**Robinson Creek Bridge Replacement on Lambert Lane**
**Mendocino County, California**
**Federal-Aid Project No. BRLO-5910(099)**
**Mendocino County Project No. B1302**
**Existing Bridge No. 10C0146**

# Bridge Design Hydraulic Study Report

Prepared for:

Mendocino County

Prepared by:

WRECO

August 2021

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Submitted to:
Mendocino County Department of Transportation

This report has been prepared by or under the supervision of the following Registered Engineer. The Registered Civil Engineer attests to the technical information contained herein and has judged the qualifications of any technical specialists providing engineering data upon which recommendations, conclusions, and decisions are based.


Kazuya Tsurushita, P.E.
Registered Civil Engineer

8/5/2021
Date

August 2021

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# Executive Summary

The County of Mendocino (County), in cooperation with the California Department of Transportation (Caltrans), proposes to replace the functionally obsolete and scour critical Lambert Lane Bridge (Bridge No. 10C0146) at Robinson Creek in order to restore service and reduce future maintenance costs. The Robinson Creek Bridge Replacement on Lambert Lane Project (Project) will replace an out-of-service bridge and improve traffic operations by widening the bridge to provide 9-foot (ft) lanes and 5-ft shoulders in each direction, as well as replace all traffic safety features to meet current standards. The existing bridge is located in the Town of Boonville in Mendocino County. The existing Lambert Lane Bridge is located approximately 0.1 miles (mi) west of the intersection of Lambert Lane and State Route (SR) 128. The Town of Boonville is located approximately 13.1 mi southwest of the City of Ukiah, Mendocino County, California.

The Project will include development and approval of an Environmental Document, development of a Project Report, development of Plans, Specification, and Estimates (PS&E), and acquiring the necessary right-of-way to construct the Project. Funding for this Project will be provided by the Highway Bridge Program (HBP) with matching funds from Federal Toll Credits. The County will be responsible for ensuring California Environmental Quality Act compliance and Caltrans will be the lead agency for National Environmental Policy Act compliance.

The existing Lambert Lane Bridge over Robinson Creek was constructed in 1954. The existing 32-ft-long, single-span reinforced concrete bridge structure is supported on tall, closed, strutted abutments founded on spread footings on top of erodible alluvial channel material. The current bridge superstructure is approximately 26-ft-wide including a concrete curb and timber railing on each side. The clear-width on the bridge is approximately 24 ft with two, 12-ft lanes. The existing approach roadway is also approximately 24-ft-wide with two, 12-ft lanes.

The *Project Report* (Quincy Engineering Inc., 2018) recommended replacement of the existing bridge with a new steel girder bridge on the existing alignment with a temporary detour for public traffic. The proposed steel girder bridge would be a 96-ft-long, 31.33-ft-wide, single-span steel girder bridge over Robinson Creek, which would be much longer than the existing bridge. The proposed bridge would have a longer span than the existing bridge to increase the channel opening, which would provide a more gradual turn of the creek when compared to the existing two 90-degree turns upstream and downstream of the existing bridge. The longer bridge would also allow the faces of the proposed bridge abutments to be elevated above the 100-year flood profile of Robinson Creek at the Project location.

The purpose of this *Bridge Design Hydraulic Study* is to present the design flow characteristics for Robinson Creek, the hydraulic characteristics at the Project site, the calculated scour potential for the proposed bridge, and recommendations regarding the need for scour countermeasures for the proposed bridge.

The design flow of Robinson Creek for the design of the proposed bridge was based on a rainfall/runoff model using United States Army Corps of Engineers' (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software following the Soil Conservation Service (SCS) unit hydrograph method. The 50- and 100-year design flows for Robinson Creek were estimated to be 1,340 and 1,750 cubic feet per second (cfs), respectively.

The hydraulics of the existing and proposed conditions were analyzed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) Version 5.0.7. The hydraulic model was developed using the channel survey data, proposed channel grading, and bridge general plans provided by Quincy Engineering Inc., and existing bridge information included in the Caltrans' Bridge Inspection Report (BIR) (2020). The existing and proposed water surface elevations (WSE) of Robinson Creek at the Project location with the 50- and 100-year design flows are summarized in the following tables.

**Summary of 50-year Water Surface Elevations**

| River Station (Existing Condition) | Location/ Distance from Existing Bridge Centerline | 50-year WSE | | WSE Change (ft) |
|---|---|---|---|---|
| | | Existing (ft NAVD 88) | Proposed (ft NAVD 88) | |
| 673 | Model Upstream Limit 450 ft Upstream | 380.92 | 380.49 | -0.43 |
| 533 | 310 ft Upstream | 380.12 | 379.16 | -0.96 |
| 375 | 153 ft Upstream | 379.28 | 376.86 | -2.42 |
| 284 | Upstream of Collapsed Retaining Wall | 378.42 | n/a[1] | n/a[1] |
| 256 | Downstream of Collapsed Retaining Wall | 374.34 | n/a[1] | n/a[1] |
| 221 | Lambert Lane Bridge Upstream Face[2] | 373.61 | 373.57 | n/a[2] |
| 221 | Lambert Lane Bridge Downstream Face[2] | 372.58 | 373.17 | n/a[2] |
| 200 | 22 ft Downstream | 373.17 | 372.92 | -0.25 |
| 156 | 65 ft Downstream | 372.71 | 372.78 | 0.07 |
| 124 | 97 ft Downstream | 372.72 | 372.71 | -0.01 |

Notes:
1. Project proposes proposed bridge with a softer and more gradual turn of the creek alignment. Proposed condition hydraulic model does not include channel cross-sections representing upstream/downstream of the collapsed retaining wall.
2. The proposed bridge is wider than the existing bridge. Therefore, the upstream/downstream faces of the existing and proposed bridges are not in the same location.
3. NAVD 88 = North American Vertical Datum of 1988.

**Summary of 100-year Water Surface Elevations**

| River Station (Existing Condition) | Location/ Distance from Existing Bridge Centerline | 100-year WSE Existing (ft NAVD 88) | 100-year WSE Proposed (ft NAVD 88) | WSE Change (ft) |
|---|---|---|---|---|
| 673 | Model Upstream Limit 450 ft Upstream | 382.01 | 381.35 | -0.66 |
| 533 | 310 ft Upstream | 381.29 | 380.04 | -1.25 |
| 375 | 153 ft Upstream | 380.45 | 377.93 | -2.52 |
| 284 | Upstream of Collapsed Retaining Wall | 379.46 | n/a[1] | n/a[1] |
| 256 | Downstream of Collapsed Retaining Wall | 375.56 | n/a[1] | n/a[1] |
| 221 | Lambert Lane Bridge Upstream Face[2] | 374.96 | 374.54 | n/a[2] |
| 221 | Lambert Lane Bridge Downstream Face[2] | 374.05 | 374.03 | n/a[2] |
| 200 | 22 ft Downstream | 373.94 | 373.74 | -0.20 |
| 156 | 65 ft Downstream | 373.53 | 373.64 | 0.11 |
| 124 | 97 ft Downstream | 373.62 | 373.60 | -0.02 |

Notes:
1. Project proposes a bridge with a softer and more gradual turn of the creek alignment. The proposed condition hydraulic model does not include channel cross-sections representing upstream/downstream conditions and/or effects of the collapsed retaining wall.
2. The proposed bridge is wider than the existing bridge. Therefore, the upstream/downstream faces of the existing and proposed bridges are not in the same location.
3. NAVD 88 = North American Vertical Datum of 1988.

The results of the hydraulic models indicated that the proposed Project would result in decreases in the WSEs upstream of Lambert Lane Bridge, and slight increases (0.11 ft or less) in the WSEs downstream of the proposed bridge. The hydrologic summary table for the proposed bridge is shown below.

| Hydrologic Summary for Robinson Creek Bridge on Lambert Lane (Bridge No. 10C0146) | | | |
|---|---|---|---|
| **Drainage Area: 4 mi$^2$** | | | |
| **Frequency** | Design Flood 50-year | Base Flood 100-year | Flood of Record n/a |
| **Discharge (cfs)** | 1,340 | 1,750 | n/a |
| **Water Surface Elevation at Bridge (ft NAVD 88)** | 373.6 | 374.5 | n/a |

Note:
1. Elevations are rounded to the nearest 0.1 ft.

The Federal Highway Administration (FHWA) and Caltrans criteria both require that the proposed bridge pass the 50-year flood with freeboard to pass drift (with 2 ft of freeboard often assumed for preliminary designs), and the 100-year flood without freeboard. Mendocino County design standards require a minimum 1 ft of freeboard for the bridges spanning over major and secondary open channels. The following table presents the minimum soffit elevations at the upstream face of the structure, the WSEs just upstream of the bridge structures, and the available freeboard for the bridge structures. Both the existing and proposed bridges have sufficient freeboard to meet the applicable criteria.

**Available Freeboard**

| Modeled Project Condition | Soffit Elevation (ft NAVD 88) | 50-year Storm Event | | 100-year Storm Event | |
|---|---|---|---|---|---|
| | | WSE (ft NAVD 88) | Freeboard (ft) | WSE (ft NAVD 88) | Freeboard (ft) |
| Existing | 385.5 | 373.6 | 11.9 | 375.0 | 10.5 |
| Proposed | 384.1 | 373.6 | 10.5 | 374.5 | 9.5 |

Note:
Elevations and freeboard height are rounded to the nearest 0.1 ft.

Scour calculations were performed based on procedures from the FHWA's *Hydraulic Engineering Circular No. 18*, "Evaluating Scour at Bridges" (HEC-18). The results of the hydraulic analysis and general channel bed properties from a nearby bridge were used to compute the scour depths. The total estimated scour depths reflect the sum of the long-term bed degradation, channel contraction scour, and local scour. The scour elevations reference the finished grade elevation at the abutments, which require scour countermeasures at the abutment embankments. The total calculated scour depths are shown in the following table:

**Proposed Bridge Total Scour Depths and Elevations**

| Support No. | Reference Elevation (ft NAVD 88) | Total Calculated Scour Depth (ft) | Total Calculated Scour Elevation (ft NAVD 88) |
|---|---|---|---|
| Abutment 1 | 382.0 | 18.0 | 364.0 |
| Abutment 2 | 382 | 16.8 | 365.2 |

Note:
Scour depths and elevations are rounded to the nearest 0.1 ft.

According to a Caltrans memorandum dated December 2017, *Hydraulic Design for Structures over Waterways*, a scour data table should also present a long-term scour elevation based upon the long-term bed degradation and contraction scour depths, and a short-term depth based upon the local scour depth. The scour elevations were based upon the local channel/ground elevations at the abutment supports, which assumes that the embankment material at the abutment will be stable. This requires scour countermeasures be included to protect the embankments in front of the abutments to reduce the potential for thalweg migration and to minimize the risk of erosion of the proposed embankment slope. The scour data summary for the proposed bridge is presented in the following table:

**Scour Data Table**

| Support No. | Long-Term (Degradation and Contraction) Scour Elevation (ft NAVD 88) | Short-Term (Local) Scour Depth (ft) |
|---|---|---|
| Abutment 1 | 372.0 | 4.6 |
| Abutment 2 | 373.2 | 3.4 |

Note:
Scour depths and elevations are rounded to the nearest 0.1 ft.

Rock slope protection (RSP) is proposed at the bridge abutments to reduce the potential for erosion and thalweg migration. Class V RSP, which has a median particle weight of ¼ ton and median particle diameter of 18 inches, is recommended at embankment slopes and the upstream side of the abutments. Class VI RSP, which has a median particle weight of 3/8 ton and a median particle diameter of 21 inches, is recommended at the downstream side of the abutments. Minimum layer thickness is 3 ft for Class V RSP and 4 ft for Class VI RSP. The RSP should be placed using Method B. Class 8 RSP geotextile filter fabric should be placed on the bank as the initial filter separator material between the RSP and the channel bank.

# Acronyms

| | |
|---|---|
| BIR | Bridge Inspection Report |
| Caltrans | California Department of Transportation |
| County | County of Mendocino |
| CFR | Code of Federal Regulations |
| CN | Curve Number |
| FEMA | Federal Emergency Management Agency |
| FHWA | Federal Highway Administration |
| FIRM | Flood Insurance Rate Map |
| FIS | Flood Insurance Study |
| ft | feet |
| HBP | Highway Bridge Program |
| HDM | Highway Design Manual |
| HEC-18 | Hydraulic Engineering Circular No. 18 |
| HEC-23 | Hydraulic Engineering Circular No. 23 |
| HEC-HMS | Hydrologic Engineering Center's Hydrologic Modeling System |
| HEC-RAS | Hydrologic Engineering Center's River Analysis System |
| HSG | Hydrologic Soil Group |
| mi | mile |
| mm | millimeter |
| NAVD 88 | North American Vertical Datum of 1988 |
| NOAA | National Oceanic and Atmospheric Administration |
| NRCS | Natural Resources Conservation Service |
| RSP | Rock Slope Protection |
| SCS | Soil Conservation Service |
| sq mi | square miles |
| SR | State Route |
| TR-55 | Technical Release 55 |
| USACE | U.S. Army Corps of Engineers |
| USGS | United States Geological Survey |
| WSE | Water Surface Elevation |

# 1 GENERAL DESCRIPTION

## 1.1 Project Description

The County of Mendocino (County), in cooperation with the California Department of Transportation (Caltrans), proposes to replace the functionally obsolete and scour critical Lambert Lane Bridge (Bridge No. 10C0146) at Robinson Creek in order to improve public safety and reduce future maintenance costs. The existing bridge is located in the Town of Boonville in Mendocino County, approximately 0.1 miles (mi) west of the intersection of Lambert Lane and State Route (SR) 128. The Town of Boonville is located approximately 13.1 mi southwest of the City of Ukiah, Mendocino County, California. See Figure 1 for the Project Location Map, Figure 2 for the Project Vicinity Map, and Figure 3 for the Project Aerial Map.

The Robinson Creek Bridge Replacement on Lambert Lane Project (Project) will include development and approval of an Environmental Document; development of a *Project Report*; development of Plans, Specification and Estimates (PS&E); and acquiring the necessary right-of-way to construct the Project. Funding for this Project will be provided by the Highway Bridge Program (HBP) with matching funds from Federal Toll Credits. The County will be responsible for California Environmental Quality Act compliance, and Caltrans will be the lead agency for the National Environmental Policy Act compliance.

The existing Lambert Lane Bridge, constructed in 1954, is scour critical and out of service. Hydraulic undermining has been documented in the Caltrans' bridge inspection reports (BIR) since 2000. The existing bridge was classified as scour critical in 2013 based on the undermining of the spread footing foundation. In February 2015, a retaining wall on the upstream side of the west roadway approach washed out and collapsed into the creek. As an emergency response, the County placed rock slope protection (RSP) where the collapse occurred to prevent continued embankment scour, which could have led to a bridge wash out and closure of Lambert Lane. In the winter storms of 2016/2017, scour further undermined the eastern abutment footing and full height of the abutment stem. Reinforcing steel is exposed as the base of the crack, while the abutment stem concrete is spalling and crushing near the top of the crack. As an emergency response, the County pumped concrete underneath the undermined footing to re-establish bearing for the abutment and to prevent further erosion underneath the abutment. In March 2019, the eastern abutment failed due to scour of the foundation and the bridge was closed. A Bailey bridge was placed over and along the same alignment as a temporary measure.

The Project will replace the out-of-service bridge and improve traffic operations by widening the bridge to provide 9-ft lanes and 5-ft shoulders in each direction and replace all traffic safety features to meet current standards. Rehabilitation and widening the existing bridge is cost prohibitive and is not considered feasible.


**Figure 1. Project Location Map**

Source: United States Geological Survey (USGS) and Environmental Systems Research Institute (ESRI) (2021)

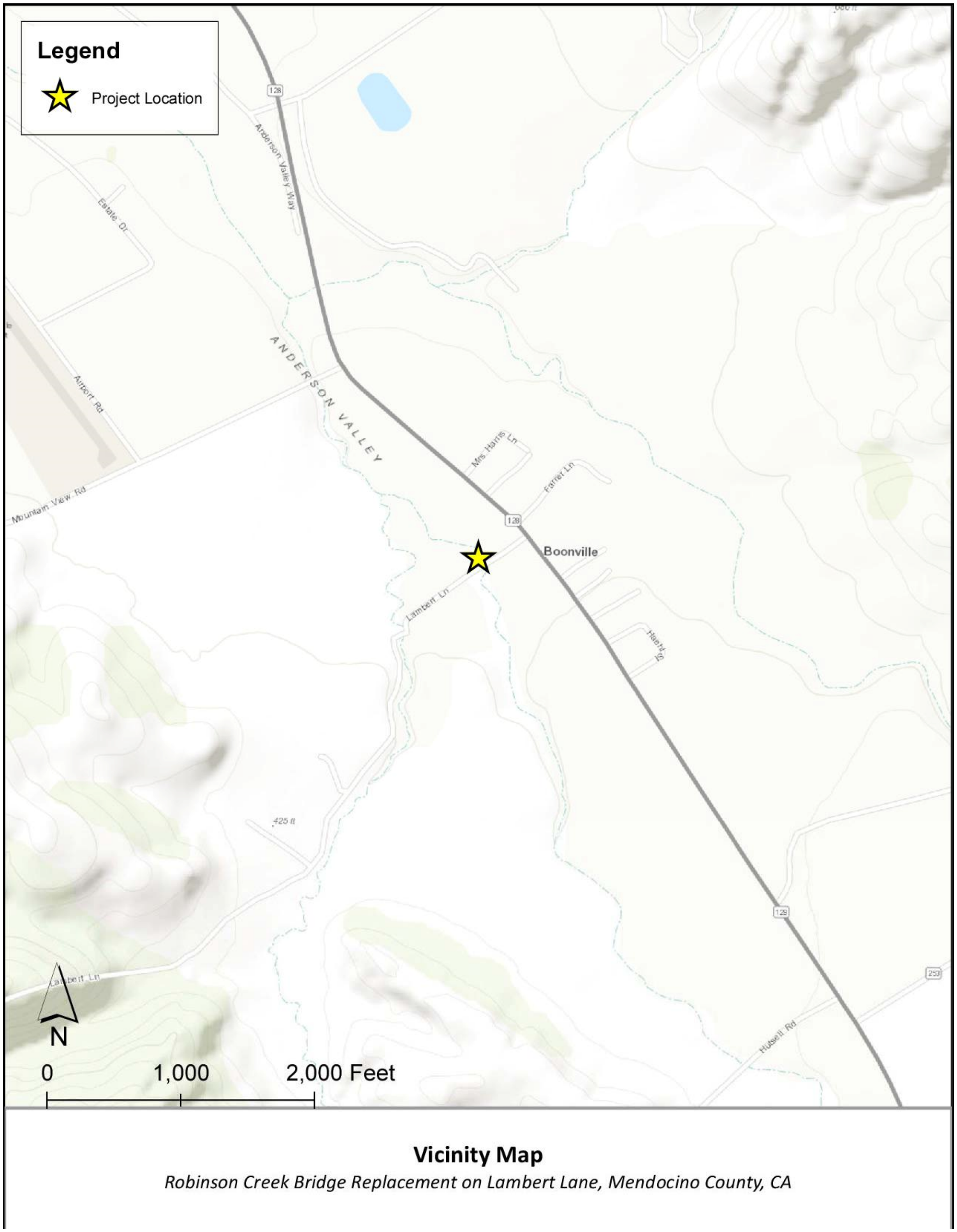


**Figure 2. Project Vicinity Map**

Source: USGS and ESRI (2021)

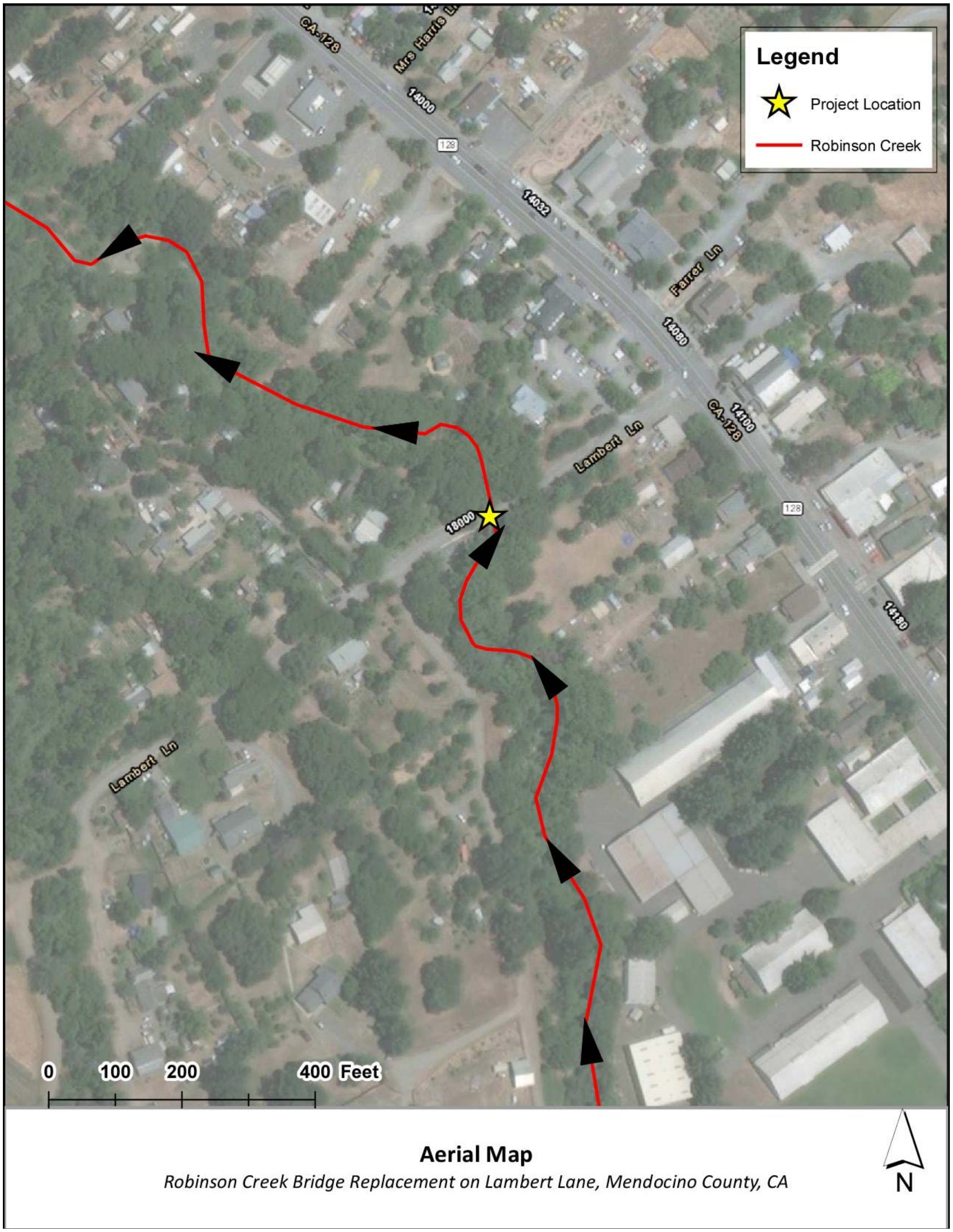


**Figure 3. Project Aerial Map**

Source: ESRI (2021)

## 1.2 Existing Bridge

The existing Lambert Lane Bridge over Robinson Creek was constructed in 1954 (see Figure 4). The existing 32-ft-long single-span reinforced concrete bridge structure located approximately 0.1 mi west of the SR 128 intersection, is supported on tall closed-strutted abutments founded on spread footings on top of erodible alluvial material (see Photo 1 and Photo 2). The current bridge superstructure is approximately 26-ft-wide, including a concrete curb and timber railing on each side. The clear-width on the bridge is approximately 24-ft with two, 12-ft lanes. The existing approach roadway is also approximately 24-ft-wide with two, 12-ft lanes.

The existing bridge was accepted into the HBP for a replacement-scoped project in 2014. The concrete slab structure is exhibiting minor cracks and light efflorescence on the bridge soffit. The concrete abutments have multiple cracks in various locations. The spread footings are exposed and have high regions of undermining. The retaining wall on the south (upstream) side of the western abutment (Abutment 1) has been undermined and collapsed into the creek in February 2015 (see Photo 3 and Photo 4). As an emergency response to prevent washout of the bridge, the County placed rock slope protection (RSP) on top of the collapsed retaining wall (see Photo 5).

In the winter of 2016/2017, the eastern abutment (Abutment 2) became completely undermined (see Photo 6). This abutment lost bearing beneath the footing and became only supported by the wingwalls on each edge of the existing bridge. As a result, structural cracking developed in the complete height of the abutment stem with reinforcing steel yielding at the base of the footing and concrete spalling and crushing at the top of the stem. This response indicates a substantial overstress of the abutment to a load path it was not designed to facilitate. As an emergency response to prevent potential collapse of the bridge, the County pumped concrete underneath the undermined abutment footing to re-establish bearing and deter further undermining of this foundation (see Photo 7).

In March of 2019, the eastern abutment experienced failure due to high flows. The left (upstream) wingwall was displaced, and severe cracking of the face of the abutment, left wingwall, and foundation were present (see Photos 8-10). The bridge was closed and a temporary Bailey bridge was installed.

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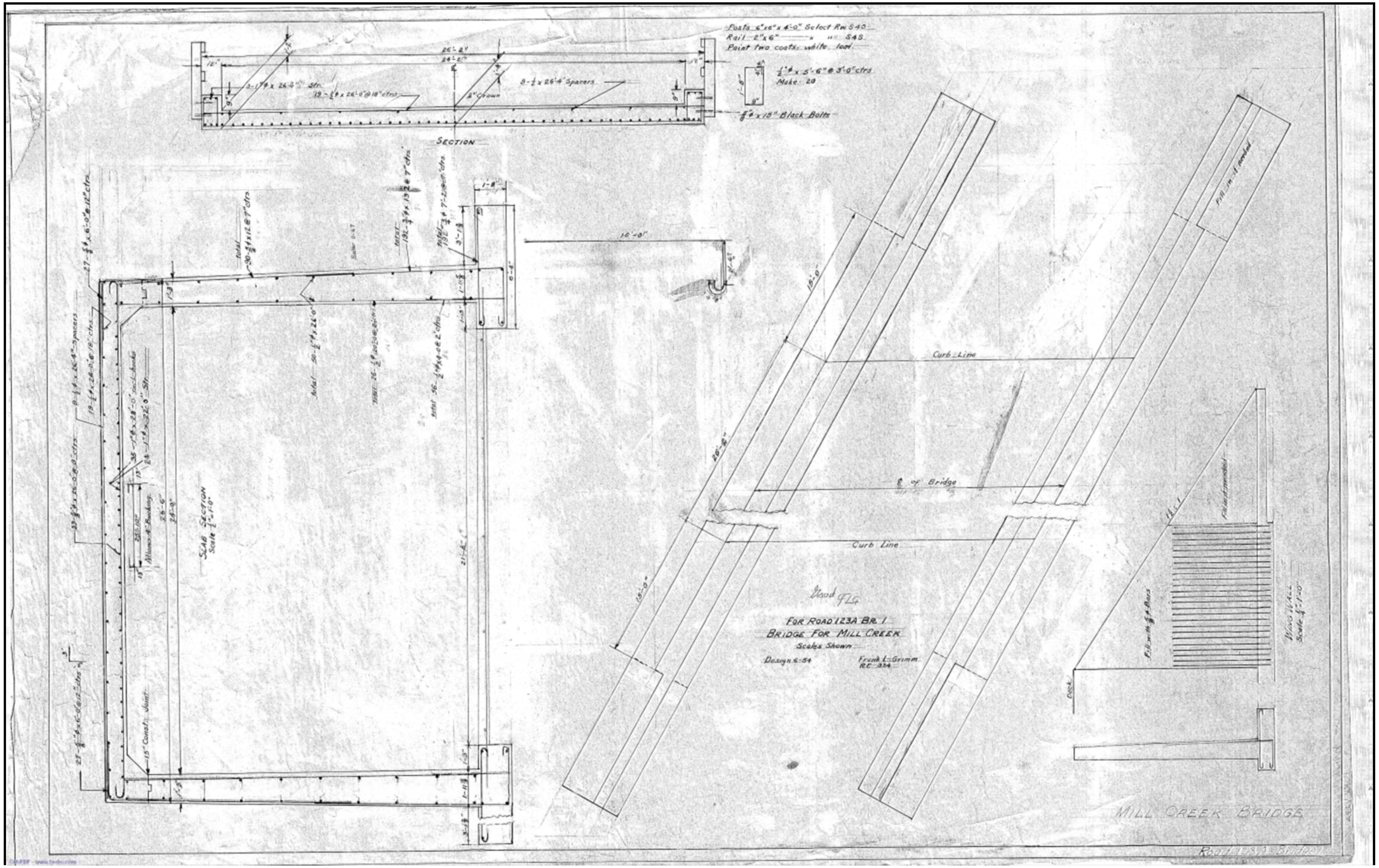


**Figure 4. Existing Bridge As-Builts**

Source: Caltrans

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**Photo 1. Existing Bridge Upstream Face (May 11, 2016)**

Source: Caltrans


**Photo 2. Existing Bridge Downstream Face (May 11, 2016)**

Source: Caltrans


**Photo 3. Collapsed Retaining Wall, View from Overbank Area (May 11, 2016)**

Source: Caltrans


**Photo 4. Collapsed Retaining Wall, View from Bottom of Channel (May 11, 2016)**

Source: Caltrans


**Photo 5. Existing Retaining Wall of Bridge Upstream (South) (May 11, 2016)**

Source: Caltrans

**Photo 6. Abutment 2 Undermined Footing (September 27, 2017)**

Source: Caltrans

**Photo 7. Scour Repair at Abutment 2 (Eastern Abutment) (September 27, 2017)**
Source: Caltrans


**Photo 8. Abutment 2 Failure, Downstream Face (May 20, 2019)**

Source: Caltrans

**Photo 9. Abutment 2 Offset Wingwall, Downstream Side (May 20, 2019)**

Source: Caltrans

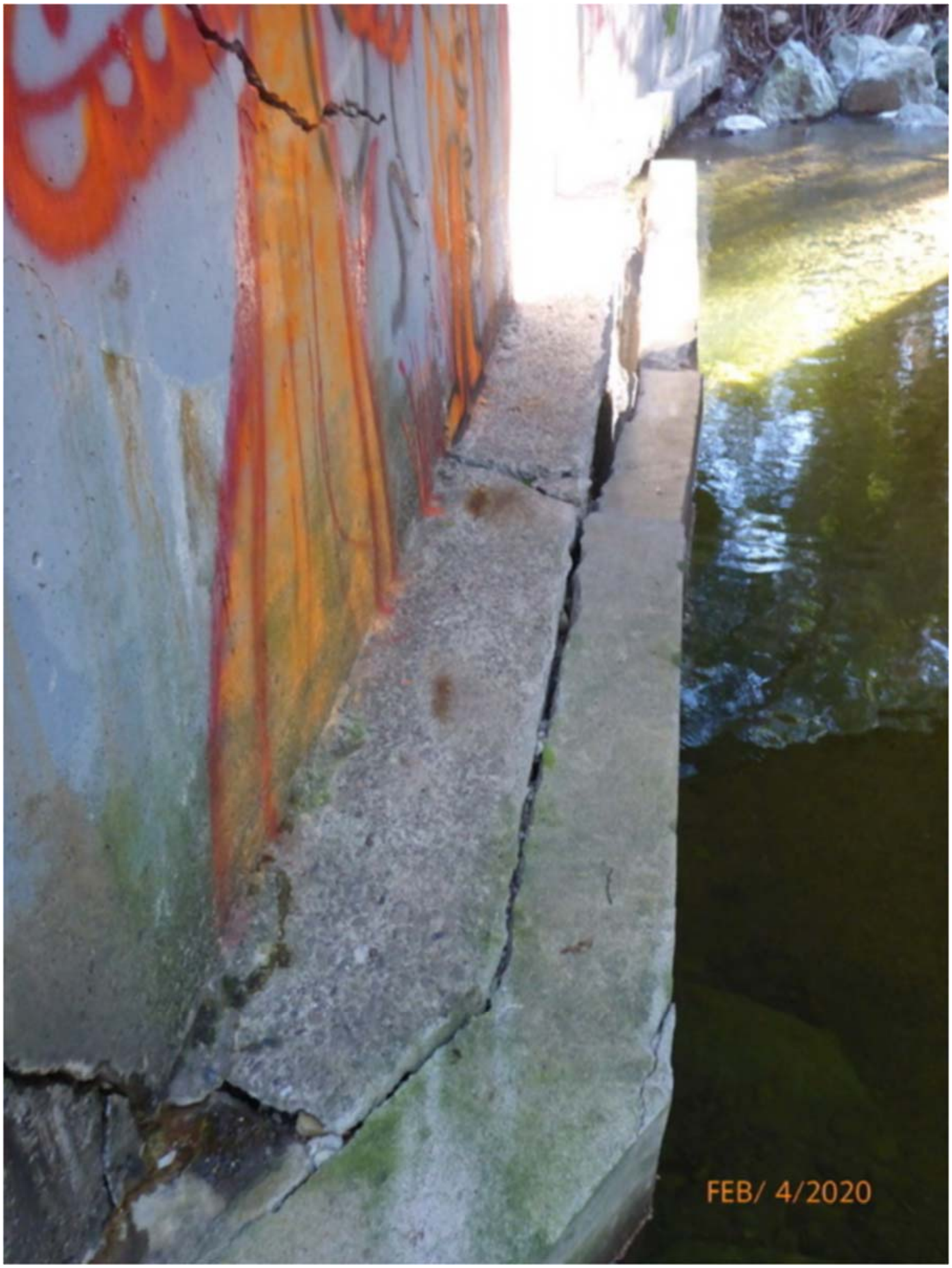


**Photo 10. Abutment 2 Foundation, Facing Upstream (Feb 4, 2020)**

Source: Caltrans

## 1.3 Proposed Bridge

The *Project Report* (Quincy, 2018) recommended replacement of the existing bridge with a new steel girder bridge on the existing alignment with a temporary detour for public traffic. The bridge general plan is shown in Figure 5. The proposed steel girder bridge would be a 96-ft-long, 31.33-ft-wide single-span bridge over Robinson Creek.

The proposed bridge would have a longer span than the existing bridge to increase the channel opening, which would provide a softer and more gradual turn of the creek when compared to the existing two 90-degree turns at the Project location. The longer bridge would also allow the faces of the proposed bridge abutment to be elevated above the 100-year flood profile of Robinson Creek at the Project location.

## 1.4 Purpose

The purpose of this *Bridge Design Hydraulic Study* is to present the design flow characteristics for the existing bridge and the proposed bridge. This report provides the calculated scour potential and recommendations on the need for scour countermeasures for the proposed bridge.

## 1.5 Key Tasks

Key tasks performed in this study included: 1) a review of available hydrologic data, 2) a hydrologic study, 3) a hydraulic analysis to determine design water surface elevations (WSE) and flow velocities for the existing and proposed conditions, 4) a scour analysis to estimate potential scour depths for the proposed condition, and 5) scour countermeasure analyses and recommendations for the proposed condition.

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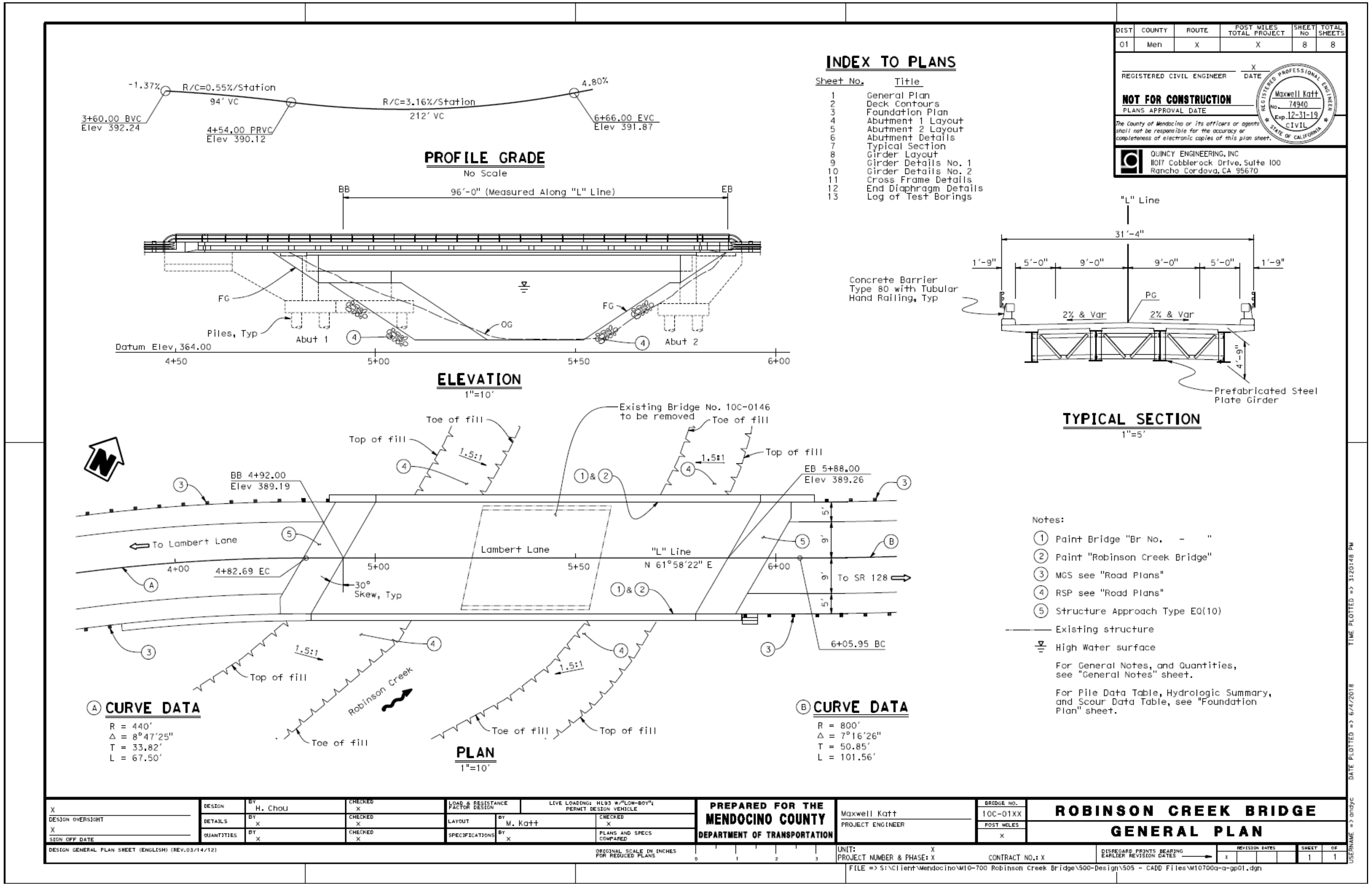


**Figure 5. Proposed Bridge General Plan**

Source: Quincy Engineering, Inc. (2021)

# 1.6 Design Criteria

The following criteria were used in the design of the proposed bridge.

## 1.6.1 Hydraulic Design Criteria

### 1.6.1.1 Federal Highway Administration Standards

The Federal Highway Administration (FHWA) criterion refers to the *California Amendments to the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications* (2014), which indicates 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 to pass the flood of record without freeboard, whichever is greater.

### 1.6.1.2 Caltrans Standards

The Caltrans 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, and the 1% probability of annual exceedance flow (100-year design discharge, or base flood) without freeboard.

### 1.6.1.3 Mendocino County Standards

According to the County of Mendocino's *Road and Development Standards* approved in August 14, 2008, bridges that span major and secondary open channels that are existing, planned, or projected at the time of channel design, shall have a minimum clearance from soffit to design water surface of 1.0 ft and shall cause no encroachment on the specified minimum freeboard in the upstream channel or waterway. This design standard was assumed to be applicable for the design of the new bridge spanning over the existing major and secondary open channels.

A major waterway is defined as a watershed with a drainage area at least 4 square miles (sq mi) in size, and is designed for an average recurrence interval of 100 years. A secondary waterway is defined as a watershed with a drainage area between 1 and 4 sq mi, and is designed for an average recurrence interval of 25 years. The watershed area of Robinson Creek at Project location is approximately 4 sq mi (see Section 2.2), and was assumed to be a major waterway.

## 1.6.2 Scour Design Criteria

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 was based on 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. The life expectancy of the bridge was considered in determining the long-term bed elevation change of the waterway; it was based on an assumed 75-year design life for a new replacement bridge.

### 1.6.3 Foundation Criteria

Per the *California Amendments to the AASHTO LRFD Bridge Design Specifications* (Caltrans, 2014), 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 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.

### 1.6.4 Rock Slope Protection Design Criteria

Two procedures for determining RSP design were considered for the proposed structure: the FHWA's *Hydraulic Engineering Circular No. 23* (HEC-23), "Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance" (Third Edition) (2009), and Caltrans' *Highway Design* Manual (HDM) (2020. The final selection considers both of these procedures and is based on engineering judgment.

## 1.7 Vertical Datum

The Project references the North American Vertical Datum of 1988 (NAVD 88).

# 2 GEOGRAPHIC SETTING

## 2.1 Geographic Location

The existing bridge is located at 39°00’28” North latitude and 123°22’04” West longitude in the Town of Boonville within Anderson Valley in southern Mendocino County (Caltrans, 2017). The existing bridge is carrying Lambert Lane and is located approximately 0.1 mi west of the intersection of Lambert Lane and SR 128 in the Town of Boonville. The Town of Boonville is located approximately 13.1 miles southwest of the City of Ukiah, Mendocino County, California.

## 2.2 Watershed Description

Robinson Creek drains a watershed area of approximately 4 sq mi at the Project Location (see Figure 6 and Appendix A for StreamStats data). Adjacent watersheds are Mill Creek to the west and Anderson Creek to the east. The Rancheria Creek watershed is located adjacent to the southern watershed boundaries of Mill and Robinson creeks. The confluence of Robinson Creek and Mill Creek is located approximately 1,000 feet downstream of Lambert Lane, and the confluence of Robinson Creek and Anderson Creek is located approximately 0.5 miles downstream of Lambert Lane. Anderson Creek is a tributary of Navarro River, which outfalls into the Pacific Ocean approximately 24.6 mi northwest of the Project site.

## 2.3 Land Use

The aerial imagery of the watershed shows land use within the Robinson Creek watershed is mostly undeveloped (see Figure 6). Developed areas within the watershed are limited to the Town of Boonville. According to Mendocino County’s *County Zoning Map*, the zones assigned inside the watershed of Robinson Creek at the Project location is residential and agricultural within the Town of Boonville (see Appendix B for County zoning map). Outside of Boonville, assigned zones are rangeland and timberland production.

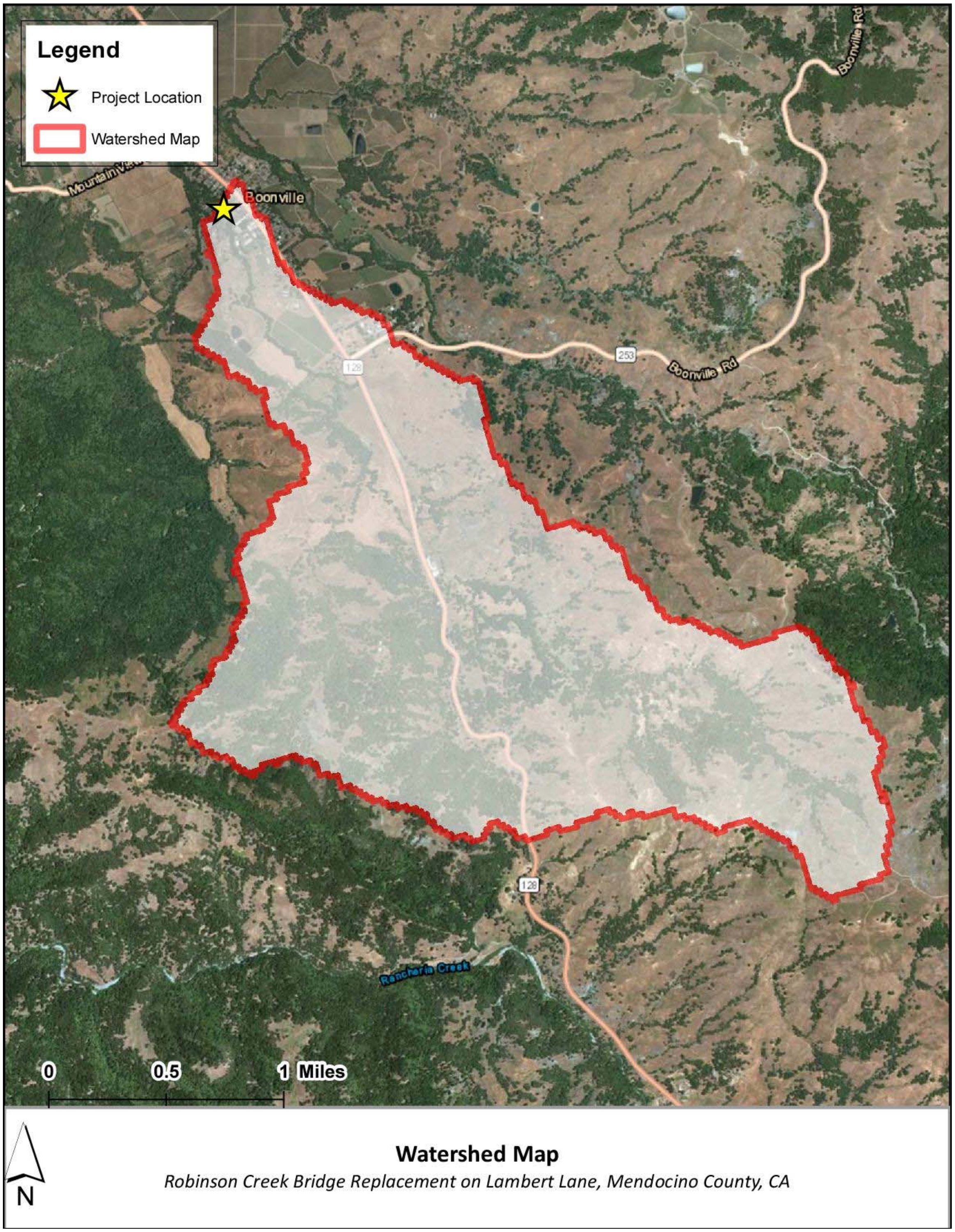


**Figure 6. Project Watershed Map**

Sources: ESRI and USGS (2021)

# 3 HYDROLOGIC ANALYSIS

The following sub-sections describe the hydrologic data sources that were used to estimate the flows for the Project site.

## 3.1 Hydrologic Design Methods

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

1. USGS Regional Regression Equations
2. Development of rainfall/runoff model using United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS)

## 3.2 Design Discharge Summary

### 3.2.1 United States Geological Survey Regional Regression Equations

This method follows the equations outlined in Caltrans' HDM (2020) Section 819.2(2). The flood-frequency equations were developed by the USGS and based on analysis of data from gaging stations. California is divided into six regions, and the Project site is within the North 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 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 that have 10 or more years of data. The updated equations were used in support of the Project's hydrologic analysis.

The regional regression equations were developed for the North Coast region using data from sites with a wide range of basin characteristics: drainage areas, ranging from 0.04 to 3,200 sq mi and mean annual precipitation ranging from 20 to 125 inches (Gotvald et al. 2012).

$$Q_{50} = 36.3(DRNAREA)^{0.870} * (PRECIP)^{0.589}$$
$$Q_{100} = 48.5(DRNAREA)^{0.866} * (PRECIP)^{0.556}$$

$Q_x$ = peak discharge for a storm event with a return period of x years, cubic feet per second (cfs)
*DRNAREA* = drainage area, sq mi
*PRECIP* = mean annual precipitation, in.

With a drainage area of 4.0 sq mi (obtained from StreamStats) and a mean annual precipitation of 44.2 inches (obtained from StreamStats), the 50- and 100-year discharges are 1,130 cfs 1,320 cubic ft per second (cfs), respectively.

### 3.2.2 HEC-HMS

The rainfall/runoff model estimated the 100-year recurrence interval design discharges. The rainfall/runoff model simulates the rainfall/runoff process and generates discharge hydrographs. The input parameters were estimated 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 Soil Conservation Service* (SCS) *Methods* (McCuen, 1982), and Chapter 810 from Caltrans' *Highway Design Manual* (2020). Some of the factors that will affect the runoff at the Project site include the watershed basin size, slopes and elevations of the basin, land uses, and soils.

As stated in Section 2.2, Robinson Creek at the Project site drains a watershed area of approximately 4.0 sq mi. For the hydrologic analysis, the watershed was modeled as one basin. The watershed delineation is shown in Figure 6. The watershed basin was modeled using the SCS curve number (CN) loss method and the SCS unit hydrograph transform method.

The SCS runoff CN is based on the cover type, hydrologic condition of that cover, and the hydrologic soil group (HSG). Cover types are typically selected based on aerial photographs and land use maps. The hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff. For this Project, the land use zoning from Mendocino County's *County Zoning Map* (as described in Section 2.3) and aerial imagery were used to determine the land uses for the Project's watershed basin.

The HSGs of the watershed were researched using the NRCS online *Web Soil Survey* (2021); see Appendix C for a map of the HSGs underlying the Project's watershed. Infiltration rates and runoff potentials are indicated by the soil's HSG. Soils may be assigned to one of four groups (A, B, C, or D). Group A has high infiltration rates (low runoff potential) and consists mainly of deep, well-drained to excessively drained sands or gravel sands. On the other end of the spectrum, Group D has very slow infiltration rates (high runoff potential) and consists chiefly of clays that have a high shrink-swell potential or soils with a clay or nearly impervious layer near the surface. The soils underlying the Project's watershed are predominantly categorized as HSG C and D. HSG C and D soils have slow infiltration rate and high runoff potential.

Based on the land use and the HSGs, a composite runoff CN value was estimated to represent the basin. In the hydrologic model, the rainfall is converted to runoff by using a CN, which is based on the watershed's soils, plant covert type and treatment, amount of impervious area, interception, and surface storage. The initial abstraction is the part of rainfall that occurs before direct stormwater runoff begins, and consists of interception, initial infiltration, surface depression storage, evapotranspiration, and other factors. The composite CN was approximately 63.7, and the initial abstraction was approximately 1.14.

The lag time was estimated using the time of concentration method identified in the Caltrans' HDM (2020), then the time of concentration was converted to lag time using a factor of 0.6 using the definition of lag time as provided by the NRCS. The lag time was estimated to be approximately 47 minutes.

The precipitation depth was obtained from the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 website for California Precipitation Frequency Data using the longitude and latitude of the approximate centroid of the watershed basin. Based on the rainfall distribution map from the NRCS, the Project is within rainfall distribution Type IA. The Project precipitation depths are shown in Appendix D. The estimated peak discharge for the 50- and 100-year design storm events were approximately 1,340 cfs and 1,750 cfs, respectively.

## 3.3 Selected Design Discharges

The regional regression equations were developed for the North Coast region using data from sites with a wide range of basin characteristics: drainage areas ranging from 0.04 to 3,200 sq mi and mean annual precipitation ranging from 20 to 125 inches (Gotvald et al. 2012). Both the rainfall/runoff model and the USGS regional regression equation methods yielded similar results. The peak flow estimated using rainfall/runoff model with the HEC-HMS software is more conservative than the peak flow estimated using the USGS regional regression equations. Therefore, peak 50- and 100-year flows estimated using the rainfall/runoff model was selected to perform hydraulic analysis of the existing and proposed conditions.

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# 4 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 Appendix E for the existing bridge and Appendix F for the proposed bridge.

## 4.1 Design Tools

The hydraulic analyses were performed for the existing and proposed conditions using the USACE's Hydrologic Engineering Center's River Analysis System (HEC-RAS) modeling software, Version 5.0.7.

## 4.2 Cross Section Data

The channel cross sections in the hydraulic model of both the existing and proposed conditions included in the HEC-RAS model were developed using the existing channel survey data provided by Quincy Engineering Inc. on 2016, and the proposed channel grading data provided by Quincy Engineering Inc. in 2021. The survey data referenced the North American Datum of 1983, California Zone II as the horizontal datum and NAVD 88 as the vertical datum. The cross section naming convention is by river station (RS), with the cross-section number increasing in the upstream direction. The upstream and downstream cross sections for the existing and proposed condition hydraulic model are at the same location, but the river reach lengths are different because of the channel regrading proposed by the Project.

The limits of the channel cross sections for the existing and proposed conditions imported into the HEC-RAS model are shown in Figure 7. The existing condition hydraulic model has a river reach length of 673 ft and 19 cross sections. The proposed condition hydraulic model has a river reach length of 659 ft and 15 cross sections. The conform points are RS 156 downstream of the Lambert Lane Bridge and RS 375/362 (Existing/Proposed) upstream of the Lambert Lane Bridge.

## 4.3 Modeled Hydraulic Structures

The HEC-RAS model of Robinson Creek at the Project location includes the existing and proposed Lambert Lane bridges. The input parameters for the existing bridge were based on the bridge as-builts included in the Caltrans BIR (2020). The input parameters for the proposed bridge were based on the bridge general plans provided by Quincy Engineering Inc.

The collapsed retaining wall upstream of the existing bridge was represented in the existing condition hydraulic model as an in-stream weir. The input parameters were based on the 2016 survey and field visit notes. The proposed condition model does not include the collapsed retaining wall because it will be removed as part of the channel realignment.

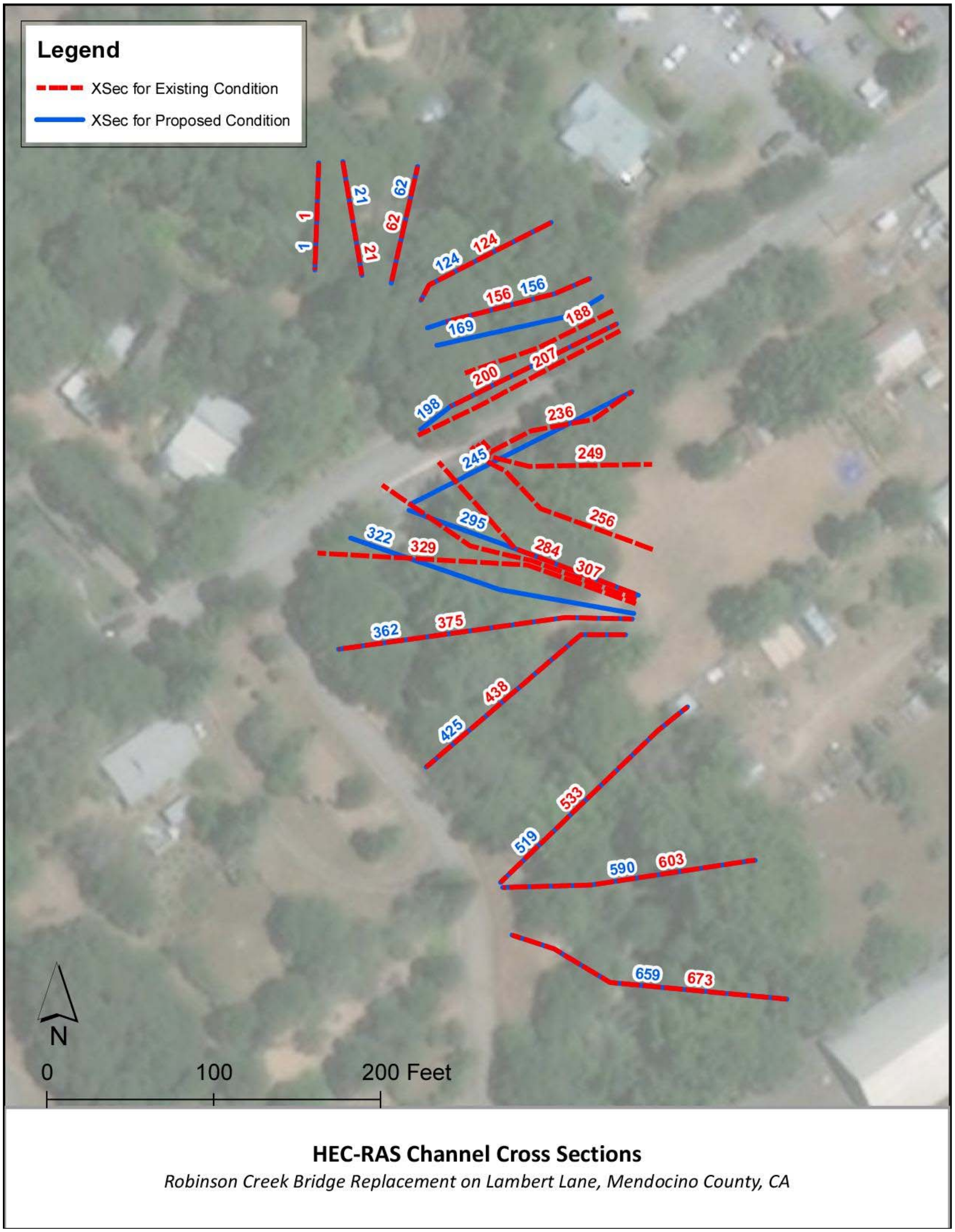


**Figure 7. Cross Section Locations for Hydraulic Model**

## 4.4 Model Boundary Condition

A normal depth slope of 0.016 ft/ft was used as the downstream reach boundary condition and was based on the survey of Robinson Creek downstream of the Lambert Lane Bridge.

## 4.5 Manning's Roughness Coefficients

Manning's roughness coefficients were used in the hydraulic model to estimate energy losses in the flow due to friction. The coefficients selected for the hydraulic models varied from 0.020 to 0.100 and are summarized in Table 1. These values were selected based on the Project Team's field visit on May 11, 2016.

**Table 1. Manning's Roughness Coefficient in the Hydraulic Model**

| Type of Channel/ Overbank Area | Manning's Roughness Coefficient |
|---|---|
| Concrete Retaining Wall (Only for Existing Condition) | 0.020 |
| Low Flow Channel, Below Existing/Proposed Bridge Structure | 0.040 |
| Low Flow Channel | 0.045 |
| Channel Bank Slope with Rock Slope Protection | 0.050 |
| Overbank Area with Modest Vegetation | 0.050 to 0.070 |
| Overbank Area with Dense Vegetation | 0.100 |

## 4.6 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 in the vicinity of the Project. These values represent a channel with a gradual transition between cross sections. The expansion and contraction coefficients used in the vicinity of the bridges were 0.5 and 0.3, respectively. These values represent the flow interference caused by the bridges and retaining wall in the existing condition.

## 4.7 Hydraulic Model Results

### 4.7.1 Water Surface Elevations

The 50- and 100-year WSEs of Robinson Creek at the Project location are summarized in Table 2 and Table 3. The hydrologic summary table for the proposed bridge, which follows the format specified in the Caltrans' Memo to Designers 16-1, is shown in Table 4. The cross-sectional view of the existing and proposed bridges in the hydraulic model, looking downstream, are presented in Figure 8 and Figure 9. The water surface profiles along Robinson Creek at the Project location are presented in Figure 10 for the 50-year storm event and Figure 11 for the 100-year storm event.

The outputs from the existing and proposed condition hydraulic analysis shows the proposed Project would result in decreases in the 50- and 100-year WSEs upstream of the Lambert Lane Bridge. The factors leading to the decreases in the 50- and 100-year WSEs upstream of the Lambert Lane Bridge are the following: removal of the collapsed retaining wall, a wider bridge opening, structures located outside of the footprint of the 50- and 100-year storm events, and proposed channel grading.

**Table 2. Robinson Creek, Summary of 50-Year Water Surface Elevations**

| River Station (Existing Condition) | Location/ Distance from Existing Bridge Centerline | 50-year WSE | | Elevation Change (ft) |
|---|---|---|---|---|
| | | Existing (ft NAVD 88) | Proposed (ft NAVD 88) | |
| 673 | Model Upstream Limit 450 ft Upstream | 380.92 | 380.49 | -0.43 |
| 533 | 310 ft Upstream | 380.12 | 379.16 | -0.96 |
| 375 | 153 ft Upstream | 379.28 | 376.86 | -2.42 |
| 284 | Upstream of Collapsed Retaining Wall | 378.42 | n/a[1] | n/a[1] |
| 256 | Downstream of Collapsed Retaining Wall | 374.34 | n/a[1] | n/a[1] |
| 221 | Lambert Lane Bridge Upstream Face[2] | 373.61 | 373.57 | n/a[2] |
| 221 | Lambert Lane Bridge Downstream Face[2] | 372.58 | 373.17 | n/a[2] |
| 200 | 22 ft Downstream | 373.17 | 372.92 | -0.25 |
| 156 | 65 ft Downstream | 372.71 | 372.78 | 0.07 |
| 124 | 97 ft Downstream | 372.72 | 372.71 | -0.01 |

Notes:
1. Project proposes a bridge with a softer and more gradual turn of the creek alignment. The proposed condition hydraulic model does not include channel cross-sections representing upstream/downstream conditions and/or effects of the collapsed retaining wall.
2. The proposed bridge is wider than the existing bridge. Therefore, the upstream/downstream faces of the existing and proposed bridges are not in the same location.

### Table 3. Robinson Creek, Summary of 100-Year Water Surface Elevations

| River Station (Existing Condition) | Location/ Distance from Existing Bridge Centerline | 100-year WSE | | WSE Change (ft) |
|---|---|---|---|---|
| | | Existing (ft NAVD 88) | Proposed (ft NAVD 88) | |
| 673 | Model Upstream Limit 450 ft Upstream | 382.01 | 381.35 | -0.66 |
| 533 | 310 ft Upstream | 381.29 | 380.04 | -1.25 |
| 375 | 153 ft Upstream | 380.45 | 377.93 | -2.52 |
| 284 | Upstream of Collapsed Retaining Wall | 379.46 | n/a[1] | n/a[1] |
| 256 | Downstream of Collapsed Retaining Wall | 375.56 | n/a[1] | n/a[1] |
| 221 | Lambert Lane Bridge Upstream Face[2] | 374.96 | 374.54 | n/a[2] |
| 221 | Lambert Lane Bridge Downstream Face[2] | 374.05 | 374.03 | n/a[2] |
| 200 | 22 ft Downstream | 373.94 | 373.74 | -0.20 |
| 156 | 65 ft Downstream | 373.53 | 373.64 | 0.11 |
| 124 | 97 ft Downstream | 373.62 | 373.60 | -0.02 |

Notes:
1. Project proposes a bridge with a softer and more gradual turn of the creek alignment. The proposed condition hydraulic model does not include channel cross-sections representing upstream/downstream conditions and/or effects of the collapsed retaining wall.
2. The proposed bridge is wider than the existing bridge. Therefore, the upstream/downstream faces of the existing and proposed bridges are not in the same location.

### Table 4. Hydrologic Summary Table for the Proposed Bridge

| Hydrologic Summary for Robinson Creek Bridge on Lambert Lane (Bridge No. 10C0146) | | | |
|---|---|---|---|
| Drainage Area: 4 mi$^2$ | | | |
| Frequency | Design Flood | Base Flood | Flood of Record |
| | 50-year | 100-year | n/a |
| Discharge (cfs) | 1,340 | 1,750 | n/a |
| Water Surface Elevation at Bridge (ft NAVD 88) | 373.6 | 374.5 | n/a |

Note:
1. Elevations are rounded to the nearest 0.1 ft.

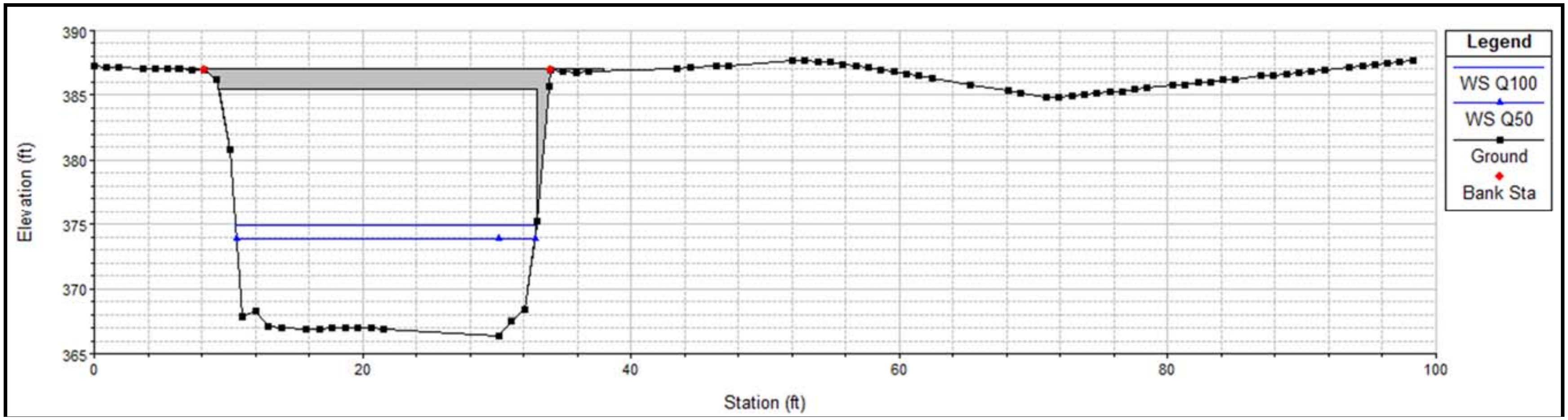


**Figure 8. Upstream Face of Existing Bridge, Looking Downstream (Northeast)**

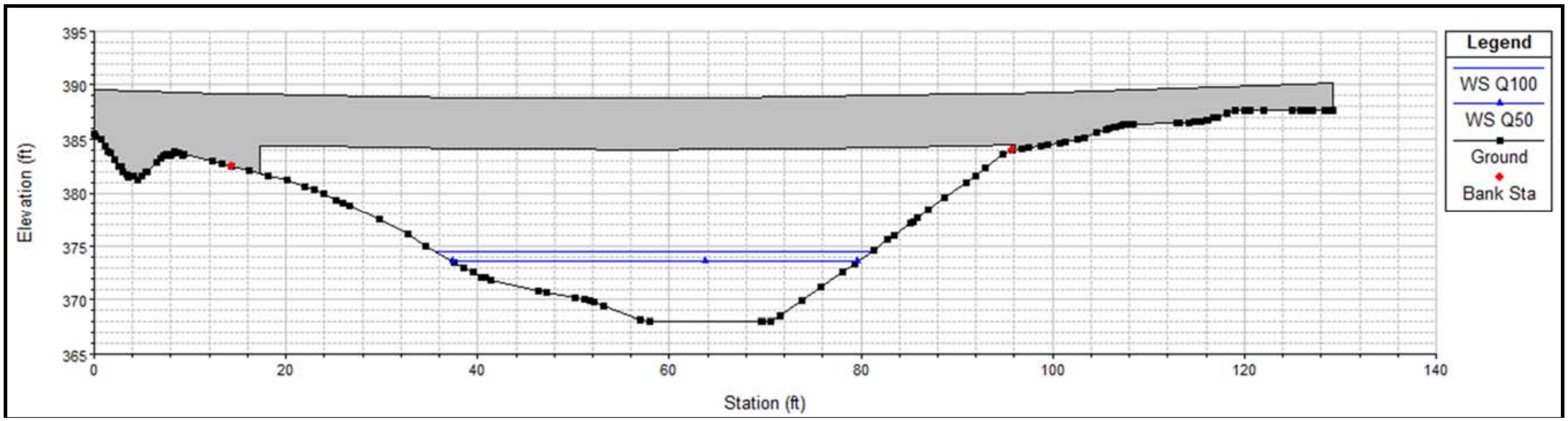


**Figure 9. Upstream Face of Proposed Bridge, Looking Downstream (Northeast)**

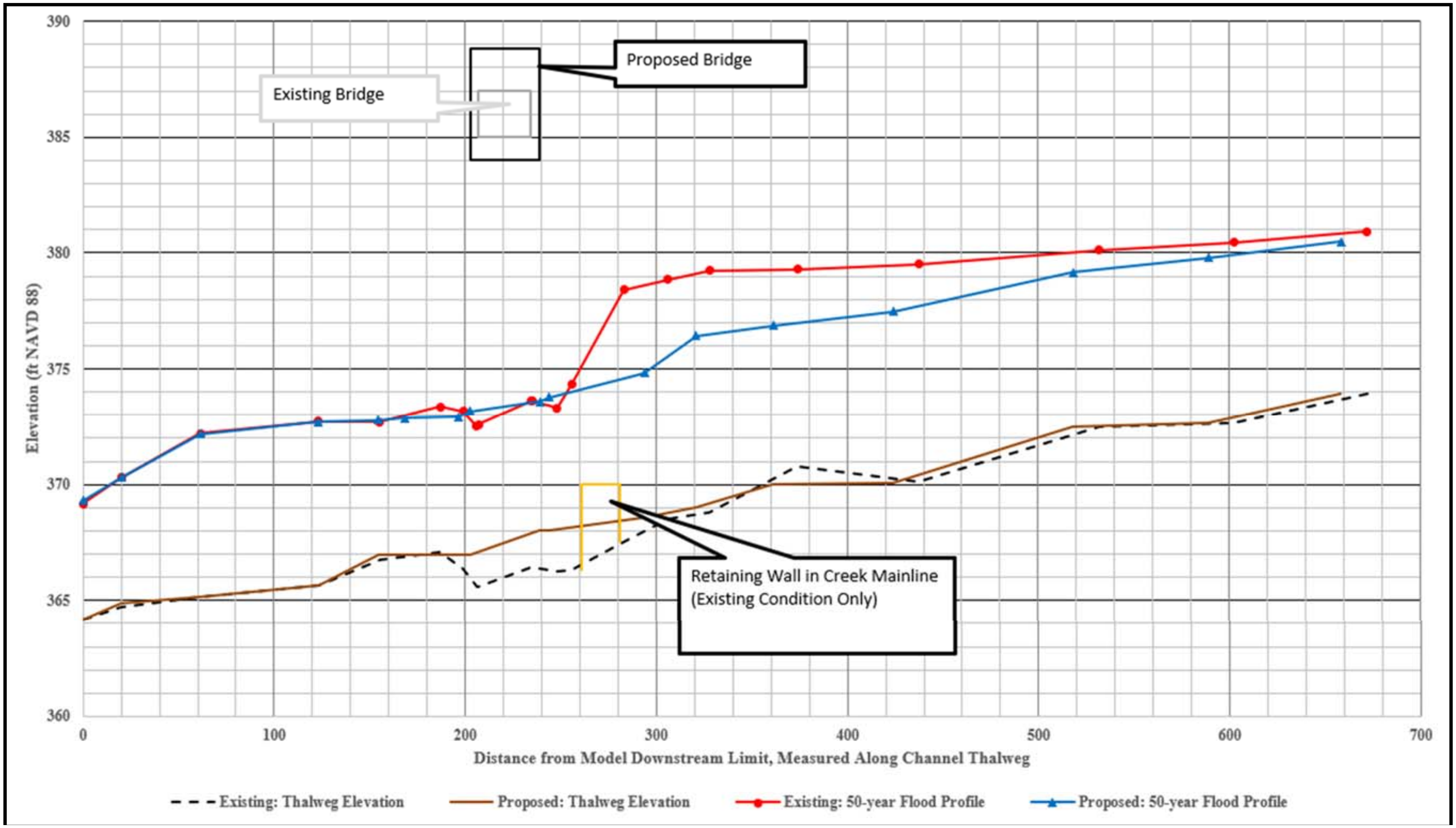


**Figure 10. Robinson Creek 50-Year Water Surface Profile at Lambert Lane**

Note: channel alignment for proposed condition is shorter at the bridge crossing. The five upstream-most cross sections for existing and proposed conditions are located in same location, as shown in Figure 7.

Source: WRECO (2021)

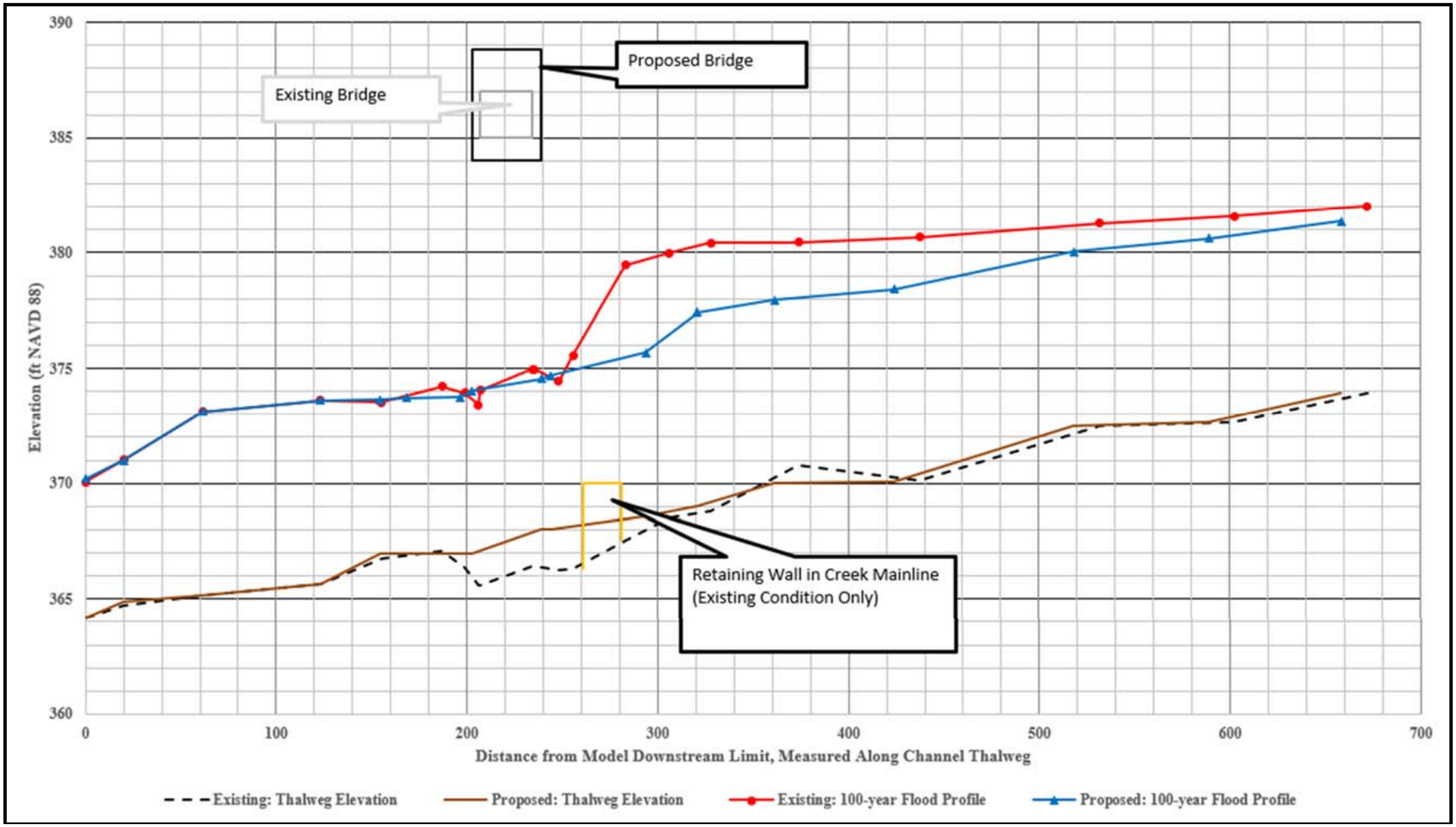


**Figure 11 Robinson Creek 100-Year Water Surface Profile at Lambert Lane**

Note: channel alignment for proposed condition is shorter at the bridge crossing. The five upstream-most cross sections for existing and proposed conditions are located in same location, as shown in Figure 7.

Source: WRECO (2021)

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### 4.7.2 Freeboard

The bridge freeboard criteria relevant for this Project is described in Section 1.6.1. To summarize, the FHWA and Caltrans criteria both require that proposed bridges pass the 50-year flood with freeboard to pass drift, and the 100-year flood without freeboard. The 2020 Caltrans HDM indicates that 2 ft of freeboard is often assumed for preliminary designs. Mendocino County's design standards require bridges over major and secondary open channels must have a minimum 1 ft of freeboard over the design flood.

The existing and proposed bridge freeboard during the 50- and 100-year storm events are summarized in Table 5. The bridge freeboard was computed using the 50- and 100-year WSEs at the bridge upstream face. The outputs from hydraulic analysis shows both the existing and proposed bridges have sufficient freeboard to meet the freeboard criteria from the FHWA, Caltrans, and Mendocino County.

**Table 5. 50-and 100-Year Water Surface Elevations and Freeboard**

| Modeled Project Condition | Soffit Elevation (ft NAVD 88) | 50-year Storm Event | | 100-year Storm Event | |
|---|---|---|---|---|---|
| | | WSE (ft NAVD 88) | Freeboard (ft) | WSE (ft NAVD 88) | Freeboard (ft) |
| Existing | 385.5 | 373.6 | 11.9 | 375.0 | 10.5 |
| Proposed | 384.1 | 373.6 | 10.5 | 374.5 | 9.5 |

Note: Elevations and freeboard height are rounded to the nearest 0.1 ft.

## 4.8 Flow Velocities

The average channel flow velocities of Robinson Creek at the Project location during 50- and 100-year storm events are presented in Table 5 and Table 7, respectively. Based on the outputs from the hydraulic analysis, the proposed Project would increase the average channel flow velocity upstream of the vicinity of the Lambert Lane Bridge because the removal of the collapsed retaining wall would minimize the flood flow obstruction during 50- and 100-year storm events. At the bridge opening, the average flow velocity would be lowered because of the wider channel opening through the bridge and the removal of existing sharp turns upstream and downstream of the bridge crossing.

**Table 6. Robinson Creek, Summary of 50-Year Average Channel Flow Velocities**

| River Station (Existing Condition) | Location/ Distance from Existing Bridge Centerline | 50-year Storm Event[1] | |
|---|---|---|---|
| | | Existing (ft/sec) | Proposed (ft/sec) |
| 673 | Model Upstream Limit 450 ft Upstream | 5.1 | 5.6 |
| 533 | 310 ft Upstream | 3.7 | 4.5 |
| 375 | 153 ft Upstream | 3.9 | 6.2 |
| 284 | Upstream of Collapsed Retaining Wall | 6.4 | n/a[2] |
| 256 | Downstream of Collapsed Retaining Wall | 13.0 | n/a[2] |
| 221 | Lambert Lane Bridge Upstream Face | 9.4 | 8.6 |
| 221 | Lambert Lane Bridge Downstream Face | 11.6 | 8.4 |
| 200 | 22 ft Downstream | 8.4 | 8.9 |
| 156 | 65 ft Downstream | 8.1 | 7.1 |
| 124 | 97 ft Downstream | 5.9 | 5.9 |

Notes:
1. Average channel flow velocities are rounded to the nearest 0.1 ft/sec.
2. Project proposes proposed bridge with a softer and more gradual turn of the creek alignment. Proposed condition hydraulic model does not include channel cross-sections representing upstream/downstream of the collapsed retaining wall.

**Table 7. Robinson Creek, Summary of 100-Year Average Channel Flow Velocities**

| River Station (Existing Condition) | Location/ Distance from Existing Bridge Centerline | 100-year Storm Event[1] | |
|---|---|---|---|
| | | Existing (ft/sec) | Proposed (ft/sec) |
| 673 | Model Upstream Limit 450 ft Upstream | 5.5 | 6.1 |
| 533 | 310 ft Upstream | 3.8 | 4.8 |
| 375 | 153 ft Upstream | 4.2 | 6.3 |
| 284 | Upstream of Collapsed Retaining Wall | 7.1 | n/a[2] |
| 256 | Downstream of Collapsed Retaining Wall | 13.5 | n/a[2] |
| 221 | Lambert Lane Bridge Upstream Face[2] | 10.1 | 8.8 |
| 221 | Lambert Lane Bridge Downstream Face[2] | 11.7 | 9.1 |
| 200 | 22 ft Downstream | 9.6 | 9.7 |
| 156 | 65 ft Downstream | 8.8 | 7.7 |
| 124 | 97 ft Downstream | 6.3 | 6.3 |

Notes:
1. Average channel flow velocities are rounded to the nearest 0.1 ft/sec.
2. Project proposes proposed bridge with a softer and more gradual turn of the creek alignment. Proposed condition hydraulic model does not include channel cross-sections representing upstream/downstream of the collapsed retaining wall.

# 5 SCOUR ANALYSIS

WRECO evaluated bridge scour per the criteria described in "Evaluating Scour at Bridges" (FHWA, 2012). The minimum design criterion for bridge scour is the 100-year design storm. 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 scour calculations assume that the channel bed material is erodible. The following sub-sections summarize the results of the analysis. The detailed scour calculations are included in Appendix G.

## 5.1 Caltrans Bridge Inspection Reports

Available Bridge Inspection Reports (BIR) for the existing bridge were reviewed for relevant scour information. The inspection performed on June 3, 2013 gave a scour critical bridge rating of "3," which represents a condition where "scour is significant enough to warrant a structural analysis of the bridge. Channel bottom is current undermining a spread footing." The BIR, dated May 20, 2020 also provided the following scour history of the existing bridge:

- 1980 inspection report noted scouring at the existing bridge
- 1986 inspection first reported exposure of Abutment 2
- 2000 inspection first reported undermining of Abutment 2
- 2013 inspection reported failure of channel wall/retaining wall on the upstream side of Abutment 1, and bridge was coded as scour critical
- 2017 inspection reported Abutment 2 was critically undermined. County per formed work to mitigate the undermining of Abutment 2 (see Photo 6 and Photo 7)
- 2019 inspection reported Abutment 2 failed due to scour. The bridge was closed and temporary Bailey bridge was installed (see Photo 8 through Photo 10).

## 5.2 Existing Channel Bed

Crawford & Associates provided particle size distribution of the two soil samples at the Project location. First sample was classified as silty sand with gravel and the median diameter was approximately 0.45 millimeters (mm). Second sample was classified as sandy silt with median diameter smaller than Sieve #200 with opening of 0.075 mm.

Soils with fine grains that pass the #200 sieve are considered cohesive soils. While there is not a clear division between cohesive and cohesionless soils, soils are divided into these two groups for the purposes of analyzing scour. Per HEC-18, a rule of thumb is that soils with 10% fines will exhibit some cohesion while soils with 35% fines will be dominated by cohesion. In general, the threshold for cohesive bed materials is a median grain size diameter that is 0.2 mm or less.

Both bed material samples tested by Crawford & Associates were at the depths approximately same as the bottom of the channel. Therefore, the contraction scour was calculated using both the cohesionless and cohesive scour equations; the cohesive scour equation resulted in deeper contraction scour, and is presented herein.

## 5.3 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.

The 2020 Caltrans BIR included six stream measurements, ranging from 1993 to 2017. The overall trend from the stream measurement shows gradual decrease in thalweg elevation, except for the year 2017 with major flood event. The measurement from year 2017 also included the channel excavation near Abutment 2 for the structure repair. The average rate of change was estimated to be 0.106 ft/year of degradation based on the 24-year period. The long-term bed elevation change was calculated to be 8.0 ft for an extrapolated 75-year design life.

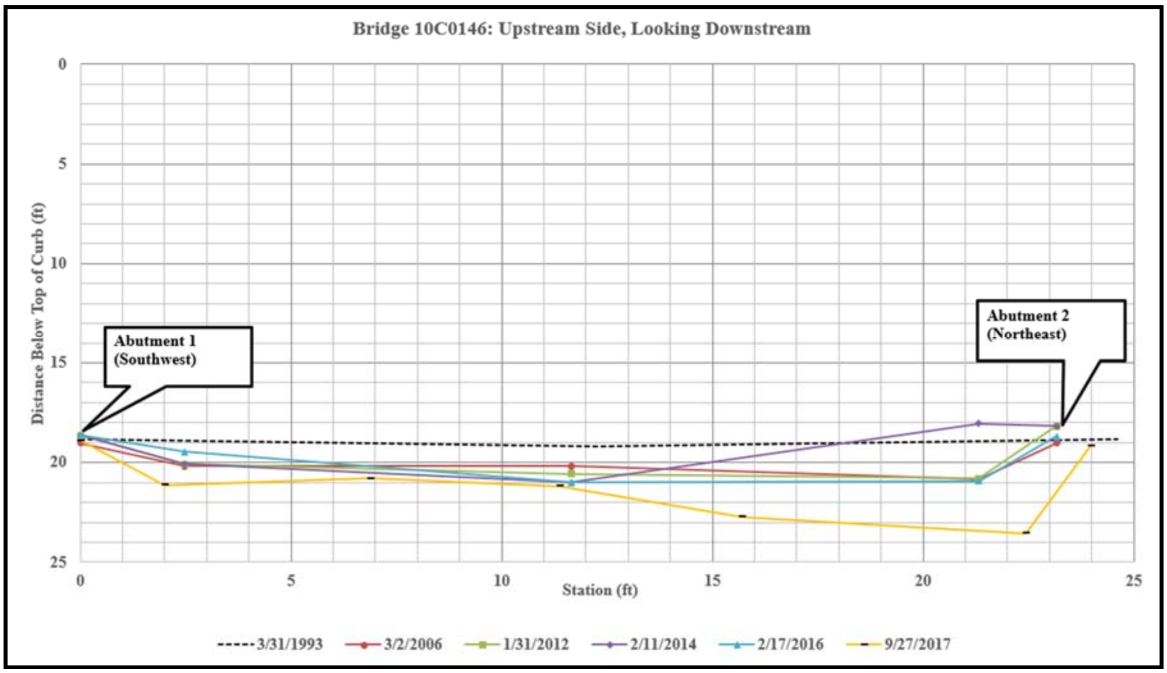


**Figure 12. Historical Stream Measurements at Upstream Face of Existing Bridge**

Source: Caltrans (2020)

## 5.4 Contraction Scour

Contraction scour occurs when the flow area of a stream is reduced by: 1) the natural contraction of the stream channel; 2) by a bridge structure; or 3) the overbank flow forced back to the channel by roadway embankments at the roadway approach to a bridge. From the fluid mechanics continuity equation for incompressible flow, a decrease in flow area results in an increase in average velocity and bed shear stress through the contraction. Hence, there is an increase in erosive forces in the contraction section, and more bed material is removed from the contracted reach than is transported into the reach. This increase in transport of bed material from the reach lowers the natural bed elevation. As the bed elevation is lowered, the flow area increases. Thus, the velocity and shear stress decrease until relative equilibrium is reached (i.e., the quantity of bed material that is transported into the reach is equal to that removed from the reach, or the bed shear stress is decreased to a value such that no sediment is transported out of the reach). Contraction scour, in a natural channel or at a bridge crossing, involves removal of material from the bed across all or most of the channel width (FHWA, 2012).

HEC-18 recommends an equation presented by the *SRICOS-EFA Method* by J.L. Briaud (2004) for estimating the contraction scour for cohesive bed materials (referred to as "ultimate contraction scour"). As described in Section 5.2, the channel bed is considered to be cohesive for the purpose of analyzing scour. Ultimate (contraction) scour is evaluated for channels that exhibit cohesiveness. The equation for estimating contraction scour, as presented in HEC-18, is as follows:

$$y_{s-ult} = 0.94\,y_1\left(\frac{1.83V_2}{\sqrt{gy_1}} - \frac{K_u\sqrt{\frac{\tau_c}{\rho}}}{gny_1^{1/3}}\right)$$

Where:

$y_{s-ult}$ = scour depth for cohesive soils, ft
$y_1$ = average depth in the upstream main channel, ft
$V_2$ = average flow velocity in the contracted section, ft/s
$g$ = gravitational acceleration, 32.2 ft/s$^2$
$K_u$ = 1.486 for U.S. Customary units, and 1.0 for S.I. units
$\tau_c$ = critical shear stress, lbs/ft$^2$
$\rho$ = density of sediment, slugs/ft$^3$
$n$ = Manning's roughness coefficient, unitless

The contraction scour was calculated to be 5.4 ft.

## 5.5 Abutment Scour

Abutment scour occurs when the bridge abutments and embankment slopes in front of the abutments block approaching flow. Abutment scour is commonly evaluated using either the Froehlich or HIRE live-bed scour equations. The HIRE equation is applicable when the ratio of the projected abutment length (the L parameter) to the flow depth (the $y_1$ parameter) is greater than 25. The Froehlich equation is applicable when the ratio of the projected abutment length to the flow depth is less than 25. Both equations assume that the bed material around bridge abutment is erodible during the 100-year storm event.

The Froehlich equation was used for this scour analysis because the ratio of the projected abutment length to the flow depth was less than 25 at both abutments. The Froehlich equation is given below:

$$y_s = y_a \left[ 2.27 K_1 K_2 \left( \frac{L'}{y_a} \right)^{0.43} Fr^{0.61} + 1 \right]$$

Where:

$y_s$ = scour depth (ft)
$K_1$ = Coefficient for abutment shape (from Table 8.1 of HEC-18)
$K_2$ = Coefficient for angle of embankment to flow
$L'$ = Length of active flow obstructed by the embankment (ft)
$Fr$ = Froude number, based on the velocity and depth adjacent to and upstream of the abutment
$y_a$ = Average depth of flow at the abutment = $A_e/L$ (ft)
- $L$ = Length of embankment projected normal to the flow (ft)
- $A_e$ = Flow area of the approach cross section obstructed by the embankment ($ft^2$)

The proposed bridge abutments would not be in contact with the 100-year flood flow (see Figure 9), but the embankment slopes in front of the proposed abutments are subject to erosion. When assuming the embankment slopes are erodible, the local abutment scour depth for the embankment slope in front of Abutment 1 (southwest) was calculated to be 4.6 ft and the local abutment scour depth for Abutment 2 (northeast) was calculated to be 3.4 ft.

## 5.6 Total Scour and Scour Countermeasures

Per the *California Amendments to the AASHTO LRFD Bridge Design Specifications* (Caltrans, 2014), foundations should be designed to withstand the conditions of scour. The total estimated scour depths reflect the sum of the long-term bed elevation change, contraction scour, and local scour, assuming the bridge is supported on soil or degradable rock.

The total calculated scour depths is the sum of long-term bed elevation change, channel contraction scour, and local scour at proposed bridge structures, and are summarized in Table 8. The total calculated scour depths and elevations for the abutments are summarized in Table 9. The scour elevation presented in Table 9 were based upon the finished grade elevation, which would be approximately 381.5 ft NAVD 88 for both Abutments 1 and 2. This approach of referencing the finished grade elevations requires the installation of scour countermeasures at the embankment slopes of the abutments to reduce their potential to erode.

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California Ammendments Chapter 2 (Short Term

**Table 8. Summary of Computed Scour Depths**

| Support No. | Degradation Scour Depth (ft) | Contraction Scour Depth (ft) | Short Term (Local Scour Depth) (ft) | Total Scour Depth (ft) |
|---|---|---|---|---|
| Abutment 1 | 8.0 | 5.4 | 4.6 | 18.0 |
| Abutment 2 | 8.0 | 5.4 | 3.4 | 16.8 |

Note:
Scour depths are rounded to the nearest 0.1 ft.

**Table 9. Proposed Abutment Total Scour Depths and Elevations**

| Support No. | Reference Elevation (ft NAVD 88) | Total Calculated Scour Depth (ft) | Total Calculated Scour Elevation (ft NAVD 88) |
|---|---|---|---|
| Abutment 1 | 382.0 | 18.0 | 364.0 |
| Abutment 2 | 382.0 | 16.8 | 365.2 |

Note:
Scour depths and elevations are rounded to the nearest 0.1 ft.

According to a Caltrans memorandum dated October 23, 2015, *Scour Data Table on Foundation Plan*, a scour data table on the Foundation Plan for all contract plans should also present a long-term scour elevation based upon the long-term bed degradation and contraction scour depths, and a short-term depth based upon the local scour depth. The scour summary table (Table 10) and scour data table (Table 11) is the format that Caltrans requires on the foundation plans.

**Table 10. Scour Summary Table**

| Long Term & Short Term Scour Depths<br>Robinson Creek Bridge on Lambert Lane (Bridge No. 10C0146) | | | |
|---|---|---|---|
| Support No. | Degradation Scour Depth (ft) | Contraction Scour Depth (ft) | Short Term (Local) Scour Depth (ft) |
| Abutment 1 | 8.0 | 5.4 | 4.6 |
| Abutment 2 | 8.0 | 5.4 | 3.4 |

**Table 11. Scour Data Table**

| Support No. | Long-Term (Degradation and Contraction) Scour Elevation (ft NAVD 88) | Short-Term (Local) Scour Depth (ft) |
|---|---|---|
| Abutment 1 | 372.0 | 4.6 |
| Abutment 2 | 373.2 | 3.4 |

Note:
Scour depths and elevations are rounded to the nearest 0.1 ft.

When scour countermeasures, such as RSP, are incorporated into the design of the bridge abutments, the potential for thalweg migration is reduced, in which case, the foundations of the bridge abutments would not be required to reference the channel thalweg elevation. The scour elevations at the abutments were based upon the proposed finished ground elevations at the abutments. The proposed bridge abutments would be designed to be self-supporting in the scour condition. The RSP class required to minimize the risk of erosion of the roadway fill and proposed embankment slope are discussed in detail in Section 6.

# 6 SCOUR AND EROSION COUNTERMEASURES

Scour countermeasures are considered for arresting scour and protecting the bank slopes at the proposed bridge abutments. HEC-23 Table 2.1 describes a multitude of scour countermeasures, which are grouped into categories. Most of the categories are for measures appropriate for large-scale scour problems. "Local Scour Armoring" (in the form of RSP) was considered as a scour countermeasure for the proposed bridge abutments to reduce the potential for thalweg migration.

RSP is a typical scour countermeasure installed at the channel bank slopes, and it 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 was calculated following FHWA's HEC-23 and Caltrans' HDM (2020). The detailed RSP calculations are included in Appendix H.

### 6.1.1 RSP Median Particle Size Determination

The following sections present the calculations to evaluate the size of RSP that would be required along the channel bank slopes at the Project location to protect the channel banks from potential erosion. The primary design concern for RSP is to determine the median particle size such that the material will not be displaced during the peak design flows. Two design guidelines/methodologies were used to determine the minimum size of material required: FHWA's HEC-23 and Caltrans' HDM (2020).

#### 6.1.1.1 FHWA HEC-23

The median stone diameter ($D_{50}$) of the RSP for the bridge abutments was calculated using the equations from HEC-23, Design Guideline 14. The following equations were used to determine the median stone diameter required for the proposed RSP erosion-control system to protect the channel slope under the bridge:

For Froude Numbers ≤ 0.80 (HEC-23, equation 14.1):

$$\frac{D_{50}}{y} = \frac{K}{S_s - 1}\left[\frac{V^2}{gy}\right]$$

For Froude Numbers > 0.80 (HEC-23, equation 14.2):

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

Where:

$D_{50}$ = median stone diameter (ft)
$V$ = characteristic average velocity in the contracted section (ft/s)
$S_s$ = specific gravity of rock riprap

$g$ = gravitational acceleration (32.2 ft/s$^2$)
$y$ = depth of flow in the contracted bridge opening (ft)
$K$ = 0.89 for a spill-through abutment and 1.02 for a vertical wall abutment

The median stone diameter is a function of velocity and depth. The average channel flow velocities and flow depths from the hydraulic analysis were selected to calculate the median stone diameter of the RSP to protect the bridge abutments. The median stone diameter for the RSP was calculated immediately upstream, at the upstream face, at the downstream face, and immediately downstream of the proposed bridge. The results from the RSP calculations and the scour countermeasure recommendations for the Project are presented in Section 6.1.2.

#### 6.1.1.2 Caltrans Highway Design Manual

The following equations included in Caltrans' HDM (2020) Chapter 870, *Bank Protection – Erosion Control* were used to estimate the weight of the RSP required to protect the proposed bridge abutments:

$$D_{30} = y\left(S_f C_S C_V C_T\right)\left[\frac{V_{des}}{\sqrt{K_1\left(S_g - 1\right)gy}}\right]^{2.5}$$

$$D_{50} = 1.2 D_{30}$$

$$K_1 = \sqrt{1 - \left[\frac{\sin\left(\theta - 14^0\right)}{32^0}\right]^{1.6}}$$

Where:

$D_{30}$ = particle size for which 30% is finer by weight (ft)
$D_{50}$ = median particle size (ft)
$y$ = local flow depth (ft)
$S_f$ = safety factor (typically 1.1)
$C_s$ = stability coefficient (0.3 for angular rock)
$C_v$ = velocity distribution coefficient (1.0 for straight channel)
$C_T$ = blanket thickness coefficient (1.0)
$g$ = acceleration due to gravity (32.2 ft/sec$^2$)
$V_{des}$ = characteristic velocity for design (ft/sec)
$K_1$ = side slope correction factor
$\theta$ = bank angle in degrees

The RSP diameter was calculated immediately upstream, at the upstream face, at the downstream face, and immediately downstream of the proposed bridge. The results from the RSP calculations and the scour countermeasure recommendations for the Project are presented in Section 6.1.2.

### 6.1.2 RSP Results and Recommendations

The RSP classes calculated at each location using the equations provided in FHWA's HEC-23 and Caltrans' HDM (2020) are shown in Table 12. WRECO recommends placing Class V RSP at the embankment slopes and upstream side of the bridge abutments. Class V RSP has an approximate median diameter of 18 inches and a median weight of ¼ ton. For the downstream side of the abutments, Class VI RSP is recommended. Class VI RSP has an approximate median diameter of 21 inches and a median weight of 3/8 ton.

**Table 12. Summary of Computed RSP Classes**

| Calculation Method | Upstream | Upstream Face | Downstream Face | Downstream |
|---|---|---|---|---|
| **FHWA HEC-23** | Class V | Class V | Class V | Class VI |
| **Caltrans HDM** | Class IV | Class IV | Class V | Class V |

According to Caltrans' HDM (2020), the minimum thickness of the RSP layer needs to be 1.5 times the median particle diameter or the maximum diameter, whichever is greater. Minimum RSP layer thickness is 3.0 ft for Class V RSP is 3.0 ft and 4.0 feet for Class VI RSP. Class 8 RSP geotextile filter fabric should be placed on the bank as a separator material between the RSP and the channel bank. Method B placement method is appropriate for both Class V and Class VI RSP. It involves dumping the rock near its planned location, and working the rock to its final position with machinery.

The footprint of application of RSP is based on guidance from HEC-23. The RSP should extend from the face of the abutment to the toe of slope, and wrap around the bridge abutments to an elevation that is 2 ft above the design WSE. The extent, upstream and downstream of the bridge, is twice the flow depth or 25 ft, whichever is less. The RSP should be keyed in vertically to the depth of the maximum calculated scour or to a minimum depth of 5 ft below the toe of slope. The guidance provided in HEC-23 also restricts the application of RSP to bank slopes 1.5:1 (horizontal to vertical), or flatter.

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# 7 REFERENCES

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# Appendix A USGS StreamStats

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# StreamStats Version 3 Beta

## Basin Characteristics Ungaged Site Report

**Date: Tues Aug 25, 2015 3:31:10 PM GMT-7**
**NAD 1983 Latitude: 39.0086 ( 39 00 31)**
**NAD 1983 Longitude: -123.3684 (-123 22 07)**

| Label | Value | Units | Definition |
|---|---|---|---|
| DRNAREA | 4 | square miles | Area that drains to a point on a stream |
| RELIEF | 1597 | feet | Maximum - minimum elevation |
| ELEVMAX | 1967 | feet | Maximum basin elevation |
| MINBELEV | 371 | feet | Minimum basin elevation |
| LAKEAREA | 0 | percent | Percentage of Lakes and Ponds |
| EL6000 | 0 | percent | Percent of area above 6000 ft |
| OUTLETELEV | 374 | feet | Elevation of the stream outlet in thousands of feet above NAVD88. |
| BASINPERIM | 14.4 | miles | Perimeter of the drainage basin as defined in SIR 2004-5262 |
| RELRELF | 111 | feet per mi | Basin relief divided by basin perimeter |
| ELEV | 881 | feet | Mean Basin Elevation |
| BSLDEM30M | 23.2 | percent | Mean basin slope computed from 30 m DEM |
| FOREST | 18.5 | percent | Percentage of area covered by forest |
| LC11IMP | 1.1 | percent | Percentage of impervious area determined from NLCD 2011 impervious dataset |
| PRECIP | 44.2 | inches | Mean Annual Precipitation |
| JANMAXTMP | 56.41 | degrees F | Mean Maximum January Temperature |
| JANMINTMP | 37.58 | degrees F | Mean Minimum January Temperature |
| ALTIND | 0.73 | thousand feet | Altitude Index |
| LC11DEV | 8.8 | percent | Percentage of land-use from NLCD 2011 classes 21-24 |
| LFPLENGTH | 5 | miles | Length of longest flow path |

# StreamStats Version 3 Beta

## Flow Statistics Ungaged Site Report

**Date: Tues Aug 25, 2015 3:30:08 PM GMT-7**
**Site Location: California**
**NAD 1983 Latitude: 39.0086 ( 39 00 31)**
**NAD 1983 Longitude: -123.3684 (-123 22 07)**
**Drainage Area: 4 mi2**

| Peak-Flow Basin Characteristics | | | |
|---|---|---|---|
| **100% 2012 5113 Region 1 North Coast (4 mi2)** | | | |
| **Parameter** | **Value** | **Regression Equation Valid Range** | |
| | | **Min** | **Max** |
| Drainage Area (square miles) | 4 | 0.04 | 3200 |
| Mean Annual Precipitation (inches) | 44.2 | 20 | 125 |

| Peak-Flow Statistics | | | | | | |
|---|---|---|---|---|---|---|
| **Statistic** | **Value** | **Unit** | **Prediction Error (percent)** | **Equivalent years of record** | **90-Percent Prediction Interval** | |
| | | | | | **Min** | **Max** |
| PK2 | 264 | ft3/s | 59 | | 108 | 645 |
| PK5 | 517 | ft3/s | 47 | | 247 | 1080 |
| PK10 | 700 | ft3/s | 44 | | 347 | 1410 |
| PK25 | 943 | ft3/s | 43 | | 482 | 1850 |
| PK50 | 1130 | ft3/s | 43 | | 576 | 2220 |
| PK100 | 1320 | ft3/s | 44 | | 659 | 2660 |
| PK200 | 1510 | ft3/s | 44 | | 748 | 3040 |
| PK500 | 1760 | ft3/s | 46 | | 851 | 3630 |


#http://pubs.usgs.gov/sir/2012/5113/#

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.

# Appendix B Mendocino County Zoning Map

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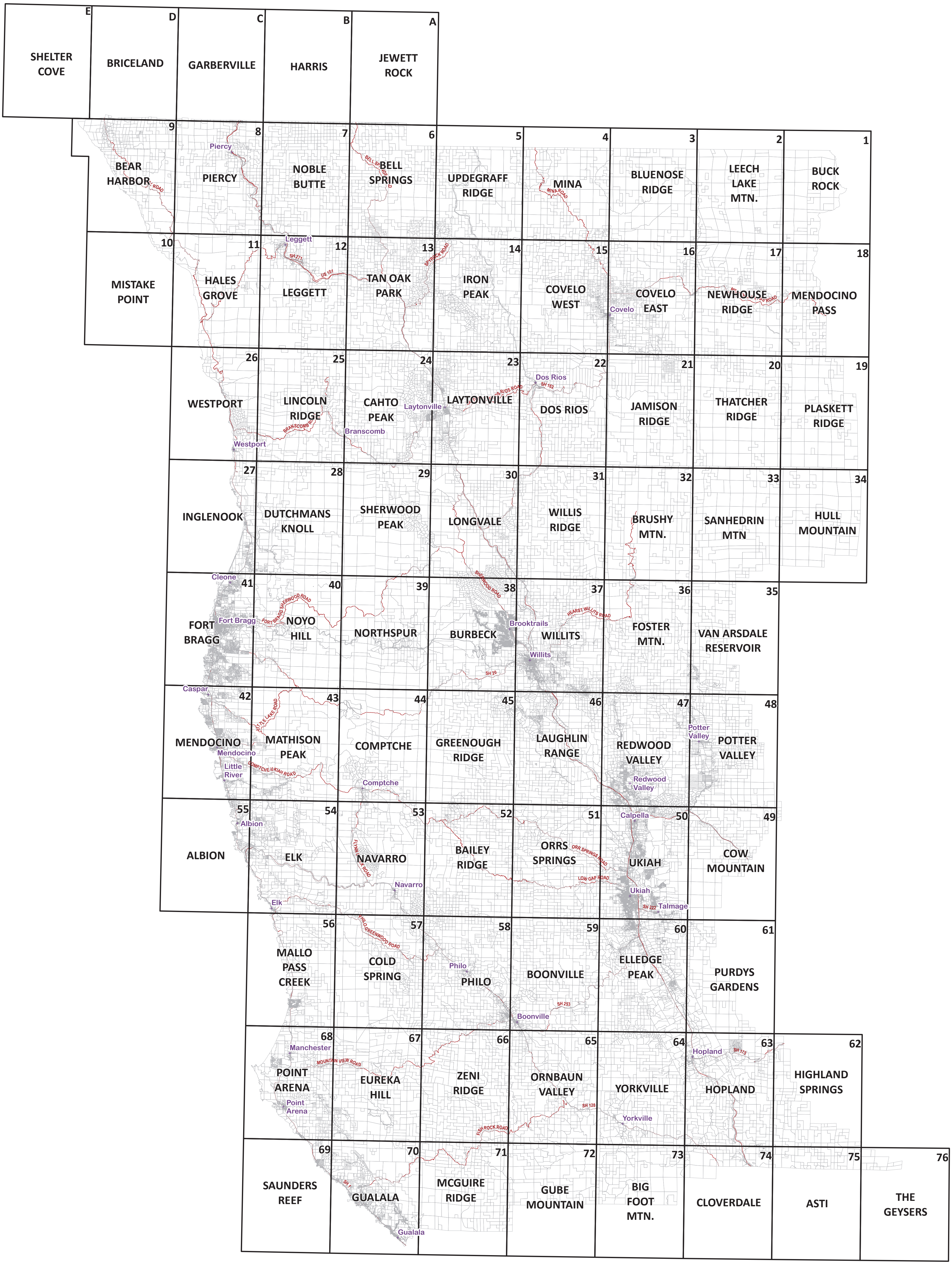
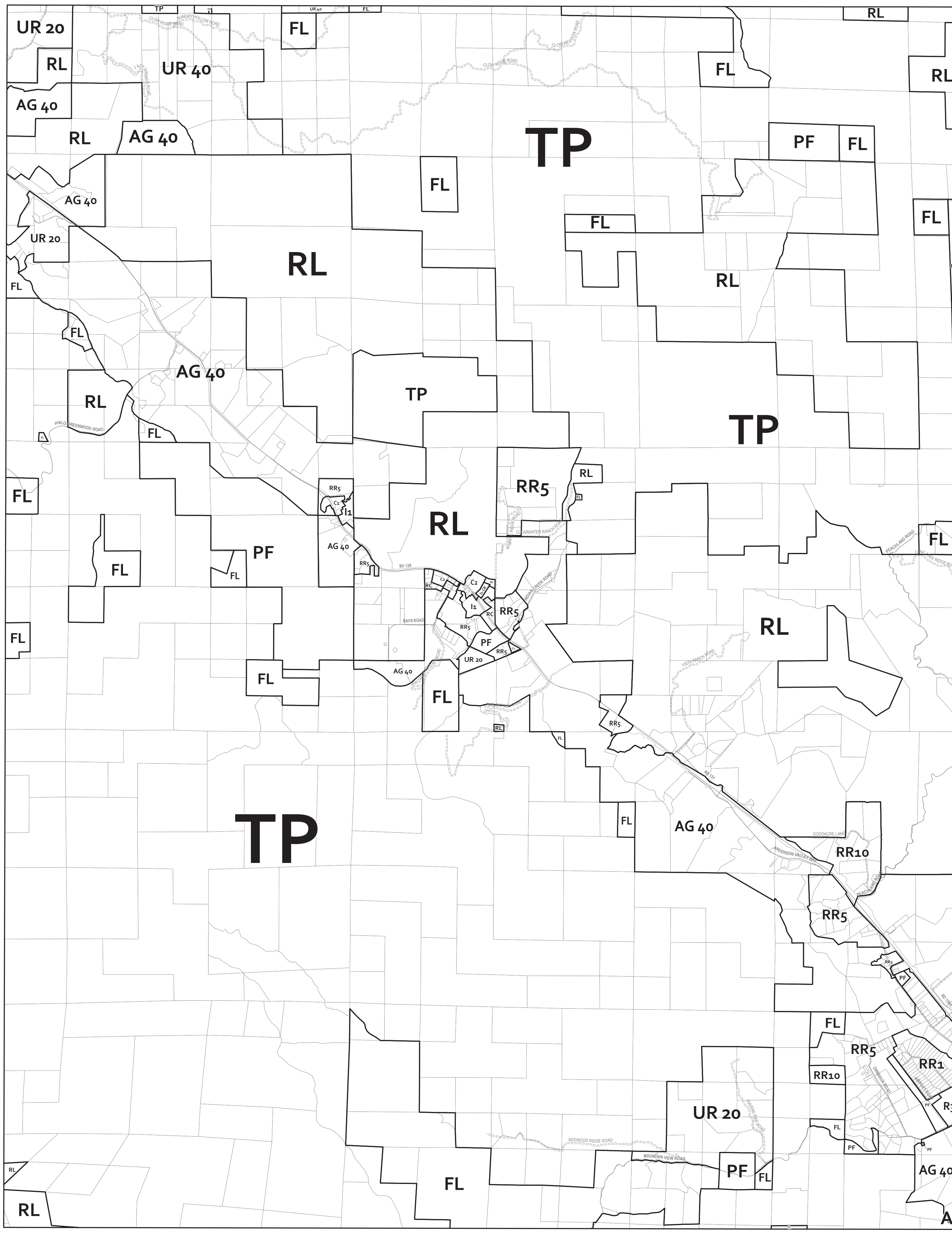



# USGS QUAD MAP INDEX for MENDOCINO COUNTY

Map produced by the Mendocino County Department of Planning & Building Services, May, 2013
This map is provided as a visual display of county information, and as such may be subject to change, correction or revision without notice.
Assessors parcel data current November, 2011. All spatial data is approximate.
Reasonable effort has been made to ensure the accuracy of the map and data provided, however errors and omissions may still exist.
Do not make a business decision based on this map without first consulting the appropriate agency.

# ZONING DISPLAY MAP




0 0.5 1 2 Miles

0 1,000 2,000 4,000 6,000 8,000 Feet

1 in = 2,000 ft

## ABBREVIATION KEY

ZONING DISPLAY MAP

PRODUCED 2018
MENDOCINO COUNTY
PLANNING & BLDG. SVCS.
**THIS IS NOT AN ADOPTED MAP**
FOR DISPLAY PURPOSES ONLY
Print Date: 5/8/2018

| | |
|---|---|
| **AG** | Agricultural Lands |
| **AG-CR** | Agricultural (Contract Rezone) |
| **AV** | Airport District |
| **C** | Coastal Commercial |
| **C-PD** | Coastal Commercial (Planned Development) |
| **C1** | Inland Limited Commercial |
| **C1-CR** | Inland Limited Commercial (Contract Rezone) |
| **C2** | Inland General Commercial |
| **C2-CR** | Inland General Commercial (Contract Rezone) |
| **C2-IS** | Inland General Commercial (Isolated Service) |
| **FL** | Forestland |
| **FV** | Fishing Village |
| **I** | Coastal Industrial |
| **I1** | Inland Limited Industrial |
| **I1-CR** | Inland Limited Industrial (Contract Rezone) |
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| **PI** | Pinoleville Industrial |
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| **PF-PD** | Public Facility (Planned Development) |
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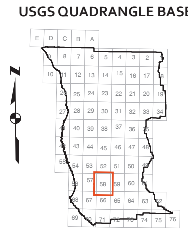
| **RC-CR** | Rural Community (Contract Rezone) |
| **RL** | Rangeland |
| **RL-PD** | Rangeland (Planned Development) |
| **SR** | Suburban Residential |
| **TP** | Timberland Production |
| **UR** | Upland Residential |
| **UR-CR** | Upland Residential (Contract Rezone) |
| **UR-PD** | Upland Residential (Planned Development) |
| **R1** | Single Family Residential |
| **R2** | Two Family Residential |
| **R3** | Multi Family Residential |
| **RMR** | Remote Residential |
| **RMR-DL** | Remote Residential (Development Limitation) |
| **RMR-PD** | Remote Residential (Planned Development) |
| **RR** | Rural Residential |
| **RR-CR** | Rural Residential (Contract Rezone) |
| **RR-DL** | Rural Residential (Development Limitation) |
| **RR-PD** | Rural Residential (Planned Development) |
| **RR-PD-DL** | Rural Residential (Planned Development Limitation) |
| **RV** | Rural Village |
| **MC** | Mendocino Commercial |
| **MFL** | Mendocino Forestland |
| **MMU** | Mendocino Mixed-Use |
| **MOS** | Mendocino Open Space |
| **MPF** | Mendocino Public Facility |
| **MRM** | Mendocino Multi-Family Residential |
| **MRR** | Mendocino Rural Residential |
| **MSR** | Mendocino Suburban Residential |
| **MTR** | Mendocino Town Residential |
| **GPD** | Gualala Planned Development |
| **GVMU** | Gualala Village Mixed Use |
| **GHMU** | Gualala Highway Mixed Use |
| **GI** | Gualala Industrial |
| **RR_ [RR_]** | Variable Density Zone (see note below) |

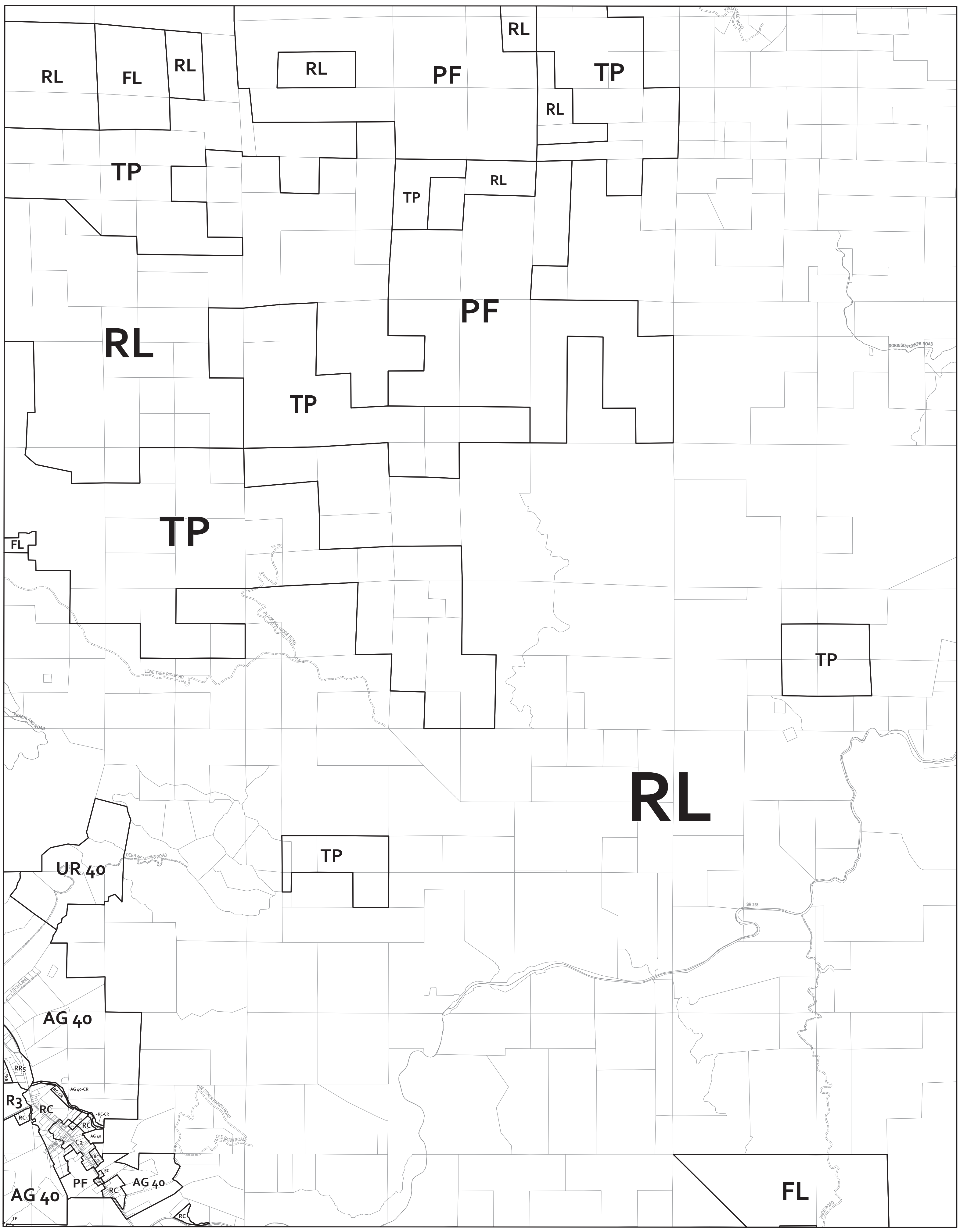
Zoning designations shown in [brackets] (coastal zone only) indicate 'variable density zones'. Per county code Sec. 3.8-10 In order to be developed to the smaller parcel size, areas indicated on the map as having a variable density zoning classification shall be required to be served by a public water system which utilizes surface waters, and which does not impact upon the ground water resource, or by completion of a hydrological study which supports those greater densities.

### PHILO

USGS QUADRANGLE BASE



# ZONING DISPLAY MAP




0 0.5 1 2 Miles

0 1,000 2,000 4,000 6,000 8,000 Feet

1 in = 2,000 ft

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| **OS-CR** | Open Space (Contract Rezone) |
| **PI** | Pinoleville Industrial |
| **PF** | Public Facility |
| **PF-PD** | Public Facility (Planned Development) |
| **RC** | Rural Community |
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| **RL-PD** | Rangeland (Planned Development) |
| **SR** | Suburban Residential |
| **TP** | Timberland Production |
| **UR** | Upland Residential |
| **UR-CR** | Upland Residential (Contract Rezone) |
| **UR-PD** | Upland Residential (Planned Development) |
| **R1** | Single Family Residential |
| **R2** | Two Family Residential |
| **R3** | Multi Family Residential |
| **RMR** | Remote Residential |
| **RMR-DL** | Remote Residential (Development Limitation) |
| **RMR-PD** | Remote Residential (Planned Development) |
| **RR** | Rural Residential |
| **RR-CR** | Rural Residential (Contract Rezone) |
| **RR-DL** | Rural Residential (Development Limitation) |
| **RR-PD** | Rural Residential (Planned Development) |
| **RR-PD-DL** | Rural Residential (Planned Development Limitation) |
| **RV** | Rural Village |
| **MC** | Mendocino Commercial |
| **MFL** | Mendocino Forestland |
| **MMU** | Mendocino Mixed-Use |
| **MOS** | Mendocino Open Space |
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ZONING DISPLAY MAP

PRODUCED 2013
MENDOCINO COUNTY
PLANNING & BLDG. SVCS.

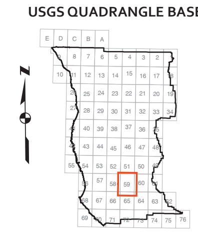
**THIS IS NOT AN ADOPTED MAP**

FOR DISPLAY PURPOSES ONLY

Print Date: 6/6/2013

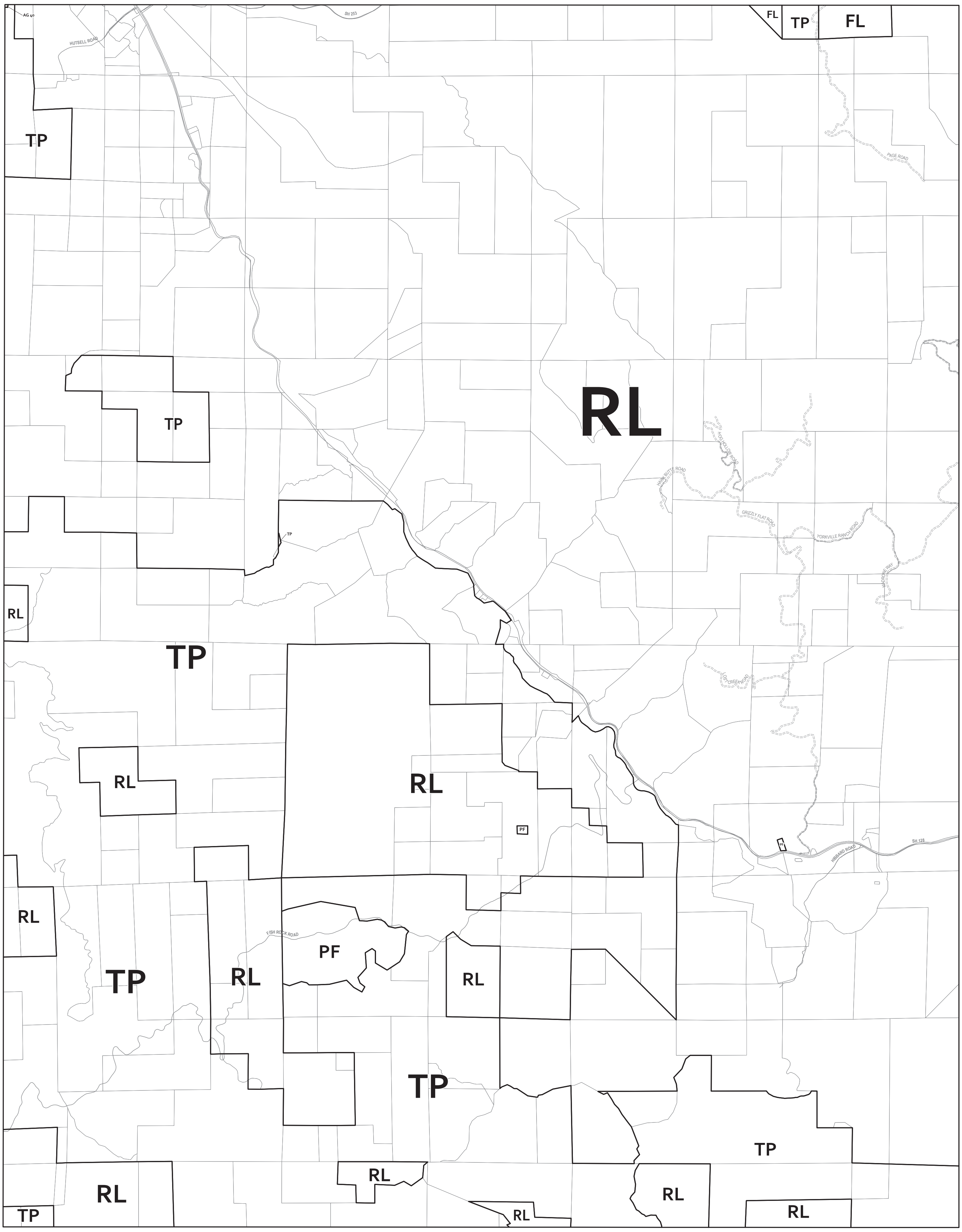
**BOONVILLE**

**USGS QUADRANGLE BASE**



SHEET 65

# ZONING DISPLAY MAP




0 0.5 1 2 Miles

Feet 0 1,000 2,000 4,000 6,000 8,000

1 in = 2,000 ft

## ABBREVIATION KEY

| | | | | | | | |
|---|---|---|---|---|---|---|---|
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| **C1-CR** | Inland Limited Commercial (Contract Rezone) | **PF-PD** | Public Facility (Planned Development) | **RMR-DL** | Remote Residential (Development Limitation) | **MRR** | Mendocino Rural Residential |
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PRODUCED 2013
MENDOCINO COUNTY
PLANNING & BLDG. SVCS.

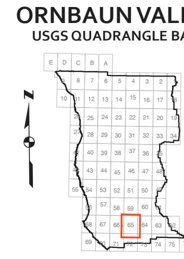
**THIS IS NOT AN ADOPTED MAP**

FOR DISPLAY PURPOSES ONLY

Print Date: 6/6/2013

**ORNBAUN VALLEY**

**USGS QUADRANGLE BASE**



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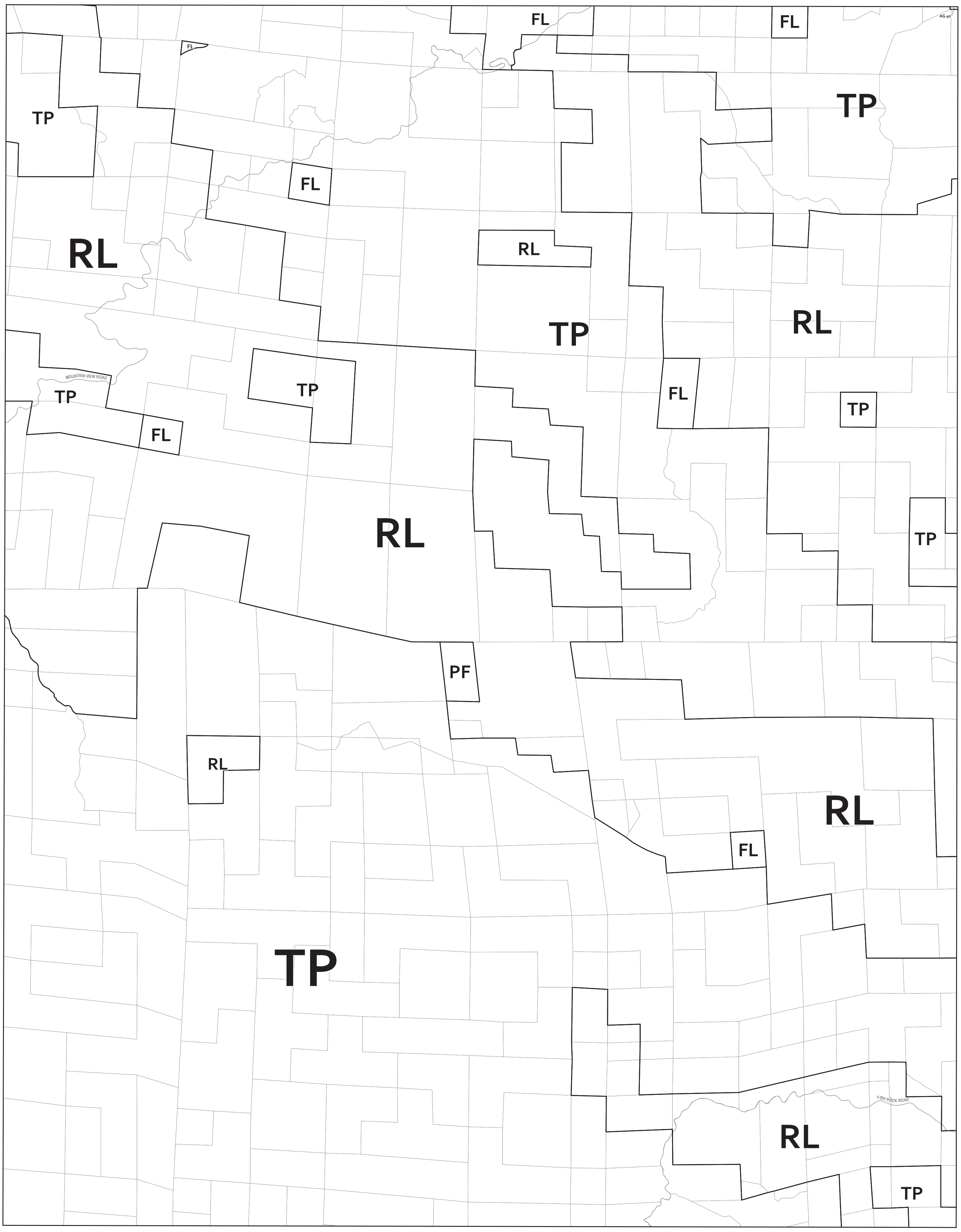


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| C1 | Inland Limited Commercial | PF | Public Facility | RMR | Remote Residential | MRM | Mendocino Multi-Family Residential |
| C1-CR | Inland Limited Commercial (Contract Rezone) | PF-PD | Public Facility (Planned Development) | RMR-DL | Remote Residential (Development Limitation) | MRR | Mendocino Rural Residential |
| C2 | Inland General Commercial | RC | Rural Community | RMR-PD | Remote Residential (Planned Development) | MSR | Mendocino Suburban Residential |
| C2-CR | Inland General Commercial (Contract Rezone) | RC-CR | Rural Community (Contract Rezone) | RR | Rural Residential | MTR | Mendocino Town Residential |
| C2-IS | Inland General Commercial (Isolated Service) | RL | Rangeland | RR-CR | Rural Residential (Contract Rezone) | GPD | Gualala Planned Development |
| FL | Forestland | RL-PD | Rangeland (Planned Development) | RR-DL | Rural Residential (Development Limitation) | GVMU | Gualala Village Mixed Use |
| FV | Fishing Village | SR | Suburban Residential | RR-PD | Rural Residential (Planned Development) | GHMU | Gualala Highway Mixed Use |
| I | Coastal Industrial | TP | Timberland Production | RR-PD-DL | Rural Residential (Planned Development Limitation) | GI | Gualala Industrial |
| I1 | Inland Limited Industrial | UR | Upland Residential | RV | Rural Village | RR_ [RR_] | Variable Density Zone (see note below) |

Zoning designations shown in [brackets] (coastal zone only) indicate 'variable density zones'. Per county code Sec. 3.8-10 In order to be developed to the smaller parcel size, areas indicated on the map as having a variable density zoning classification shall be required to be served by a public water system which utilizes surface waters, and which does not impact upon the ground water resource, or by completion of a hydrological study which supports those greater densities.

ZONING DISPLAY MAP

PRODUCED 2013
MENDOCINO COUNTY
PLANNING & BLDG. SVCS.

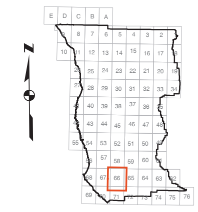
**THIS IS NOT AN ADOPTED MAP**

FOR DISPLAY PURPOSES ONLY

Print Date: 6/10/2013

## ZENI RIDGE

### USGS QUADRANGLE BASE



# Appendix C USDA Web Soil Survey

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United States Department of Agriculture

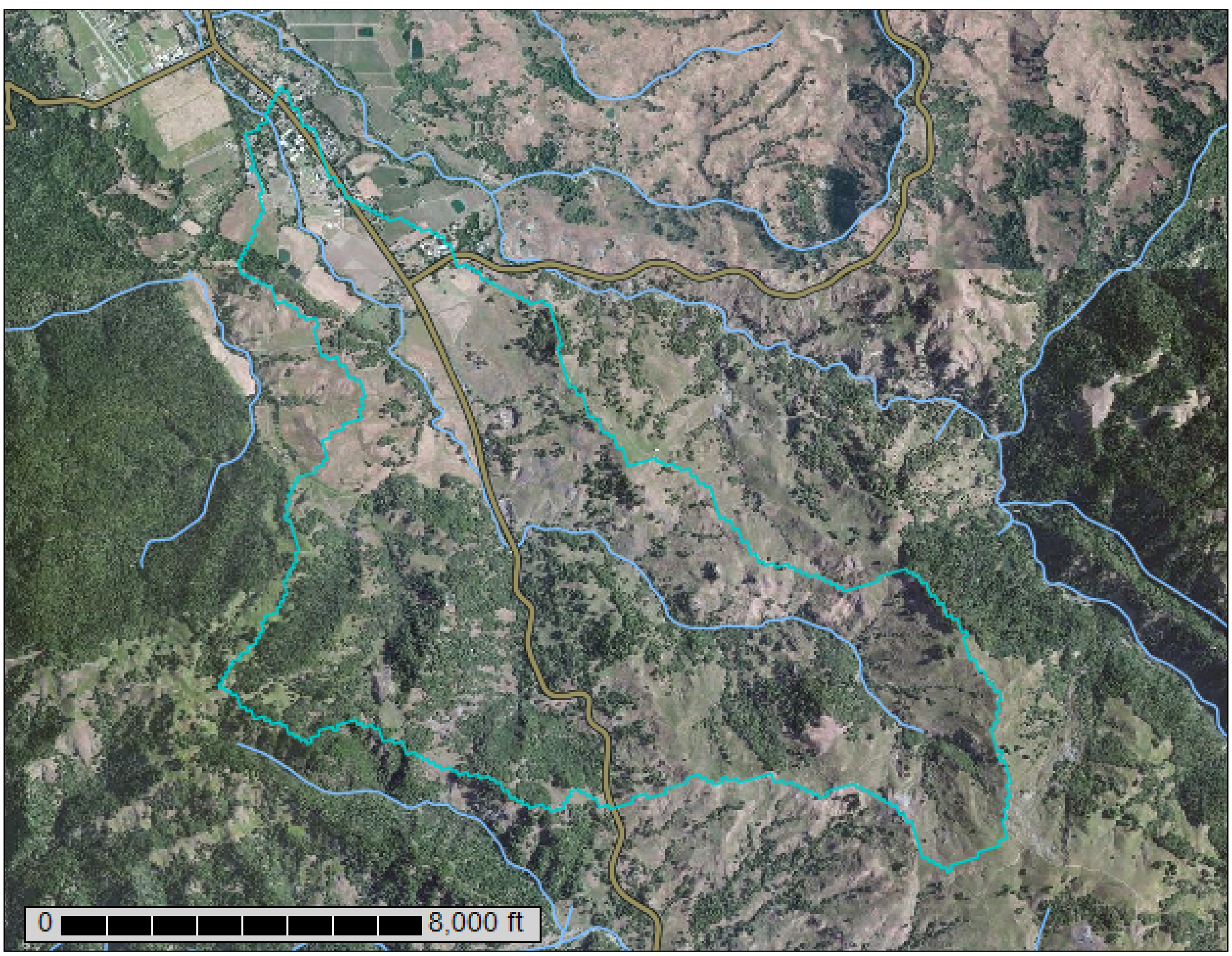
NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

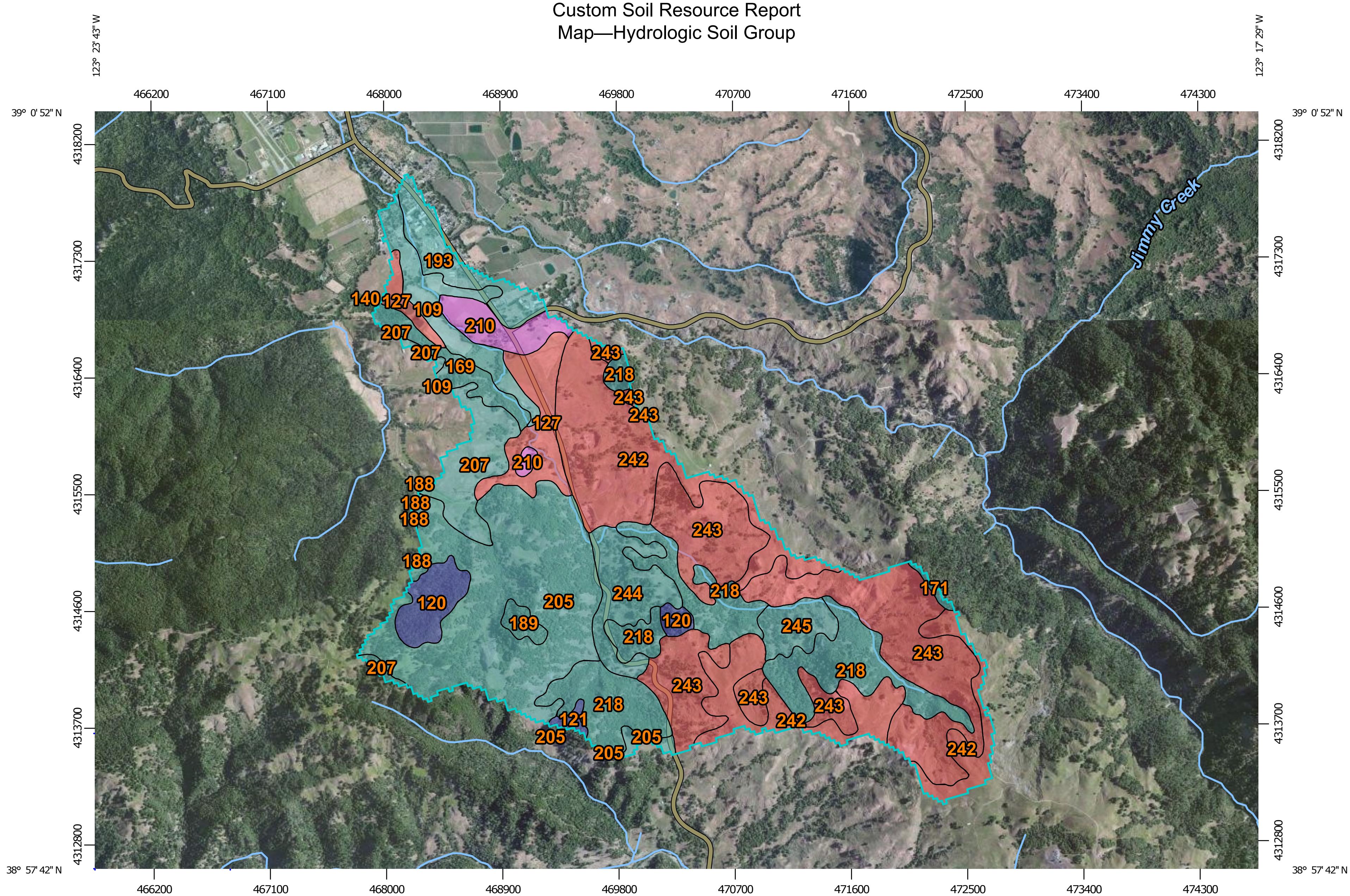
# Custom Soil Resource Report for

# Mendocino County, Western Part, California




September 23, 2016

# Map—Hydrologic Soil Group




Map Scale: 1:41,200 if printed on A landscape (11" x 8.5") sheet.

N

Meters: 0, 500, 1000, 2000, 3000

Feet: 0, 2000, 4000, 8000, 12000

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

## MAP LEGEND

**Area of Interest (AOI)**
- Area of Interest (AOI)

**Soils**

**Soil Rating Polygons**
- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

**Soil Rating Lines**
- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

**Soil Rating Points**
- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

**Water Features**
- Streams and Canals

**Transportation**
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

**Background**
- Aerial Photography

## MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Mendocino County, Western Part, California
Survey Area Data: Version 10, Sep 30, 2014

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jun 16, 2010—Aug 14, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

## Table—Hydrologic Soil Group

| Hydrologic Soil Group— Summary by Map Unit — Mendocino County, Western Part, California (CA694) | | | | |
|---|---|---|---|---|
| **Map unit symbol** | **Map unit name** | **Rating** | **Acres in AOI** | **Percent of AOI** |
| 109 | Boontling loam, 2 to 9 percent slopes | C | 92.0 | 3.6% |
| 120 | Casabonne-Wohly complex, 30 to 50 percent slopes | B | 70.5 | 2.8% |
| 121 | Casabonne-Wohly-Pardaloe complex, 50 to 75 percent slopes | B | 8.4 | 0.3% |
| 127 | Cole loam, 0 to 5 percent slopes | D | 113.0 | 4.4% |
| 140 | Feliz loam, 0 to 5 percent slopes | B | 0.0 | 0.0% |
| 169 | Hopland-Witherell-Squawrock complex, 30 to 50 percent slopes | C | 53.3 | 2.1% |
| 171 | Hopland-Wohly complex, 50 to 75 percent slopes | C | 5.2 | 0.2% |
| 188 | Ornbaun-Zeni complex, 30 to 50 percent slopes | B | 1.1 | 0.0% |
| 189 | Ornbaun-Zeni complex, 50 to 75 percent slopes | C | 16.8 | 0.7% |
| 193 | Pinole loam, 2 to 9 percent slopes | C | 81.2 | 3.2% |
| 205 | Squawrock-Garcia-Witherell complex, 15 to 50 percent slopes | C | 484.7 | 19.1% |
| 207 | Squawrock-Witherell complex, 15 to 50 percent slopes | C | 108.9 | 4.3% |
| 210 | Talmage gravelly loam, 0 to 2 percent slopes | A | 63.2 | 2.5% |
| 218 | Updegraff-Hopland-Woodin complex, 30 to 50 percent slopes | C | 344.1 | 13.5% |
| 242 | Yorkville-Squawrock-Witherell complex, 15 to 30 percent slopes | D | 423.1 | 16.6% |
| 243 | Yorkville-Squawrock-Witherell complex, 30 to 50 percent slopes | D | 524.0 | 20.6% |
| 244 | Yorkville-Yorktree-Squawrock complex, 15 to 30 percent slopes | C | 103.0 | 4.1% |
| 245 | Yorkville-Yorktree-Squawrock complex, 30 to 50 percent slopes | C | 50.0 | 2.0% |
| **Totals for Area of Interest** | | | **2,542.4** | **100.0%** |

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# Appendix D NOAA Atlas 14

**NOAA Atlas 14, Volume 6, Version 2**
**Location name: Boonville, California, USA***
**Latitude: 38.9842°, Longitude: -123.3503°**
**Elevation: 511.12 ft****
* source: ESRI Maps
** source: USGS

**POINT PRECIPITATION FREQUENCY ESTIMATES**

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

## PF tabular

**PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]**

| Duration | Average recurrence interval (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min | 0.140 (0.125-0.159) | 0.172 (0.152-0.195) | 0.213 (0.188-0.243) | 0.247 (0.217-0.286) | 0.295 (0.248-0.355) | 0.332 (0.272-0.410) | 0.371 (0.295-0.471) | 0.412 (0.316-0.541) | 0.469 (0.342-0.648) | 0.513 (0.360-0.739) |
| 10-min | 0.201 (0.178-0.228) | 0.246 (0.218-0.280) | 0.305 (0.270-0.349) | 0.355 (0.310-0.409) | 0.423 (0.355-0.508) | 0.476 (0.390-0.588) | 0.532 (0.422-0.676) | 0.590 (0.453-0.776) | 0.672 (0.491-0.929) | 0.735 (0.515-1.06) |
| 15-min | 0.243 (0.216-0.276) | 0.297 (0.264-0.339) | 0.369 (0.327-0.422) | 0.429 (0.375-0.495) | 0.511 (0.429-0.615) | 0.576 (0.471-0.710) | 0.643 (0.511-0.817) | 0.714 (0.548-0.938) | 0.812 (0.593-1.12) | 0.889 (0.623-1.28) |
| 30-min | 0.342 (0.304-0.389) | 0.419 (0.371-0.477) | 0.520 (0.460-0.594) | 0.604 (0.529-0.697) | 0.720 (0.604-0.866) | 0.811 (0.664-1.00) | 0.905 (0.719-1.15) | 1.00 (0.772-1.32) | 1.14 (0.835-1.58) | 1.25 (0.878-1.80) |
| 60-min | 0.504 (0.448-0.573) | 0.617 (0.547-0.703) | 0.767 (0.678-0.876) | 0.890 (0.779-1.03) | 1.06 (0.891-1.28) | 1.20 (0.978-1.48) | 1.33 (1.06-1.70) | 1.48 (1.14-1.95) | 1.69 (1.23-2.33) | 1.85 (1.29-2.66) |
| 2-hr | 0.774 (0.688-0.880) | 0.939 (0.833-1.07) | 1.15 (1.02-1.31) | 1.32 (1.16-1.52) | 1.55 (1.30-1.86) | 1.72 (1.41-2.12) | 1.90 (1.51-2.41) | 2.07 (1.59-2.73) | 2.31 (1.69-3.20) | 2.50 (1.75-3.60) |
| 3-hr | 1.01 (0.898-1.15) | 1.22 (1.08-1.39) | 1.49 (1.31-1.70) | 1.70 (1.49-1.96) | 1.98 (1.66-2.38) | 2.19 (1.79-2.70) | 2.40 (1.90-3.04) | 2.61 (2.00-3.43) | 2.89 (2.11-4.00) | 3.10 (2.18-4.47) |
| 6-hr | 1.58 (1.40-1.80) | 1.90 (1.69-2.17) | 2.31 (2.04-2.63) | 2.62 (2.29-3.03) | 3.04 (2.55-3.65) | 3.34 (2.74-4.13) | 3.65 (2.90-4.63) | 3.95 (3.03-5.19) | 4.34 (3.17-6.00) | 4.64 (3.25-6.68) |
| 12-hr | 2.33 (2.07-2.65) | 2.85 (2.53-3.25) | 3.51 (3.10-4.01) | 4.02 (3.52-4.64) | 4.69 (3.94-5.64) | 5.18 (4.24-6.39) | 5.66 (4.50-7.20) | 6.14 (4.72-8.08) | 6.76 (4.94-9.35) | 7.23 (5.07-10.4) |
| 24-hr | 3.35 (3.01-3.80) | 4.21 (3.78-4.78) | 5.28 (4.73-6.02) | 6.12 (5.44-7.03) | 7.22 (6.21-8.56) | 8.03 (6.77-9.72) | 8.82 (7.26-10.9) | 9.61 (7.70-12.2) | 10.6 (8.19-14.1) | 11.4 (8.49-15.6) |
| 2-day | 4.42 (3.98-5.02) | 5.57 (5.00-6.33) | 7.03 (6.29-8.01) | 8.17 (7.26-9.39) | 9.68 (8.33-11.5) | 10.8 (9.10-13.1) | 11.9 (9.80-14.8) | 13.0 (10.4-16.6) | 14.5 (11.1-19.2) | 15.5 (11.6-21.3) |
| 3-day | 5.19 (4.67-5.90) | 6.55 (5.88-7.44) | 8.26 (7.40-9.41) | 9.62 (8.54-11.0) | 11.4 (9.81-13.5) | 12.7 (10.7-15.4) | 14.1 (11.6-17.4) | 15.4 (12.3-19.6) | 17.1 (13.2-22.7) | 18.4 (13.7-25.2) |
| 4-day | 5.84 (5.25-6.63) | 7.38 (6.62-8.39) | 9.32 (8.35-10.6) | 10.8 (9.64-12.5) | 12.9 (11.1-15.2) | 14.3 (12.1-17.4) | 15.8 (13.0-19.6) | 17.3 (13.8-22.0) | 19.2 (14.8-25.4) | 20.6 (15.3-28.2) |
| 7-day | 7.28 (6.54-8.26) | 9.24 (8.29-10.5) | 11.7 (10.4-13.3) | 13.6 (12.0-15.6) | 16.0 (13.7-19.0) | 17.7 (15.0-21.5) | 19.4 (16.0-24.1) | 21.1 (16.9-26.9) | 23.3 (17.9-30.9) | 24.9 (18.5-34.1) |
| 10-day | 8.36 (7.52-9.50) | 10.7 (9.56-12.1) | 13.5 (12.0-15.3) | 15.6 (13.9-17.9) | 18.3 (15.8-21.7) | 20.3 (17.1-24.6) | 22.2 (18.3-27.5) | 24.0 (19.2-30.6) | 26.3 (20.3-34.9) | 28.0 (20.9-38.4) |
| 20-day | 11.2 (10.0-12.7) | 14.3 (12.8-16.2) | 18.0 (16.2-20.6) | 20.9 (18.5-24.0) | 24.4 (21.0-28.9) | 26.9 (22.6-32.5) | 29.2 (24.0-36.2) | 31.4 (25.2-40.0) | 34.2 (26.3-45.3) | 36.2 (26.9-49.6) |
| 30-day | 13.5 (12.2-15.4) | 17.3 (15.5-19.6) | 21.8 (19.5-24.8) | 25.1 (22.3-28.8) | 29.2 (25.1-34.7) | 32.1 (27.0-38.8) | 34.8 (28.6-43.1) | 37.3 (29.9-47.5) | 40.4 (31.1-53.6) | 42.7 (31.8-58.5) |
| 45-day | 17.0 (15.3-19.3) | 21.7 (19.5-24.6) | 27.1 (24.3-30.9) | 31.1 (27.7-35.8) | 36.1 (31.0-42.8) | 39.5 (33.3-47.8) | 42.6 (35.1-52.8) | 45.6 (36.5-58.0) | 49.2 (37.9-65.2) | 51.7 (38.5-70.9) |
| 60-day | 20.2 (18.1-22.9) | 25.5 (22.9-29.0) | 31.7 (28.4-36.1) | 36.3 (32.2-41.6) | 41.8 (35.9-49.6) | 45.6 (38.4-55.2) | 49.1 (40.4-60.8) | 52.4 (42.0-66.7) | 56.3 (43.4-74.7) | 59.1 (44.0-81.0) |

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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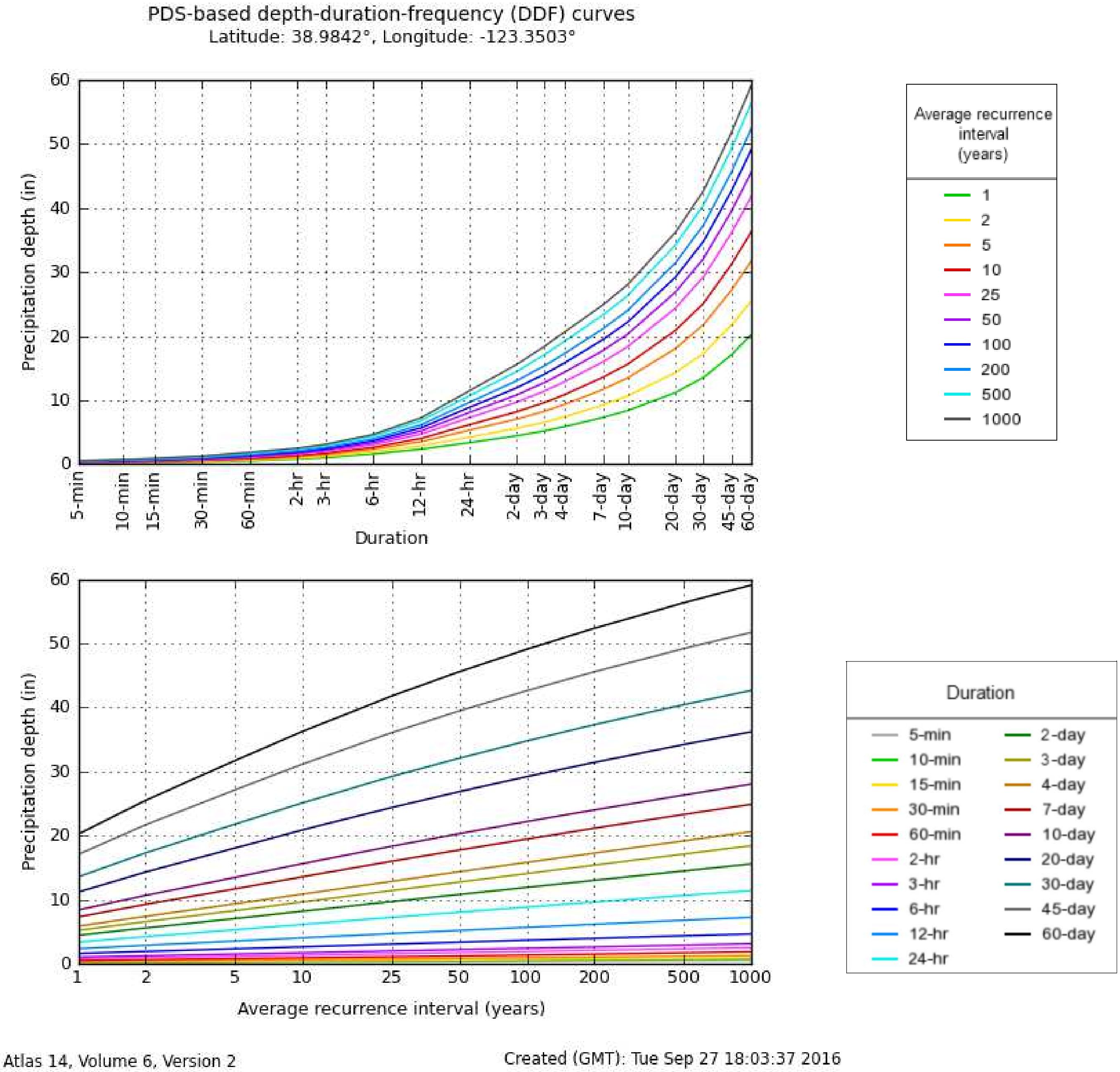
## PF graphical

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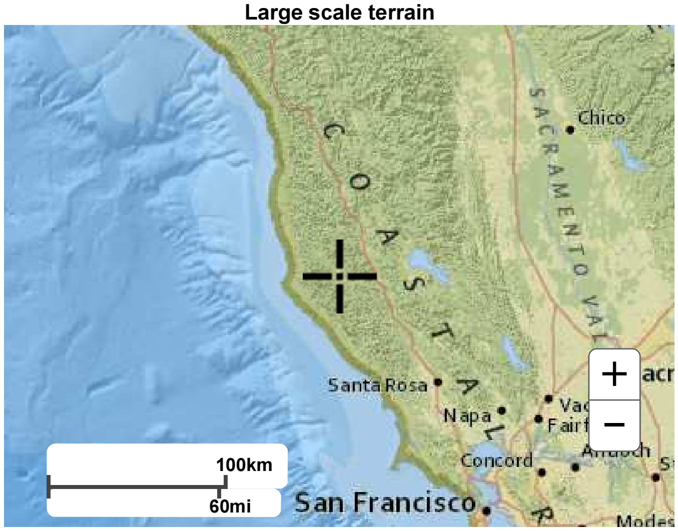
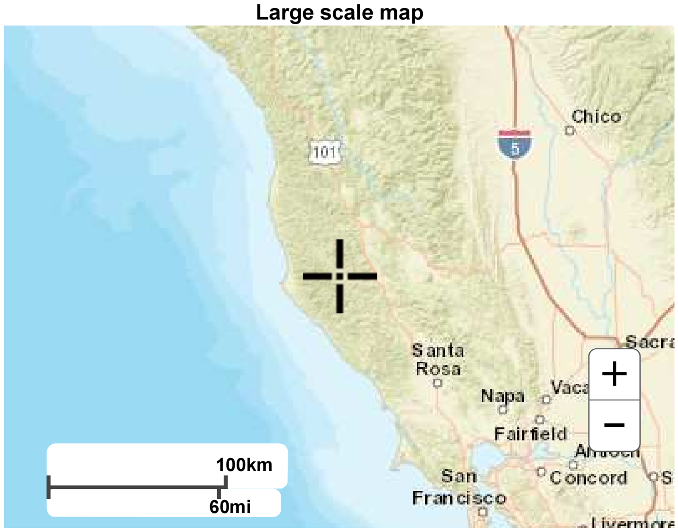
## Maps & aerials

**Small scale terrain**

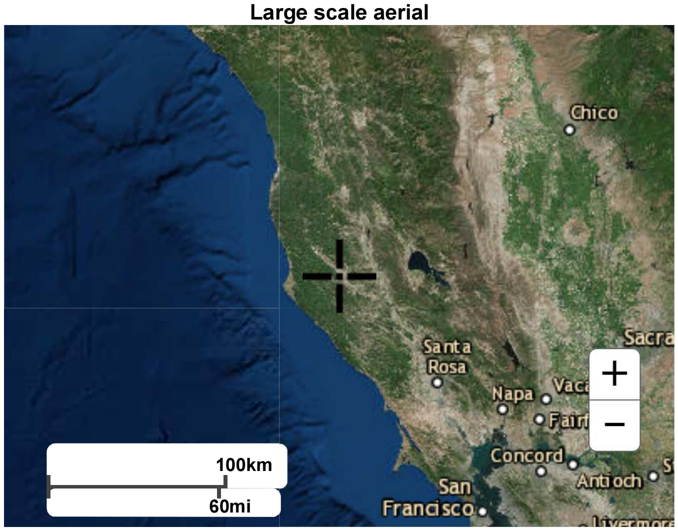

**Large scale terrain**




**Large scale map**




**Large scale aerial**

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US Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
National Water Center
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

# Appendix E Hydraulic Analysis, Existing Condition

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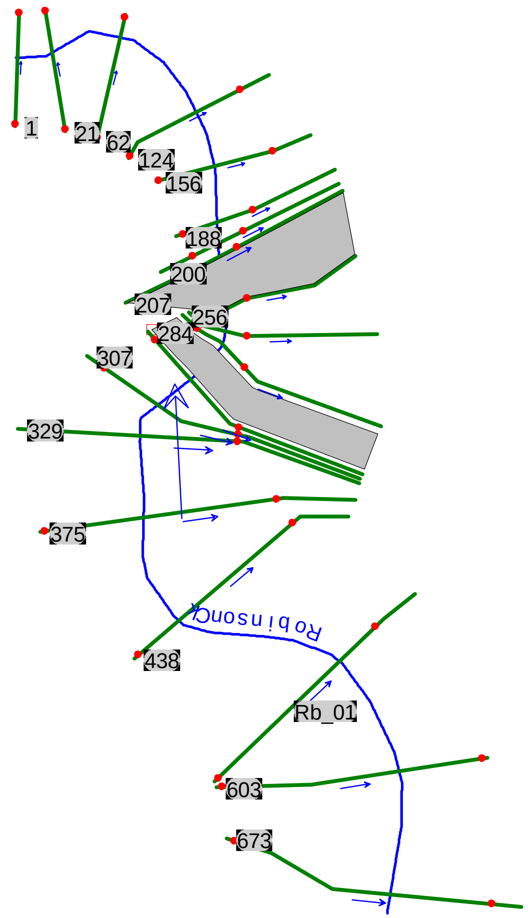
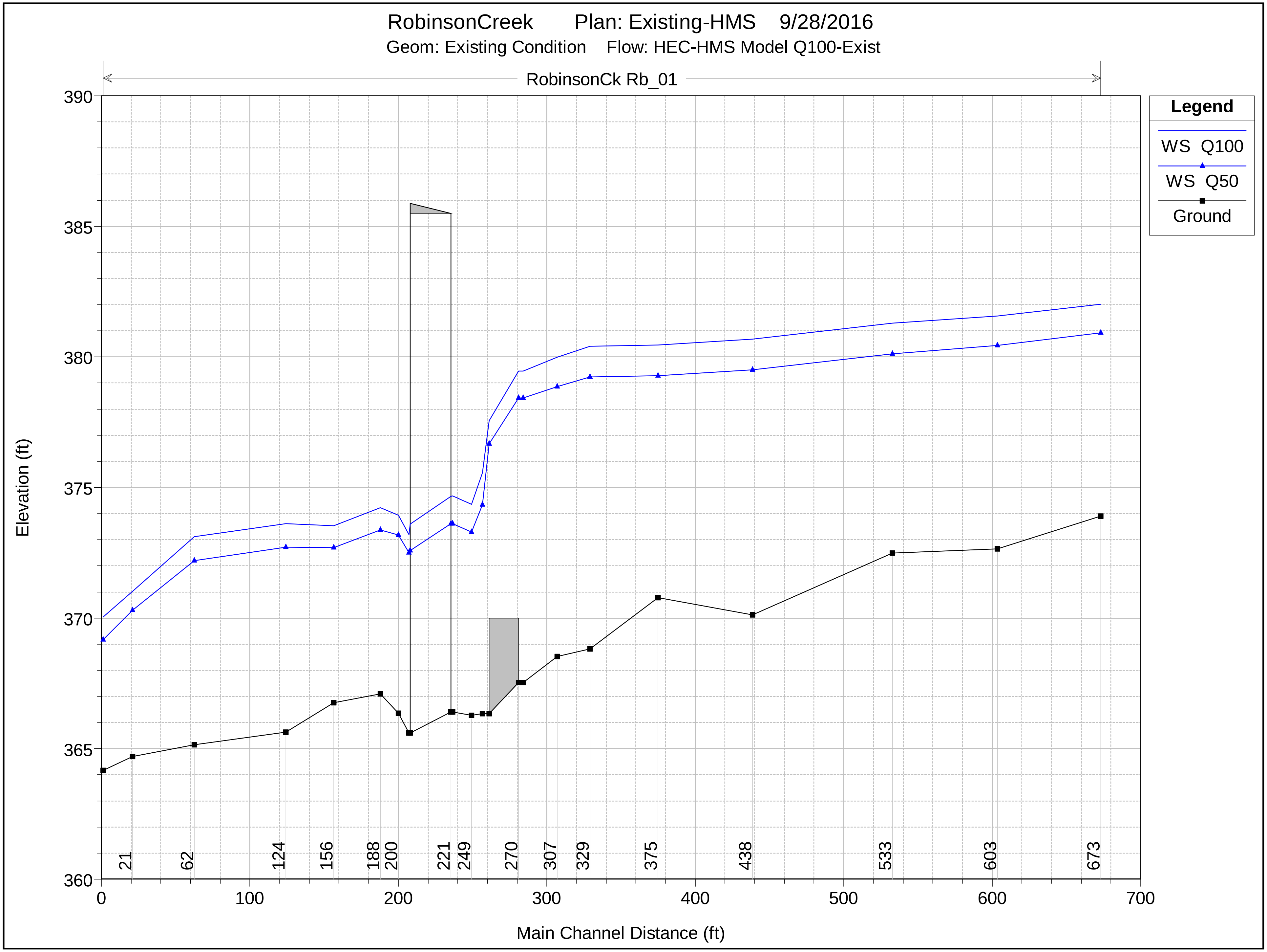


1
21
62
124
156
188
200
207
256
284
307
329
375
438
RobinsonC
Rb_01
603
673



RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
RobinsonCk Rb_01
Legend
WS Q100
WS Q50
Ground
Elevation (ft)
Main Channel Distance (ft)
390
385
380
375
370
365
360
0
100
200
300
400
500
600
700
21
62
124
156
188
200
221
249
270
307
329
375
438
533
603
673

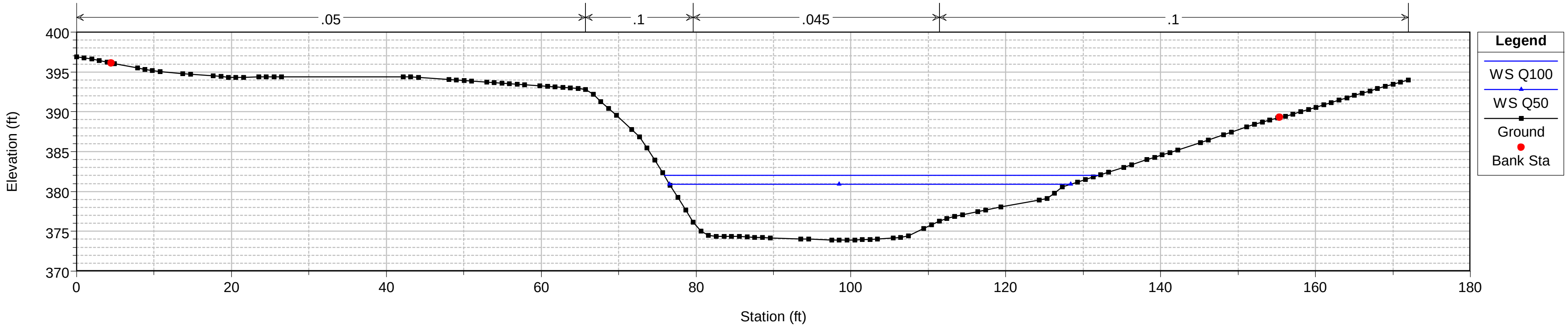
HEC-RAS Plan: Exist-HMS River: RobinsonCk Reach: Rb_01

| 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) | |
| Rb_01 | 673 | Q100 | 1750.00 | 373.90 | 382.01 | | 382.48 | 0.007933 | 5.45 | 321.01 | 56.02 | 0.40 |
| Rb_01 | 673 | Q50 | 1340.00 | 373.90 | 380.92 | | 381.33 | 0.007604 | 5.11 | 262.01 | 51.81 | 0.40 |
| | | | | | | | | | | | | |
| Rb_01 | 603 | Q100 | 1750.00 | 372.65 | 381.57 | | 381.93 | 0.006960 | 4.81 | 363.64 | 67.10 | 0.36 |
| Rb_01 | 603 | Q50 | 1340.00 | 372.65 | 380.44 | | 380.77 | 0.007640 | 4.62 | 290.06 | 63.44 | 0.38 |
| | | | | | | | | | | | | |
| Rb_01 | 533 | Q100 | 1750.00 | 372.49 | 381.29 | | 381.52 | 0.004125 | 3.83 | 456.48 | 77.31 | 0.28 |
| Rb_01 | 533 | Q50 | 1340.00 | 372.49 | 380.12 | | 380.32 | 0.004569 | 3.65 | 367.55 | 74.66 | 0.29 |
| | | | | | | | | | | | | |
| Rb_01 | 438 | Q100 | 1750.00 | 370.13 | 380.68 | | 381.03 | 0.006244 | 4.76 | 367.76 | 57.29 | 0.33 |
| Rb_01 | 438 | Q50 | 1340.00 | 370.13 | 379.50 | | 379.81 | 0.006357 | 4.44 | 301.89 | 54.77 | 0.33 |
| | | | | | | | | | | | | |
| Rb_01 | 375 | Q100 | 1750.00 | 370.79 | 380.45 | | 380.73 | 0.003234 | 4.24 | 412.34 | 60.83 | 0.29 |
| Rb_01 | 375 | Q50 | 1340.00 | 370.79 | 379.28 | | 379.51 | 0.003137 | 3.92 | 342.04 | 58.74 | 0.29 |
| | | | | | | | | | | | | |
| Rb_01 | 329 | Q100 | 1750.00 | 368.82 | 380.41 | | 380.58 | 0.002010 | 3.29 | 531.82 | 76.17 | 0.22 |
| Rb_01 | 329 | Q50 | 1340.00 | 368.82 | 379.23 | | 379.38 | 0.001853 | 3.01 | 444.58 | 71.81 | 0.21 |
| | | | | | | | | | | | | |
| Rb_01 | 307 | Q100 | 1750.00 | 368.53 | 379.98 | | 380.47 | 0.007405 | 5.61 | 312.09 | 49.29 | 0.39 |
| Rb_01 | 307 | Q50 | 1340.00 | 368.53 | 378.86 | | 379.28 | 0.006874 | 5.17 | 259.37 | 44.67 | 0.38 |
| | | | | | | | | | | | | |
| Rb_01 | 284 | Q100 | 1750.00 | 367.54 | 379.46 | 376.31 | 380.24 | 0.011306 | 7.05 | 248.29 | 39.40 | 0.49 |
| Rb_01 | 284 | Q50 | 1340.00 | 367.54 | 378.42 | 375.21 | 379.06 | 0.010227 | 6.41 | 208.98 | 36.22 | 0.47 |
| | | | | | | | | | | | | |
| Rb_01 | 270 | | Inl Struct | | | | | | | | | |
| | | | | | | | | | | | | |
| Rb_01 | 256 | Q100 | 1750.00 | 366.34 | 375.56 | 375.56 | 378.39 | 0.041057 | 13.50 | 129.59 | 23.05 | 1.00 |
| Rb_01 | 256 | Q50 | 1340.00 | 366.34 | 374.34 | 374.34 | 376.95 | 0.035665 | 12.98 | 103.26 | 19.84 | 1.00 |
| | | | | | | | | | | | | |
| Rb_01 | 249 | Q100 | 1750.00 | 366.28 | 374.35 | 374.35 | 377.35 | 0.018540 | 13.87 | 126.13 | 21.34 | 1.01 |
| Rb_01 | 249 | Q50 | 1340.00 | 366.28 | 373.30 | 373.30 | 375.88 | 0.019834 | 12.88 | 104.02 | 20.43 | 1.01 |
| | | | | | | | | | | | | |
| Rb_01 | 236 | Q100 | 1750.00 | 366.41 | 374.67 | 372.93 | 376.40 | 0.007209 | 10.53 | 166.16 | 22.40 | 0.68 |
| Rb_01 | 236 | Q50 | 1340.00 | 366.41 | 373.62 | 371.99 | 374.99 | 0.006752 | 9.39 | 142.78 | 22.18 | 0.65 |
| | | | | | | | | | | | | |
| Rb_01 | 221 BR U | Q100 | 1750.00 | 366.41 | 374.66 | 372.95 | 376.39 | 0.007245 | 10.55 | 165.89 | 22.40 | 0.68 |
| Rb_01 | 221 BR U | Q50 | 1340.00 | 366.41 | 373.61 | 371.99 | 374.99 | 0.006788 | 9.40 | 142.54 | 22.18 | 0.65 |
| | | | | | | | | | | | | |
| Rb_01 | 221 BR D | Q100 | 1750.00 | 365.60 | 373.60 | 373.21 | 376.06 | 0.011590 | 12.60 | 138.83 | 23.00 | 0.90 |
| Rb_01 | 221 BR D | Q50 | 1340.00 | 365.60 | 372.58 | 372.25 | 374.67 | 0.012005 | 11.58 | 115.68 | 22.81 | 0.91 |

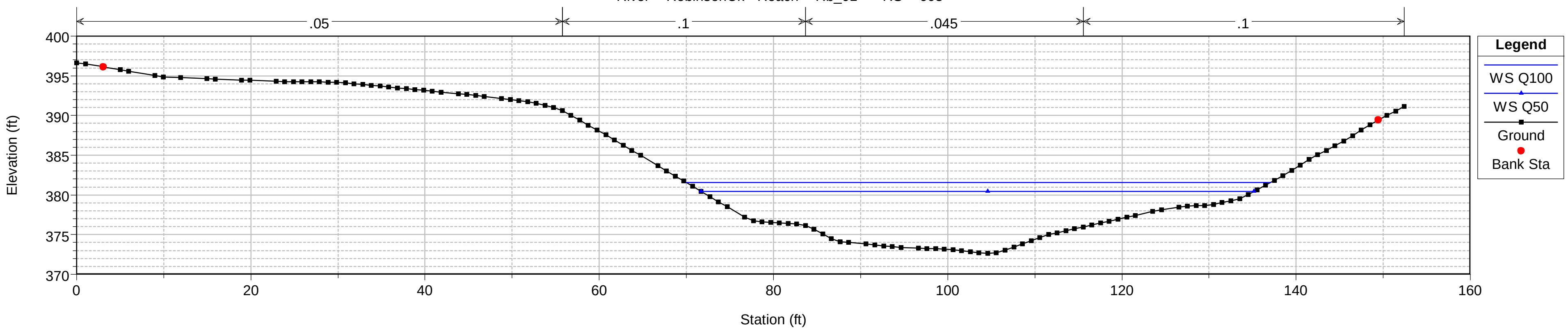
HEC-RAS  Plan: Exist-HMS   River: RobinsonCk   Reach: Rb_01 (Continued)

| 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) | |
| | | | | | | | | | | | | |
| Rb_01 | 207 | Q100 | 1750.00 | 365.60 | 373.20 | 373.20 | 376.03 | 0.014337 | 13.50 | 129.65 | 22.92 | 1.00 |
| Rb_01 | 207 | Q50 | 1340.00 | 365.60 | 372.51 | 372.26 | 374.66 | 0.012568 | 11.75 | 114.00 | 22.79 | 0.93 |
| | | | | | | | | | | | | |
| Rb_01 | 200 | Q100 | 1750.00 | 366.36 | 373.94 | | 375.37 | 0.009630 | 9.60 | 182.30 | 29.52 | 0.68 |
| Rb_01 | 200 | Q50 | 1340.00 | 366.36 | 373.17 | | 374.27 | 0.008369 | 8.38 | 159.92 | 29.19 | 0.63 |
| | | | | | | | | | | | | |
| Rb_01 | 188 | Q100 | 1750.00 | 367.09 | 374.23 | | 375.11 | 0.006420 | 7.49 | 233.78 | 38.36 | 0.53 |
| Rb_01 | 188 | Q50 | 1340.00 | 367.09 | 373.37 | | 374.06 | 0.005819 | 6.67 | 200.85 | 37.73 | 0.51 |
| | | | | | | | | | | | | |
| Rb_01 | 156 | Q100 | 1750.00 | 366.76 | 373.53 | | 374.73 | 0.012427 | 8.78 | 199.24 | 40.45 | 0.70 |
| Rb_01 | 156 | Q50 | 1340.00 | 366.76 | 372.71 | | 373.71 | 0.011896 | 8.05 | 166.53 | 38.73 | 0.68 |
| | | | | | | | | | | | | |
| Rb_01 | 124 | Q100 | 1750.00 | 365.63 | 373.62 | | 374.24 | 0.008144 | 6.33 | 276.55 | 55.79 | 0.50 |
| Rb_01 | 124 | Q50 | 1340.00 | 365.63 | 372.72 | | 373.26 | 0.008102 | 5.87 | 228.12 | 52.30 | 0.50 |
| | | | | | | | | | | | | |
| Rb_01 | 62 | Q100 | 1750.00 | 365.15 | 373.12 | | 373.74 | 0.007946 | 6.34 | 276.21 | 56.15 | 0.50 |
| Rb_01 | 62 | Q50 | 1340.00 | 365.15 | 372.20 | | 372.74 | 0.008496 | 5.94 | 225.44 | 54.15 | 0.51 |
| | | | | | | | | | | | | |
| Rb_01 | 21 | Q100 | 1750.00 | 364.70 | 371.02 | 371.02 | 373.06 | 0.024514 | 11.47 | 152.64 | 37.44 | 1.00 |
| Rb_01 | 21 | Q50 | 1340.00 | 364.70 | 370.30 | 370.30 | 372.06 | 0.025324 | 10.64 | 125.91 | 36.50 | 1.01 |
| | | | | | | | | | | | | |
| Rb_01 | 1 | Q100 | 1750.00 | 364.17 | 370.05 | 369.25 | 371.53 | 0.016009 | 9.77 | 179.17 | 36.94 | 0.78 |
| Rb_01 | 1 | Q50 | 1340.00 | 364.17 | 369.18 | 368.53 | 370.46 | 0.016017 | 9.08 | 147.60 | 35.81 | 0.79 |

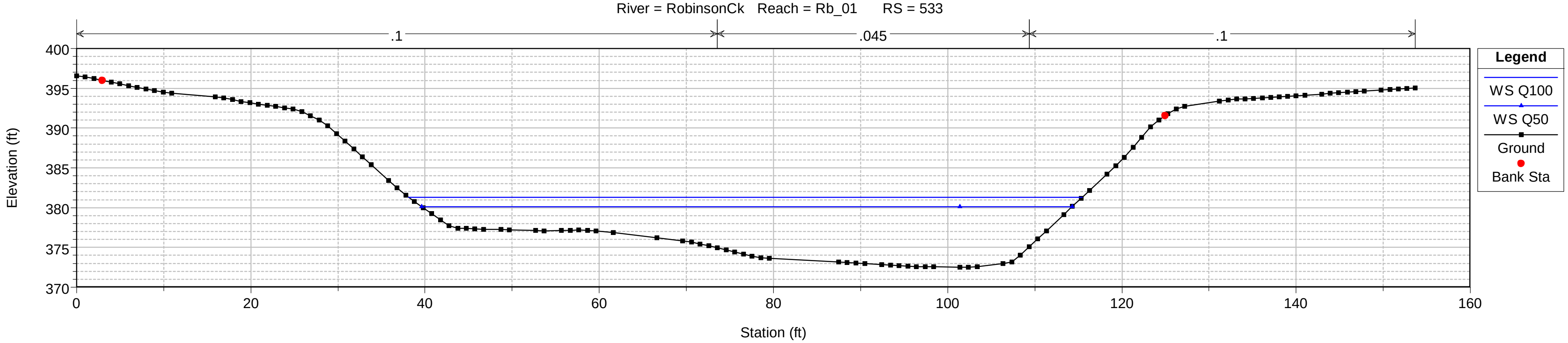
RobinsonCreek    Plan: Existing-HMS    9/28/2016
Geom: Existing Condition    Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk    Reach = Rb_01    RS = 673    Model US Limit

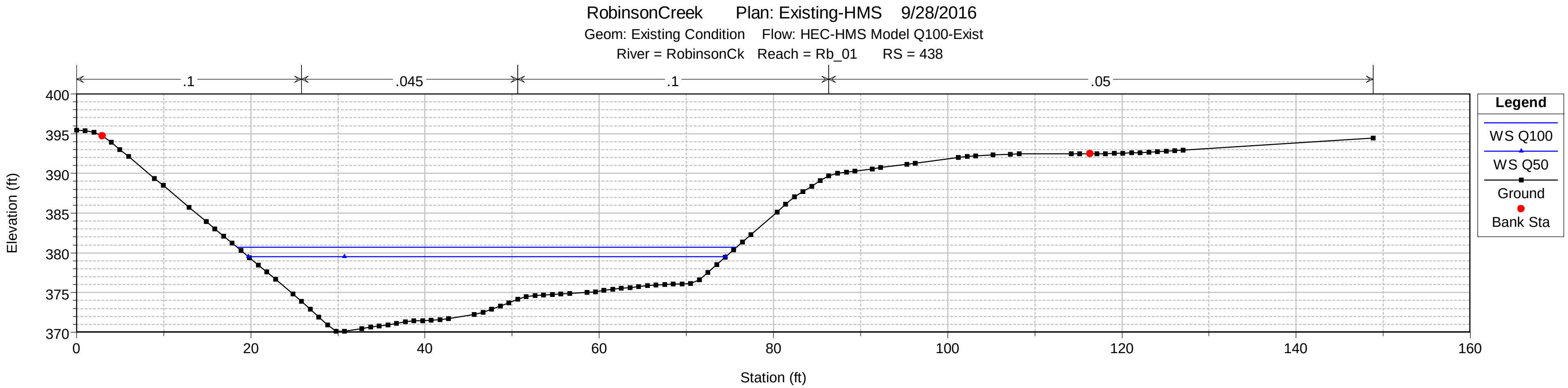


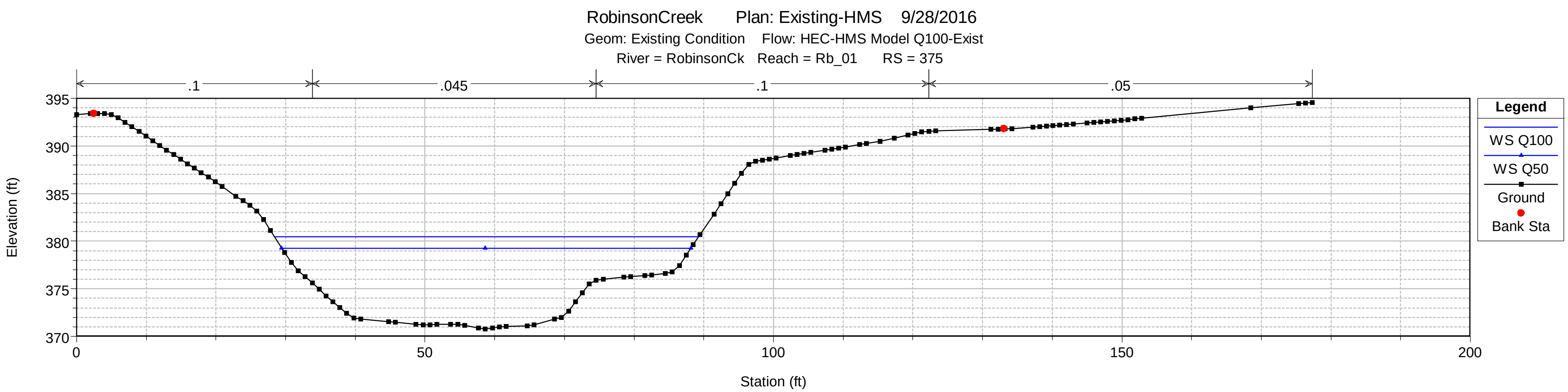

RobinsonCreek    Plan: Existing-HMS    9/28/2016
Geom: Existing Condition    Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk    Reach = Rb_01    RS = 603

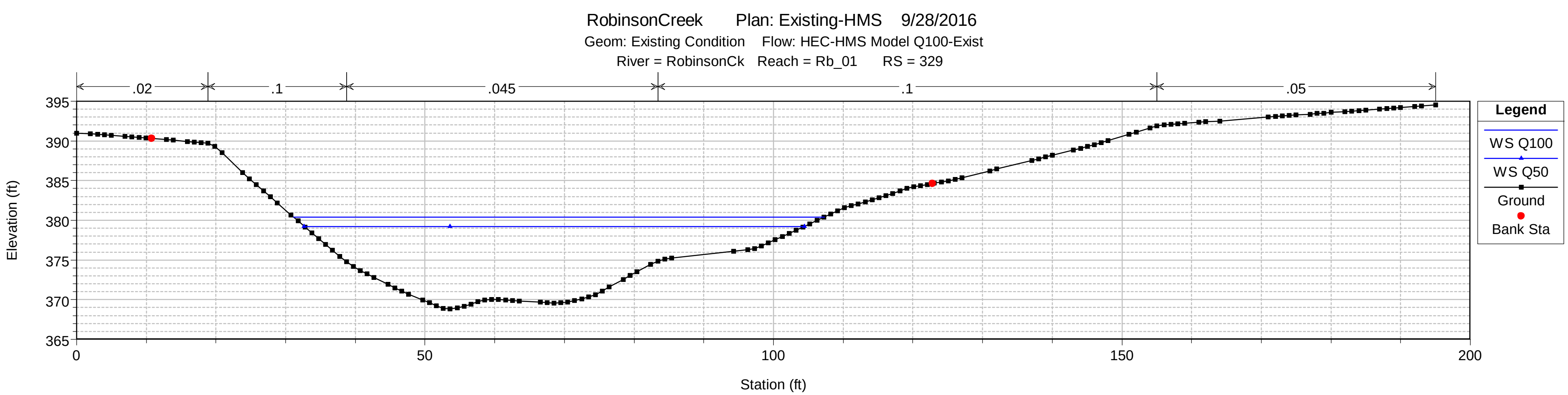


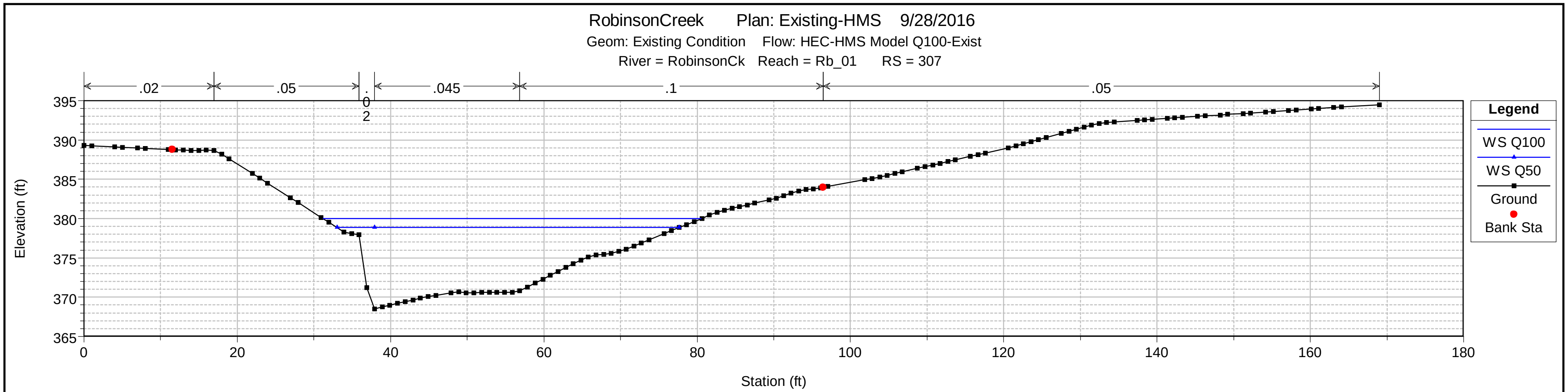

RobinsonCreek    Plan: Existing-HMS    9/28/2016
Geom: Existing Condition    Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk    Reach = Rb_01    RS = 533

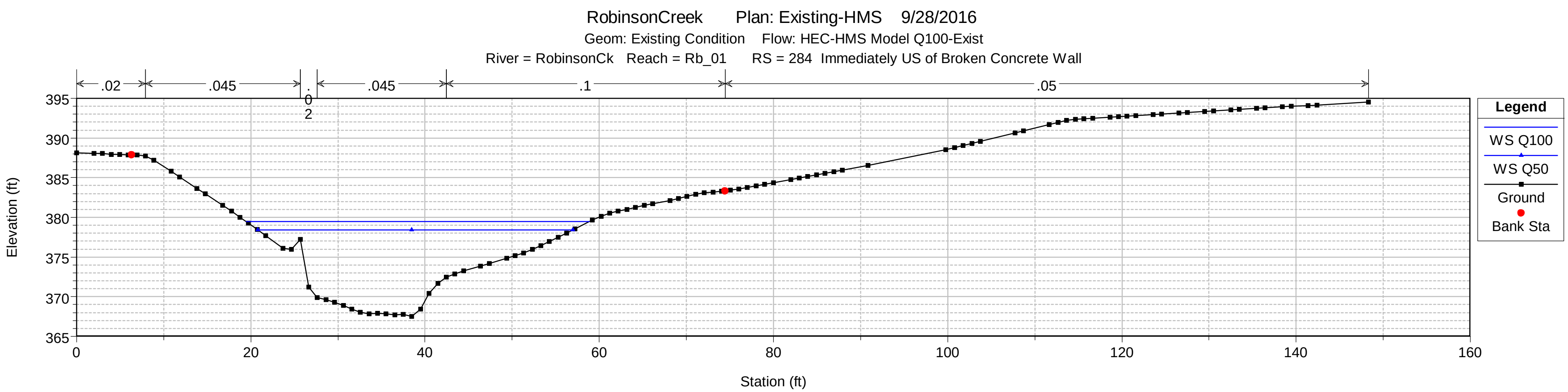


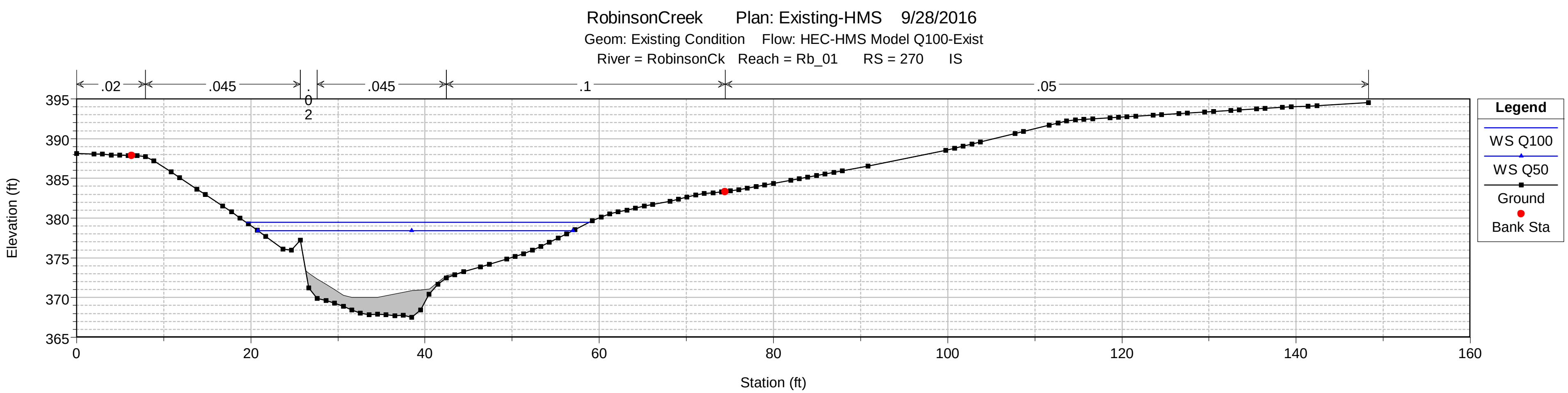

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 438
.1
.045
.1
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

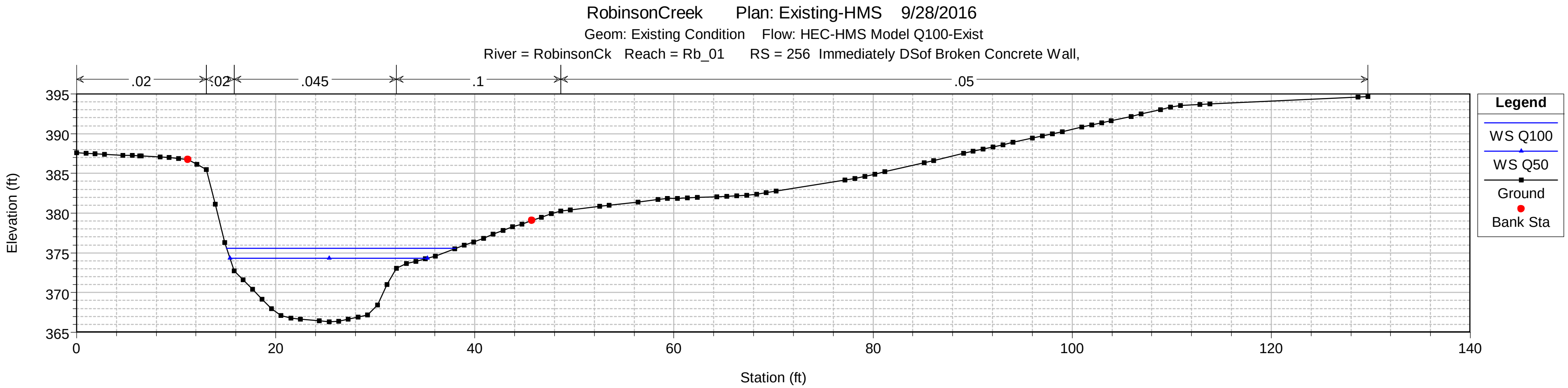

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 375
.1
.045
.1
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

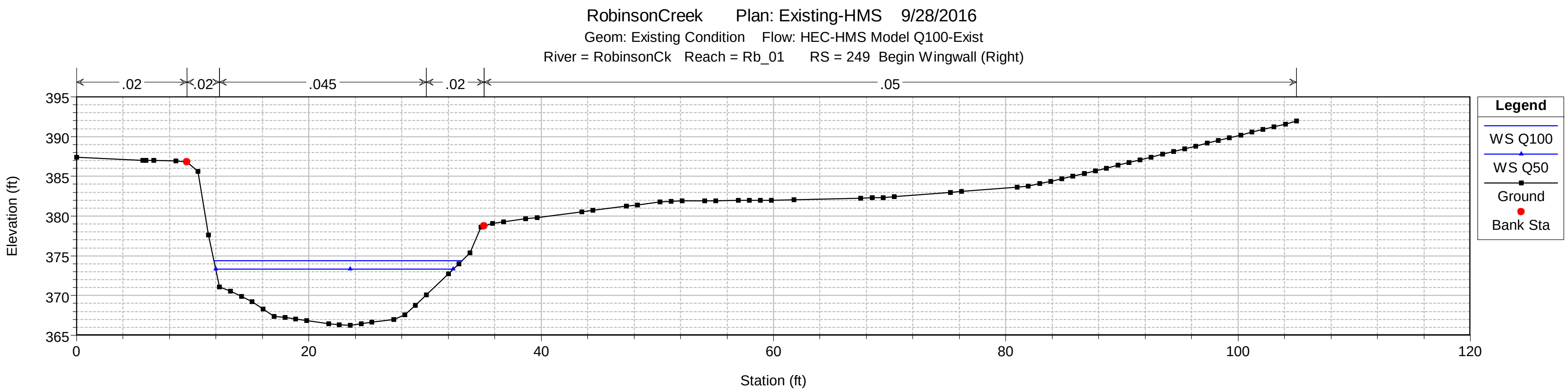

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 329
.02
.1
.045
.1
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

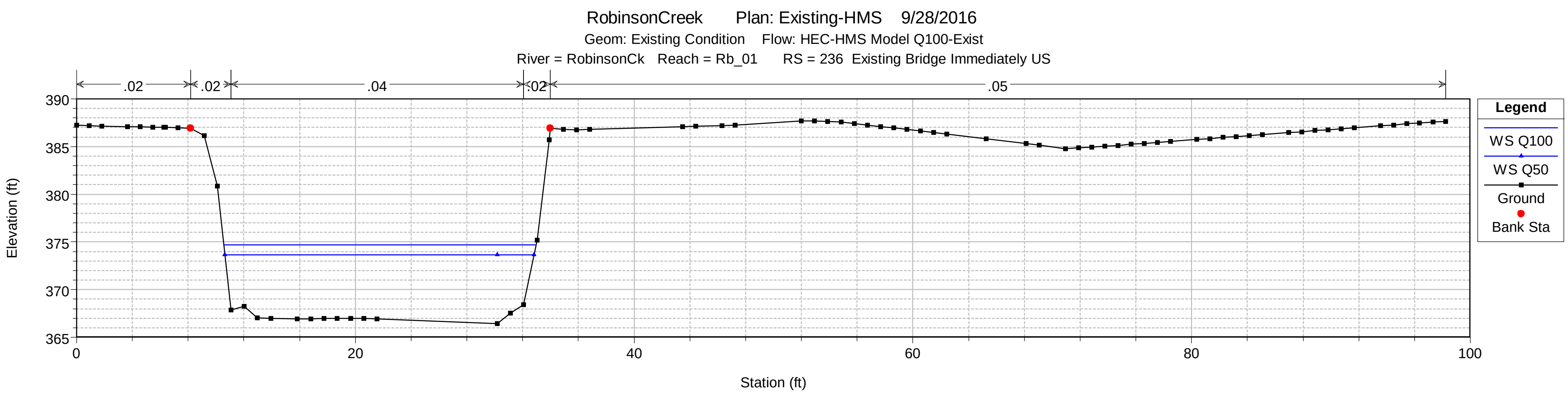

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 307
.02
.05
0
2
.045
.1
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

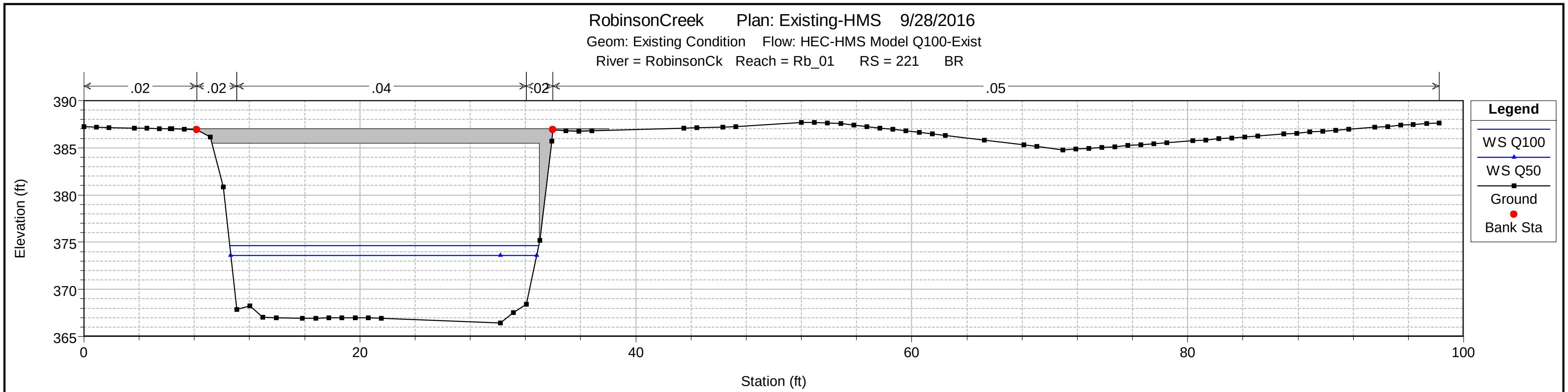

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 284 Immediately US of Broken Concrete Wall
.02
.045
0
2
.045
.1
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

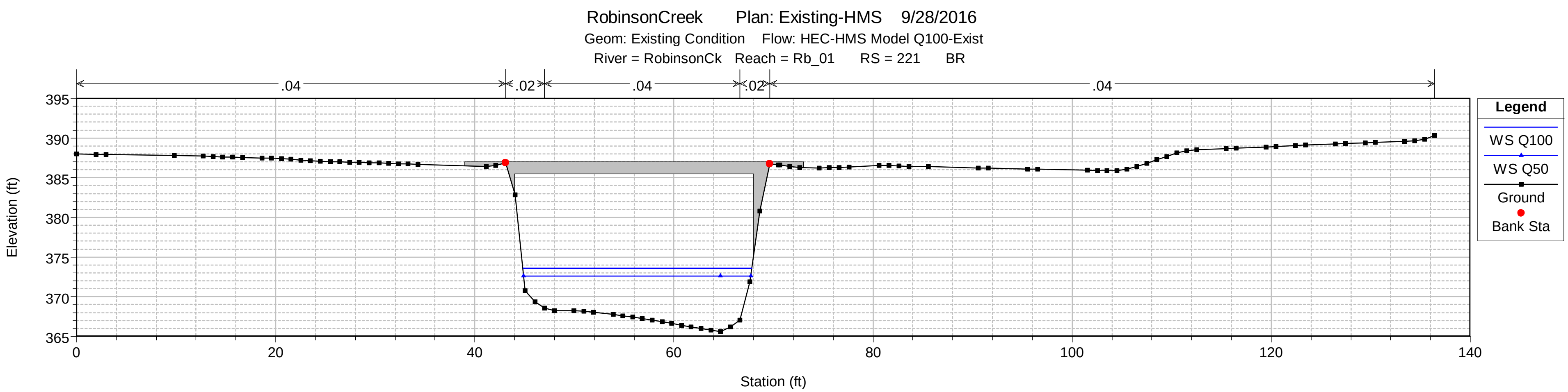

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 270 IS
.02
.045
0
2
.045
.1
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

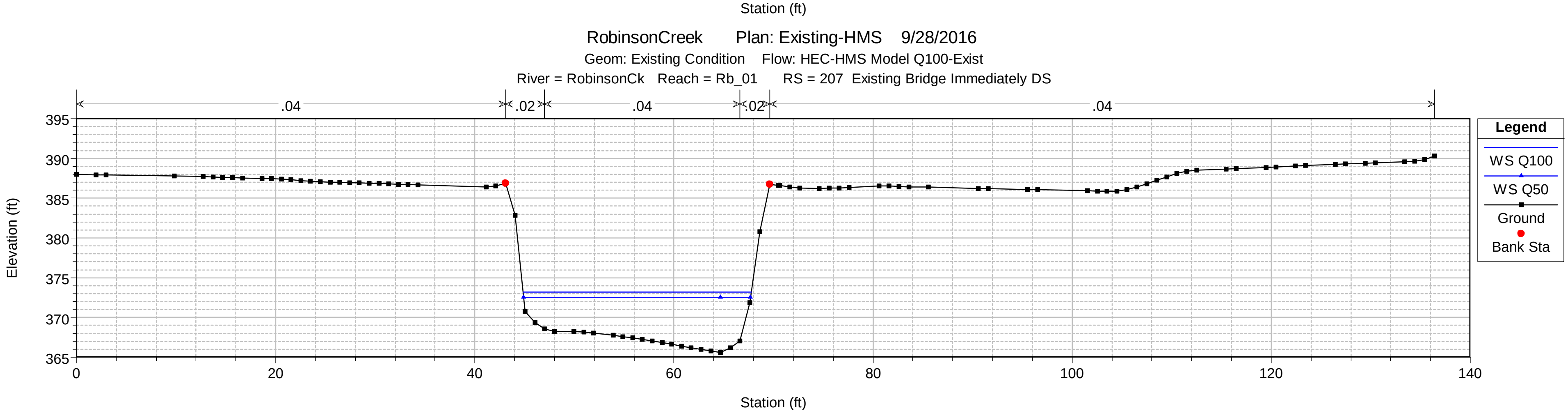

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 256 Immediately DSof Broken Concrete Wall,
.02
.02
.045
.1
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

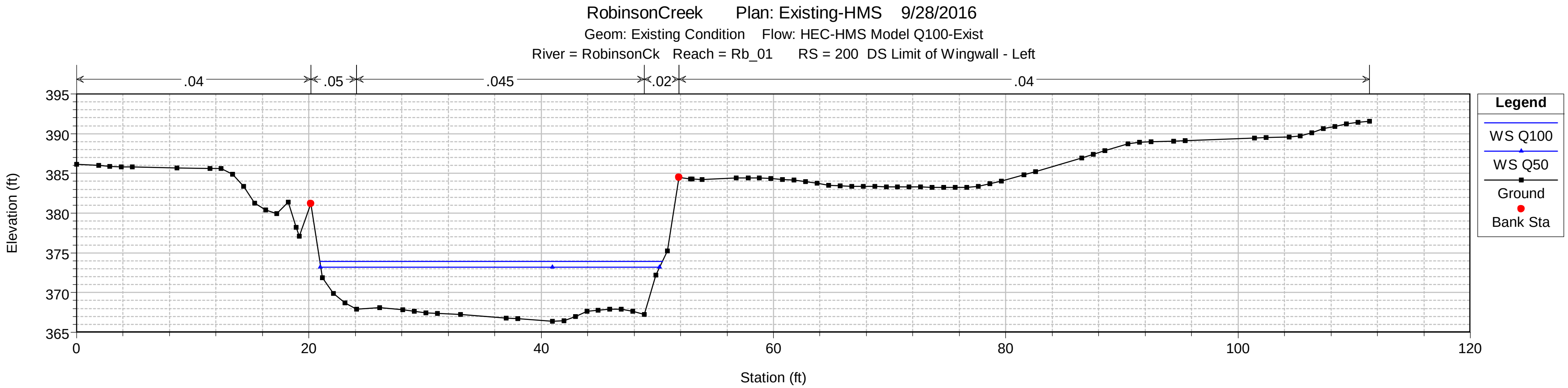

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 249 Begin Wingwall (Right)
.02
.02
.045
.02
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

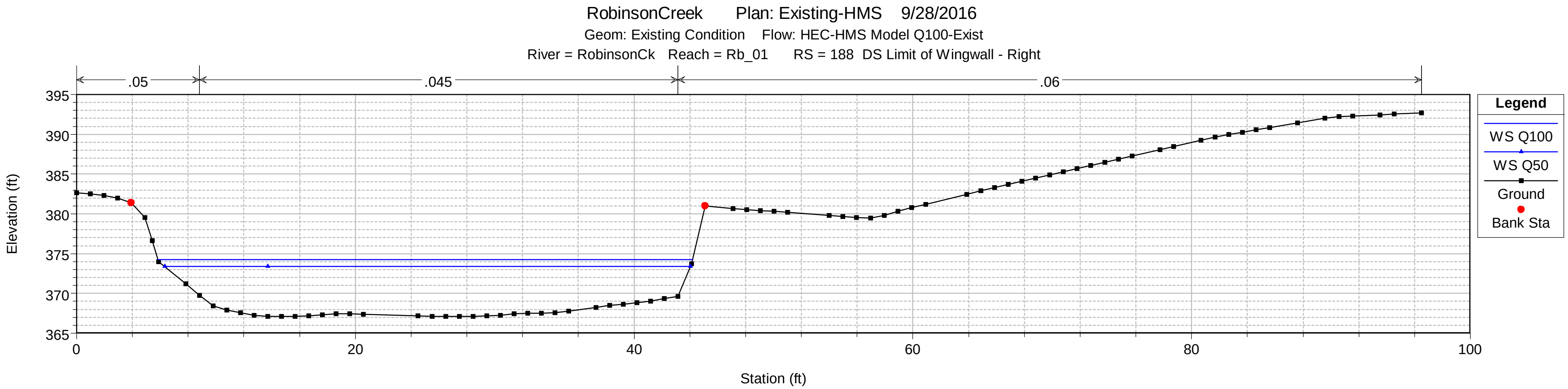

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 236 Existing Bridge Immediately US
.02
.02
.04
.02
.05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

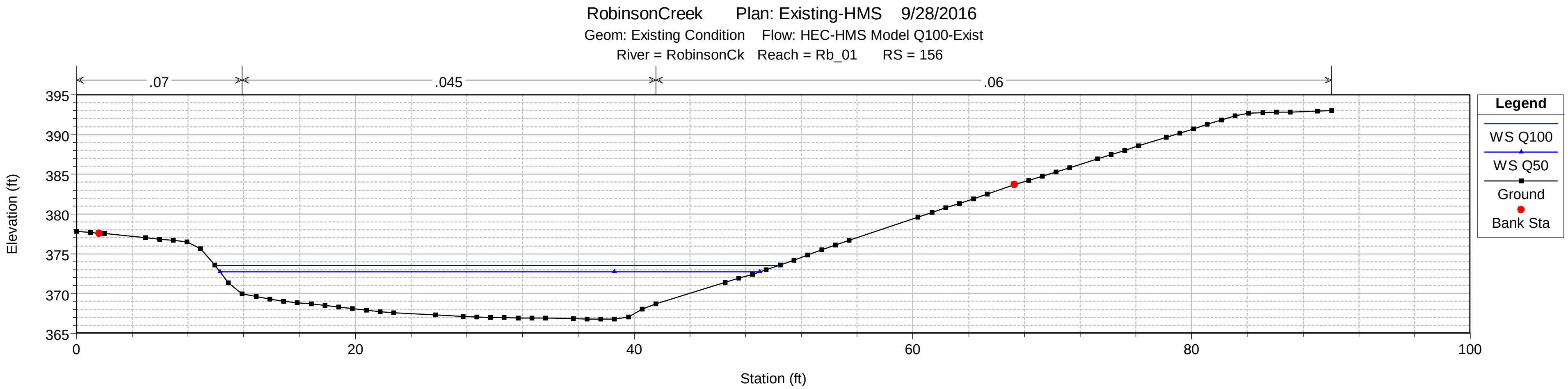

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 221 BR
.02 .02 .04 .02 .05
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

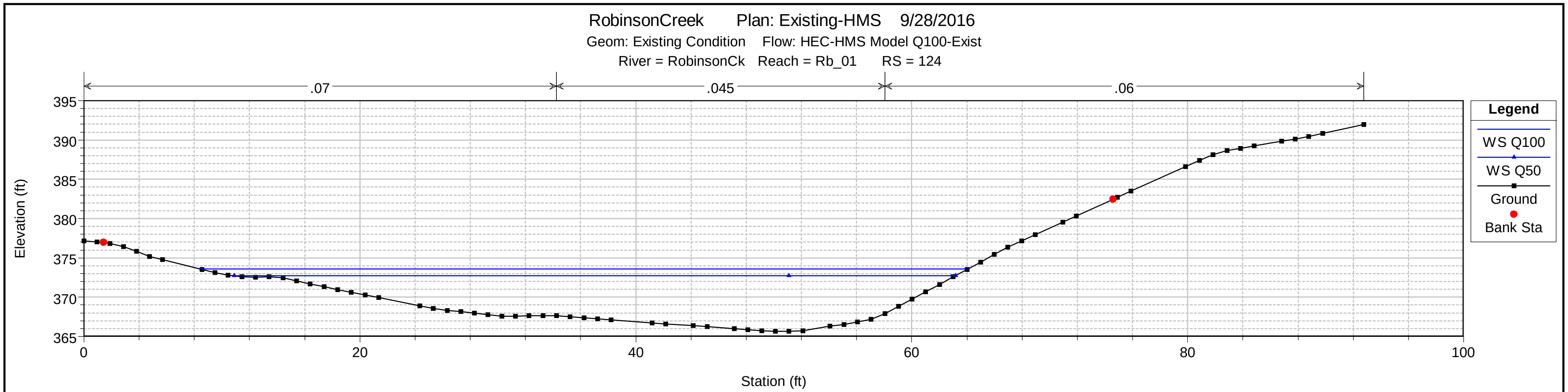

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 221 BR
.04 .02 .04 .02 .04
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta


RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 207 Existing Bridge Immediately DS
.04 .02 .04 .02 .04
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

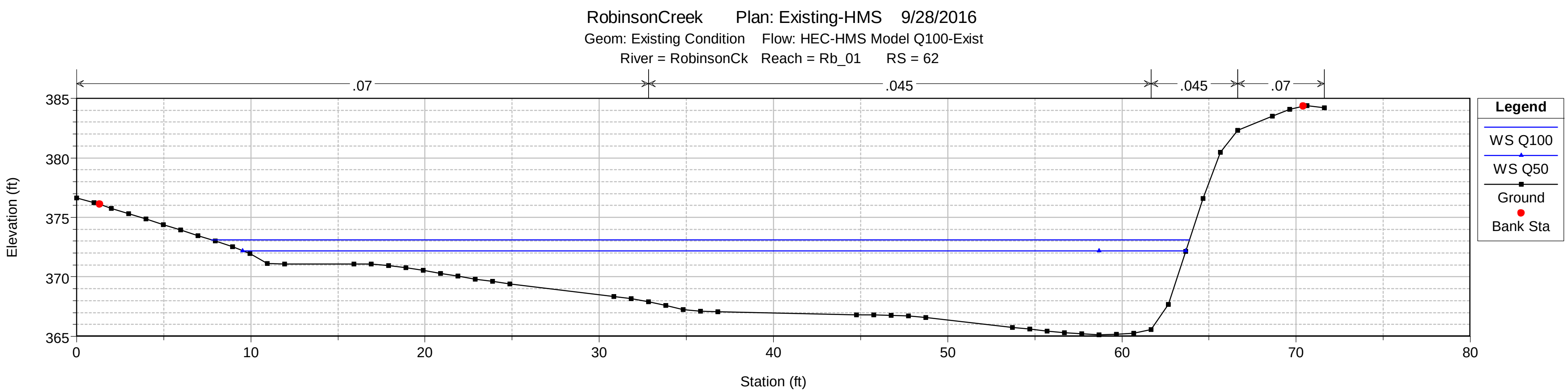

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 200 DS Limit of Wingwall - Left
.04
.05
.045
.02
.04
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta


RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 188 DS Limit of Wingwall - Right
.05
.045
.06
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

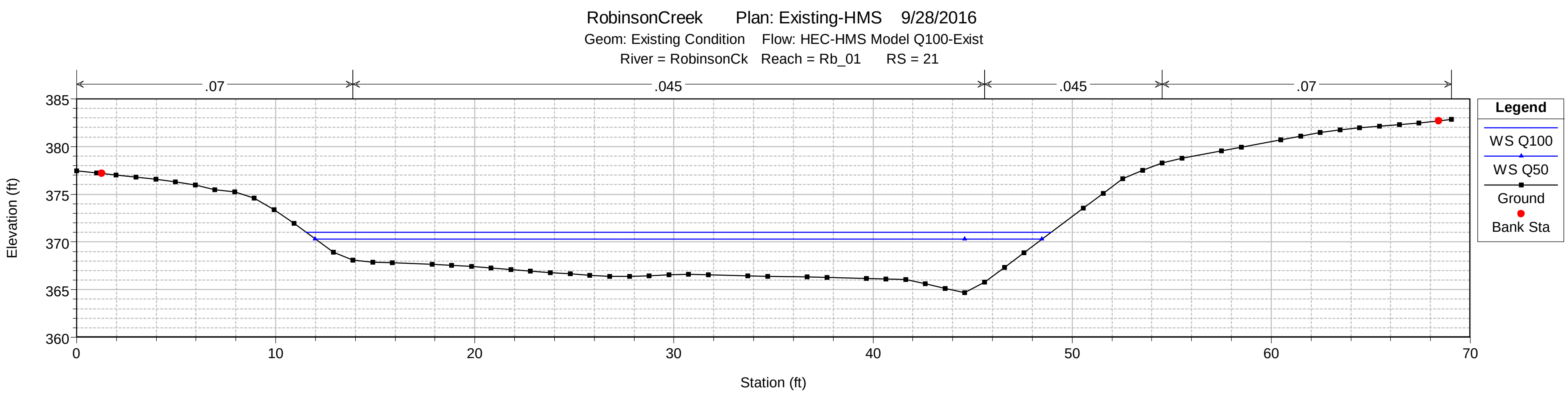

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 156
.07
.045
.06
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta



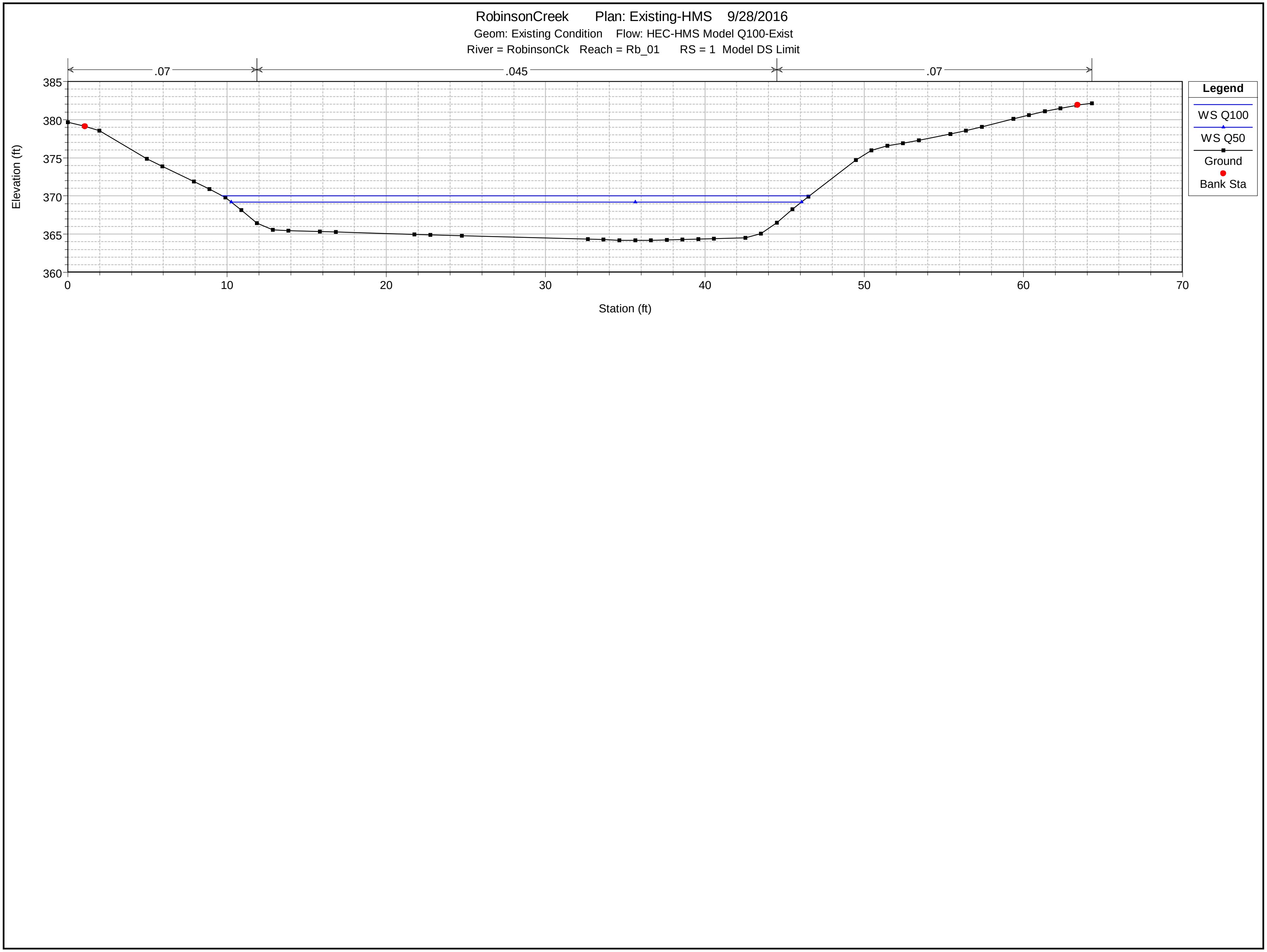
RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 124
.07
.045
.06
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 62
.07
.045
.045
.07
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 21
.07
.045
.045
.07
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta



RobinsonCreek Plan: Existing-HMS 9/28/2016
Geom: Existing Condition Flow: HEC-HMS Model Q100-Exist
River = RobinsonCk Reach = Rb_01 RS = 1 Model DS Limit
.07
.045
.07
Elevation (ft)
385
380
375
370
365
360
0
10
20
30
40
50
60
70
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

# Appendix F Hydraulic Analysis, Proposed Condition

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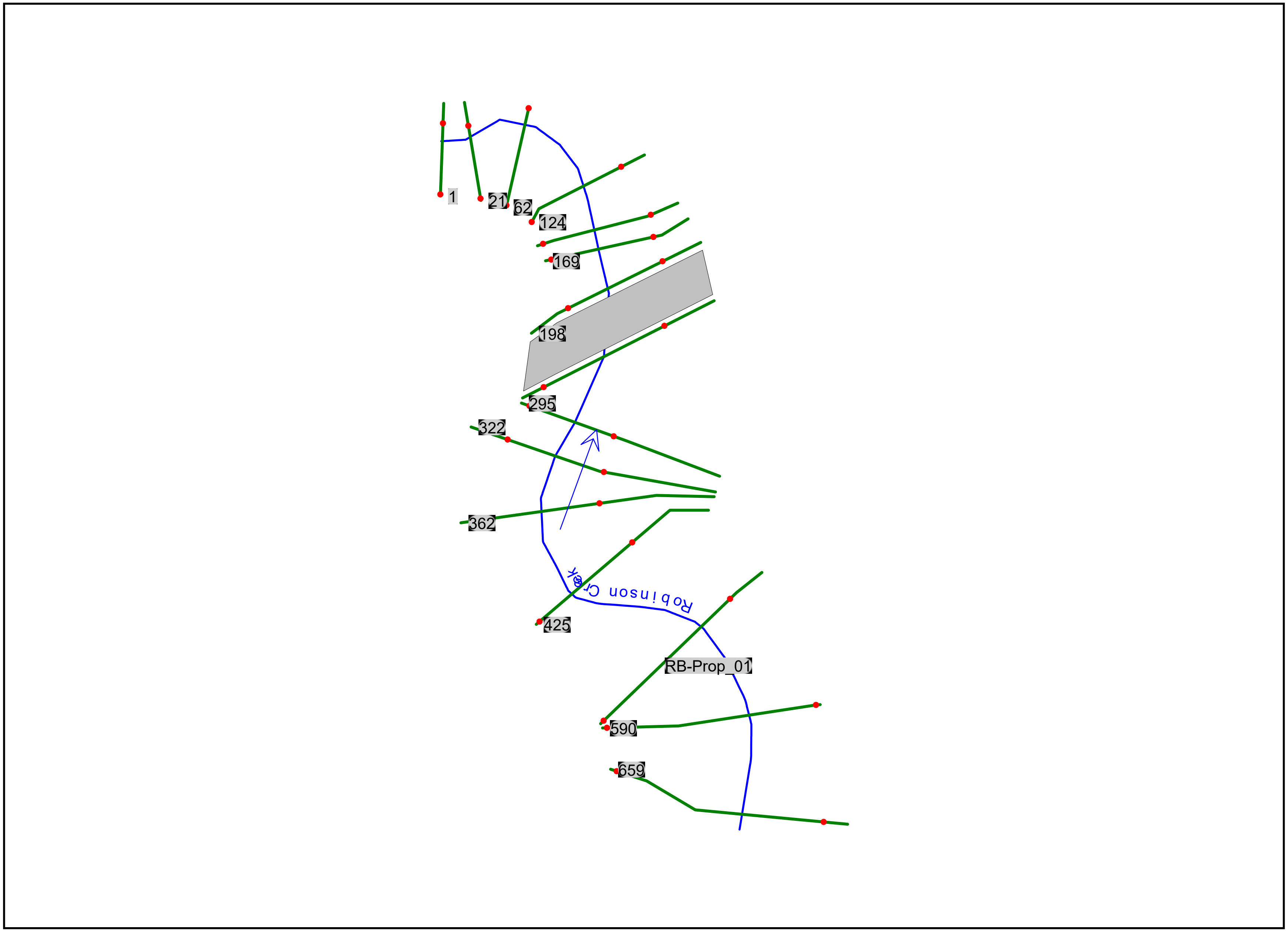
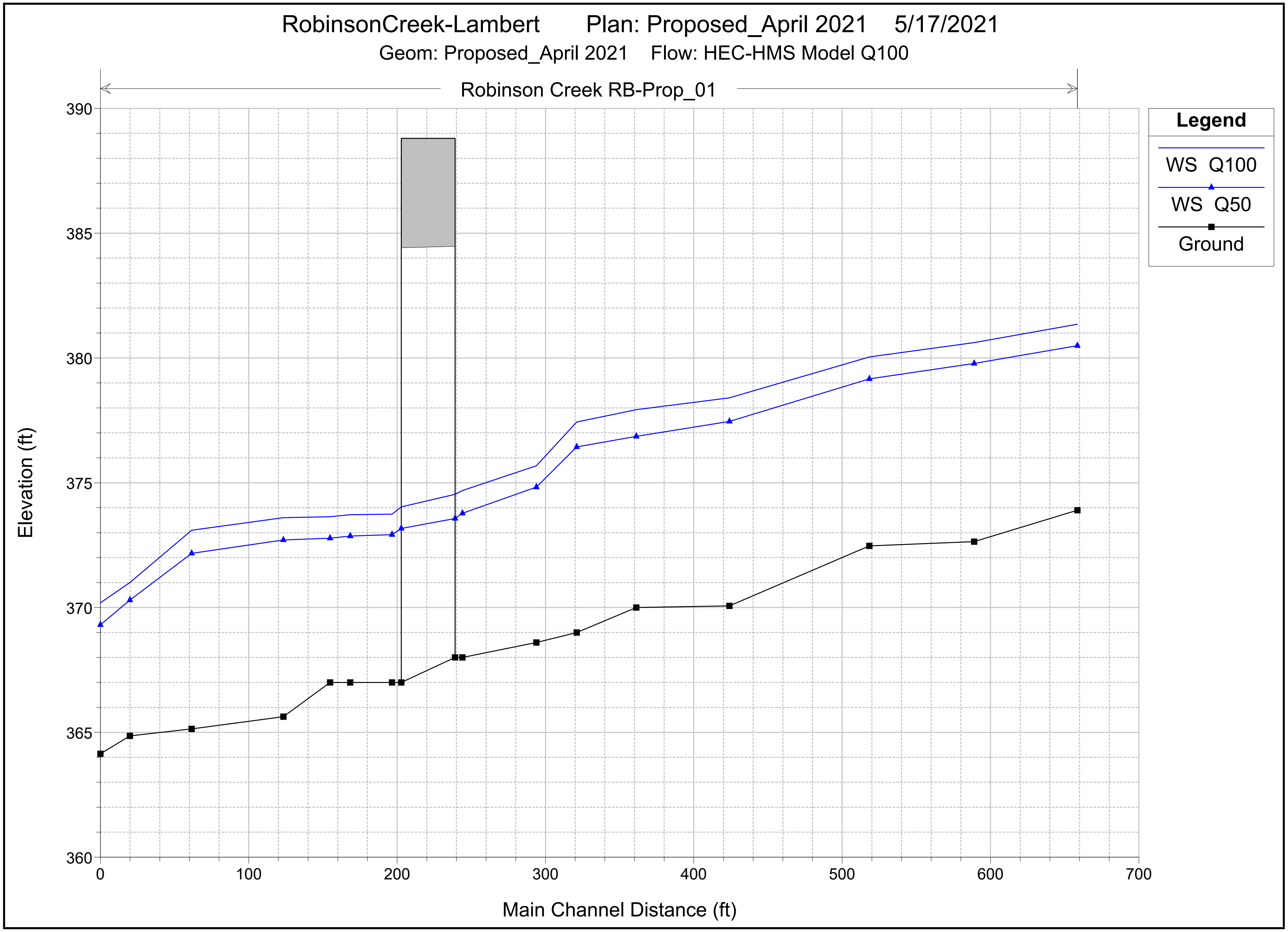

1
21
62
124
169
198
295
322
362
425
RB-Prop_01
590
659
Robinson Creek


RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
Robinson Creek RB-Prop_01
Legend
WS Q100
WS Q50
Ground
Elevation (ft)
Main Channel Distance (ft)
390
385
380
375
370
365
360
0
100
200
300
400
500
600
700

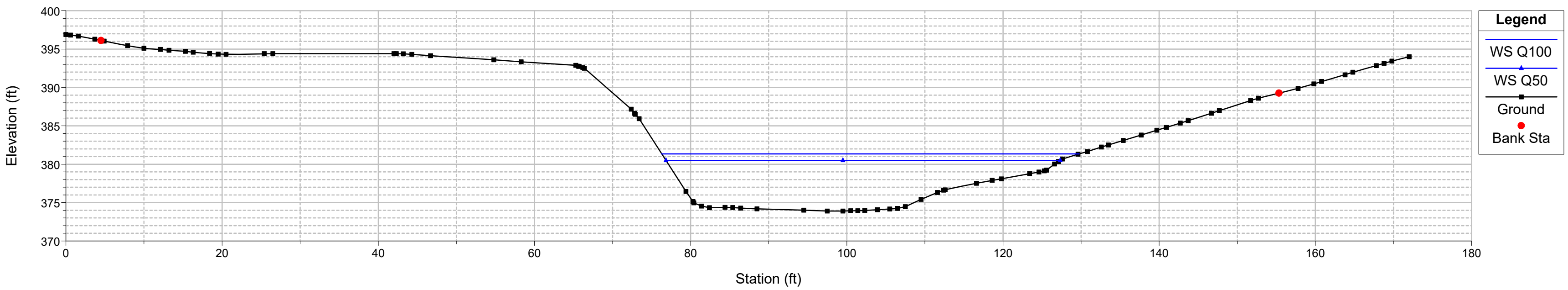
HEC-RAS Plan: proposed april 2021 River: Robinson Creek Reach: RB-Prop_01

| 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) | |
| RB-Prop_01 | 659 | Q100 | 1750.00 | 373.90 | 381.35 | | 381.94 | 0.010564 | 6.14 | 285.13 | 53.45 | 0.47 |
| RB-Prop_01 | 659 | Q50 | 1340.00 | 373.90 | 380.49 | | 380.98 | 0.009441 | 5.57 | 240.71 | 50.48 | 0.45 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 590 | Q100 | 1750.00 | 372.64 | 380.62 | | 381.14 | 0.011829 | 5.80 | 301.50 | 64.15 | 0.47 |
| RB-Prop_01 | 590 | Q50 | 1340.00 | 372.64 | 379.78 | | 380.23 | 0.011929 | 5.38 | 248.89 | 61.53 | 0.47 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 519 | Q100 | 1750.00 | 372.47 | 380.04 | | 380.40 | 0.008181 | 4.84 | 361.69 | 74.49 | 0.39 |
| RB-Prop_01 | 519 | Q50 | 1340.00 | 372.47 | 379.16 | | 379.48 | 0.008625 | 4.51 | 297.17 | 72.53 | 0.39 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 425 | Q100 | 1750.00 | 370.07 | 378.40 | | 379.21 | 0.020131 | 7.20 | 243.03 | 52.42 | 0.59 |
| RB-Prop_01 | 425 | Q50 | 1340.00 | 370.07 | 377.46 | | 378.19 | 0.022469 | 6.89 | 194.42 | 50.38 | 0.62 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 362 | Q100 | 1750.00 | 370.00 | 377.93 | | 378.55 | 0.005583 | 6.34 | 276.08 | 56.96 | 0.51 |
| RB-Prop_01 | 362 | Q50 | 1340.00 | 370.00 | 376.86 | | 377.45 | 0.006612 | 6.17 | 217.06 | 53.54 | 0.54 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 322 | Q100 | 1750.00 | 369.00 | 377.43 | | 378.28 | 0.006791 | 7.38 | 237.03 | 45.12 | 0.57 |
| RB-Prop_01 | 322 | Q50 | 1340.00 | 369.00 | 376.43 | | 377.17 | 0.006510 | 6.89 | 194.40 | 40.12 | 0.55 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 295 | Q100 | 1750.00 | 368.60 | 375.68 | 375.68 | 377.84 | 0.022635 | 11.79 | 148.45 | 34.41 | 1.00 |
| RB-Prop_01 | 295 | Q50 | 1340.00 | 368.60 | 374.83 | 374.83 | 376.75 | 0.023108 | 11.14 | 120.31 | 31.25 | 1.00 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 245 | Q100 | 1750.00 | 368.00 | 374.69 | 373.63 | 375.81 | 0.010410 | 8.50 | 205.99 | 46.09 | 0.71 |
| RB-Prop_01 | 245 | Q50 | 1340.00 | 368.00 | 373.78 | 372.94 | 374.80 | 0.011388 | 8.10 | 165.49 | 42.93 | 0.73 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 220 | | Bridge | | | | | | | | | |
| | | | | | | | | | | | | |
| RB-Prop_01 | 198 | Q100 | 1750.00 | 367.00 | 373.74 | | 375.19 | 0.012130 | 9.66 | 181.18 | 38.28 | 0.78 |
| RB-Prop_01 | 198 | Q50 | 1340.00 | 367.00 | 372.92 | | 374.15 | 0.011974 | 8.90 | 150.61 | 35.92 | 0.77 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 169 | Q100 | 1750.00 | 367.00 | 373.72 | | 374.68 | 0.007657 | 7.86 | 222.65 | 44.94 | 0.62 |
| RB-Prop_01 | 169 | Q50 | 1340.00 | 367.00 | 372.87 | | 373.68 | 0.007490 | 7.23 | 185.34 | 42.31 | 0.61 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 156 | Q100 | 1750.00 | 367.00 | 373.64 | | 374.57 | 0.007504 | 7.73 | 226.49 | 45.42 | 0.61 |
| RB-Prop_01 | 156 | Q50 | 1340.00 | 367.00 | 372.78 | | 373.57 | 0.007397 | 7.11 | 188.55 | 43.12 | 0.60 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 124 | Q100 | 1750.00 | 365.63 | 373.60 | | 374.23 | 0.008204 | 6.34 | 275.83 | 55.75 | 0.50 |
| RB-Prop_01 | 124 | Q50 | 1340.00 | 365.63 | 372.71 | | 373.25 | 0.008165 | 5.89 | 227.39 | 52.20 | 0.50 |
| | | | | | | | | | | | | |

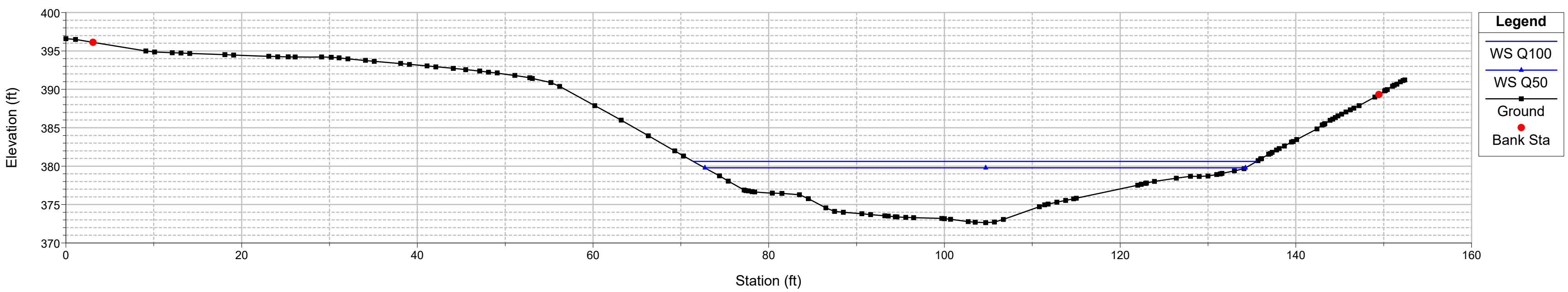
HEC-RAS Plan: proposed april 2021 River: Robinson Creek Reach: RB-Prop_01 (Continued)

| 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) | |
| RB-Prop_01 | 62 | Q100 | 1750.00 | 365.14 | 373.10 | | 373.73 | 0.008003 | 6.36 | 275.23 | 55.88 | 0.51 |
| RB-Prop_01 | 62 | Q50 | 1340.00 | 365.14 | 372.17 | | 372.73 | 0.008627 | 5.97 | 224.41 | 54.07 | 0.52 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 21 | Q100 | 1750.00 | 364.86 | 371.00 | 371.00 | 373.05 | 0.024707 | 11.46 | 152.64 | 37.40 | 1.00 |
| RB-Prop_01 | 21 | Q50 | 1340.00 | 364.86 | 370.30 | 370.30 | 372.04 | 0.025082 | 10.58 | 126.69 | 36.51 | 1.00 |
| | | | | | | | | | | | | |
| RB-Prop_01 | 1 | Q100 | 1750.00 | 364.14 | 370.19 | 369.24 | 371.58 | 0.016006 | 9.44 | 185.32 | 37.21 | 0.75 |
| RB-Prop_01 | 1 | Q50 | 1340.00 | 364.14 | 369.31 | 368.52 | 370.50 | 0.016021 | 8.76 | 152.97 | 36.04 | 0.75 |

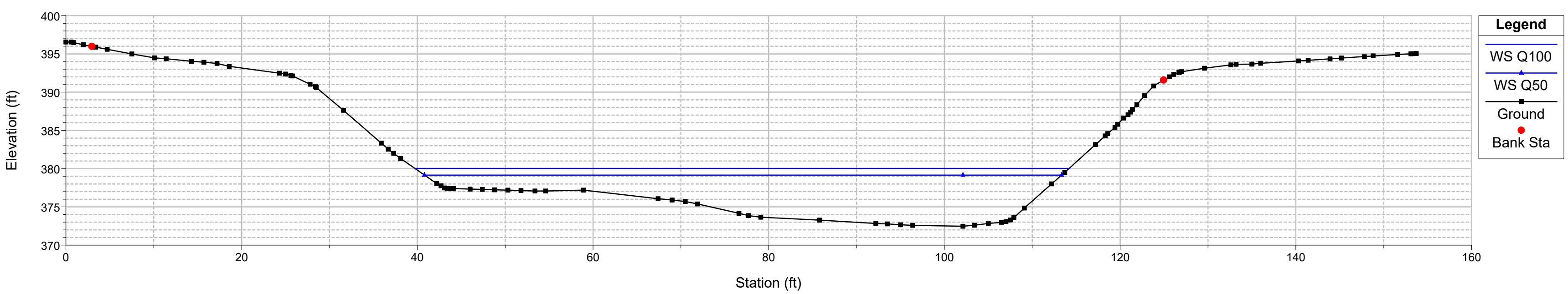
RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 659 Model US Limit

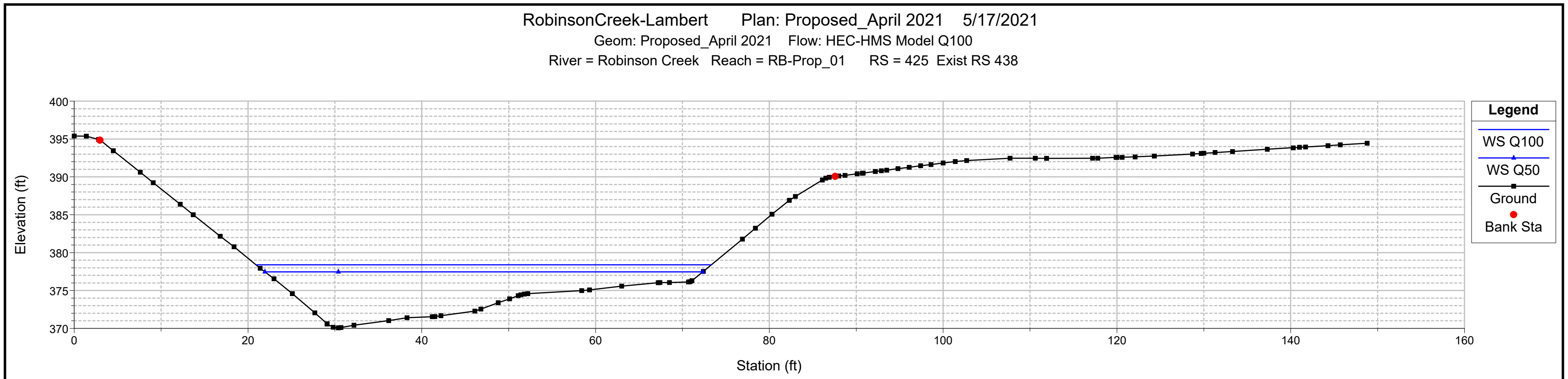


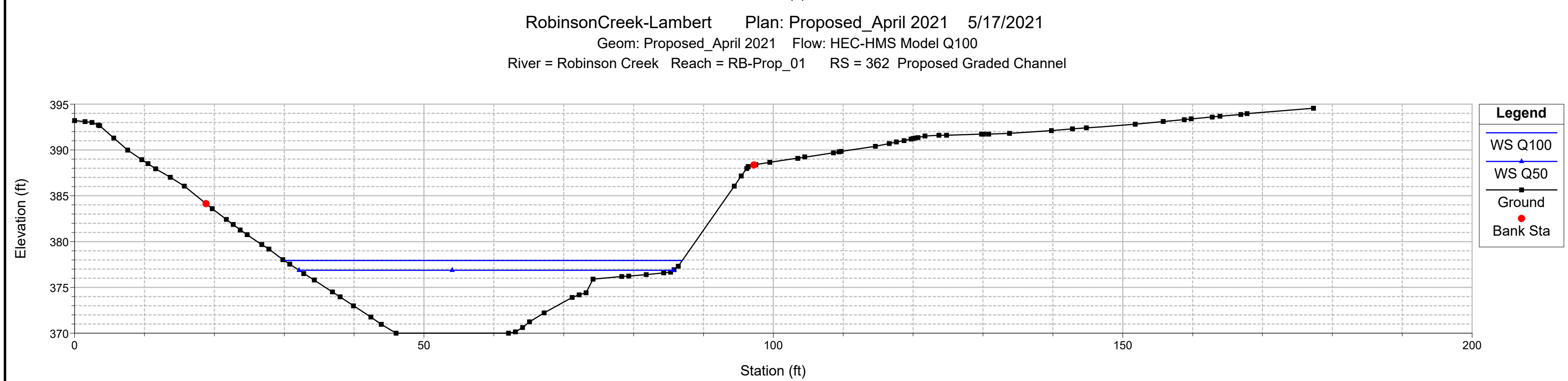

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 590 Exist RS 603

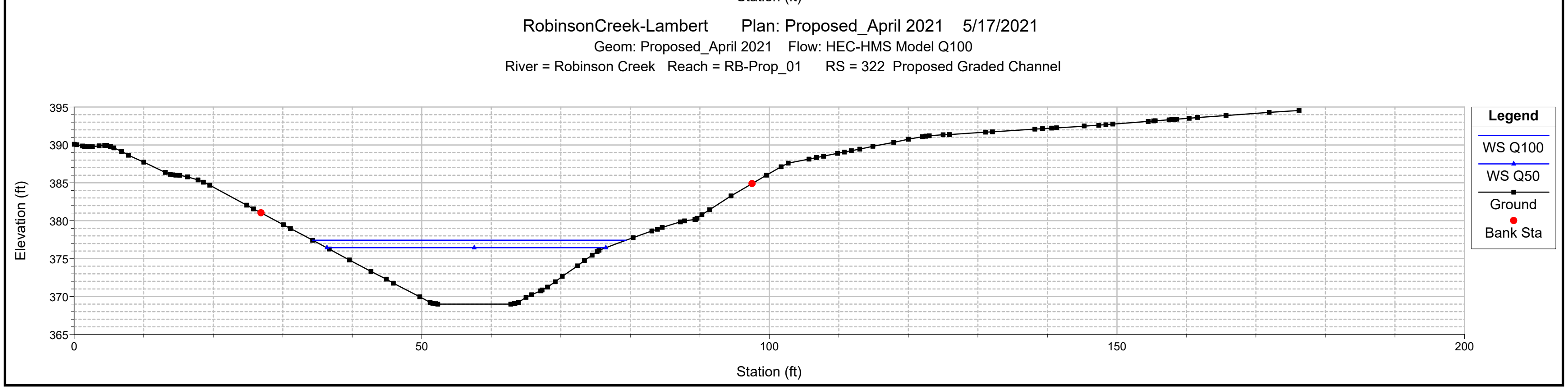



RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 519 Exist RS 533

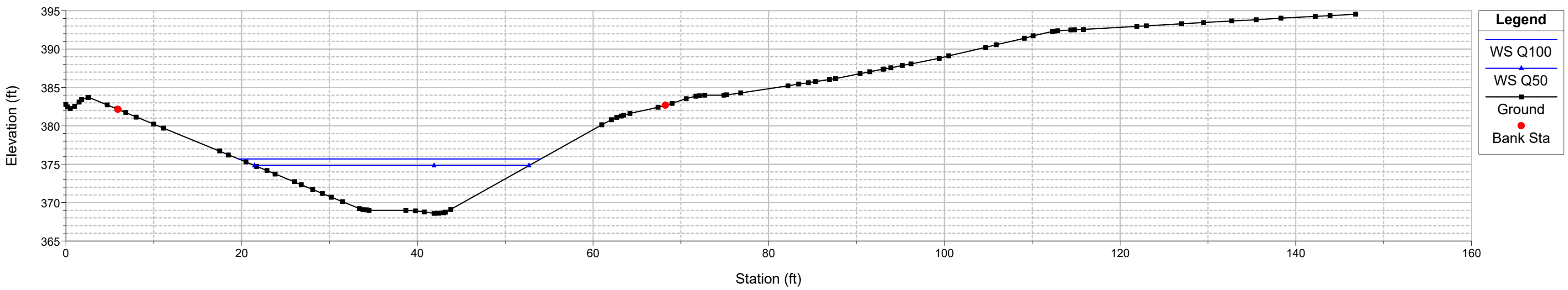



RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 425 Exist RS 438
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

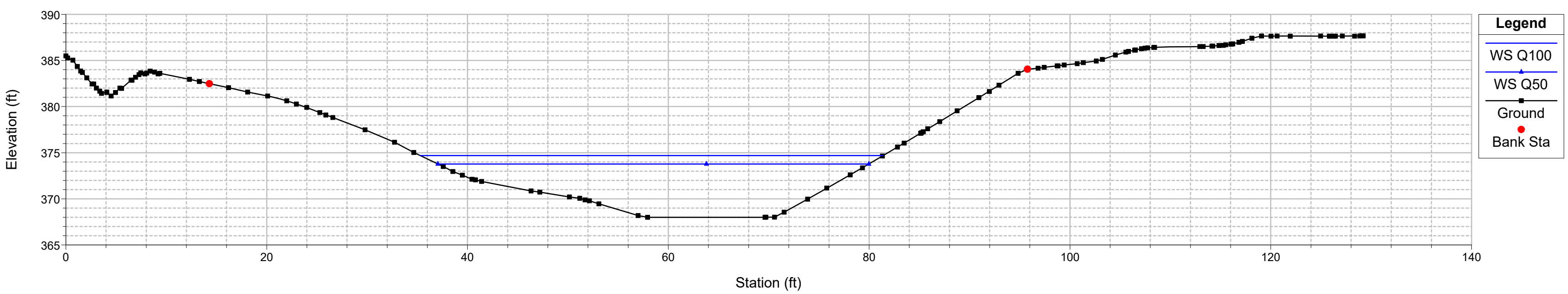

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 362 Proposed Graded Channel
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta


RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 322 Proposed Graded Channel
Elevation (ft)
Station (ft)
Legend
WS Q100
WS Q50
Ground
Bank Sta

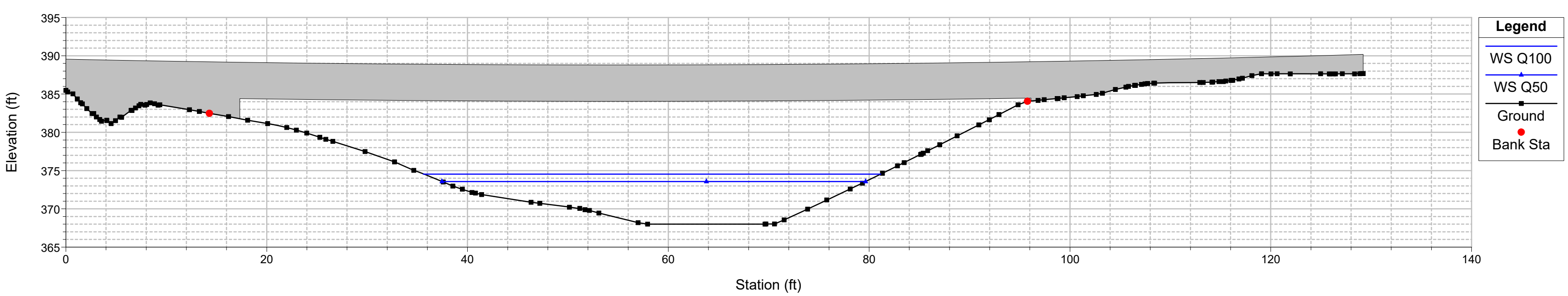
RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 295



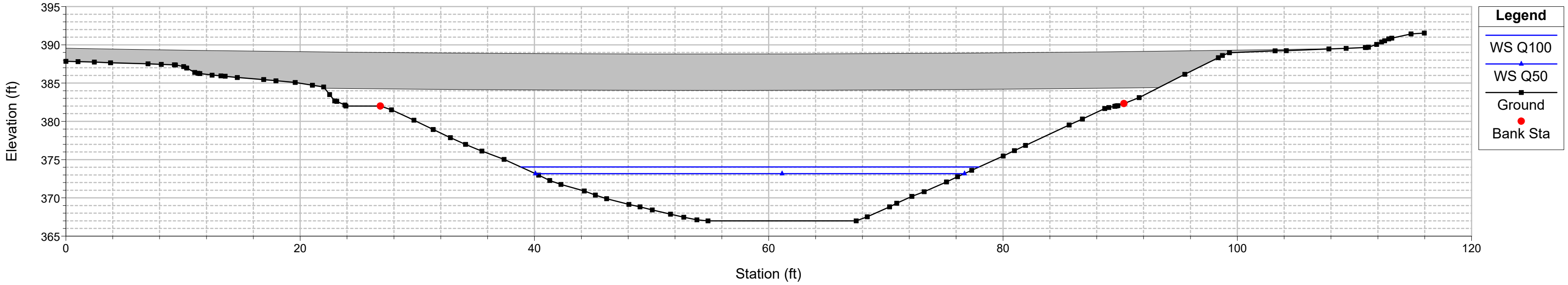

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 245 Upstream of Proposed Bridge



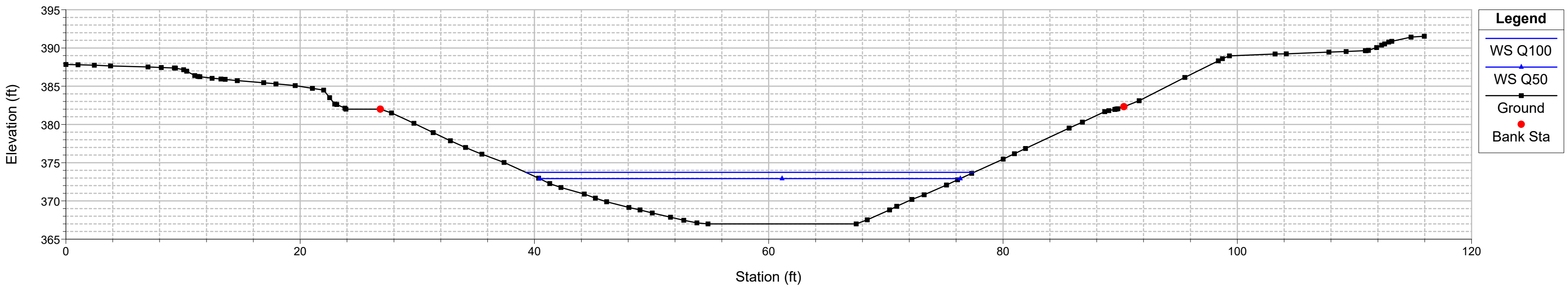

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 220 BR



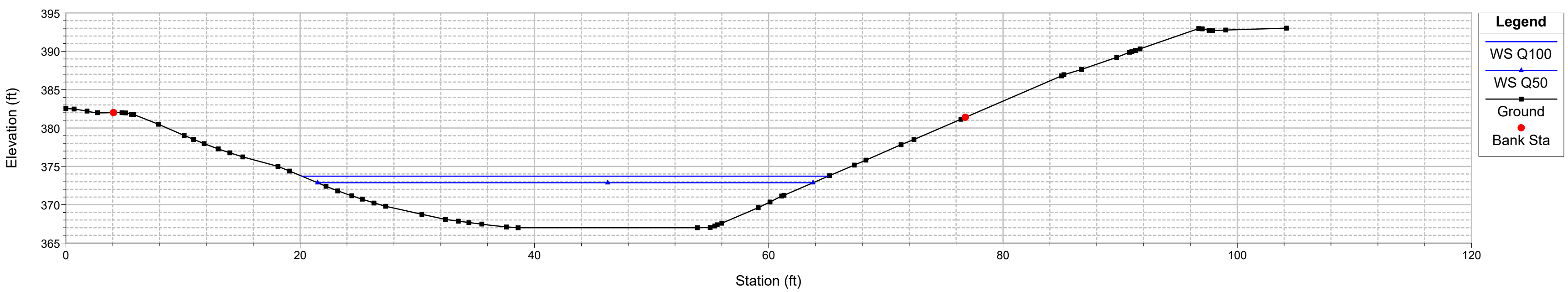
RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 220 BR



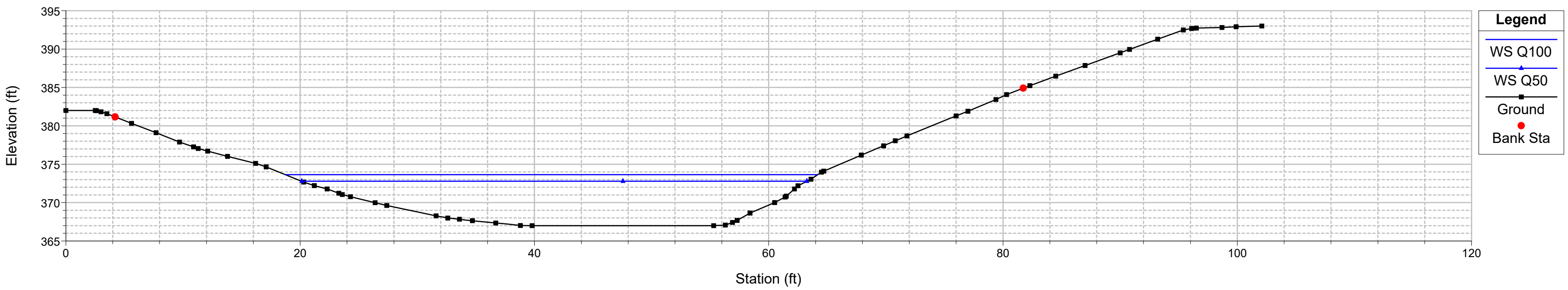

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 198 Downstream of Proposed Bridge



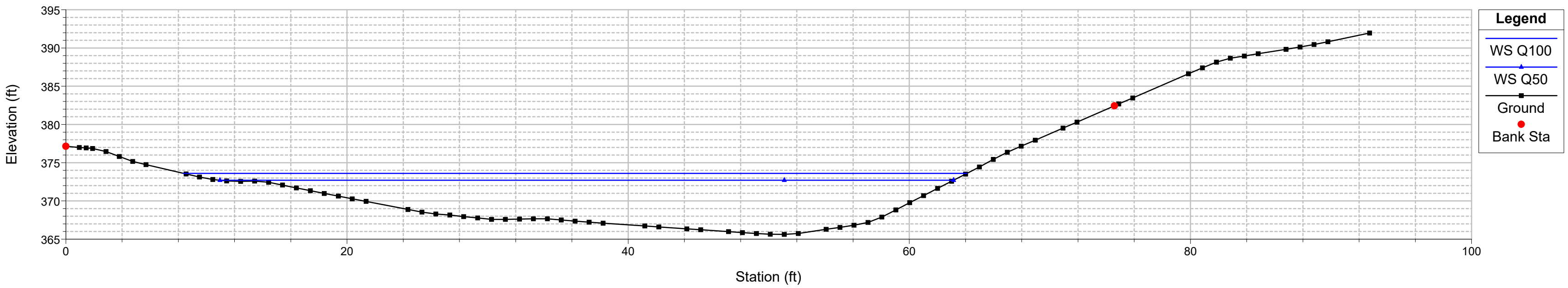

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 169



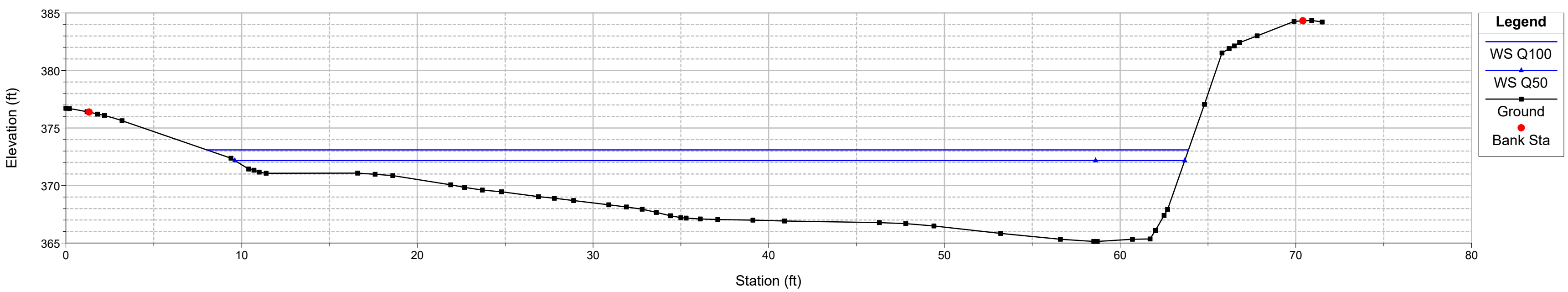
RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 156 DS Limit of Proposed Channel Grading



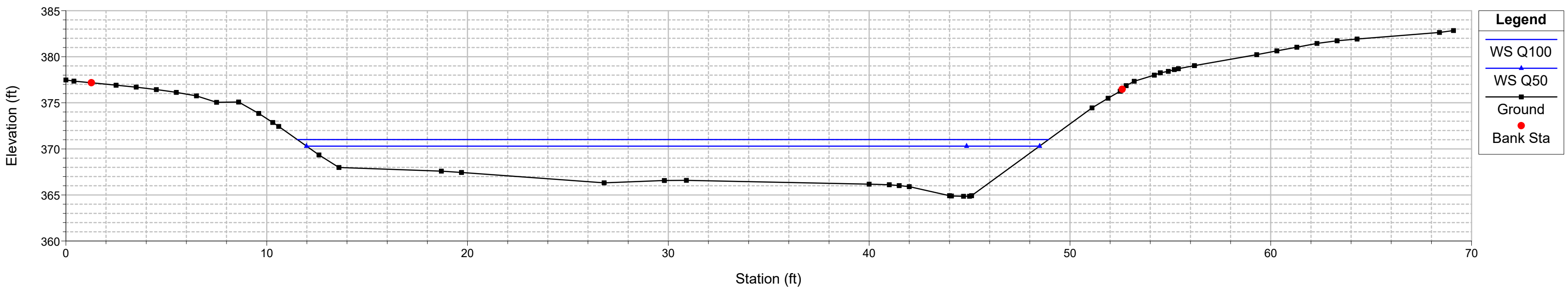

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 124



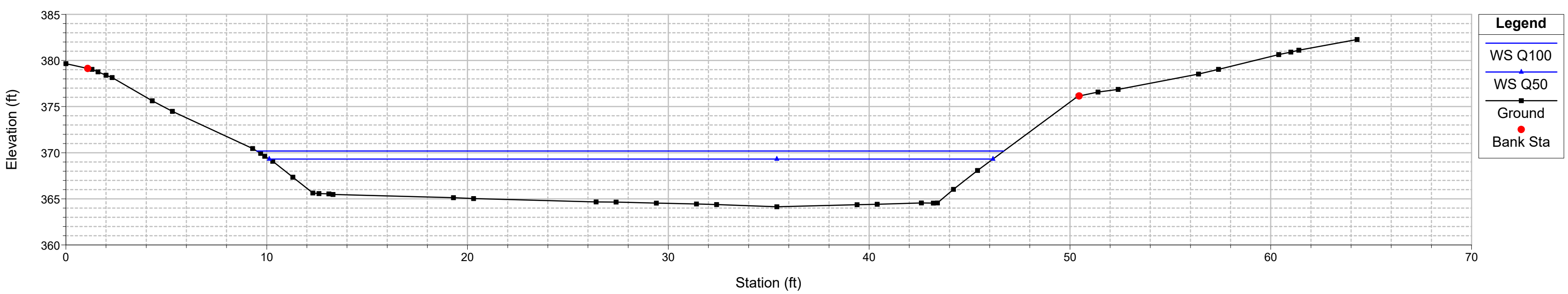

RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 62



RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 21




RobinsonCreek-Lambert Plan: Proposed_April 2021 5/17/2021
Geom: Proposed_April 2021 Flow: HEC-HMS Model Q100
River = Robinson Creek Reach = RB-Prop_01 RS = 1



# Appendix G Scour Analysis

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## Robinson Creek Bridge Replacement on Lambert Lane
## Mendocino County, California
### Ultimate (Contraction) Scour

100-year flow (1,750 cfs)
Calculation guideline from HEC-18 5th Edition
Proposed

**Equation 6.7:**

$$\tau = \gamma \left( \frac{V_2 n}{K_u} \right)^2 y_o^{-1/3}$$

| Variable | English Units | | Metric Units | | Description |
|---|---|---|---|---|---|
| $\tau$ | 2.8 | lb/ft^2 | 135.9 | N/m^2=Pa | initial shear stress for a specific flow |
| g | 62.4 | lb/ft^3 | 9800 | N/m^3 | unit weight of water (62.4 lb/ft^3 and 9800 N/m^3) |
| $V_2$ | 8.8 | ft/s | 2.7 | m/s | average velocity in contracted section |
| n | 0.046 | | 0.046 | | Manning's roughness coefficient |
| $K_u$ | 1.486 | | 1 | | 1.486 for U.S. Customary, and 1.0 for S.I. |
| $y_o$ | 4.3 | ft | 1.3 | m | Upstream flow depth |
| $\tau_c$ | 0.004 | lb/ft^2 | 0.2 | N/m^2=Pa | Critical shear stress (from Figure 6.11) |
| CHECK | Contraction scour will occur | | | | If initial shear stress exceeds critical value, then contraction scour will occur during that flow period, and the ultimate scour is computed from Equation 6.6. |

**Equation 6.6:**

$$y_{s-ult} = 0.94 y_1 \left( \frac{1.83 V_2}{\sqrt{g y_1}} - \frac{K_u \sqrt{\frac{\tau_c}{\rho}}}{g n y_1^{1/3}} \right)$$

| Variable | English Units | | Metric Units | | Description |
|---|---|---|---|---|---|
| $y_1$ | 4.3 | ft | 1.3 | m | Upstream average flow depth |
| $V_2$ | 8.8 | ft/s | 2.7 | m/s | Average velocity in contracted section |
| $\tau_c$ | 0.00 | | 0.2 | N/m^2=Pa | Critical shear stress of channel bed material |
| n | 0.046 | | 0.046 | | Manning's roughness coefficient |
| $K_u$ | 1.486 | | 1 | | 1.486 for U.S. Customary, and 1.0 for S.I. |
| $\rho$ | 2.8 | slugs/ft^3 | 1450 | kg/m^3 | Density of channel bed material (from 1250 to 1800) |
| g | 32.2 | ft/s^2 | 9.81 | m/s^2 | acceleration due to gravity |
| $D_{50}$ | | | 0.45 | mm | grain size for which 50% of bed material is finer |
| $y_{s\_ult}$ | 5.4 | ft | 1.7 | m | Ultimate contraction scour |

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Fax: 925.941.0018
www.wreco.com

# Robinson Creek Bridge Replacement on Lambert Lane
# Mendocino County, California
## Local Scour at Abutments - Froehlich or HIRE

100-year flow (1,750 cfs)
Calculation guideline from HEC-18 5th Edition
Proposed

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

**Left Overbank = Abutment Abutment 1 (Southwest)**

| | | |
|---|---|---|
| Water surface elevation | 374.5 | ft |
| Channel elevation | 370.0 | ft |
| y1 = depth of flow at abutment on the overbank or in the main channel = | 4.5 | ft |
| L = length of embankment projected normal to flow = | 33.9 | ft |
| Ratio of projected embankment length to flow depth = L/y1 = | 7.5 | |
| Abutment scour equation to be used = | Froehlich | |

**Froehlich's Live Bed Abutment Scour Equation**

| | | |
|---|---|---|
| L' = length of active flow obstructed by the embankment = | 16.3 | ft |
| ya = average depth of flow on the flood plain = | 1.23 | ft |
| Ae = flow area of the approach cross section obstructed by the embankment = | 7.0 | ft^2 |
| Ve = flow velocity = | 4.0 | ft/s |
| Qe = flow obstructed by the abutment and approach embankment = Ae * Ve = | 28 | ft^3/s |
| Fr = Froude Number of approach flow upstream of the abutment = | 0.64 | |
| ϴ = abutment skew = | 60 | degrees |
| K1 = coefficient for abutment shape = | 0.55 | |
| K2 = coefficient for angle of embankment shape = (ϴ/90)^0.13 = | 0.95 | |
| Ys = abutment scour = ya*(2.27*k1*k2*((L'/ya)^0.43)*(Fr^0.61)+1) = | **4.6** | **ft** |

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# Robinson Creek Bridge Replacement on Lambert Lane
# Mendocino County, California
## Local Scour at Abutments - Froehlich or HIRE

100-year flow (1,750 cfs)
Calculation guideline from HEC-18 5th Edition
Proposed

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

**Right Overbank = Abutment Abutment 2 (Northeast)**

| | | |
|---|---|---|
| Water surface elevation | 374.5 | ft |
| Channel elevation | 370.0 | ft |
| y1 = depth of flow at abutment on the overbank or in the main channel = | 4.5 | ft |
| L = length of embankment projected normal to flow = | 22.3 | ft |
| Ratio of projected embankment length to flow depth = | 4.9 | |
| Abutment scour equation to be used = | Froehlich | |

**Froehlich's Live Bed Abutment Scour Equation**

| | | |
|---|---|---|
| L' = length of active flow obstructed by the embankment = | 7.9 | ft |
| ya = average depth of flow on the flood plain = | 1.05 | ft |
| Ae = flow area of the approach cross section obstructed by the embankment = | 6.0 | ft^2 |
| Ve = flow velocity = | 3.5 | ft/s |
| Qe = flow obstructed by the abutment and approach embankment = Ae * Ve = | 21 | ft^3/s |
| Fr = Froude Number of approach flow upstream of the abutment = | 0.61 | |
| ϴ = abutment skew = | 120 | degrees |
| K1 = coefficient for abutment shape = | 0.55 | |
| K2 = coefficient for angle of embankment shape = (ϴ/90)^0.13 = | 1.0381068 | |
| Ys = abutment scour = ya*(2.27*k1*k2*((L'/ya)^0.43)*(Fr^0.61)+1) = | **3.4** | **ft** |

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# Appendix H Scour Countermeasure Calculations

## Robinson Creek Bridge Replacement on Lambert Lane
## Mendocino County, California
### Streambank Rock Slope Protection
### Calculation guideline from Caltrans Highway Design Manual

Input from HEC-RAS for Proposed Alternative, July 2018 version

100-year Flow (1,750 cfs)

Input

| Location along stream: | Upstream | Upstream Face | Downstream Face | Downstream | |
|---|---|---|---|---|---|
| $V_{avg}$ | 8.5 | 8.8 | 9.1 | 9.7 | ft/s |
| g | 32.2 | 32.2 | 32.2 | 32.2 | ft/s$^2$ |
| Depth based on | Average | Average | Average | Average | |
| y | 4.5 | 4.4 | 4.9 | 4.7 | ft |
| $S_f$ | 1.1 | 1.1 | 1.1 | 1.1 | |
| $C_s$ | 0.3 | 0.3 | 0.3 | 0.3 | |
| Cross section location: | Outside of bend | Outside of bend | Outside of bend | Outside of bend | |
| $C_v$ | 1.17 | 1.17 | 1.16 | 1.16 | |

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

| | | | | | |
|---|---|---|---|---|---|
| $R_c$ | 165 | 165 | 165 | 165 | ft |
| W | 46.1 | 45.6 | 39.1 | 38.3 | ft |
| $C_t$ | 1.0 | 1.0 | 1.0 | 1.0 | |
| $S_g$ | 2.65 | 2.65 | 2.65 | 2.65 | |
| Type of channel: | Trapezoidal | Trapezoidal | Trapezoidal | Trapezoidal | |
| $V_{des}$ | 10.9 | 11.2 | 11.1 | 11.7 | ft/s |
| $K_1$ | 0.72 | 0.72 | 0.72 | 0.72 | |
| $\theta$ | 33.7 | 33.7 | 33.7 | 33.7 | degrees |
| SS | 1.5 | 1.5 | 1.5 | 1.5 | |
| $D_{30}$ | 1.1 | 1.2 | 1.1 | 1.3 | ft |
| $D_{50}$ | 1.3 | 1.4 | 1.3 | 1.5 | ft |
| $D_{50}$ | **15.7** | **17.0** | **16.1** | **18.5** | inches |
| | IV | IV | V | V | RSP Class |
| | **300 lb** | **300 lb** | **1/4 ton** | **1/4 ton** | Median particle weight |
| | **15** | **15** | **18** | **18** | Median particle diameter (inches) |

## Robinson Creek Bridge Replacement on Lambert Lane
## Mendocino County, California
### Rock Slope Protection Calculations for Abutments
### Calculation guideline from HEC-23 3rd Edition

Input from HEC-RAS for Proposed Alternative, July 2018 version
100-year Flow (1,750 cfs)

| Location | Upstream | Upstream Face | Downstream Face | Downstream | |
|---|---|---|---|---|---|
| V | 8.5 | 8.8 | 9.1 | 9.7 | ft/s |
| g | 32.2 | 32.2 | 32.2 | 32.2 | $ft/s^2$ |
| y | 4.5 | 4.4 | 4.9 | 4.7 | ft |
| Fr | 0.71 | 0.74 | 0.72 | 0.78 | |
| Equation | **Equation 14.1** | **Equation 14.1** | **Equation 14.1** | **Equation 14.1** | |

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 | 4.5 | 4.4 | 4.9 | 4.7 | 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 | 8.5 | 8.8 | 9.1 | 9.7 | average velocity in contracted section, ft/s |
| g | 32.2 | 32.2 | 32.2 | 32.2 | gravitational acceleration, $ft/s^2$ |
| $D_{50}$ | 1.4 | 1.5 | 1.6 | 1.8 | median stone diameter, ft |
| $D_{50}$ | **16.6** | **17.8** | **19.1** | **21.5** | median stone diameter, inches |

| | | | | |
|---|---|---|---|---|
| V | V | V | VI | RSP Class |
| 1/4 ton | 1/4 ton | 1/4 ton | 3/8 ton | Median particle weight |
| 18 | 18 | 18 | 21 | 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 | 4.5 | 4.4 | 4.9 | 4.7 | 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 | 8.5 | 8.8 | 9.1 | 9.7 | 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 | N/A | N/A | N/A | median stone diameter, ft |
| $D_{50}$ | N/A | N/A | N/A | N/A | median stone diameter, inches |

| | | | | |
|---|---|---|---|---|
| | | | | RSP Class |
| | | | | Median particle weight |
| | | | | Median particle diameter (inches) |