subsequent BIRs from February 2014 and November 2015 did not include additional stream measurements and also did not note any scour issues. The stream measurement from the 2012 BIR was compared with the survey for the Project from 2020. The measurements in the 2012 BIR were relative to the top of rail. The deck elevations from the survey were adjusted using an assumed height of 0.5 ft for the curb. See Figure 10, which shows a comparison of the two stream measurements.

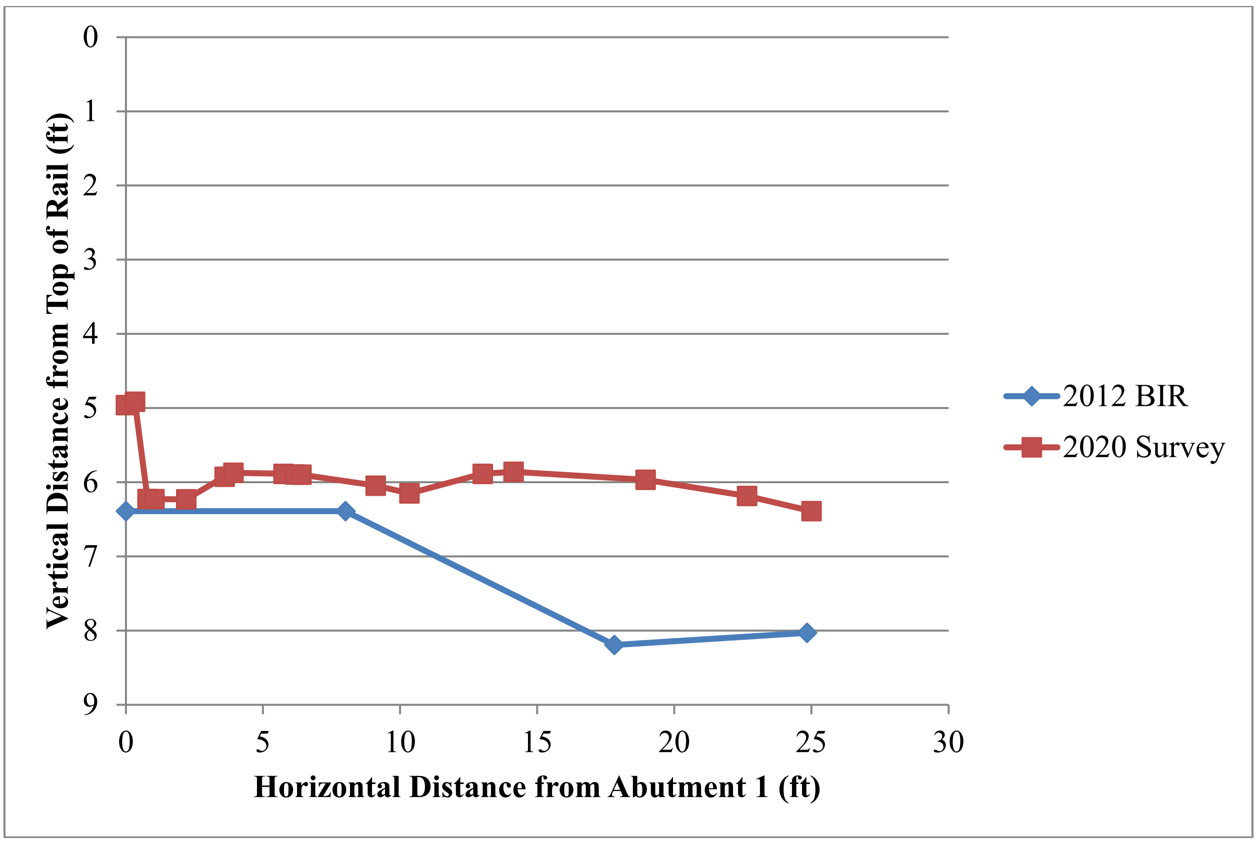

Figure 10. Historical Stream Measurements at Upstream Face of Existing Bridge

Source: BIR (Caltrans) and Survey (Wood Rodgers 2020b)

Based on the comparison of the limited available historical cross section information, the channel does not appear to be degrading. The bridge should continue to be monitored for signs of degradation or aggradation. Historical anecdotal information from nearby property owners indicate that sedimentation occurred in the channel over 20 years ago (Personal communication, Chris Hodge, Wood Rodgers, April 10, 2020). The nearby property owners also noted the creek bed has been relatively stable in the recent past (last 5 to 10 years). Based on review of historical photos and the longitudinal profile through the site, it seems that there is a constant slope through the Project site, which would indicate a constant sediment transport capacity and little evidence of sediment accumulation.

Contraction Scour

Contraction scour occurs when the flow area of a stream is reduced by: 1) the natural contraction of the stream channel; 2) a bridge structure; or 3) the overbank flow forced back to the channel. For estimating contraction scour of cohesionless bed materials, HEC-18 recommends using the live-bed contraction scour equation when the critical velocity of the bed material is less than the mean velocity in the main channel, and considers clear-water contraction scour when the critical velocity of the bed material is greater than the mean velocity. Because the critical velocity was greater than the mean velocity in the channel, the contraction scour for the Project site was calculated using the clear-water equation. The contraction scour was calculated to be 2.3 ft.

Abutment Scour

Abutment scour occurs when the bridge abutments and roadway embankment block approaching flow. According to HEC-18, local scour at the bridge abutment is commonly evaluated using either the Froehlich or HIRE live-bed scour equation. The HIRE equation is applicable when the ratio of the projected abutment length to the flow depth is greater than 25. The Froehlich equation was used for the scour analysis because the ratio of the Project abutment length to the flow depth was less than 25 for the proposed bridge. The abutment scour was calculated to be 5.6 ft at the southeast (end bridge [EB] side) abutment and 5.0 ft at the northwest (begin bridge [BB] side) abutment.

Total Scour

The total scour is the sum of long-term bed elevation change, local scour, and contraction scour. The calculated scour depths for the proposed bridge are summarized in Table 8 (see Appendix for detailed calculations). The total scour listed in the table is a combination of all scour components, assuming bed materials are erodible up to the depth of calculated scour.

Table 8. Scour Summary Table

Support No.	Degradation Scour Depth (ft)	Contraction Scour Depth (ft)	Short Term (Local) Scour Depth (ft)	Total Scour Depth (ft)
Southeast Abutment	0	2.3	5.6	7.9
Northwest Abutment	0	2.3	5.0	7.3

Per the *California Amendments to the AASHTO LRFD Bridge Design Specifications* (Caltrans 2019), foundations should be designed to withstand the conditions of scour. Caltrans' *Memo to Designers 16-1* (2017) provides additional guidance on foundation placement:

> The top of a spread footing must be placed at or below the anticipated total scour (Degradation + Contraction + Local) elevation (*LRFD 2.6.4.4.2 and LRFD-BDS-CA Figure C2.6.4.4.2-1*) unless founded on competent, scour-resistant bedrock.
>
> The top of a pile cap footing must be placed at or below the estimated degradation plus contraction scour depth (*LRFD 2.6.4.4.2 and LRFD-BDS-CA Figure C2.6.4.4.2-2*). The bottom of a pile cap footing should be placed at or below the anticipated Total Scour elevation.

The calculated long-term scour elevations and short-term scour depths are presented in Table 9. The bridge foundations should be designed to support the bridge with no lateral support down to the thalweg elevation minus the total scour depth.

Table 9. Scour Data Table

Support No.	Long-term (Degradation and Contraction) Scour Elevation (ft)	Short-term (Local) Scour Depth (ft)
Southeast Abutment	505.0	5.6
Northwest Abutment	505.0	5.0

The long-term scour elevation was calculated by subtracting the contraction scour depth from the channel thalweg elevation (507.3 ft NAVD 88), which was based on the channel cross section at the upstream face of the bridge. The scour data table (see Table 9) is the format that Caltrans requires on the foundation plans.

SCOUR AND EROSION COUNTERMEASURES

RSP generally consists of rocks on channel and structure boundaries to limit the effects of erosion. It is the most common type of scour countermeasure due to its general availability, ease of installation, and relatively low cost. RSP sizing calculations were performed to estimate a minimum rock size/class to protect the embankment slopes of the proposed bridge from erosion.

Two methods were used to determine the RSP size for the proposed bridge: Hydraulic Engineering Circular No. 23 (HEC-23) (FHWA 2009) and the HDM (Caltrans 2020). The calculation following the HEC-23 resulted in Class III RSP (150 pound [lb] median particle weight), and the calculation following the HDM resulted in Class II RSP (60 lb median particle weight). See Appendix for calculations.

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A minimum size of Class IV RSP is recommended to protect the abutment embankment slopes of the proposed bridge based on engineering judgment. Class IV RSP has a median particle weight of 300 lb and a median particle diameter of 15 inches. The minimum layer thickness of the Class IV (300 lb) RSP is 2.5 ft. The RSP should be placed using Method B, which involves dumping rock near its planned location, and working the rock to its final position with machinery. A Class 8 RSP geotextile filter fabric should be placed on the bank as the initial filter separator material between the layer of RSP and the channel bank. The RSP should extend from 2 ft above the design 100-year water surface elevations, from the faces of the abutments to the toes of slope, and wrap around the embankment fill slopes (see Figure 11). The RSP should be keyed in vertically a minimum of 5 ft below the toe of slope.

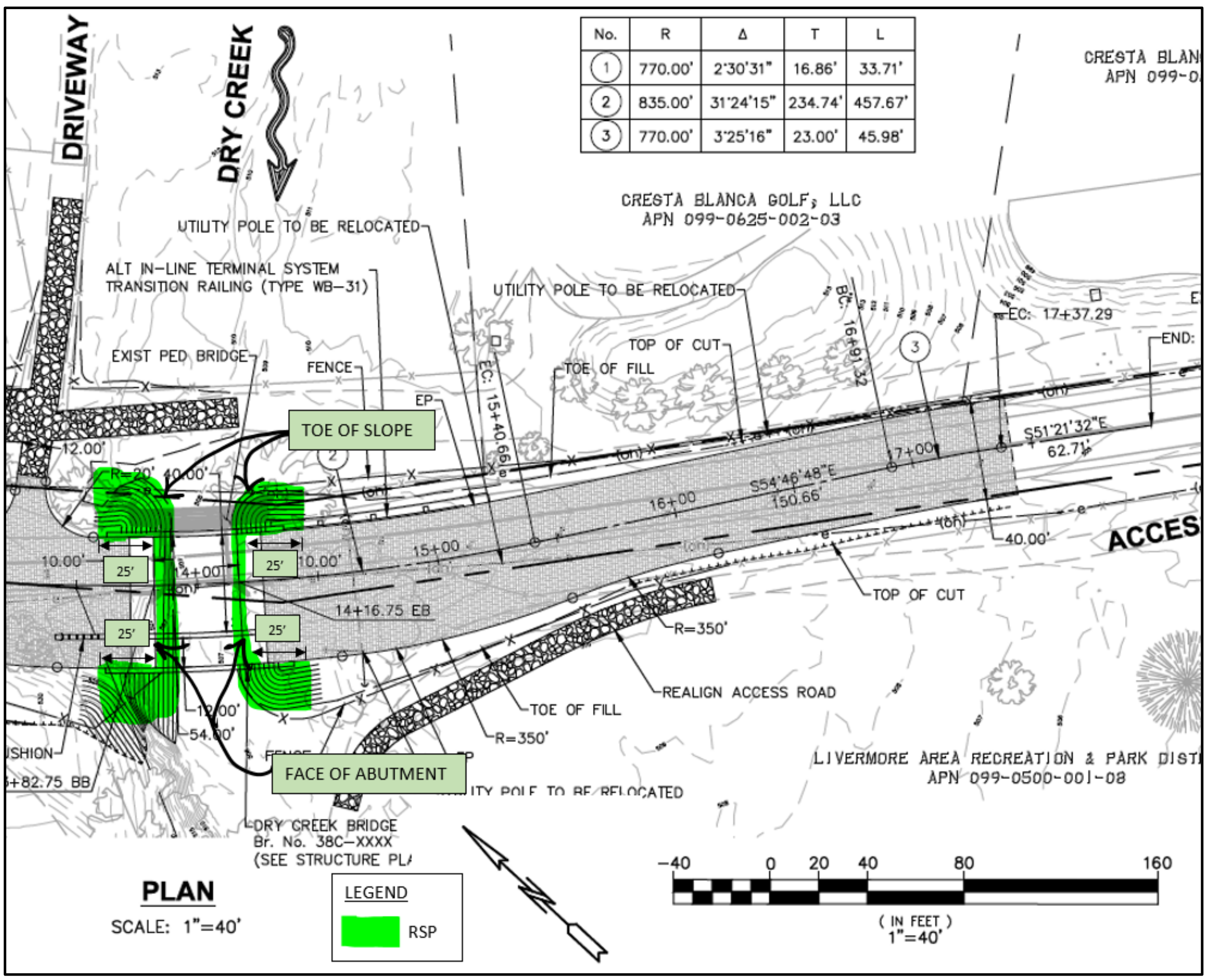

Figure 11. Conceptual RSP Limits

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APPENDIX

- USGS StreamStats
- Lag Time Calculation
- HEC-RAS Existing Condition Output
- HEC-RAS Proposed Condition Output
- Scour Calculations
- Scour Countermeasure Calculations

Arroyo Road at Dry Creek StreamStats Report

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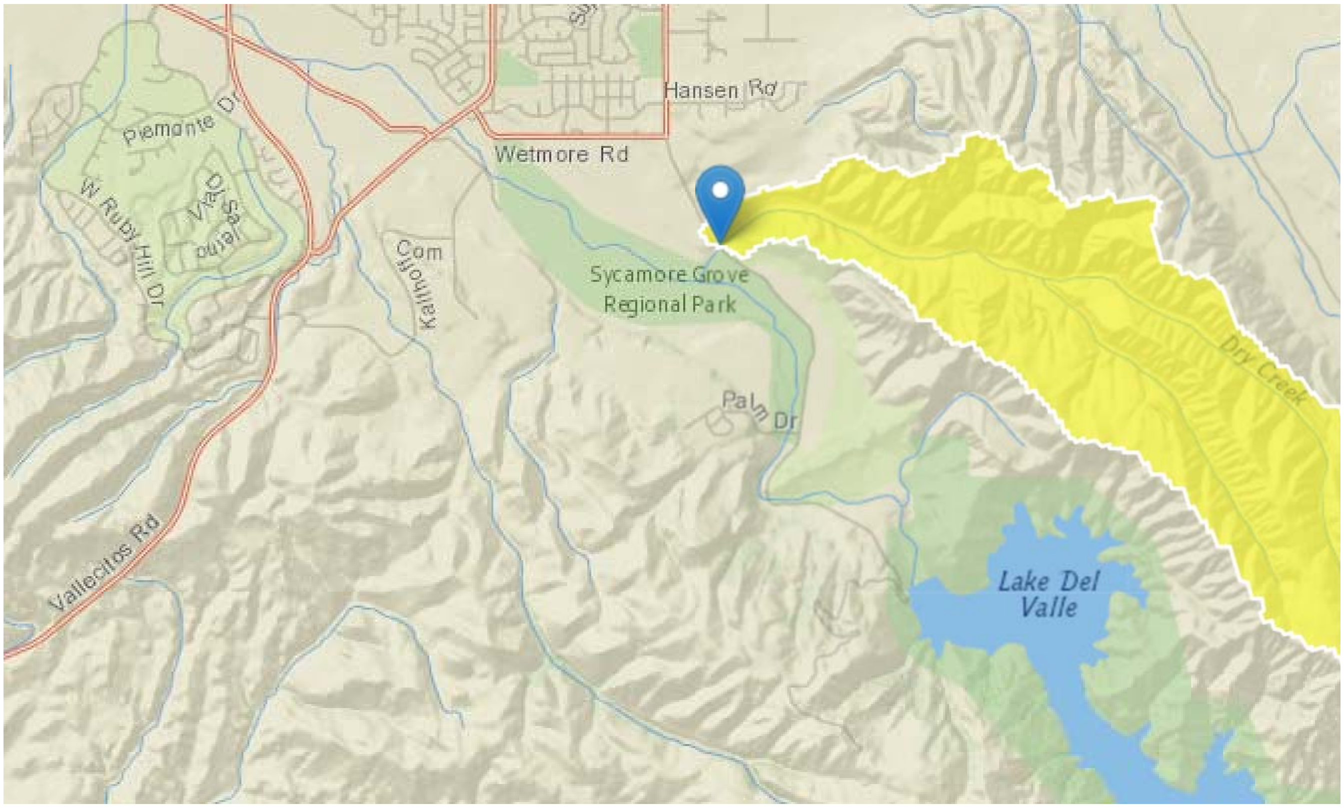
Workspace ID: CA20200218181840938000
Clicked Point (Latitude, Longitude): 37.63772, -121.76356
Time: 2020-02-18 10:18:58 -0800



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
BASINPERIM	Perimeter of the drainage basin as defined in SIR 2004-5262	12.6	miles
BSLDEM30M	Mean basin slope computed from 30 m DEM	24.9	percent
CENTROIDX	Basin centroid horizontal (x) location in state plane coordinates	-2221812.7	meters
CENTROIDY	Basin centroid vertical (y) location in state plane units	1923919.2	meters

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	2.8	square miles
EL6000	Percent of area above 6000 ft	0	percent
ELEV	Mean Basin Elevation	992	feet
ELEVMAX	Maximum basin elevation	1401	feet
FOREST	Percentage of area covered by forest	4.29	percent
JANMAXTMP	Mean Maximum January Temperature	55.41	degrees F
JANMINTMP	Mean Minimum January Temperature	37.65	degrees F
LAKEAREA	Percentage of Lakes and Ponds	0	percent
LC11DEV	Percentage of developed (urban) land from NLCD 2011 classes 21-24	2.5	percent
LC11IMP	Average percentage of impervious area determined from NLCD 2011 impervious dataset	0.3	percent
LFPLENGTH	Length of longest flow path	5	miles
MINBELEV	Minimum basin elevation	507	feet
OUTLETELEV	Elevation of the stream outlet in thousands of feet above NAVD88.	507	feet
PRECIP	Mean Annual Precipitation	19.4	inches
RELIEF	Maximum - minimum elevation	894	feet
RELRELF	Basin relief divided by basin perimeter	71.1	feet per mi

Peak-Flow Statistics Parameters[2012 5113 Region 4 Central Coast]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	2.8	square miles	0.11	4600
PRECIP	Mean Annual Precipitation	19.4	inches	7	46

Peak-Flow Statistics Flow Report[2012 5113 Region 4 Central Coast]

PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	SEp
2 Year Peak Flood	23.3	ft^3/s	3.54	153	162
5 Year Peak Flood	81.5	ft^3/s	20.9	318	97
10 Year Peak Flood	151	ft^3/s	47	485	79.4
25 Year Peak Flood	269	ft^3/s	93.1	780	69.9
50 Year Peak Flood	382	ft^3/s	140	1050	66.2
100 Year Peak Flood	498	ft^3/s	181	1370	66.9
200 Year Peak Flood	627	ft^3/s	227	1730	67.6
500 Year Peak Flood	806	ft^3/s	272	2390	71.5

Peak-Flow Statistics Citations

Gotvald, A.J., Barth, N.A., Veilleux, A.G., and Parrett, Charles,2012, Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p., 1 pl. (http://pubs.usgs.gov/sir/2012/5113/)

Application Version: 4.3.11

Project

P19070 Arroyo Road Bridge

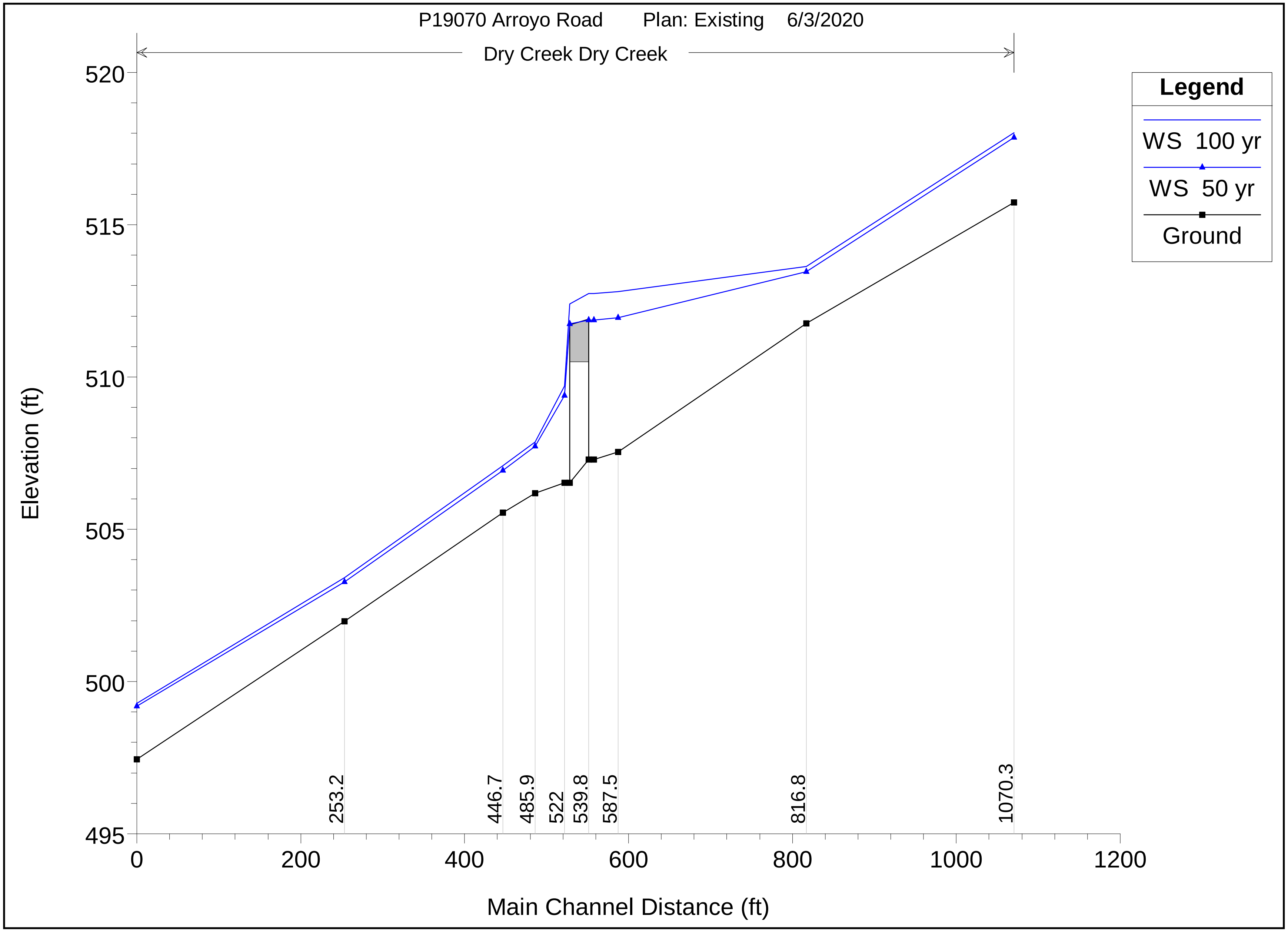
<u>HEC-HMS input Lag Time using Lag Method</u>

L = Lag = ((l^.8)*((S+1)^0.7))/(1900*(Y^0.5))

l =	hydraulic length
S =	Maximum retention
Y =	Slope in percent

S = (1000/CN)-10

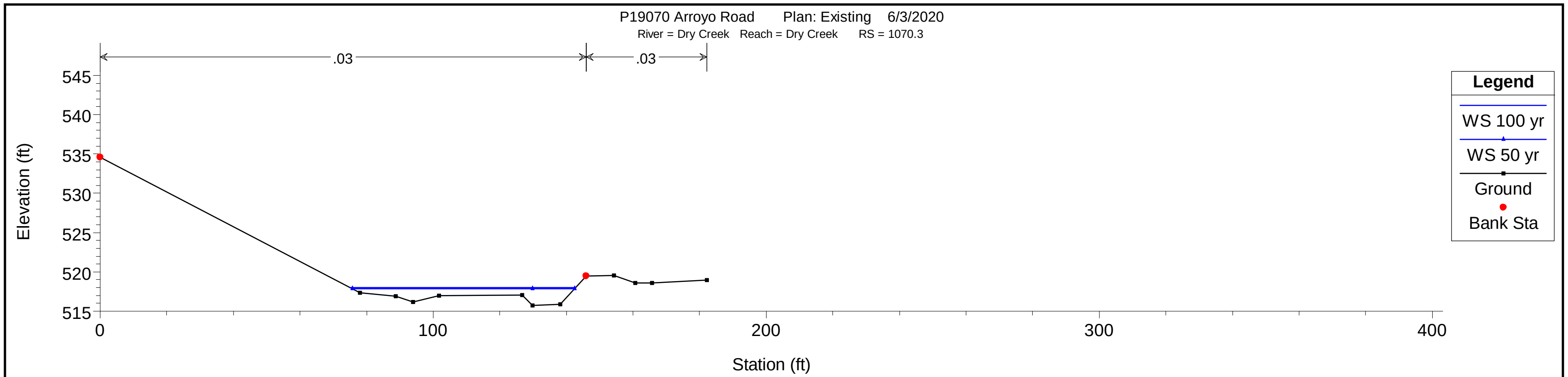
CN = Curve Number =	83	Brush-weed-grass Type D - poor condition
S =	2.05	
l =	25000	ft (estimate)
Y =	3.2	%
L =	2.1	hrs
Tc = 5/3 * L =	3.5	hrs
	127.1	minutes

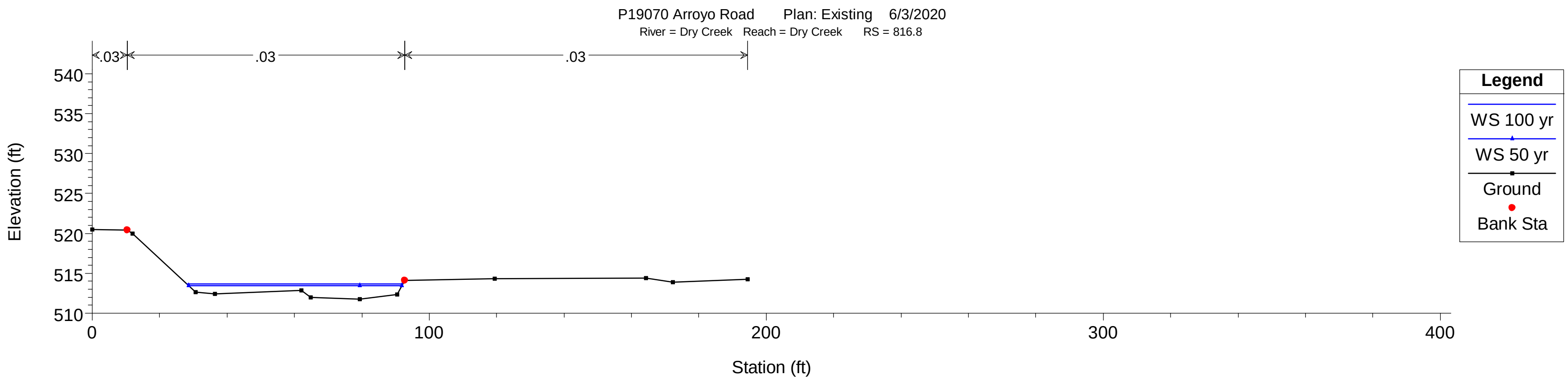


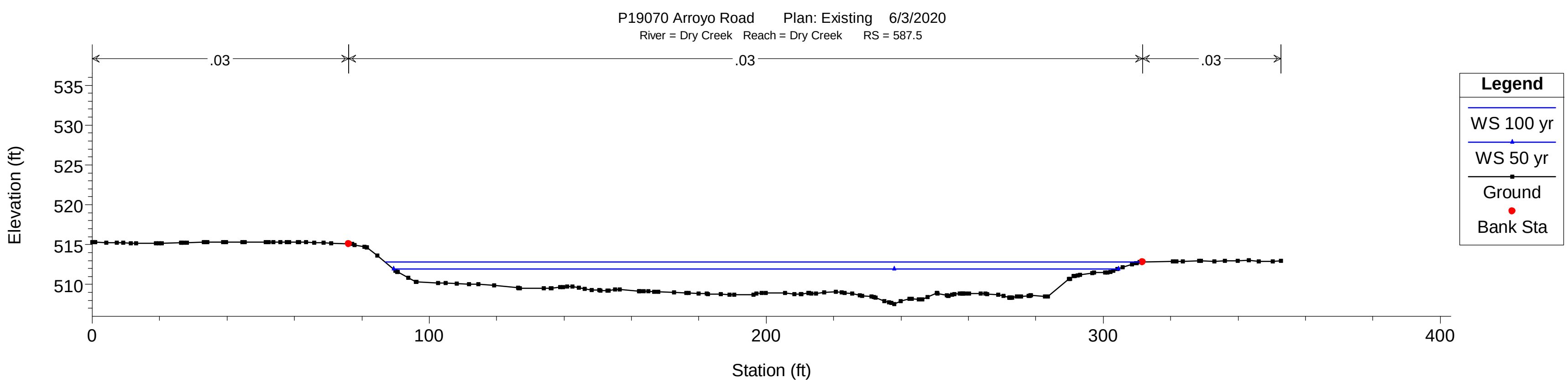
P19070 Arroyo Road Plan: Existing 6/3/2020
Dry Creek Dry Creek
Legend
WS 100 yr
WS 50 yr
Ground
Elevation (ft)
520
515
510
505
500
495
0
200
400
600
800
1000
1200
Main Channel Distance (ft)
253.2
446.7
485.9
522
539.8
587.5
816.8
1070.3

HEC-RAS Plan: Existing River: Dry Creek Reach: Dry Creek

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Dry Creek	1070.3	100 yr	530.00	515.73	518.03	518.03	518.66	0.012942	6.39	82.96	67.81	1.02
Dry Creek	1070.3	50 yr	430.00	515.73	517.86	517.86	518.42	0.013468	5.99	71.82	66.70	1.02
Dry Creek	816.8	100 yr	530.00	511.76	513.64	513.64	514.29	0.012564	6.48	81.77	64.00	1.01
Dry Creek	816.8	50 yr	430.00	511.76	513.46	513.46	514.04	0.013124	6.07	70.86	63.36	1.01
Dry Creek	587.5	100 yr	530.00	507.53	512.80		512.81	0.000040	0.70	757.52	223.88	0.07
Dry Creek	587.5	50 yr	430.00	507.53	511.95		511.96	0.000063	0.75	570.40	215.03	0.08
Dry Creek	558	100 yr	530.00	507.30	512.74	510.25	512.80	0.000294	2.12	293.20	103.37	0.18
Dry Creek	558	50 yr	430.00	507.30	511.86	509.95	511.95	0.000496	2.44	203.08	99.58	0.22
Dry Creek	539.8		Bridge									
Dry Creek	522	100 yr	530.00	506.52	509.70	509.70	510.90	0.009817	8.80	60.22	52.73	1.00
Dry Creek	522	50 yr	430.00	506.52	509.39	509.39	510.43	0.010280	8.21	52.39	51.38	1.00
Dry Creek	485.9	100 yr	530.00	506.18	507.87	507.87	508.43	0.013180	6.04	87.73	78.89	1.01
Dry Creek	485.9	50 yr	430.00	506.18	507.72	507.72	508.21	0.013721	5.64	76.22	78.37	1.01
Dry Creek	446.7	100 yr	530.00	505.54	507.08	507.08	507.65	0.013052	6.04	87.82	78.99	1.01
Dry Creek	446.7	50 yr	430.00	505.54	506.94	506.94	507.43	0.013653	5.64	76.19	78.45	1.01
Dry Creek	253.2	100 yr	530.00	501.98	503.40	503.40	503.80	0.014703	5.06	104.73	134.90	1.01
Dry Creek	253.2	50 yr	430.00	501.98	503.26	503.26	503.64	0.014781	4.93	87.16	117.08	1.01
Dry Creek	0	100 yr	530.00	497.45	499.28	499.28	499.63	0.014752	4.75	111.53	158.31	1.00
Dry Creek	0	50 yr	430.00	497.45	499.18	499.18	499.50	0.016002	4.49	95.77	157.34	1.01







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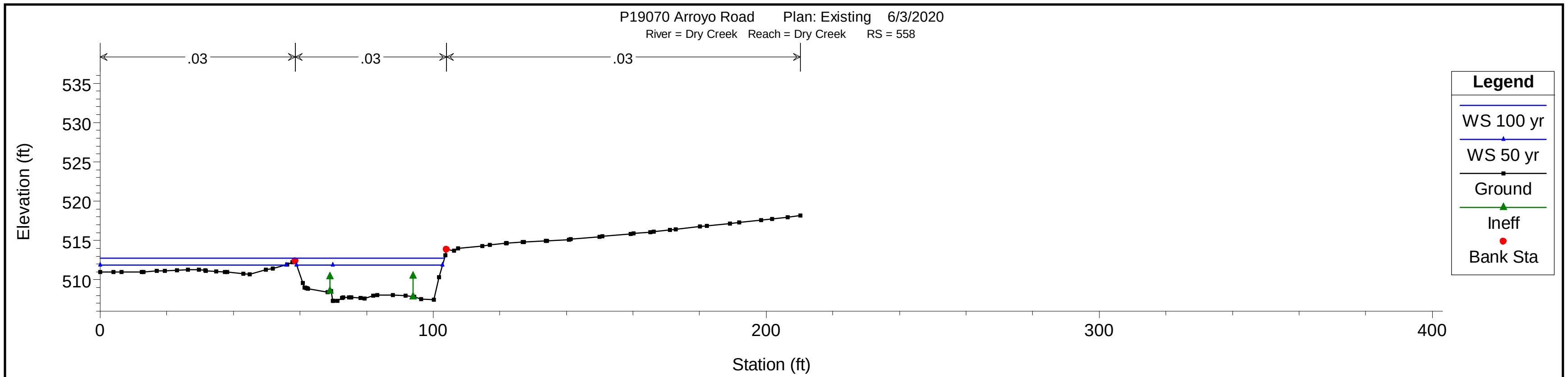

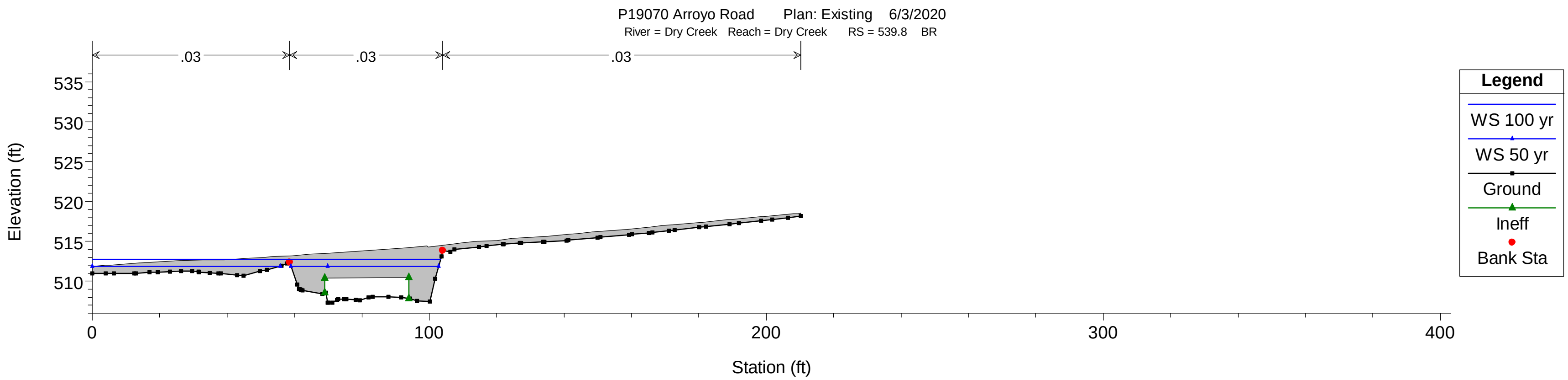

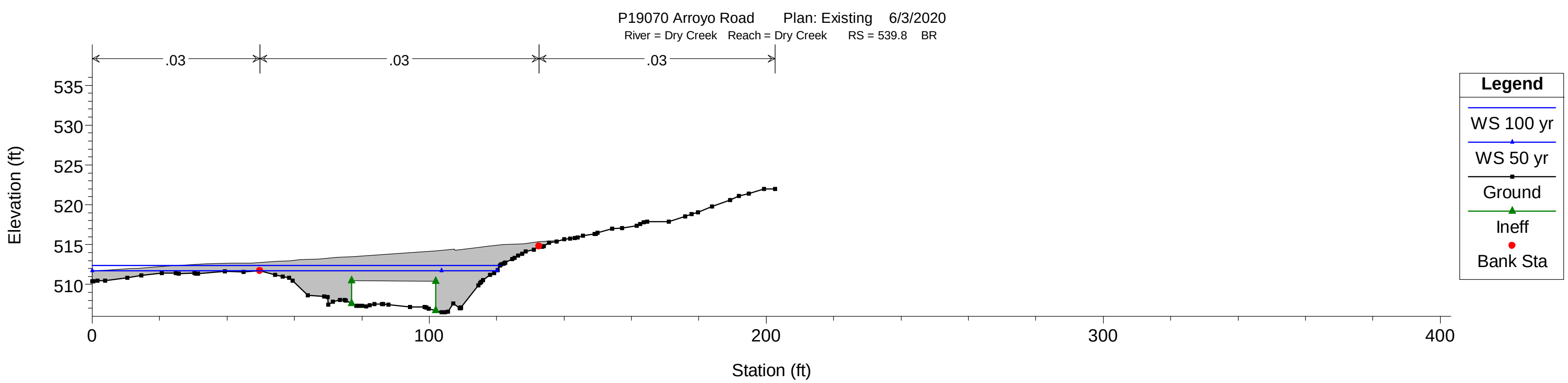

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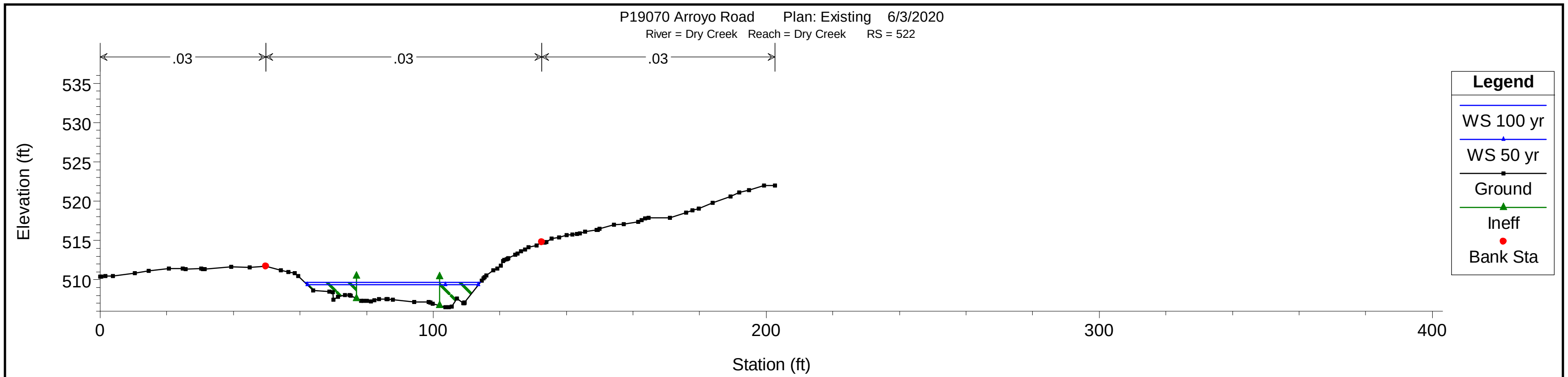

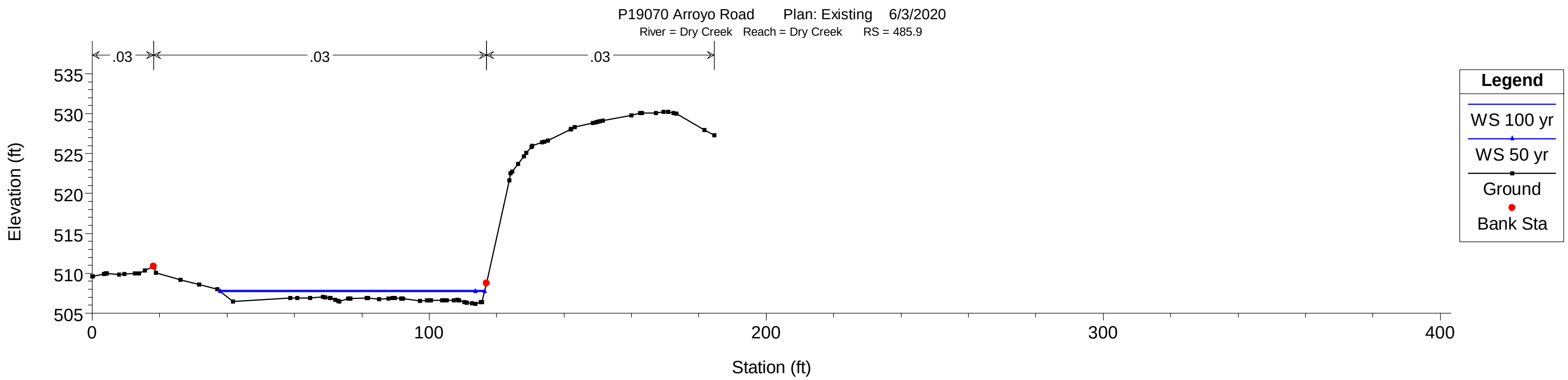

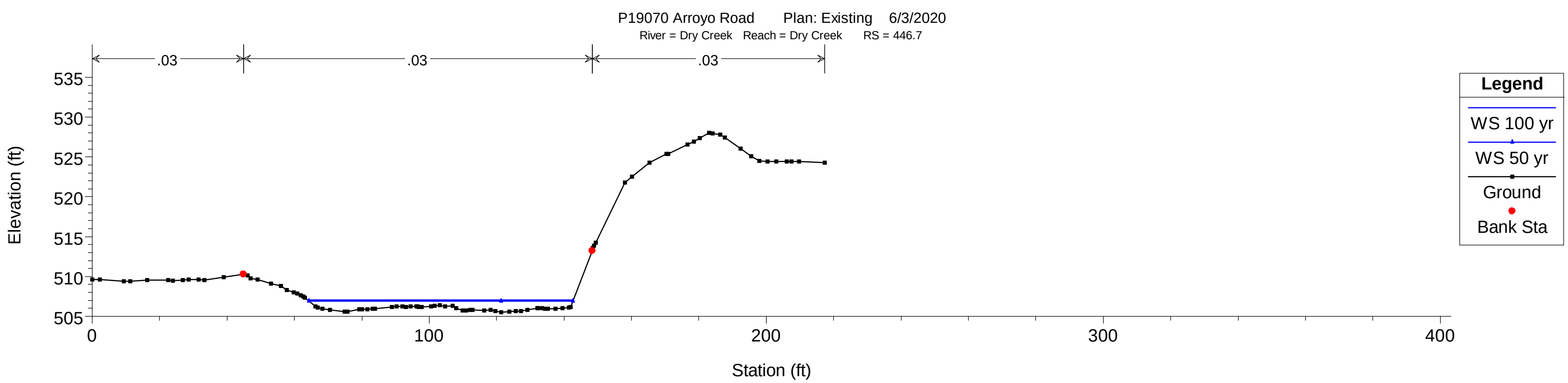

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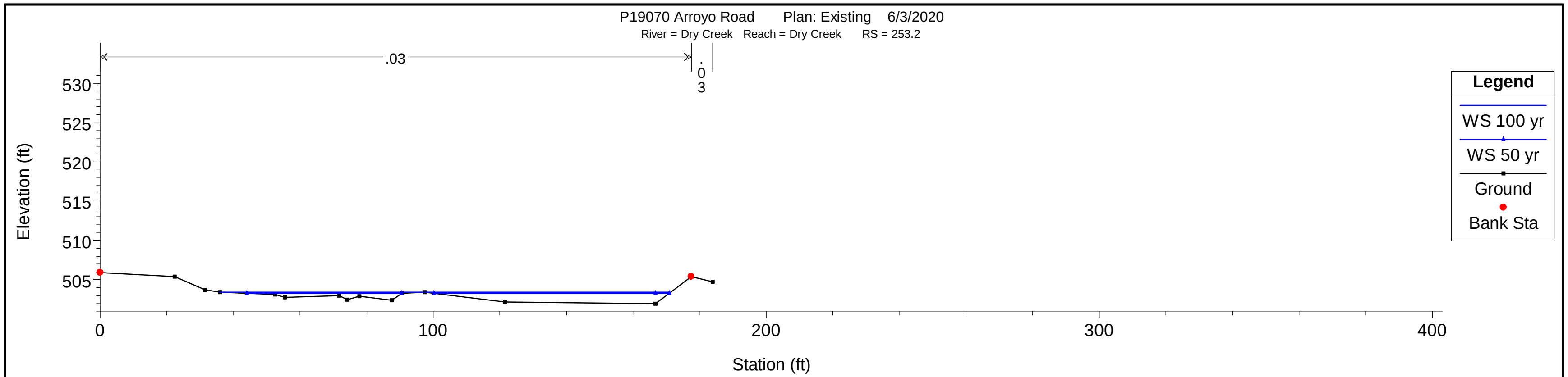

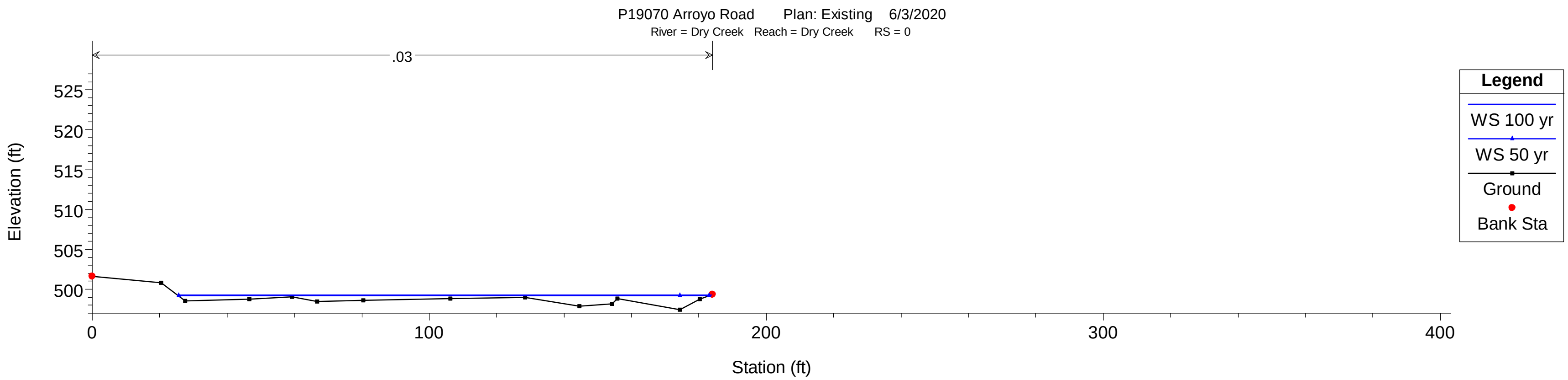

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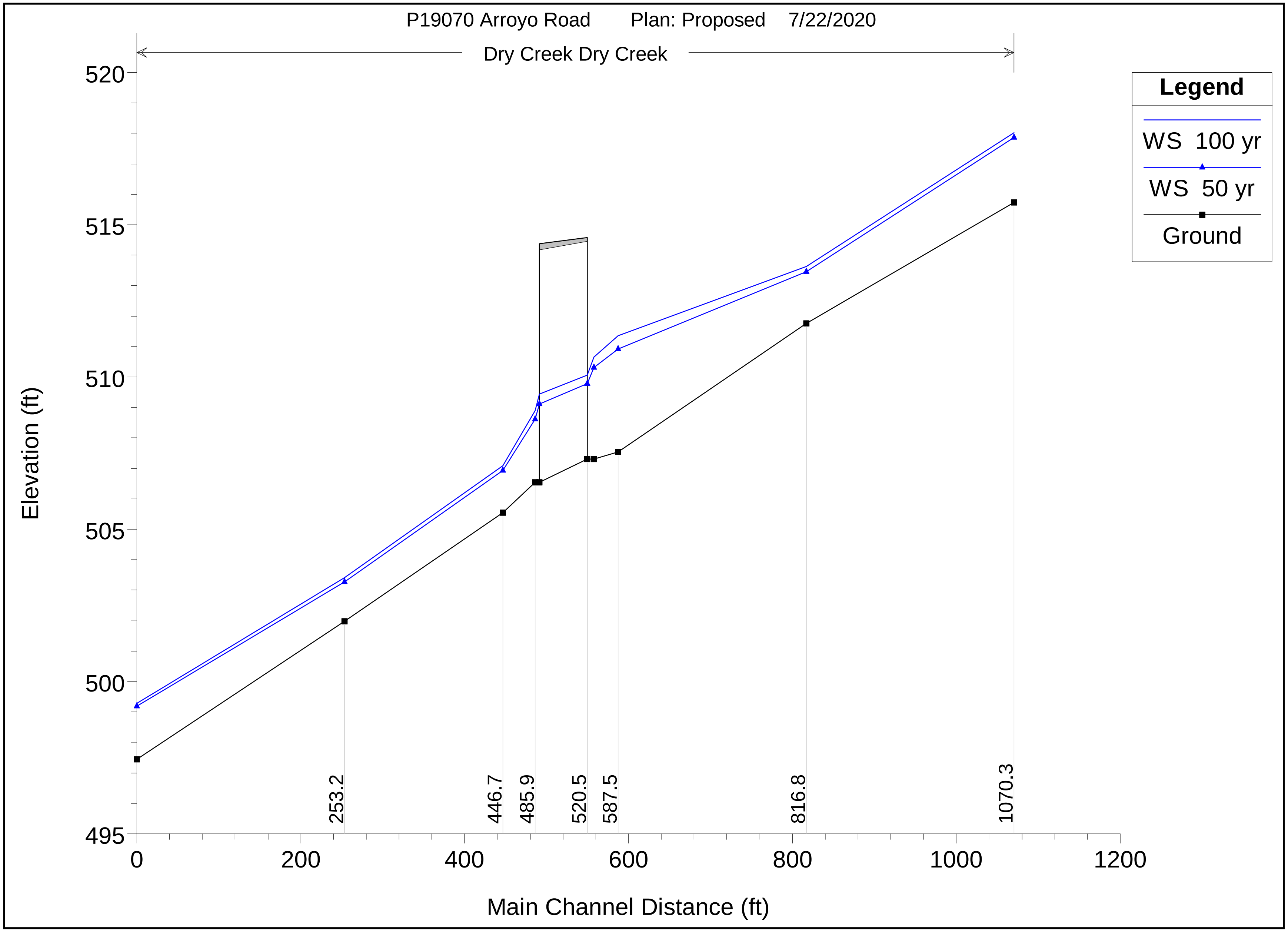
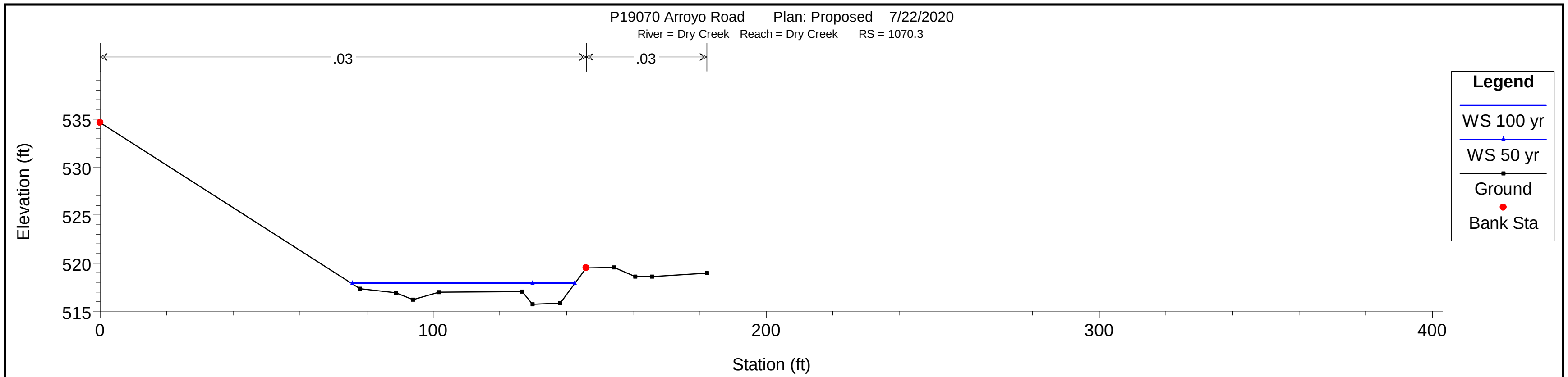
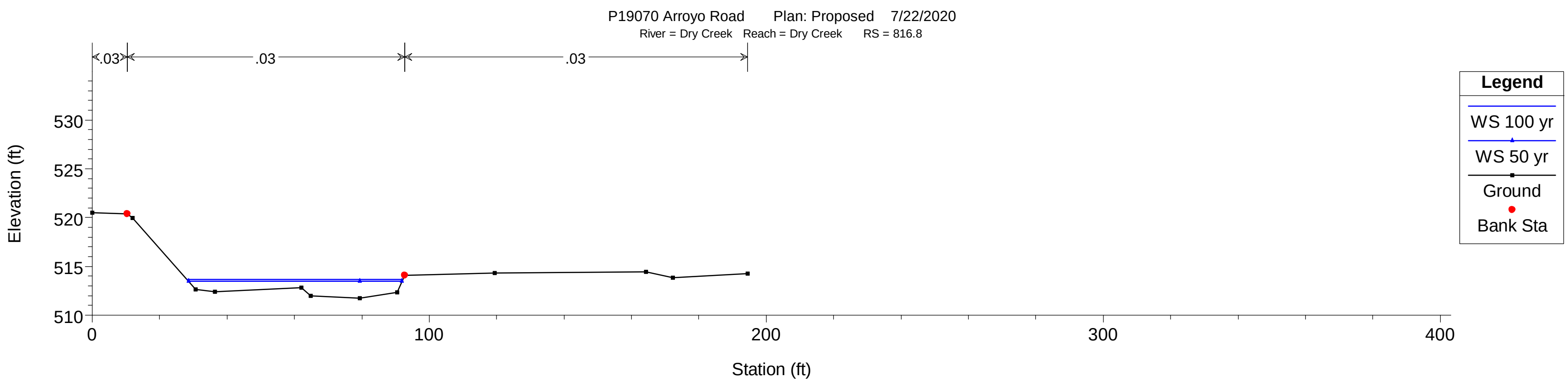


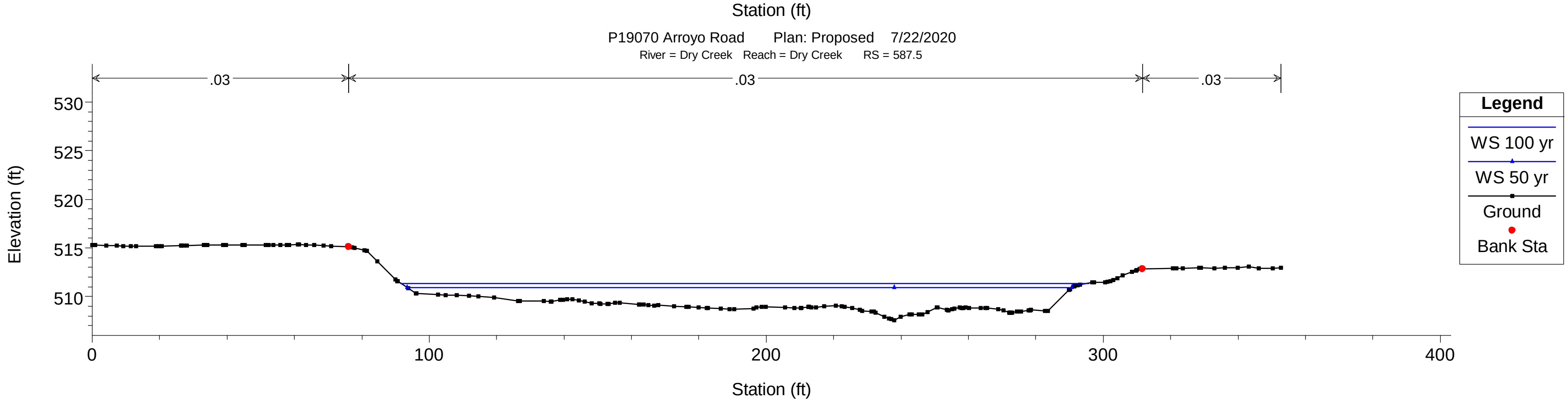
P19070 Arroyo Road Plan: Proposed 7/22/2020
Dry Creek Dry Creek
Legend
WS 100 yr
WS 50 yr
Ground
Elevation (ft)
520
515
510
505
500
495
253.2
446.7
485.9
520.5
587.5
816.8
1070.3
0
200
400
600
800
1000
1200
Main Channel Distance (ft)

HEC-RAS Plan: Proposed River: Dry Creek Reach: Dry Creek

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Dry Creek	1070.3	100 yr	530.00	515.73	518.03	518.03	518.66	0.012942	6.39	82.96	67.81	1.02
Dry Creek	1070.3	50 yr	430.00	515.73	517.86	517.86	518.42	0.013468	5.99	71.82	66.70	1.02
Dry Creek	816.8	100 yr	530.00	511.76	513.64	513.64	514.29	0.012564	6.48	81.77	64.00	1.01
Dry Creek	816.8	50 yr	430.00	511.76	513.46	513.46	514.04	0.013124	6.07	70.86	63.36	1.01
Dry Creek	587.5	100 yr	530.00	507.53	511.36		511.38	0.000205	1.19	445.32	204.07	0.14
Dry Creek	587.5	50 yr	430.00	507.53	510.92		510.95	0.000267	1.20	358.21	197.25	0.16
Dry Creek	558	100 yr	530.00	507.30	510.65	510.05	511.30	0.004854	6.47	81.96	43.11	0.69
Dry Creek	558	50 yr	430.00	507.30	510.32	509.77	510.87	0.004946	5.98	71.89	41.76	0.68
Dry Creek	520.5		Bridge									
Dry Creek	485.9	100 yr	530.00	506.54	508.90	508.90	509.97	0.010186	8.28	64.02	39.21	1.00
Dry Creek	485.9	50 yr	430.00	506.54	508.62	508.62	509.55	0.010727	7.73	55.60	38.08	1.00
Dry Creek	446.7	100 yr	530.00	505.54	507.08	507.08	507.65	0.013052	6.04	87.82	78.99	1.01
Dry Creek	446.7	50 yr	430.00	505.54	506.94	506.94	507.43	0.013653	5.64	76.19	78.45	1.01
Dry Creek	253.2	100 yr	530.00	501.98	503.40	503.40	503.80	0.014703	5.06	104.73	134.90	1.01
Dry Creek	253.2	50 yr	430.00	501.98	503.26	503.26	503.64	0.014781	4.93	87.16	117.08	1.01
Dry Creek	0	100 yr	530.00	497.45	499.28	499.28	499.63	0.014752	4.75	111.53	158.31	1.00
Dry Creek	0	50 yr	430.00	497.45	499.18	499.18	499.50	0.016002	4.49	95.77	157.34	1.01







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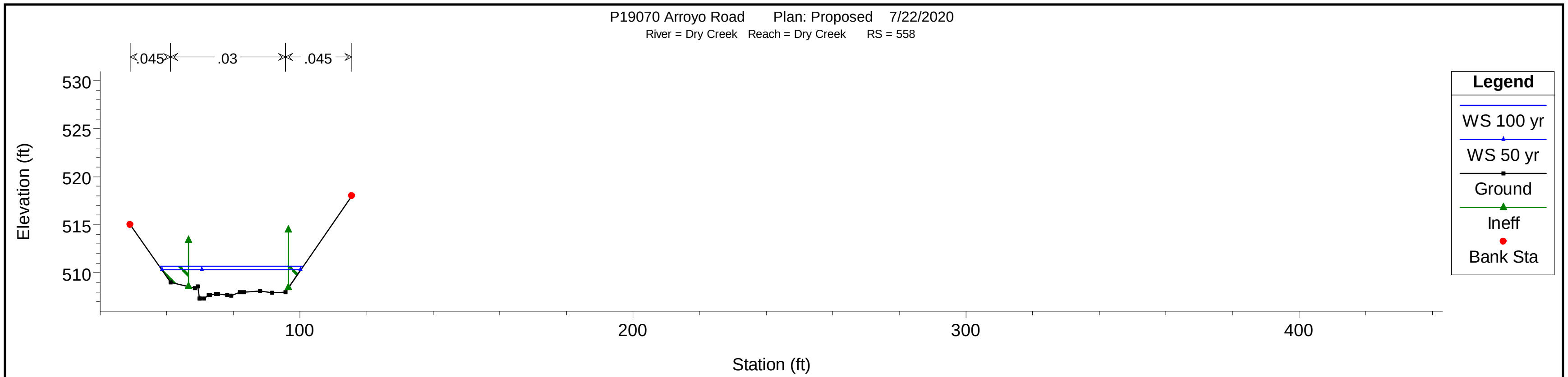
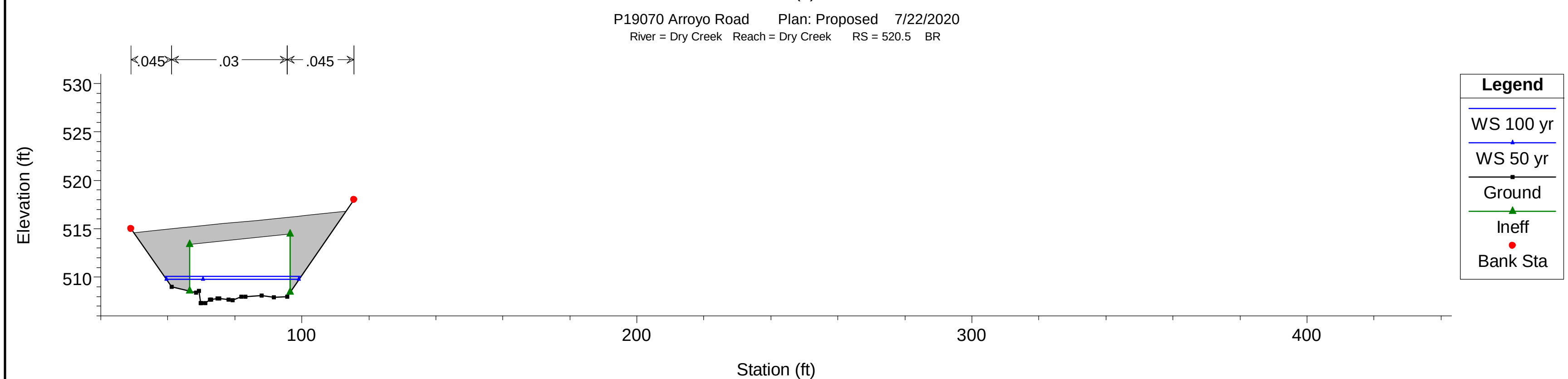
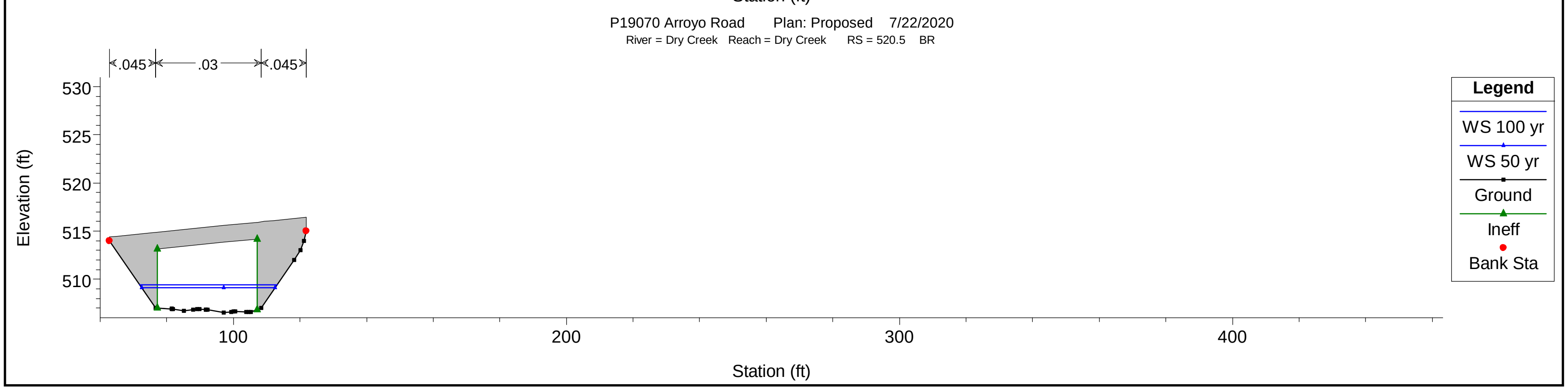
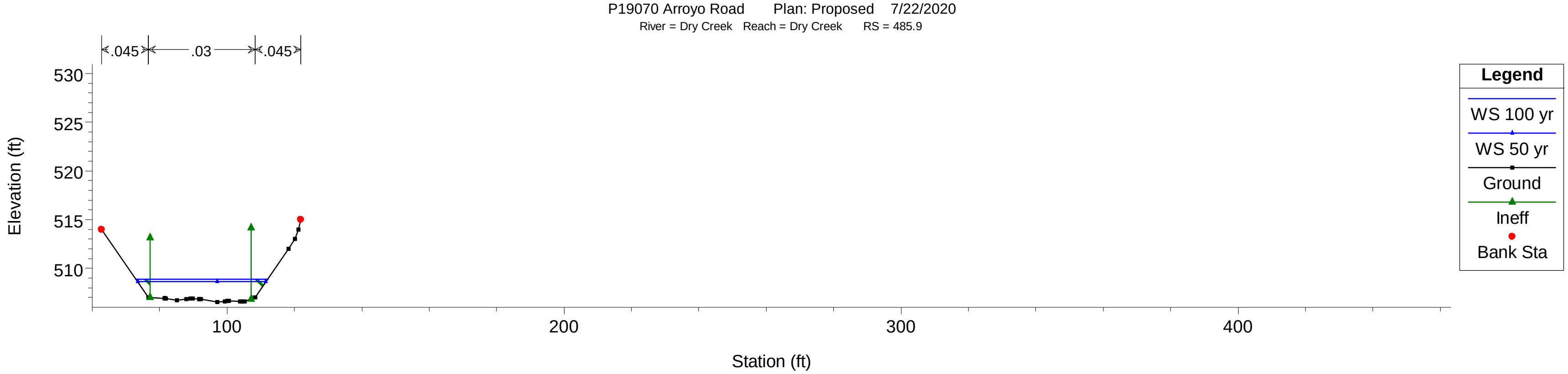
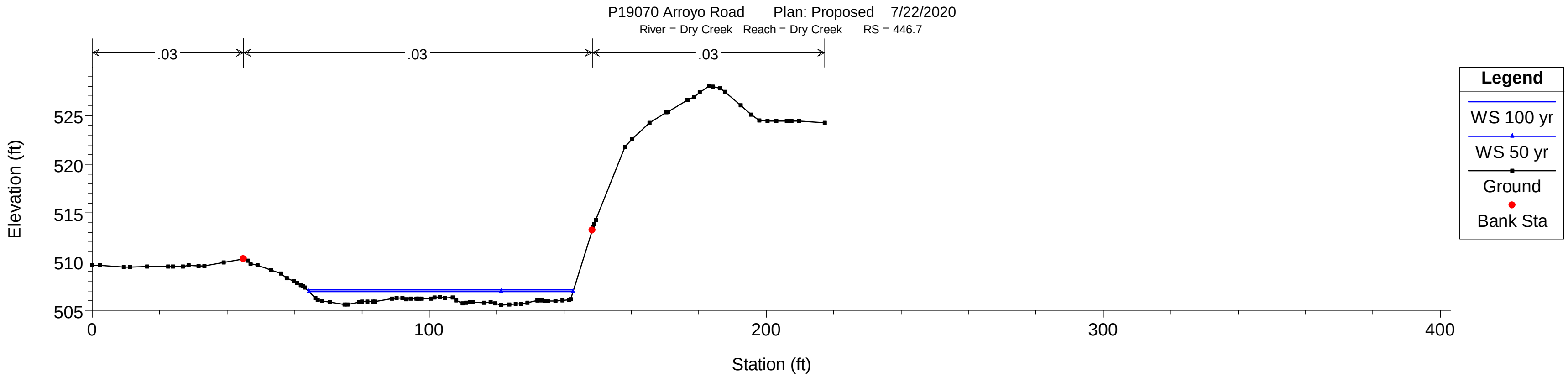


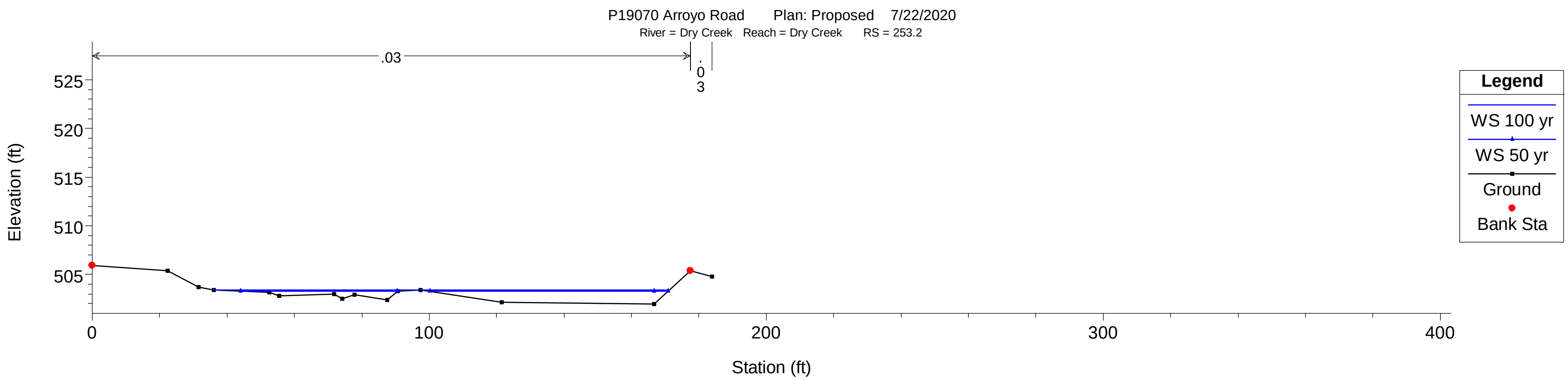




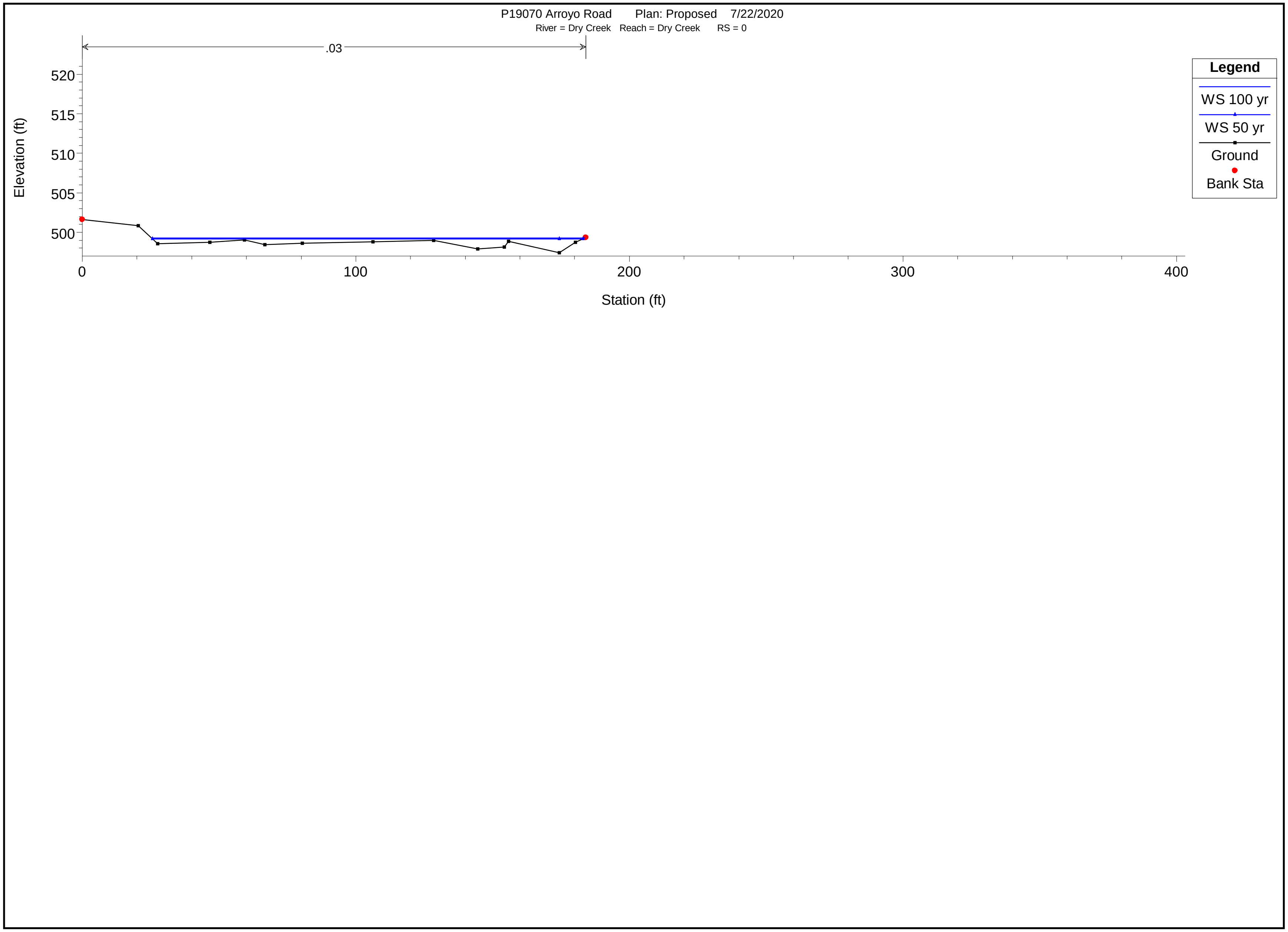
1 in Horiz. = 52 ft 1 in Vert. = 18 ft





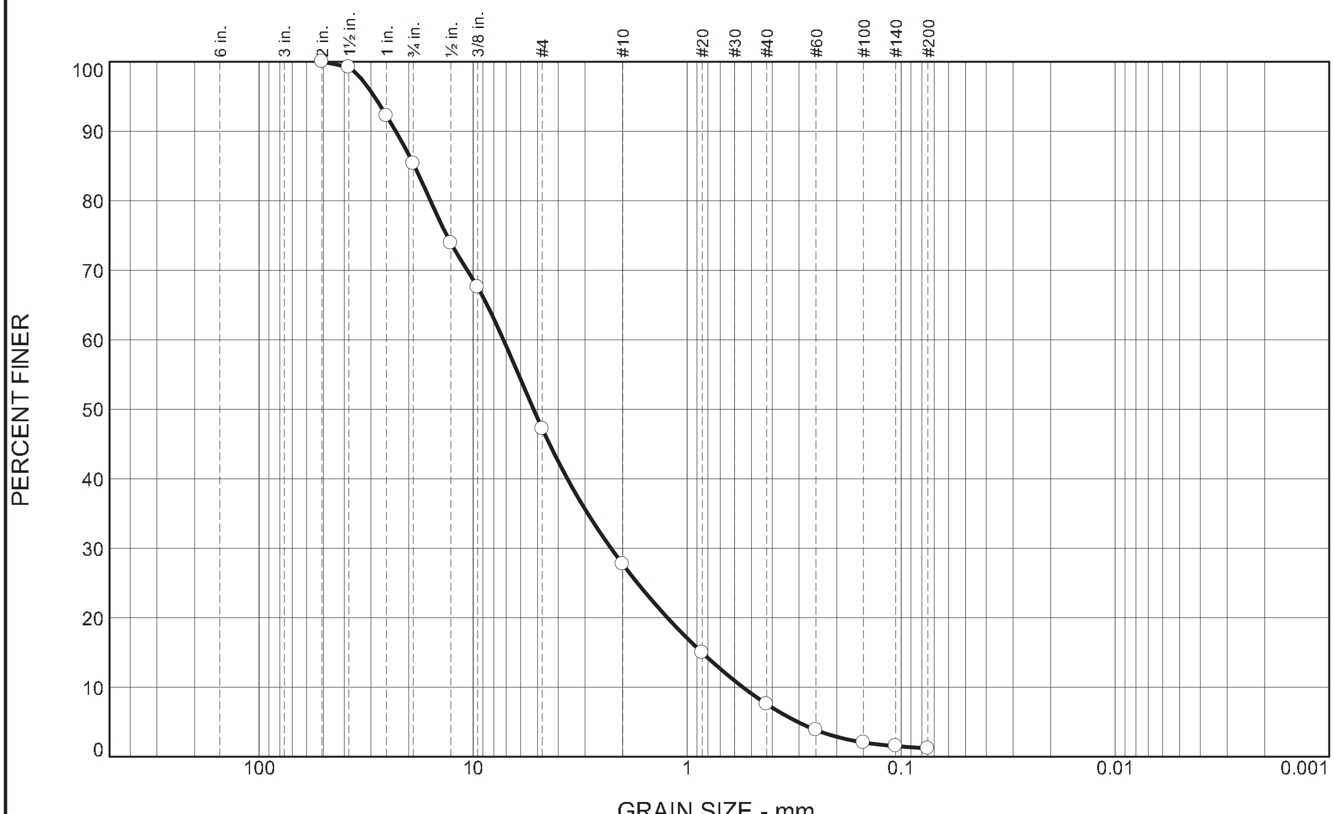


1 in Horiz. = 52 ft 1 in Vert. = 18 ft



1 in Horiz. = 52 ft 1 in Vert. = 18 ft

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	15	38	19	20	7	1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2.0"	100		
1.5"	99		
1"	92		
3/4"	85		
1/2"	74		
3/8"	68		
#4	47		
#10	28		
#20	15		
#40	8		
#60	4		
#100	2		
#140	2		
#200	1.2		

* (no specification provided)

Material Description

Well-graded GRAVEL with SAND, brown

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 22.9830 D_{85}= 18.7977 D_{60}= 7.2143
D_{50}= 5.2209 D_{30}= 2.2675 D_{15}= 0.8515
D_{10}= 0.5481 C_u= 13.16 C_c= 1.30

Classification

USCS= GW AASHTO=

Remarks

Channel Sample

Source of Sample: P19070 Arroyo Road Bridge **Depth:** 0-2'
Sample Number: HA-20-003, S1 **Date:**

Blackburn Consulting

W. Sacramento, CA

Client: WRECO
Project: WRECO Lab Testing
Project No: 3390.X **Figure**

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Bridge Replacement Project on Arroyo Road at Dry Creek
City of Livermore, Alameda County, California
Contraction Scour

100-year Flow
Calculation guideline from HEC-18 5th Edition
Proposed Bridge

Units = (SI or English)	English	
Ku = constant = 6.19 (SI) or 11.17 (English)	11.17	
g = acceleration due to gravity =	32.2	ft/s^2

Channel

Vchannel = Mean velocity of flow in main channel just upstream of bridge =	1.2	ft/s
D50channel = grain size in channel for which 50% of bed material is finer =	0.0171	ft
Yochannel = existing depth in the contracted channel section before scour =	2.1	ft
Ychannel = depth of flow just upstream of bridge in channel =	2.2	ft
VcD50channel = Ku*(Ychannel^(1/6))*(D50channel^(1/3))	3.3	ft/s
Contraction scour equation for channel =	**Clear Water Equation**	

Clear Water Equation

Ku = constant = 0.0077 (English) or 0.025 (SI) =	0.0077	
Q = Discharge through bridge associated with the width W =	530	ft^3/s
Dm = Diameter of the smallest non transportable particle in the bed material in contracted section = 1.25*d50 =	0.021	ft
W = Bottom width of contracted section less pier widths =	29.8	ft
Y2channel = average depth in contracted section after scour = ((Ku*(Q^2))/((Dm^(2/3))*(W^2)))^(3/7) =	4.39	ft
Ys channel = Y2 channel - Yo channel =	**2.3**	**ft**

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Bridge Replacement Project on Arroyo Road at Dry Creek
City of Livermore, Alameda County, California
Local Scour at Abutments - Froehlich or HIRE

100-year Flow
Calculation guideline from HEC-18 5th Edition
Proposed Bridge

Units = (SI or English)	English	
g = acceleration due to gravity =	32.2	ft/s^2

Left Overbank = Abutment EB (Southeast)

Water surface elevation	510.1	ft
Channel elevation	507.3	ft
y1 = depth of flow at abutment on the overbank or in the main channel =	2.8	ft
L = length of embankment projected normal to flow =	8.1	ft
Ratio of projected embankment length to flow depth = L/y1 =	2.9	
Abutment scour equation to be used =	Froehlich	

Froehlich's Live Bed Abutment Scour Equation

L' = length of active flow obstructed by the embankment =	21.9	ft
ya = average depth of flow on the flood plain =	3.1	ft
Ae = flow area of the approach cross section obstructed by the embankment =	68.0	ft^2
Ve = flow velocity =	1.2	ft/s
Qe = flow obstructed by the abutment and approach embankment = Ae * Ve =	84	ft^3/s
Fr = Froude Number of approach flow upstream of the abutment =	0.12	
ϴ = abutment skew =	90	degrees
K1 = coefficient for abutment shape =	0.55	
K2 = coefficient for angle of embankment shape = (ϴ/90)^0.13 =	1	
Ys = abutment scour = ya*(2.27*k1*k2*((L'/ya)^0.43)*(Fr^0.61)+1) =	**5.6**	**ft**

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City of Livermore, Alameda County, California
Local Scour at Abutments - Froehlich or HIRE

100-year Flow
Calculation guideline from HEC-18 5th Edition
Proposed Bridge

Units = (SI or English)	English	
g = acceleration due to gravity =	32.2	ft/s^2

Right Overbank = Abutment BB (Northwest)

Water surface elevation	510.1	ft
Channel elevation	507.3	ft
y1 = depth of flow at abutment on the overbank or in the main channel =	2.8	ft
L = length of embankment projected normal to flow =	4.8	ft
Ratio of projected embankment length to flow depth =	1.7	
Abutment scour equation to be used =	Froehlich	

Froehlich's Live Bed Abutment Scour Equation

L' = length of active flow obstructed by the embankment =	21.9	ft
ya = average depth of flow on the flood plain =	2.7	ft
Ae = flow area of the approach cross section obstructed by the embankment =	59.8	ft^2
Ve = flow velocity =	1.1	ft/s
Qe = flow obstructed by the abutment and approach embankment = Ae * Ve =	67	ft^3/s
Fr = Froude Number of approach flow upstream of the abutment =	0.12	
Θ = abutment skew =	90	degrees
K1 = coefficient for abutment shape =	0.55	
K2 = coefficient for angle of embankment shape = (Θ/90)^0.13 =	1	
Ys = abutment scour = ya*(2.27*k1*k2*((L'/ya)^0.43)*(Fr^0.61)+1) =	**5.0**	**ft**

Bridge Replacement Project on Arroyo Road at Dry Creek

City of Livermore, Alameda County, California

Streambank Rock Slope Protection

Calculation guideline from Caltrans Highway Design Manual

Proposed Bridge

100-year Flow

Input

Location along stream:	Upstream	Upstream Face	Downstream Face	Downstream	
V_{avg}	6.5	8.3	6.6	8.3	ft/s
g	32.2	32.2	32.2	32.2	ft/s^2
Depth based on	Average	Average	Average	Average	
y	2.7	2.1	2.7	2.1	ft
S_f	1.1	1.1	1.1	1.1	
C_s	0.3	0.3	0.3	0.3	
Cross section location:	Straight channel	Straight channel	Straight channel	Straight channel	
C_v	1.00	1.00	1.00	1.00	

For outside of bends, need R_c and W:

Note: these parameters also affect the V_{des}; for natural channels, $V_{des}=V_{avg}$ for $R_c/W>26$

Note: these parameters also affect the V_{des}; for trapezoidal channels, $V_{des}=V_{avg}$ for $R_c/W>8$

R_c	26	26	26	26	ft
W	1.0	1.0	1.0	1.0	ft
C_t	1.0	1.0	1.0	1.0	
S_g	2.65	2.65	2.65	2.65	
Type of channel:	Natural	Natural	Natural	Natural	
V_{des}	6.5	8.3	6.6	8.3	ft/s
K_1	0.72	0.72	0.72	0.72	
θ	33.7	33.7	33.7	33.7	degrees
SS	1.5	1.5	1.5	1.5	
D_{30}	0.3	0.6	0.3	0.6	ft
D_{50}	0.3	0.7	0.4	0.7	ft
D_{50}	4.2	8.2	4.5	8.3	inches
	I	II	I	II	RSP Class
	20 lb	**60 lb**	**20 lb**	**60 lb**	Median particle weight
	6	**9**	**6**	**9**	Median particle diameter (inches)

Bridge Replacement Project on Arroyo Road at Dry Creek

City of Livermore, Alameda County, California

Rock Slope Protection Calculations for Abutments

Calculation guideline from HEC-23 3rd Edition

Proposed Bridge

100-year Flow

Location	Upstream	Upstream Face	Downstream Face	Downstream	
V	6.5	8.3	6.6	8.3	ft/s
g	32.2	32.2	32.2	32.2	ft/s^2
y	2.7	2.1	2.7	2.1	ft
Fr	0.69	1.00	0.71	1.00	
Equation	**Isbash**	**Equation 14.2**	**Isbash**	**Equation 14.2**	

For Froude Numbers $(V/(gy)^{1/2})<=0.80$, Isbash relationship (Equation 14.1)

$$D_{50} = \frac{yK}{(S_s - 1)}\left[\frac{V^2}{gy}\right]$$

y	2.7	2.1	2.7	2.1	depth of flow in the contracted bridge opening, ft
K	1.02	1.02	1.02	1.02	1.02 for vertical wall abutment, 0.89 or for spill-through abutment
S_s	2.65	2.65	2.65	2.65	specific gravity of rock
V	6.5	8.3	6.6	8.3	average velocity in contracted section, ft/s
g	32.2	32.2	32.2	32.2	gravitational acceleration, ft/s^2
D_{50}	0.8	N/A	0.8	N/A	median stone diameter, ft
D_{50}	9.6	N/A	10.1	N/A	median stone diameter, inches

III		III		RSP Class
150 lb		150 lb		Median particle weight
12		12		Median particle diameter (inches)

For Froude Numbers $(V/(gy)^{1/2})>0.80$, Equation 14.2

$$D_{50} = \frac{yK}{(S_s - 1)}\left[\frac{V^2}{gy}\right]^{0.14}$$

y	2.7	2.1	2.7	2.1	depth of flow in the contracted bridge opening, ft
K	0.69	0.69	0.69	0.69	0.61 for spill-through abutment, 0.69 or for vertical wall abutment
S_s	2.65	2.65	2.65	2.65	specific gravity of rock
V	6.5	8.3	6.6	8.3	average velocity in contracted section, ft/s
g	32.2	32.2	32.2	32.2	gravitational acceleration, ft/s^2
D_{50}	N/A	0.9	N/A	0.9	median stone diameter, ft
D_{50}	N/A	10.7	N/A	10.7	median stone diameter, inches

	III		III	RSP Class
	150 lb		150 lb	Median particle weight
	12		12	Median particle diameter (inches)