DENNEHOTSO LOOP ROAD
NR6460 & NR6461
Drainage Report

Dibble Project No. 101411.01

December 22, 2023

DIBBLE

DENNEHOTSO LOOP ROAD
NR6460 & NR6461

Drainage Report

Apache County, Arizona

Dibble Project No. 101411.01

Prepared For: Navajo Department of Transportation (NDOT)
PO Box 4620
Window Rock, AZ 86515

December 22, 2023

Prepared By: Dibble
Josh Papworth, PE, CFM
Senior Engineer – Flood Control
1626 N Litchfield Road, Suite 150
Goodyear, AZ 85395
Dibble & Associates Consulting Engineers, Inc., dba Dibble

Table of Contents

List of Figures

List of Tables

Appendices

List of Abbreviations

AASHTO	American Association of Highway and Transportation Officials
ADOT	Arizona Department of Transportation
BIA	Bureau of Indian Affairs
CFS	Cubic Feet per Second
CMP	Corrugated metal pipe
CSPA	Corrugated Steel Pipe Arch
Elev	Elevation
EMS	Emergency Medical Service
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIRM	Federal Insurance Rate Map
FIS	Flood Insurance Study
ft	Feet
hr	Hour
HW	Headwater
in.	Inch
NAD83	Northern American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NDOT	Navajo Department of Transportation
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Services
PDDM	Project Development and Design Manual
Q	Discharge
RCP	Reinforced Concrete Pipe
ROW	Right-of-Way
sf	Square-Foot
TW	Tailwater
USACE	U.S Army Corps of Engineers
USBR	U.S Bureau of Reclamation
USDA	U.S Department of Agriculture
USGS	United States Geological Survey

EXECUTIVE SUMMARY

The Dennehotso community on the Navajo Nation in Apache County, Arizona, is served by a network of unpaved roads that become difficult to pass after storm events. The Navajo Division of Transportation (NDOT) has contracted Dibble to provide analysis and design for improvements to the roadway network, also known as Dennehotso Loop Road. Improvements include roadway paving, a bridge crossing of Laguna Creek and drainage structures under the proposed roadway. Laguna Creek runs through the middle of Dennehotso Loop Road and currently has a bridge crossing on the east side of the loop road and a low flow crossing at the west end of the loop road.

Existing analysis shows that, although the terrain surrounding Dennehotso Loop Road drains towards Laguna Creek, there are no direct washes or swales that convey runoff from the drainage area directly to Laguna Creek. There are a series of ponding areas which fill and overtop, eventually draining toward the creek. The largest existing ponding area is Dennehotso Loop Road itself. The runoff that accumulates in the existing road eventually overtops and drains towards Laguna Creek by ponding into existing turnouts and adjacent farm fields. There are also two irrigation ditches parallel to Laguna Creek that restrict runoff flowing directly to Laguna Creek. It is recommended that the existing drainage pattern be maintained allowing runoff to pond in roadside ditches and pipes which eventually drain to existing low areas, moving runoff towards Laguna Creek. Where possible, the turnouts that are affected by existing runoff will be moved to reduce the impact that the storm events have on the turnouts.

There are existing levees on the west and north side of Dennehotso Loop Road that were installed to divert and contain the runoff in retention areas. There is a breech in the levee which allows the runoff to cross Dennehotso Loop Road and drain toward Laguna Creek. The wash created by the breech crosses a culturally sensitive area near Dennehotso Loop Road. The double barrel 6-foot by 3-foot box culvert proposed at that crossing is sized based on the existing wash dimensions instead of hydrologic/hydraulic analysis to limit the disturbance to the culturally sensitive area. Armoring will be added to the wash near culturally sensitive areas to limit further degradation of the site.

A new, single span, concrete bridge crossing of Laguna Creek is proposed. As part of the new bridge construction, an existing 6-inch waterline will be relocated to a location just downstream of the new bridge abutments and encased. Revetment mattresses (wire-tied riprap) will provide stabilization of the wash banks at the new crossing, protecting the bridge from wash scour and bed degradation.

1. INTRODUCTION

1.1 Project Description

NDOT has identified the need to improve the Dennehotso community road network. This project was included in the engineering On-Call project list. Dennehotso is a farming community, with an approximate population of 800, located in Apache County, Arizona in the Navajo Nation, approximately 26 miles northeast of Kayenta, Arizona. The community is comprised of private residences, the Assembly of God Church, the Dennehotso Chapter House, and the Dennehotso Boarding School. Dennehotso is located on the north side of US 160 and is serviced by a paved and unpaved loop road network comprised of Navajo Roads N6460 and N6461, also known as Dennehotso Loop Road. The unpaved roads become difficult to pass during storm events causing inconvenience to travelers, dangerous conditions, and they require continuous maintenance. Dibble has analyzed the existing drainage patterns of the project area, including the roadways and the surrounding terrain, to help design the roadway improvements. It is recommended that the existing drainage patterns should be maintained, and the roadway improvements will be designed to be protected during storm events.

This drainage report for the Dennehotso Loop Road was prepared to document data collection efforts, methodologies and calculations, alternatives analyses, and recommendations for the roadway drainage system and the Dennehotso Loop crossings of Laguna Creek and the levee breech wash.

1.2 Study Area

The project site is located in Sections 21, 22, 23, 26, 27, 28, 33 and 34 of Township 40 North, Range 23 East, Apache County, Arizona. The existing drainage areas impacting the project site consists of a mixture of hillside areas, desert rangeland and mountain terrain with rock outcrop areas. The project location and primary elements can be seen as **Figure 1**.

There are three access roads between US 160 and Dennehotso Loop Road:

- The West Connector Road, which comprises the west segment of Dennehotso Loop Road, is unpaved outside of the US160 right-of-way.
- The Central Connector Road is paved from US160 to a subdivision within Dennehotso.
- The East Connector Road is the main access for the Dennehotso Boarding School and is chip sealed from the US160 right-of-way to Dennehotso Loop Road.

Area flooding is typically caused by heavy rains, monsoons, or tropical storms. The period of extreme flooding starts in mid-July and can extend into the late fall months. The monsoons typically occur mid-July through mid-September. Flooding in the fall months generally occurs from tropical storms.

There are no clear natural washes or swales crossing Dennehotso Loop Road conveying runoff to Laguna Creek. The drainage characteristics have been modified over the years due to farming and grazing. Drainage is conveyed towards Laguna Creek by a series of ponding areas which eventually overtop the roadway and flow towards the creek. The largest ponding area is Dennehotso Loop Road itself. Off-site runoff draining toward Laguna Creek is captured by Dennehotso Loop Road. There are two irrigation ditches parallel to Laguna Creek, one to the north and one to the south, which further restrict runoff flowing directly to Laguna Creek.

The runoff that ponds in Dennehotso Loop Road from the West Connector Road intersection to the existing Laguna Creek Bridge has six outlet locations where the runoff drains north or west towards Laguna Creek. The runoff that ponds in Dennehotso Loop Road from the existing Laguna Creek Bridge to the West Connector Road intersection has ten outlet locations where the runoff drains south or east towards Laguna Creek. Most of the ponding outlets are located on existing driveway turnouts, which have also been graded lower than the surrounding areas. There are some sporadic locations where the road is higher than the surrounding terrain and the runoff from the road sheet flows into the surrounding areas. These areas are mostly on the west and east portions of the loop road near the retention basin and bridge.

The East and Central Connector Roads are higher than surrounding terrain and therefore runoff from these roads sheet flows to the surrounding areas where it ponds. There are no locations where off-site runoff crosses the East and Central Connector Roads. The West Connector Road is below the surrounding terrain and the off-site runoff drains into and is conveyed in the roadway to the north, similar to Dennehotso Loop Road.

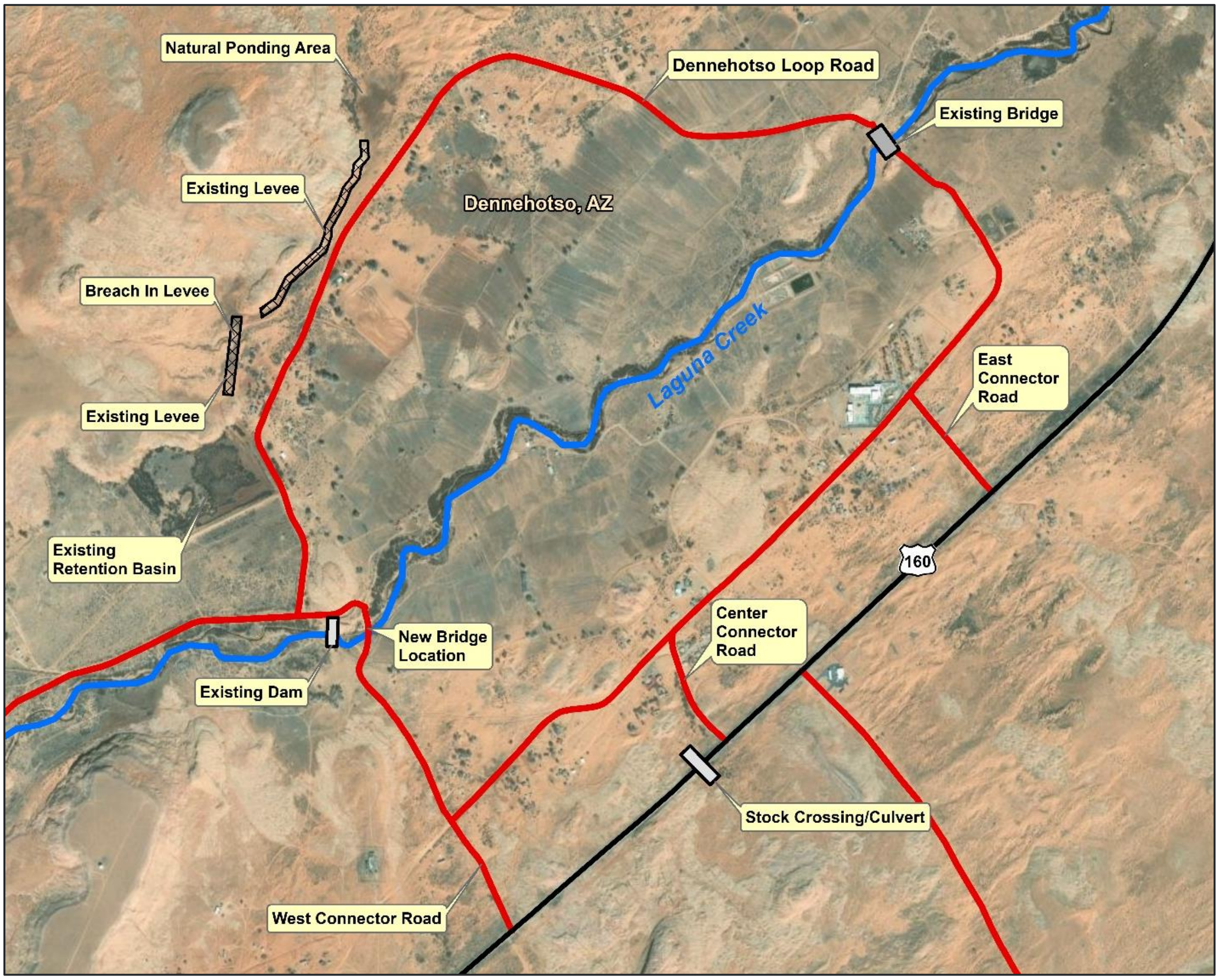


Figure 1 - Project Location Map

Laguna Creek flows from southwest to northeast through the community, crossing the Dennehotso Loop Road at two locations. A small concrete dam on the west side of Dennehotso was constructed in the 1920's to control Laguna Creek peak flows and to store and divert water for irrigation. This dam is located immediately upstream of the west section of the Dennehotso Loop Road crossing of Laguna Creek. A six-inch PVC waterline crosses the creek at the existing dip crossing location. A photo of the dam and low flow crossing is provided as **Figure 2**. The downstream crossing of Laguna Creek, on the east section of Dennehotso Loop Road, was improved with a mechanically stabilized earth bridge, which was constructed by the Federal Lands Highway in 2015.

Figure 2 - Existing Dam and Low Flow Crossing at Laguna Creek (October 16, 2014)

There are two existing levees within the project area: one between two rock outcroppings west of Dennehotso Loop road and one at the base of a rock outcropping north Dennehotso Loop Road. The levees were installed to protect residential structures and farm fields from flooding by diverting existing washes to either a retention basin to the south or a natural ponding area to the north. A breech in the levee has allowed the flows from the existing wash to cross Dennehotso Loop Road and outlet into farm fields to the southeast. The area around the wash crossing of Dennehotso Loop Road has been designated as a culturally sensitive site on both sides of the road. **Figure 3** shows the crossing of the wash created by the levee breech at Dennehotso Loop Road.

The off-site flows from the terrain surrounding Dennehotso Loop Road is limited by US 160 to the south and levees and retention basins on the west and north. There is only one culvert crossing US 160 and though the culvert may convey some runoff, its main purpose is for stock and pedestrian crossing of US 160. Any runoff conveyed by the culvert is limited from draining towards Dennehotso Loop Road by a rock outcropping located approximately 400 feet north of the culvert outlet.

Figure 3 - Levee Breech Crossing of Dennehotso Loop Road (October 16, 2014)

1.3 FEMA Floodplain

There is no flood map created for this location of the Navajo Nation. Laguna Creek is not listed in the Navajo County Flood Insurance Study (FIS). The project is located on the unprinted FIRM Panel 04001C0650E.

2. DATA COLLECTION

2.1 Site Visits

As part of the data collection efforts for this project, Dibble met with NDOT representatives at the project site on October 16, 2014 and took photographs to help support the hydraulic analysis assumptions. Field photographs are included in **Appendix A**.

2.2 Survey

A site survey was performed by Cooper Aerial Surveys Company and provided to Dibble on December 8, 2014. The survey provided an aerial photo of the area around and within the Dennehotso Loop Road as well topographic information for a 300-foot-wide corridor along the proposed loop road and connector road improvements. Data was provided on Navajo Nation horizontal datum and NAVD88 vertical datum. The water surface elevation data provided in this study is on NAVD88 vertical datum.

2.3 Existing Reports

In 2011, the Arizona Department of Transportation (ADOT) Bridge Group completed a bridge hydraulics report on the US 160 crossing of Laguna Creek crossing, approximately 3.3 miles downstream of the western Dennehotso Loop Road crossing proposed as part of the current project (**Reference 1**). That report included HEC-HMS hydrology and HEC-RAS hydraulic analysis that provided results for reference used in subsequent design of the now constructed eastern Dennehotso Loop Road crossing of Laguna Creek.

The Western Federal Lands Highway Division (WFLHD) of the U.S. Department of Transportation Federal Highway Administration (FHWA) provided design of the eastern Dennehotso Loop Road crossing of

Laguna Creek Bridge in 2014. As part of the design, two documents were produced, a geotechnical memorandum (**Reference 2**) and the *Dennehotso Bridge Replacement Final Hydraulics Report* (**Reference 3**). The geotechnical memorandum provides soil descriptions and recommendations on the bridge foundation. The hydraulics report provides hydrology and hydraulic analysis in support of the Laguna Creek Bridge design.

3. DESIGN CRITERIA

NDOT has requested that the standards and hydrology analysis completed by FHWA on the downstream, eastern Dennehotso Loop Road Bridge crossing of Laguna Creek be applied to the current bridge crossing of Laguna Creek. As such, the hydraulic design flood frequency established for this project is the 50-year storm, for which 2 feet of freeboard shall be provided beneath the bridge low chord. Based on FHWA guidance, the corresponding scour design flood frequency is the 100-year storm, and the scour design check flood frequency is the 200-year storm. Further, Bureau of Indian Affairs (BIA) criteria specifies that each crossing be designed as a “dry” crossing which would convey the 100-year flow under the roadway without overtopping. This requirement is adopted for this project as well.

NDOT has provided the locations of several culturally sensitive sites within the project area and has requested that any proposed design limit disturbance in these areas.

4. STUDY APPROACH AND METHODOLOGY

The design methodology followed guidance provided in the following publications:

- *Highway Drainage Guidelines,* AASHTO,2005.
- *Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites,* U.S. Geological Survey, 1993.
- *Guidelines for Geometric Design of Very Low-Volume Local Roads*, AASHTO, 2001.
- *Low Volume Roads Best Management Practices Field Guide*, USDA Forest Service, 2003.
- *State Standard for Watercourse Bank Stabilization 7-98*, ADWR, 1998.
- *Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona*, Simon, Li & Associates, 1998.
- *Computing Degradation and Local Scour*, USBR, 1984.

4.1 Roadway Drainage

An initial analysis of the drainage patterns for off-site and on-site flows revealed that very little runoff from the south side of US 160 crosses the highway into the project area. Dennehotso Loop Road has an untreated surface and is between one and three feet below the surrounding terrain due to years of grading maintenance. The terrain is generally flat sloping towards the loop road between US 160 and Dennehotso Loop Road. There are no defined washes conveying runoff towards the loop road. It is assumed that rainfall in this area is mostly retained in small ponding areas which can be seen as patches of vegetation in the aerial photography.

The off-site runoff from the north of the project is limited by levees and retention areas. There is one area where the levee is breached and runoff crosses Dennehotso Loop Road and flows toward Laguna Creek. The wash created by the breech crosses a culturally sensitive area near Dennehotso Loop Road.

The runoff that drains into the existing roadway is usually limited to a corridor on either side of the road. There are no defined washes or drainage corridors, and the existing drainage patterns adjacent to the existing roadway will be maintained while protecting the proposed roadway. Exhibits showing the existing drainage patterns and proposed drainage patterns are located in **Appendix B**.

The culturally sensitive sites near the levee breech wash will limit the drainage structure dimensions that can be installed at the Dennehotso Loop Road crossing. NDOT has requested that the drainage structure at this location not be sized based on hydrology and hydraulics, but rather in matching the existing wash dimensions in order to protect the culturally sensitive sites as much as possible.

4.2 Laguna Creek Crossing

4.2.1 Hydrology Methodology

For design of a new bridge crossing of Laguna Creek at the west end of the Dennehotso Loop Road, NDOT directed Dibble to make use of the hydrologic analysis that was done for the downstream, eastern Dennehotso Loop Road bridge crossing of Laguna Creek, constructed in 2015. There are no major inflows between the two projects, so it is reasonable to conclude that the creek discharges are applicable to the proposed bridge location, approximately 1.5 miles upstream. The *Dennehotso Bridge Replacement Final Hydraulics Report* (final hydraulics report) was produced by FHWA (specifically, WFLHD) for the downstream bridge. It included discussion of the previous hydrology done by ADOT as part of the *Initial Bridge Hydraulics Report for Laguna Creek Bridge* (US 160 hydraulics report), 2011. The relevant data from that FHWA final hydraulics report is presented in this section, and the entire report is included in **Appendix C**.

Laguna Creek originates from Tsegi Canyon and flows northeast. The wash flows just north of the Town of Kayenta, and crosses US 160 around MP 420.1. The annual precipitation is approximately 9 inches based on StreamStats (**Reference 4**). The entire watershed is within the Navajo Nation and development is sparse consisting of rural residences and ranching. There are irrigation ditches that divert flow in the area.

The total drainage area to the Laguna Creek US 160 bridge is 484 square miles. As part of the US 160 hydraulics report, a HEC-HMS hydrologic model was created to estimate flows at the bridge. The Green and Ampt methodology and the Clark unit hydrograph was used to estimate rainfall losses with NOAA 14 Atlas rainfall data. The contributing area was delineated into ten drainage basins. As part of the final hydraulics report, peak flows were calculated using the USGS Regression calculation (**Reference 5**), and peak flows were compared.

The project is in Flood Region 8. USGS StreamStats was used for computing the drainage area (454 square miles), average basin slope (16.8 percent), and average basin elevation (6,050 feet). The regression equations significantly overpredicted the station values used in the regression analysis, suggesting the regression equations may be overly conservative in some areas.

The 2, 10, 50, and 100-year flood discharges predicted by the USGS regression equations. The 50-year design discharge predicted by the USGS regression equation overestimated flows compared to the 50-year calculated by the HEC-HMS model. The 100-year flows from the regression equation were similar to the 100-year flow from the HEC-HMS hydrologic model. A comparison of the peak discharges calculated by ADOT using HEC-HMS and by FHWA using regression equations is provided in **Table 1**. Also shown in **Table 1** are the discharge values selected for the current design of the western Dennehotso Loop Road crossing of Laguan Creek.

Table 1 - Peak Discharges (cfs)

Estimate Method	Drainage Area (mi²)	Recurrence Interval					
		2-Year	5-Year	10-Year	50-Year	100-Year	200-Year
FHWA USGS Regression Equation	454	1,388	4,052	7,958	10,241	15,949	
ADOT US 160 HEC-HMS	484			6,895	10,826	23,370	
Current Design	454	1,388	4.052	7,958	10,241	15,949	12,000

The 200-year discharge is required to perform scour check analyses. USGS does not publish an equation with which to estimate the 200-year discharge; therefore a 200-year storm discharge was estimated by plotting peak discharges against return period for the 2-year through 500-year storm events and fitting a curve. The resulting peak discharge for the 200-year event was 12,000 cfs.

4.2.2 Hydraulics Methodology

A one-dimensional (1D), steady state HEC-RAS analysis was prepared to analyze the flow characteristics at the Laguna Creek crossing location. The cross-section geometry, reach lengths, and Manning's "n" values were generated using the aerial and topographic mapping information. The results of the HEC-RAS analyses were used to understand the existing hydraulic conditions, model the proposed condition, and compute the estimated scour depths. Cross sections were created approximately every 100-feet using the topographic mapping. Manning's n-values were updated based on aerial imagery and field observations. Design flow rates used in the HEC-RAS model were taken from the previous study done at the downstream bridge location as discussed in the previous section and are shown in **Table 1**.

Results of the 1D HEC-RAS modeling supported that creek flow will break out from the creek, upstream of the existing dam and new bridge location. The magnitudes of these breakouts were determined using lateral weir structures within the HEC-RAS program. The analysis was done for both the existing and proposed condition, the proposed condition resulting in less breakout of flows for each return period. The difference in breakout flows between the two conditions was less than 7%. The proposed condition breakout peak discharges are summarized in **Table 2**.

Table 2 – Laguna Creek Proposed Condition Breakout Discharges

Storm	North Lateral Wier (cfs)	South Lateral Wier (cfs)
50-Year	1468	1101
100-Year	2256	1435
200-Year	2881	1687

The breakout of these flows reduces the design discharge at the new bridge location as compared locations upstream; however, there was some concern that these break outs may rejoin the creek prior to the new crossing. To assess this possibility a two-dimensional (2D) HEC-RAS analysis was performed. **Figure 4** provides the analysis extents. This analysis concluded that the north break out will not rejoin the creek prior to the bridge crossing. The south breakout may rejoin the creek by way of Dennehotso Loop Road; the location is shown on **Figure 4**. The magnitude of flow returning to the creek varied by design storm frequency as shown in **Table 3**. These flow rates were added to the design discharges within the 1D HEC-RAS model at the cross section just upstream of the bridge as part of the hydraulic and scour analyses.

Table 3 – Rejoining Discharges at Dennehotso Road

Storm	Discharge (cfs)
50-Year	37
100-Year	63
200-Year	84

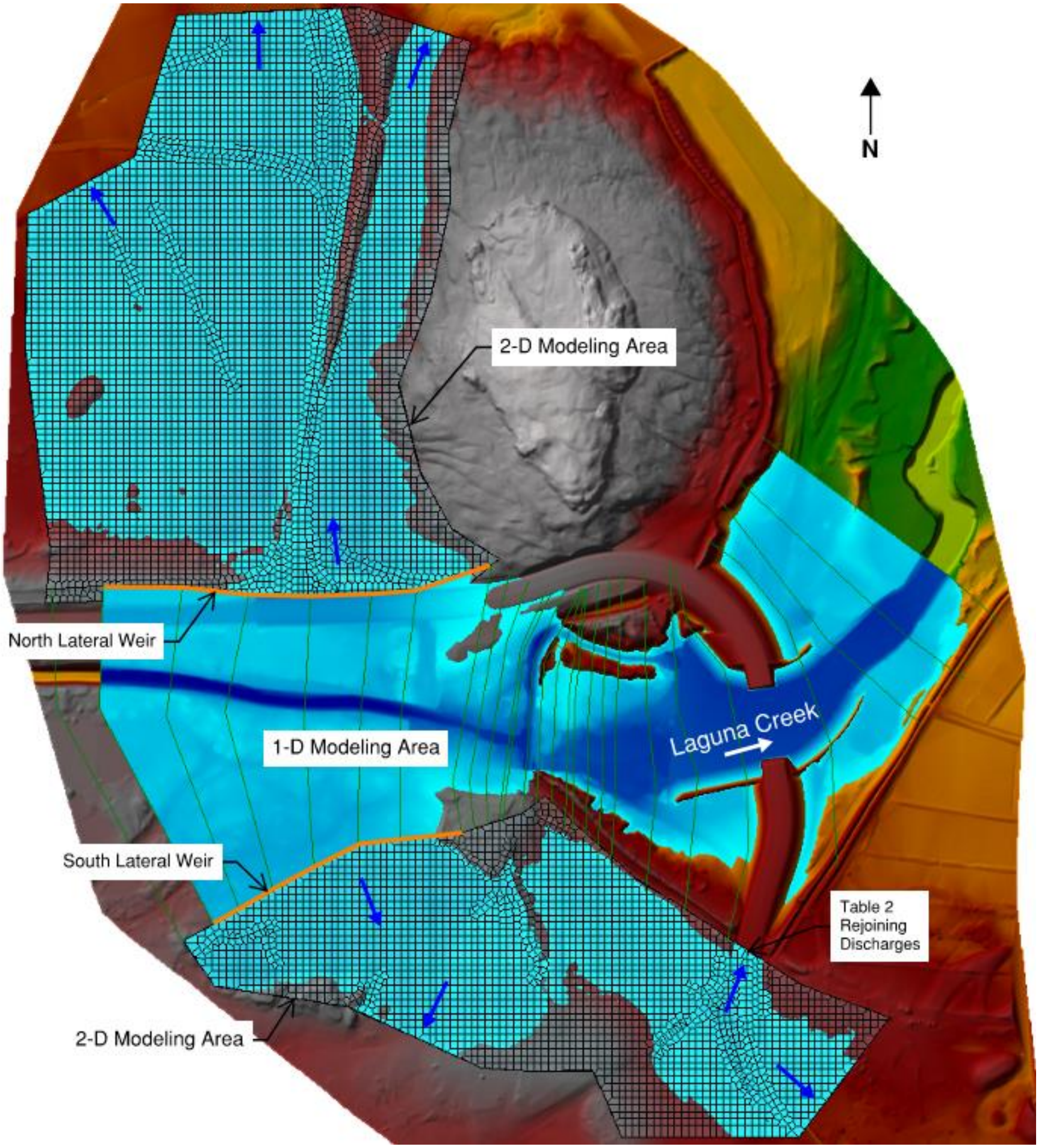


Figure 4 – Laguna Creek 2-D Modeling Areas

4.2.3 Scour Analysis

A scour analysis was done using the information from the geotechnical report and the results from the 1D HEC-RAS model. The analysis methodology and recommendations are presented in a memorandum that is included in **Appendix E**. The analysis presented in the memorandum provided an analysis of the 100-year storm event, the scour design flood frequency. A subsequent analysis was performed of the 200-year storm event, the scour design check flood frequency. The 200-year scour design check resulted in the more robust scour protection requirement. It should be noted that the original 100-year scour analysis did not include the addition of the rejoining breakout discharge described in **Section 4.2.2**. Therefore, to confirm the findings, the calculations were updated with the revised discharges. This and the 200-year storm event scour analysis are included in **Appendix E**.

There are two areas of concern with the proposed bridge that will require scour protection, the bridge abutments and the area downstream of the bridge where an existing 6-inch waterline is to be relocated. The scour depths for these locations are shown in **Table 4**.

Table 4 - Recommended Scour Depths

Location	Total Scour Depth (ft)
Bridge Abutments	13.2
Downstream of Bridge (Waterline Crossing)	9.0

5. RESULTS AND RECOMMENDATIONS

5.1 Roadway Drainage

The proposed roadway should sheet off into surrounding farm fields and existing ponding areas wherever possible. In areas where the proposed roadway is lower than the surrounding terrain, it is recommended that the roadway include roadside ditches that act as retention areas. This will match the current drainage of the existing ponding areas of the existing roadway. The outlets of the proposed ditches should match the locations where the existing roadway ponding overtops to the surrounding areas. The ditches and roadway should be designed such that if the ditches overtop, the runoff will overtop the roadway before overtopping into the adjacent residential areas. The culverts used to convey runoff should be 24-inches wherever possible for ease of maintenance. The area is mainly sheet flow with no incised channels, arched pipes with an equivalent diameter of 24-inches can be used to lower the amount of fill required.

Existing utilities and culturally sensitive sites may limit the depth of proposed roadside ditches. The size of the proposed roadside ditches and culverts are not significant and should match the existing drainage patterns.

The wash created by the levee breech crosses Dennehotso Loop Road at culturally sensitive sites. The box culvert at this location should be sized to match the existing wash dimension to provide a safe roadway crossing of the wash while limiting the disturbance to the culturally sensitive sites. A double 6-foot span 3-foot height box culvert will best match the existing wash dimensions based on the topographic survey. The culturally sensitive areas on either side of the wash should be protected with riprap placed directly on the wash side slopes. The bottom of the wash should also be protected with riprap immediately upstream and downstream of the culvert to reduce erosion.

5.2 Bridge Hydraulic Results

The proposed bridge at the Dennehotso Road crossing is a single span concrete bridge with abutments on either side of the Laguna Creek crossing. The low chord of the bridge was set at least 2 feet above the 50-year water surface elevation of 5030.3. The banks around the bridge have been designed with gabion mattresses with 2 to 1 side slopes. The top of the bank was set at least 1-foot above the 100-year water surface elevation through the crossing. Modeling supports that construction of the proposed bridge will result in an approximate 1-foot rise in the 100-year water surface elevation for the portion of the creek that is downstream of the existing dam. The resulting water surface is contained within the creek banks and there are no structures present. The change in water surface elevation does not extend upstream of the dam in any significant way. The proposed condition HEC-RAS model results have been included in **Appendix D**.

5.3 Bank Protection Design

The geotechnical report and proposed condition hydraulic model were used to calculate the expected scour depth. The scour report and subsequent scour calculation for the 200-year scour check flood frequency has been included in **Appendix E**. Bank stabilization was designed using guidance provided in the Arizona State Standard for Watercourse Bank Stabilization (**Reference 6**). The geotechnical report indicated there is sandstone located at the bridge location; however, the subsurface limits and integrity are not clearly known. Therefore, revetment mattress (wire-tired riprap) was selected for bank/abutment protection. This consists of revetment mattress armoring of the proposed bank and extension of the mattress onto the wash bed. In the event that bed material is eroded, the revetment mattress will lower into the depression to maintain protection of the bank toe. A 6-inch waterline will be located to just downstream of the new bridge abutments. The majority of this relocated waterline will be protected by the revetment mattress, but there is a portion of waterline that is not protected and will be provided concrete encasement.

6. REFERENCES

Arizona Department of Transportation Bridge Group Bridge Hydraulics Section, *Initial Bridge Hydraulics Report for Laguna Creek Bridge*, Holbrook District – Apache County, February, 2011, Prepared by Mahmud Hasan and Approved by Itty P. Itty.

U.S. Department of Transportation Federal Highway Administration Geotechnical Memorandum GM10-14, *Final Foundation Recommendations Dennehotso Bridge AZ TR NAV 6460(1)*, April 2, 2014, From Robert Kraig Geotechnical Engineer to Keith Wong Project Manager.

U.S. Department of Transportation Federal Highway Administration Western Federal Lands Highway Division, *Dennehotso Bridge Replacement Final Hydraulics Report AZ TR NAV 6460(1)*, May 21, 2014, From Sven Leon WFLHD Hydraulics Engineer to Keith Wong WFLHD Project Manager.

US Geological Survey, StreamStats, Version 4.2.0

US Geological Survey, *Analysis of the Magnitude and Frequency of Peak Discharges for the Navajo Nation in Arizona, Utah, Colorado, and New Mexico*, 2006, USGS SIR 2006-5306.

Arizona Department of Water Resources flood Mitigation Section, *Watercourse Bank Stabilzation SSA 7-98,* May 1998.

Appendix A Field Photographs

Laguna Creek Dam, looking east

Laguna Creek Dam, looking southeast

Laguna Creek Dam, looking southeast

Laguna Creek Dam outlet, looking southeast

Laguna Creek looking west, upstream

Dennehotso Loop Road, showing typical incised roadway

Dennehotso Loop Road, showing typical incised roadway

Breakout wash, to be abandoned per NDOT

Levee breakout wash at Dennehotso Loop Road, downstream

West levee/retention area on the right, Dennehotso Loop Road

Levee breakout wash at Dennehotso Loop Road, upstream

New Laguna Creek Bridge, looking north

New Laguna Creek Bridge, looking north

Appendix B Roadway Drainage Patterns

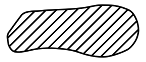
DENNEHOTSO LOOP ROAD
EXISTING DRAINAGE
PATTERN
N
Not To Scale
LEGEND
Ponding
Flow Direction
KEYMAP


DENNEHOTSO LOOP ROAD
EXISTING DRAINAGE
PATTERN
N
Not To Scale
LEGEND
Ponding
Flow Direction
KEYMAP

DENNEHOTSO LOOP ROAD EXISTING DRAINAGE PATTERN

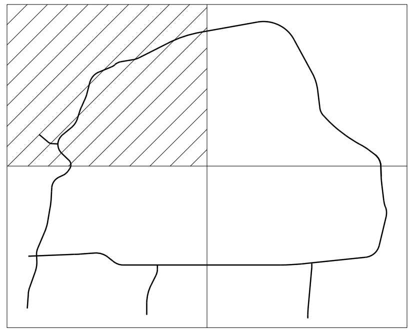
Not To Scale

LEGEND



Ponding

Flow Direction



KEYMAP


DENNEHOTSO LOOP ROAD
EXISTING DRAINAGE
PATTERN
N
Not To Scale
LEGEND
Ponding
Flow Direction
KEYMAP


DENNEHOTSO LOOP ROAD
PROPOSED DRAINAGE
PATTERN
N
Not To Scale
LEGEND
Pipe Culvert
Roadside Ditch
KEYMAP


DENNEHOTSO LOOP ROAD
PROPOSED DRAINAGE
PATTERN
N
Not To Scale
LEGEND
Pipe Culvert
Roadside Ditch
KEYMAP

DENNEHOTSO LOOP ROAD
PROPOSED DRAINAGE
PATTERN


DENNEHOTSO LOOP ROAD
PROPOSED DRAINAGE
PATTERN
N
Not To Scale
LEGEND
Pipe Culvert
Roadside Ditch
KEYMAP

Appendix C Hydrologic Memorandum

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Western Federal Lands Highway Division
610 E. Fifth Street
Vancouver, WA 98661-3801

DENNEHOTSO BRIDGE REPLACEMENT
FINAL HYDRAULICS REPORT

To:	Keith Wong, WFLHD Project Manager
From:	Sven Leon, P.E., WFLHD Hydraulics Engineer
Date:	May 21, 2014
Project:	AZ TR NAV 6460(1) – Dennehotso Bridge Replacement

Background

The Navajo Nation is replacing the existing Dennehotso Bridge (BIA Route N6460), Apache County, Arizona. The bridge crosses the Laguna Creek immediately downstream of the Dennehotso Community (Fig. 1). Western Federal Lands Highway Division (WFLHD) will develop the construction plans and specifications. Results of the site morphologic, hydrologic, and hydraulic analyses and recommendations for the bridge design and construction are presented.

Conclusions and Recommendations

The proposed design is intended to achieve an acceptable balance between the amount of approach road raise, abutment height, bridge length, channel excavation, approach road erosion risk, debris entanglement risk, and maintenance.

Bridge Low Chord

The stream is expected to transport a moderate amount of small to moderately large woody debris. Adequate clearance between the bottom of the bridge structure and design water surface level is needed for passing the woody debris and preventing damage to the bridge or abutment structures. The Arizona Department of Transportation requires a minimum clearance of 1 foot above the 50-year flood for low volume roads. Federal Highway Administration (FHWA) recommends a minimum clearance of 2 feet above the 50-year flood. Flood water tends to spread out over a wide floodplain. Flood flow is not expected to get deep enough to overtop the bridge deck or Geosynthetic Reinforced Soil Integrated (GRS) abutments. Given the tendency for flood water overtopping the banks to spread out across the floodplain, a clear span bridge configuration, and assuming routine debris removal, a minimum 1 foot above the 50-year clearance criteria is considered adequate for passing the expected woody debris.

A minimum bridge low chord elevation of 5,001.6 feet (project datum) for the left (looking downstream) abutment and 5,002.6 feet for the right abutment is recommended (measured at the upstream bridge face). The elevations provide 1 foot of clearance above the 50-year flood (5,000.6 feet) for the left abutment and 2 feet for the right abutment. The bridge deck is sloped 2 percent for drainage. A bridge with this low chord elevation requires raising the approach road profile 2 to 5 feet. The proposed low chord approximately matches the existing bridge low chord. Set the top of the GRS abutment walls equal to the adjacent bridge deck surface elevation for minimizing the risk of the abutment walls being overtopped by flood water.

Approach Road Overtopping

The proposed approach road profiles are only raised in the vicinity of the bridge. The left approach road is approximately 270 feet long and the right approach road approximately 240 feet long. The left approach road would have a 2.0 percent grade and the right a 2.6 percent grade. The raised segments only partially block the floodplain flow. Overtopping and erosion of the left approach road occurs for storm runoff and floods equal to and larger than the 10-year. Overtopping and erosion of the right approach road is predicted for storm runoff and floods equal to and larger than the 50-year.

Waterway Width

Maximize the flood flow capacity through the new bridge waterway by matching the downstream channel width and depth. The existing 50-feet wide channel upstream of the bridge has capacity for approximately 4,000 cubic feet per second (cfs) (10-year flood) before the banks are overtopped. The existing 90-feet wide channel immediately downstream of the bridge has capacity for approximately 8,000 cfs (50-year flood). Predicted hydraulic capacity of the proposed bridge assumes a single span, minimum waterway width of 92 feet, and excavating the stream bottom beneath the bridge to bedrock, approximately elevation 4,993.5 feet. A shorter bridge or less channel excavation would increase the frequency of flood water overtopping the stream banks and approach road embankments.

Channel Alignment and Abutment Location

The left stream bank has migrated to the north, resulting in a sharp stream bend immediately upstream of the existing bridge and a skewed flow alignment through the bridge. Future lateral bank migration is expected, but is limited by the sandstone bedrock outcropping. Place the right abutment near the existing bridge right abutment. Place the left abutment behind the existing bridge left abutment for achieving the design waterway width, improving flow alignment, and accommodating expected future lateral bank migration.

Stream Avulsion

The existing bridge is undersized for the estimated 10-year flood discharge. The center pier also collects woody debris. Floodwater could easily overtop the banks and flow around the bridge structure, incising a new channel and resulting in a stream avulsion. The proposed bridge is expected to increase flow conveyance capacity and reduce the amount of debris entangling on the structure. Both will dramatically decrease the stream avulsion risk.

Stream Profile Degradation

No evidence was found suggesting the channel profile is expected to degrade significantly in the 80 to 100-year service life of the proposed bridge.

Scour

The soft bedrock sandstone limits scour. Assuming the proposed bridge has a service life of 80 to 100 years, a bedrock erosion depth of 16 to 20 inches can be expected over the life of the bridge. To prevent the abutments from being undermined, place the bottom of the GRS abutments at least 18 to 24 inches into the bedrock.

Flood water and storm runoff will flow along and over the approach roads. Erosion is expected to expose the geosynthetic reinforcement in the integrated approach zones. The erosion could also expose and remove fill soil behind the GRS abutment. The GRS abutments are not expected to be damaged with the erosion of the road embankment material. Protect the approach road embankments from being eroded by installing riprap between the front face of the GRS abutments and the end of the integrated approach zone. Set the revetment crest elevation at the top of the GRS wall. Place the riprap toe on the bedrock channel bottom. Grade the finished surface of the riprap at 1.75(h):1(v). Use Class 5 riprap, placed in a minimum 4 feet thick layer. Grout the lower 2 feet of riprap where bearing on bedrock. Place the riprap on a geotextile underlayment where not bearing directly on bedrock. See Drawing H.10 and H.11 for riprap plan and sections. Installing the riprap and grouted-riprap is expected to reduce the frequency and extent of future road embankment erosion repair.

Stream Impacts

The proposed bridge waterway width and channel excavation is intended to closely match the existing stream channel immediately downstream of the bridge. Flow conveyance, sediment transport, sediment deposition, and woody debris conveyance through the bridge waterway should be similar to the existing natural channel immediately downstream of the bridge. A minor amount of stream bank erosion is expected along the left bank immediately downstream of the bridge. The left stream bank immediately upstream of the bridge is expected to continue to migrate laterally to the north. The extent and rate of migration is limited by the soft sandstone bedrock that outcrops along the lower left stream bank.

Estimated environment quantities below ordinary-high-water (2-year flood event):

- Channel excavation area- 2,700 square feet
- Channel excavation volume- 340 cubic yards
- Riprap fill area- 420 square feet
- Riprap fill volume- 30 cubic yards

Floodplain and Flood-rise Impacts

Based on the hydraulic modeling, the proposed bridge is not expected to increase flooding of adjacent property and insurable structures. Raising the approach road profile completely across the floodplain would block floodplain flow and increase the level of flooding. Impacts to the bridge hydraulics and flooding to upstream properties would need to be evaluated for any future modifications to the approach road profile.

Construction

Constructing the proposed bridge may require heavy track-mounted equipment operating on the stream bed, possibly in water up to 2 feet deep. Divert stream flow as needed for completing bridge abutment installation and riprap installation. During lower flow periods, December 1 to May 31, temporary flow deflectors and structures used for isolating in-stream work areas must have a minimum height of 3.0 feet above the stream bottom and be stable assuming 6 feet per second parallel flow. During higher flow periods, June 1 to November 30, temporary flow deflectors and structures used for isolating in-stream work areas must have a minimum height of 5.0 feet above the stream bottom and be stable assuming 8 feet per second parallel flow. Flow diversion structures must be able to convey the flood flow expected at the time of construction.

The hydraulic capacity of the bridge waterway relies on excavating the channel to a minimum elevation of 4993.5 feet. Verify during construction that the minimum elevation can be obtained. If the elevation cannot be obtained, contact the WFLHD Hydraulics Engineer.

Operation and Maintenance

After flood events woody debris should be removed from the bridge structure and GRS abutments. Assuming the average large woody debris capable of entangling in the bridge superstructure protrudes 2 feet above the water surface, the proposed design is expected to require removing woody debris from the bridge superstructure after a 25-year flood event. Riprap placed for controlling road embankment erosion should be inspected annually and after each extreme flood event. Replace or reposition dislodged stone. The approach roads are expected to be overtopped by storm runoff and flood water similar to what is occurring now. The approach roads should be inspected for erosion annually and after each extreme flood event. Rebuild any eroded road embankment. Areas experiencing frequent erosion may need riprap armoring.

Site Conditions

The existing bridge (161N64600) was constructed in 1975. It has two 30 feet long spans. The masonry wing-wall abutments and center pier are founded on soft, erodible sandstone bedrock (Photo 1). The top of the bridge deck is perched approximately 2 feet above the adjacent floodplain and approach roads (Photos 1, 3, and 7). Floodwater overtopping the stream banks flows across the approach roads where the approach roads are flush with the floodplain. Floodwater flows parallel to the approach roads where there is fill, causing erosion of the road fill and alluvial soil (Photo 6).

A 5 to 6 feet high waterfall is located approximately 80 feet downstream of the existing bridge (Photos 2 and 3). A second, 6 to 8 feet high waterfall is located approximately 200 feet downstream of the existing bridge (Photo 2). Based on review of satellite imagery (Google Earth Pro), both the lower and upper waterfalls have not migrated upstream significantly since 1997. There is sharp stream bend on the left stream bank immediately upstream of the existing bridge (Photo 5). Stream flow is directed at a skewed angle through the bridge opening. Based on satellite imagery (Google Earth Pro), the stream bank has migrated to the north approximately 8 to 10 feet since 1997.

Channel pattern immediately upstream and downstream of the project site is linear (Photos 2 and 4). The channel at the bridge crossing is incised 4 to 6 feet in fluvial sand deposits and 1 to 2 feet in the sandstone bedrock (Photos 4 and 5). Active channel width is 35 to 40 feet upstream of the bridge and 60 to 70 feet immediately downstream. Active channel depth (ordinary-high-water) is approximately 2 to 3 feet. Stream bank top is 5 to 6 feet above channel bottom. Height of debris entangled on bank vegetation and bridge pier indicate the site has experienced water depths during flooding of 4 to 6 feet (Photo 8). Flood-prone (50-year flood event) width is estimated to be 80 to 100 feet. Flood-prone depth is approximately 5 to 6 feet. Channel slope is approximately 1 percent.

Sand and soft, erodible sandstone bedrock comprise the stream bed. Sand comprises the nearly vertical stream banks. The stream banks are highly erodible, but appear relatively stable where vegetated (Photo 4). Based on observed woody debris, available bank-side vegetation, and expected flood flow depths, the stream can carry a moderate amount of small to large woody debris.

Hydrology

Laguna Creek originates from Tsegi Canyon and flows northeast. The wash flows just north of the Town of Kayenta, and crosses US 160 around MP 420.1. Mean annual precipitation is approximately 9 inches (StreamStats). The entire watershed is within the Navajo Nation. Development is sparse, primarily rural residences and ranching. Diversions for irrigation occur upstream.

Peak flood discharges are best estimated from stream flow gaging stations near the site. The USGS operated a stream flow gaging station on Laguna Creek immediately upstream of the project bridge from 1997 to 2005 (USGS 09379180). The gaging station only has 10 years of data, too short of a time period for computing statistically accurate peak flood discharges. It is also too short for developing a reliable flood history for the bridge site. Recorded peak floods ranged from 179 to 1,690 cfs. Largest flood occurred in 1997.

Hydrology was obtained from the Initial Bridge Hydraulics Report for Laguna Creek Bridge, Feb. 2011, Arizona Department of Transportation, Bridge Group, Bridge Hydraulics Section. The Laguna Creek State Highway Bridge is located approximately 1.4 miles downstream of the project bridge. Total drainage area is 484 square miles. The study used the Green and Ampt equation for rainfall loss calculation, Clark unit hydrograph, and available NOAA rainfall data for developing a HEC-HMS model. The watershed was divided into ten sub basins. Three sub basins are desert and hill-slope rangeland. The remaining sub basins are considered as desert and flat rangeland.

Hydrology was also developed using USGS regression equations from Analysis of the Magnitude and Frequency of Peak Discharges for the Navajo Nation in Arizona, Utah, Colorado, and New Mexico, 2006, USGS SIR 2006-5306. The project is in Flood Region 8. USGS StreamStats was used for computing the drainage area (454 square miles), average basin slope (16.8 percent), and average basin elevation (6,050 feet). The USGS regression equations estimates are based on flow and drainage basin data collected for area stream gage stations. The nearest gage station with equivalent drainage area (523 square miles), average basin slope (24.2 percent), and average basin elevation (6,940 feet) is approximately 50 miles to the east, Mancos River near Towaoc, Colorado (USGS 9371000). The regression equations significantly over predicted the station values used in the regression analysis, suggesting the regression equations may be overly conservative in some areas.

The 50-year flood discharge predicted by the USGS regression equations is 1,063 cfs more than what was estimated for the Laguna Creek State Highway Bridge (6,895 cfs). The Laguna Creek State Highway Bridge HEC-HMS model-derived peak discharge estimates are based on measured drainage basin factors and rainfall. Arizona Department of Transportation considers the HEC-HMS model to be more applicable to the Laguna Creek State Highway Bridge project site than available regression equations.

The 2, 5, 10, 25, 50, 100, and 500-year flood discharges predicted by the USGS regression equations were used for developing the bridge design. The 50-year design discharge predicted by the USGS regression equations when compared to the 50-year design discharge used for the Laguna Creek state Highway Bridge appears overly conservative. The 100-year discharge is approximately the same. Peak flood discharges used for the Laguna Creek state Highway Bridge and estimated with the USGS regression equations are presented in Table 1.

Flooding can be caused by heavy rains, monsoons, or tropical storm remnants. The period of extreme flooding starts in mid-July and could extend into the late fall months. Monsoons typically occur mid-July through mid-September. Extreme flooding in the fall months generally occurs from tropical storm remnants.

<u>Water Surface Elevations and Flow Velocities</u>

Water surface elevations and flow velocities were estimated using the Hydrologic Engineering Center River Analysis System (HEC-RAS 4.1), a computer program that performs one-dimensional steady flow calculations. Cross sections across the channel and floodplain parallel to expected flow direction were generated using ground topographic survey data (Fig. 2). The study reach extended downstream approximately 240 feet and upstream approximately 160 feet. Manning’s roughness coefficients for the channel and flood plain were estimated using guidelines in FHWA-TS-84-204. A 0.030 roughness coefficient was applied for the relatively smooth and straight bedrock channel beneath and downstream of the bridge and 0.035 for the moderately irregular, relatively smooth bedrock channel upstream of the bridge. A 0.045 roughness coefficient was applied for the rougher overbank areas. Flow over the downstream-most waterfall was assumed to be supercritical. Flow for the remaining modeled reach was assumed to be subcritical. The energy slopes at the upstream stations were assumed to equal the water surface slope. The model was calibrated with apparent bankfull and high water levels determined in the field. Water surface elevations and design flow velocities are summarized in Table 2. The HEC-RAS analysis is attached.

Scour

The sandstone bedrock the bridge abutments will be placed on is subject to erosion. Two modes of bedrock erosion occur; plucking of relative intact rock blocks and abrasion of the bedrock surface. The sandstone is soft and massive with relatively few joints and fractures. The joints tend to be smooth and planar with little observed alteration material. Based on these observations, the primary mode of bedrock erosion is expected to be abrasion. Abrasion is more gradual, occurring over relatively longer time periods. The amount and type of sediment bed-load and the frequency and duration of floods are the dominant factors. Without testing the sandstone bedrock and developing a flood duration hydrograph, it is difficult to predict the erosion rate with certainty. The testing and analysis requires site-specific data.

The bedrock erosion rate may be estimated from erosion observed at the site. The existing bridge was constructed in 1975. The bottom edge of the right (looking downstream) masonry wing-wall was observed to be 6 to 8 inches above the bedrock surface (photo 9). Assuming the bedrock surface at the time of construction was at the same elevation as the bottom of the wing-wall, approximately 8inches of erosion has occurred in 39 years.

Floodplain and Flood-rise Limitations

The site is located within the Navajo Nation immediately downstream of the Dennehotso Community. The site is not mapped by the Navajo Nation or the Federal Emergency Management Agency (FEMA) as being in a special flood hazard area. A detailed FEMA mapping study has not been completed for the site. No base flood elevations have been determined.

The nearest property with insurable structures is located approximately 700 feet upstream of the bridge. The structures are located above the estimated 100-year flood water surface elevation.

attachments: Tables 1 and 2
Figures 1 and 2
Photographs 1 to 9
Riprap Plan and Details
HECRAS Results

Table 1. Peak Discharges (ft3/sec)

Estimate Method	Drainage Area (mi2)	Recurrence Intervals (years) 2	5	10	25	50	100	500
USGS Reg. Eqn.	454	1,388	2,849	4,052	6,297	7,958	10,241	15,949
State HWY Bridge	484					6,895	10,826	23,370
Design	454	**1,388**	**2,849**	**4,052**	**6,297**	**7,958**	**10,241**	**15,949**

Notes:

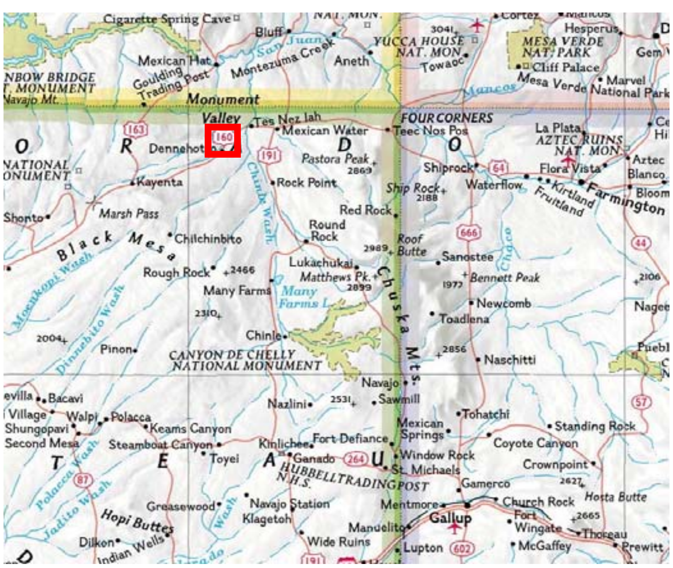
1. USGS - USGS Regression Equations, "Analysis of the Magnitude and Frequency of Peak Discharges for the Navajo Nation", SIR 2006-5306, 2006. AVG DA elev 6050 feet, AVG DA slope 16.8%.
2. "Initial Bridge Hydraulics Report for Laguna Creek", Arizona Department of Transportation, Feb. 2011.

Table 2. Water Surface Elevations and Flow Velocities

	Recurrence Intervals (years)							
					50			
Location	**2**	**5**	**10**	**25**	**SHWB**	**USGS**	**100**	**500**
Right Abut Low Chord Elev (Feet)	5002.6	5002.6	5002.6	5002.6	5002.6	5002.6	5002.6	5002.6
WS Elevation (Feet)	4996.0	4997.1	4998.0	4999.6	5000.0	5000.6	5002.0	5003.5
Clearance LC to WS (Feet)	6.6	5.5	4.6	3.0	2.6	2.0	0.6	-0.9
Left Abut Low Chord Elev (Feet)	5001.6	5001.6	5001.6	5001.6	5001.6	5001.6	5001.6	5001.6
WS Elevation (Feet)	4996.0	4997.1	4998.0	4999.6	5000.0	5000.6	5002.0	5003.5
Clearance LC to WS (Feet)	5.6	4.5	3.6	2.0	1.6	1.0	-0.4	-1.9
Right Approach Road Overtopped	No	No	No	No	Yes	Yes	Yes	Yes
Left Approach Road Overtopped	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Design Flow Velocity (Feet/sec)	6.0	9.0	10.0	12.0	12.0	12.0	11.0	7.0

Notes:

1. Negative number denotes water flowing against bridge superstructure.
2. Maximum estimated water surface elevation is 5003.5 feet before flood water overtops natural levees and spreads out over left-bank floodplain.
3. Right and left - looking downstream.
4. USGS is 50-year discharge using USGS regression.
5. SHWB is 50-year discharge using State Highway Bridge design fllow.
6. Low chord elevation at upstream bridge face.



Map printed from National Geographic TOPO

0 1,000 feet

N

▲ Dennehotso Bridge

☐ Project Site Location

FIGURE 1

LOCATION MAP

Dennehotso Bridge

HECRAS cross section and number
Stream flow direction

0 100 feet

Map printed from Google Earth Pro, imagery date June 4, 2010.

FIGURE 2

DENNEHOTSO BRIDGE

HECRAS CROSS SECTIONS

Photos

Dennehotso Bridge

PHOTO 1

Existing bridge - looking upstream from below upper waterfall.

Fall drops 4 to 6 feet. Soft sandstone bedrock exposed along channel bottom.

PHOTO 2

Downstream channel from existing bridge deck.

Channel relatively straight. Channel drops over two waterfalls. Soft sandstone bedrock exposed along channel bottom.

PHOTO 3

Upper waterfall immediately downstream of bridge.

Fall drops 4 to 6 feet. Soft sandstone bedrock exposed along channel bottom.

Photos

Dennehotso Bridge

PHOTO 4

Upstream channel from existing bridge deck.

Channel relatively straight. Soft sandstone bedrock exposed along channel bottom.

PHOTO 5

Upstream left bank from bridge deck.

Stream bank bends sharply upstream of bridge. Bank is migrating laterally to the north, causing a poor flow alignment through bridge. Soft sandstone bedrock exposed in lower 12 to 24 inches of stream bank limits migration.

PHOTO 6

Upstream right bank area from bridge deck.

Flood water flowing along approach has eroded into alluvium. Soft sandstone bedrock exposed in erosion gully, stream channel bottom, and overbank area.

Photos

Dennehotso Bridge

PHOTO 7

Upstream side of bridge crossing.

Existing bridge slightly perched above adjacent floodplain. Water flowing across floodplain overtops and erodes approach roads.

PHOTO 8

Looking downstream at center pier of bridge.

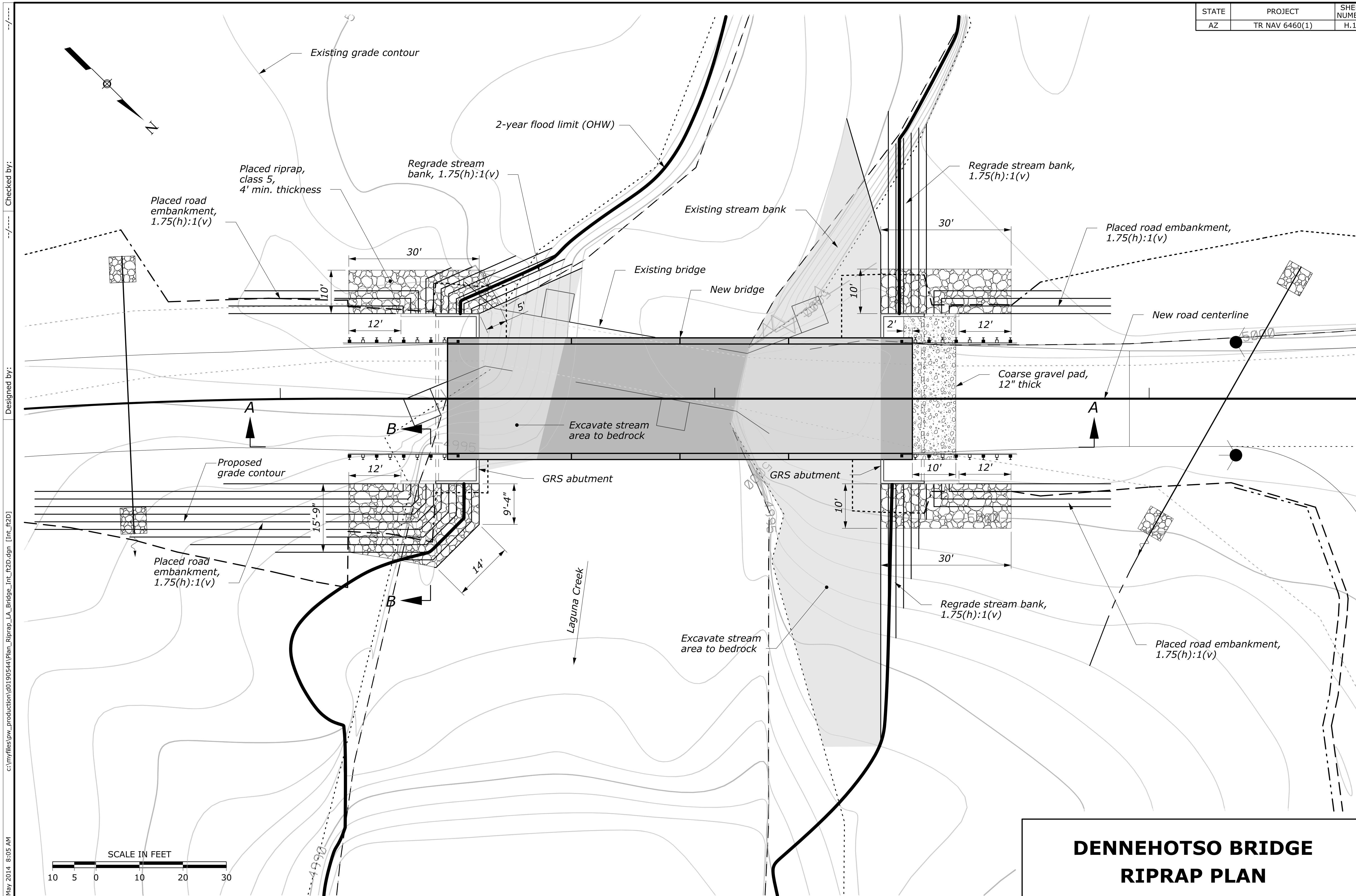
Woody debris entangles on bridge pier.

PHOTO 9

Downstream right abutment wingwall.

Soft sandstone bedrock exposed along channel bottom. Bottom of masonry 4 to 8 inches above bedrock bottom.

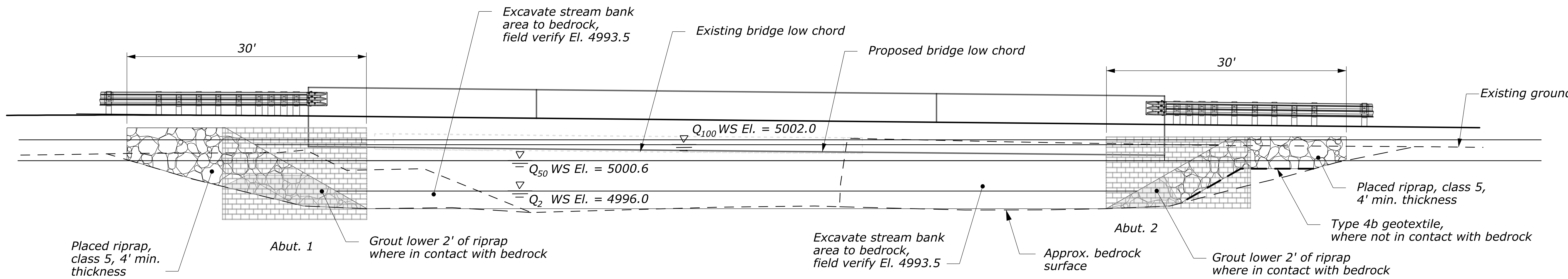
STATE	PROJECT	SHEET NUMBER
AZ	TR NAV 6460(1)	H.10



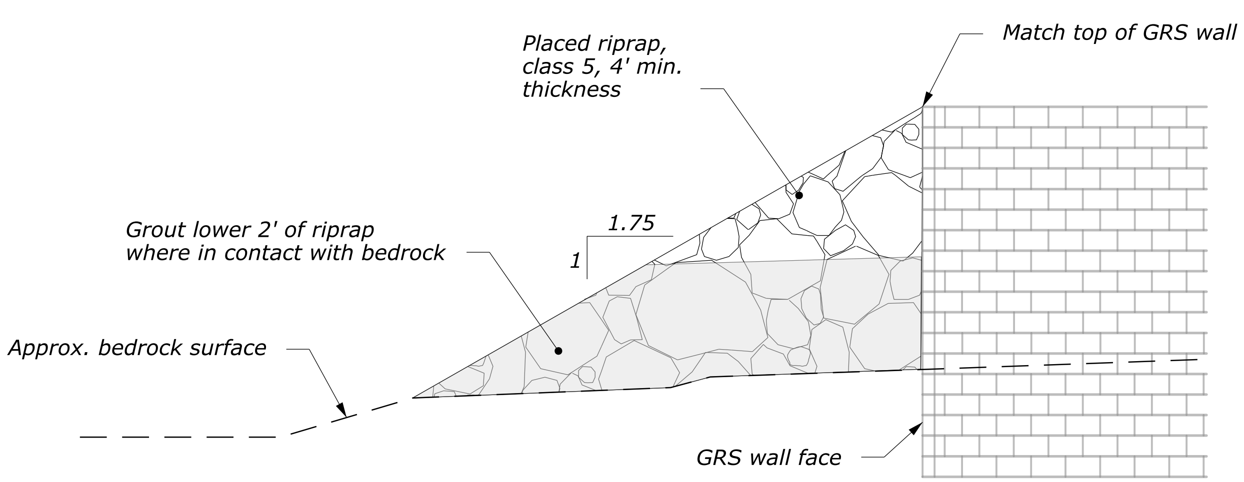
DENNEHOTSO BRIDGE
RIPRAP PLAN

Designed by:
Checked by:
c:\myfiles\pw_production\d0190544\Plan_Riprap_LA_Bridge_Int_ft2D.dgn [Int_ft2D]
9 May 2014 8:05 AM

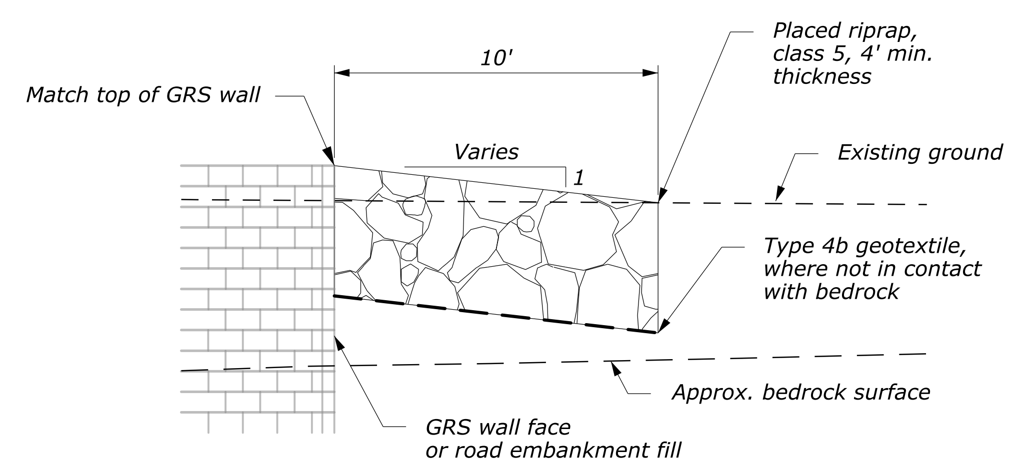
STATE	PROJECT	SHEET NUMBER
AZ	TR NAV 6460(1)	H.11



SECTION A



SECTION B



TYPICAL RIPRAP TRENCH

Notes:

1. Section A at downstream bridge face, water surface elevations given at upstream bridge face.

DENNEHOTSO BRIDGE
RIPRAP DETAILS

21 May 2014 3:39 PM
c:\myfiles\pw_production\d0190544\Sections_Riprap_LA_Bridge_2_Int_ft2D.dgn [Int_ft2D]
Designed by:
--/----
Checked by:
--/----

HECRAS Results

FLOOD DISCHARGE ESTIMATES
UNGAGED ARIZONA SITES

Project: Dennehotso Bridge | **File:** reg-spec2011

Desc: Major Drainage Peak Flow | **By:** S. Leon

Region: Navajo/BIA 8 | **Date:** 3/17/2014

Exceed Prob.	Coefficients R	a	b	c	Error
0.50	1.08E+07	0.457	NA	-1.350	110%
0.20	1.71E+10	0.372	0.360	-1.980	72%
0.10	8.79E+10	0.343	0.395	-2.100	59%
0.04	3.91E+11	0.310	0.432	-2.190	50%
0.02	8.47E+11	0.287	0.460	-2.230	48%
0.01	1.53E+12	0.265	0.477	-2.250	49%
0.002	4.24E+12	0.224	0.513	-2.280	59%

Equation: Q = R(A^a)(S^b)(E^c)

Source: Peak Discharges Navajo Nation
SIR 2006-5306
A = Area
S = Average Basin Slope
E = Average Basin Elevation

Culvert Type	HW/D	K			M	a
CMP Projectin	1.0	0.5			0.667	2.827

Station	Drain. Area (sq mi)	Slope (%)	Avg Elev (ft)	Estimated Discharge (Q) Exceedance Probability 0.50 (cfs)	0.20 (cfs)	0.10 (cfs)	0.04 (cfs)	0.02 (cfs)	0.01 (cfs)	0.002 (cfs)	0.02 Design (cfs)	Min. Culvert Dia (ft)
Minimum	0.06	0.0231	4320									
Maximum	4350	0.4447	7750									
Dennehotso Bridge												
USGS Reg. Eqns	454.0	0.168	6050	1,388	2,849	4,052	6,297	7,958	10,241	15,949	7,958	26.4
State HWY Bridge	484.0	NA	NA					6,895	10,826	23,370		
DESIG				1,388	2,849	4,052	6,297	7,958	10,241	15,949		
General Minor	0.000001	0.05	5000.00	0	2	4	12	23	45	152	23	2.5
	0.000002	0.05	5000.00	0	2	5	15	28	54	178	28	2.8
	0.000003	0.05	5000.00	0	2	6	16	31	60	195	31	2.9
	0.000005	0.05	5000.00	0	3	7	19	36	69	218	36	3.1
	0.000010	0.05	5000.00	1	4	9	24	44	82	255	44	3.3
	0.000020	0.05	5000.00	1	5	11	30	54	99	298	54	3.6
	0.000040	0.05	5000.00	1	6	14	37	66	119	348	66	3.9

Notes:

a = ((HW/D)/K)^(1/M)

K = Constant from Table 9, HDS-5

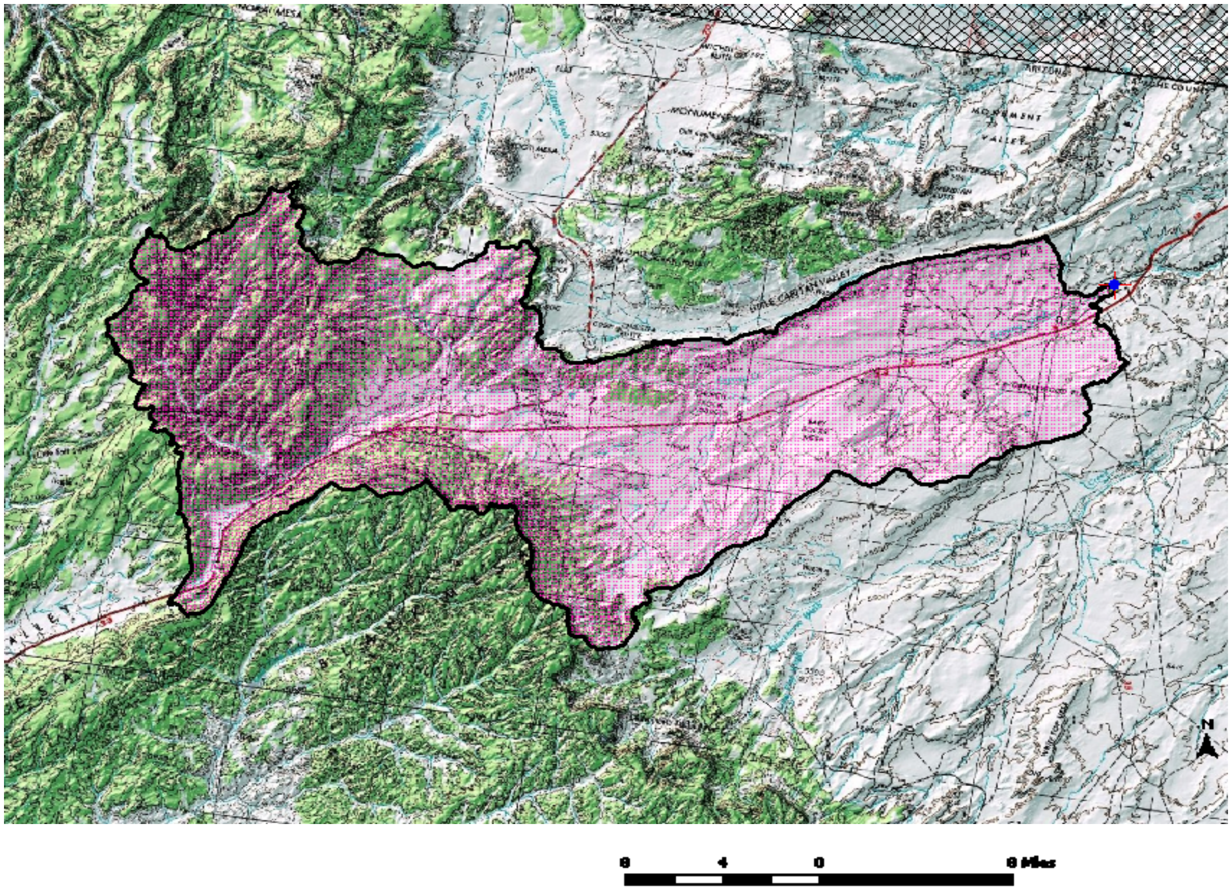
M = Constant from Table 9, HDS-5

D = [Q/(0.7844x(1/K^1/M))]^.4 from HDS-5, equation 27. Assumes HW/D < 1.2 ,unsubmerged.

USGS
Arizona StreamStats

StreamStats Print Page

Dennehotso Bridge



Explanation

- NHDHGage
- NHDHDam
- Gaging Station, Continuous Record
- Low Flow, Partial Record
- Peak Flow, Partial Record
- Peak and Low Flow, Partial Record
- Stage Only
- Low Flow, Partial Record, Stage
- Miscellaneous Record
- Unknown
- GlobalWatershedPoint
- Dendritic Stream Network
- GlobalWatershed
- Excludepoly

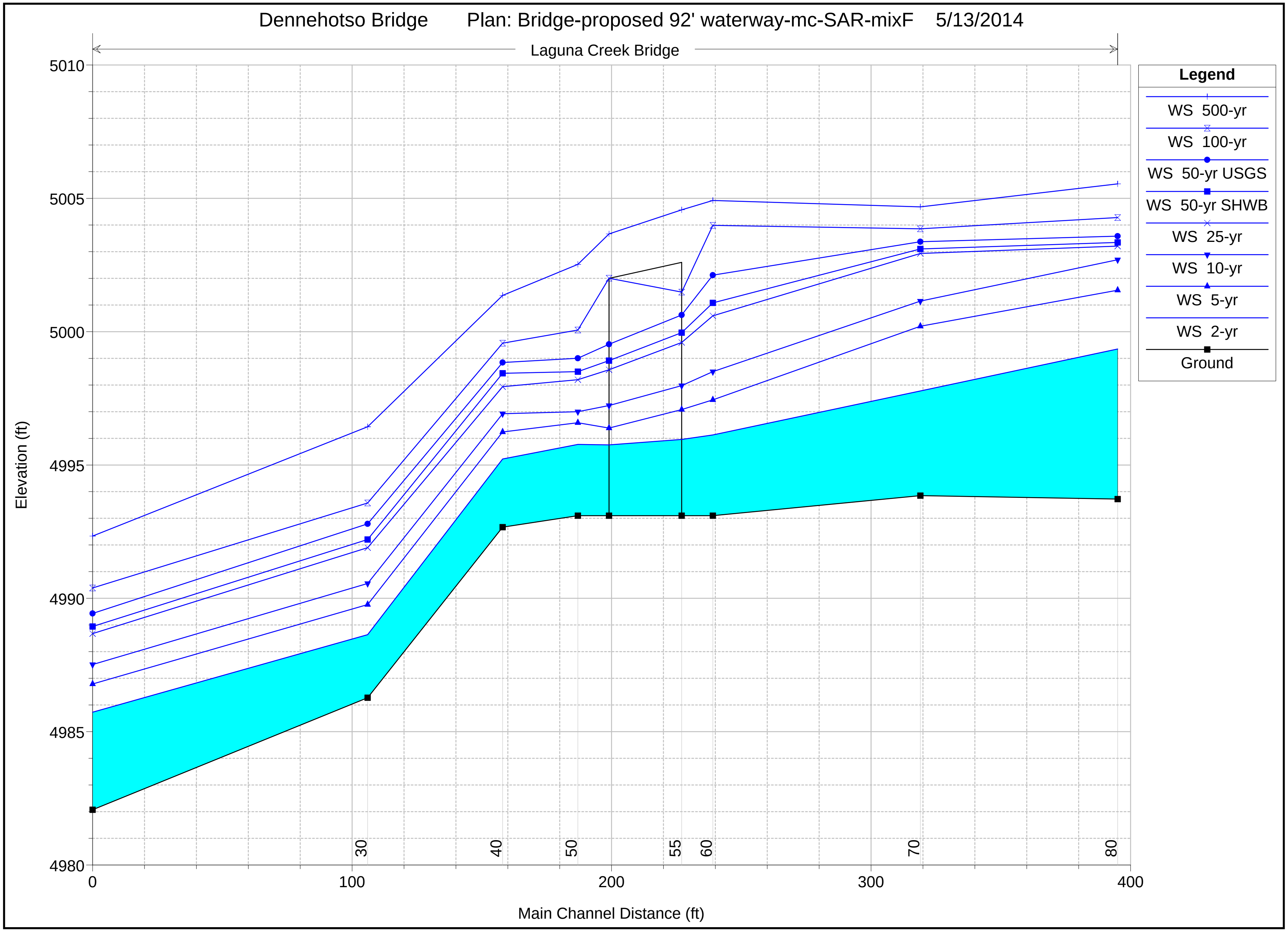
5/6/2014 10:47:12 AM

USGS Arizona StreamStats

Basin Characteristics Report

Date: Tue May 6 2014 10:52:42 Mountain Daylight Time
NAD27 Latitude: 36.8536 (36 51 13)
NAD27 Longitude: -109.8437 (-109 50 37)
NAD83 Latitude: 36.8536 (36 51 13)
NAD83 Longitude: -109.8444 (-109 50 40)

Parameter	Value
Area in square miles	454.33
Mean Basin Elevation in feet (Analysis cell size: 10 m)	6050
Mean basin slope computed from 10 m DEM, in percent (Analysis cell size: 10 m)	16.8
Mean annual precipitation, in inches (Analysis cell size: 900 m)	9.11



Dennehotso Bridge
Plan: Bridge-proposed 92' waterway-mc-SAR-mixF
5/13/2014
Laguna Creek Bridge
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Elevation (ft)
5010
5005
5000
4995
4990
4985
4980
30
40
50
55
60
70
80
0
100
200
300
400
Main Channel Distance (ft)

HEC-RAS Plan: 92ww-mc-SAR-mixF River: Laguna Creek Reach: Bridge

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	Max Chl Dpth
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft)
Bridge	80	2-yr	1388.00	4993.72	4999.35		4999.84	0.003273	5.60	248.15	70.53	0.51	5.63
Bridge	80	5-yr	2849.00	4993.72	5001.55		5002.23	0.002599	6.81	511.11	235.02	0.49	7.83
Bridge	80	10-yr	4052.00	4993.72	5002.70	5000.78	5003.35	0.002234	7.10	841.00	389.11	0.47	8.97
Bridge	80	25-yr	6297.00	4993.72	5003.21	5002.91	5004.30	0.003610	9.46	1061.46	470.92	0.61	9.49
Bridge	80	50-yr SHWB	6895.00	4993.72	5003.34	5003.15	5004.52	0.003891	9.94	1127.10	492.66	0.63	9.62
Bridge	80	50-yr USGS	7958.00	4993.72	5003.58	5003.50	5004.90	0.004309	10.68	1248.50	530.52	0.67	9.86
Bridge	80	100-yr	10241.00	4993.72	5004.28	5004.28	5005.55	0.004131	11.06	1652.25	606.16	0.66	10.56
Bridge	80	500-yr	15949.00	4993.72	5005.54	5005.24	5006.80	0.003989	11.90	2442.46	641.27	0.67	11.82
Bridge	70	2-yr	1388.00	4993.85	4997.78	4997.78	4999.29	0.013301	9.87	140.63	46.86	1.00	3.93
Bridge	70	5-yr	2849.00	4993.85	5000.20	5000.20	5001.83	0.006944	10.56	326.84	138.55	0.80	6.35
Bridge	70	10-yr	4052.00	4993.85	5001.15	5001.15	5002.96	0.006800	11.63	478.21	182.41	0.81	7.30
Bridge	70	25-yr	6297.00	4993.85	5002.93	5002.93	5004.01	0.003800	10.24	1137.14	518.16	0.63	9.08
Bridge	70	50-yr SHWB	6895.00	4993.85	5003.10	5003.10	5004.21	0.003924	10.55	1223.89	520.82	0.64	9.25
Bridge	70	50-yr USGS	7958.00	4993.85	5003.37	5003.37	5004.53	0.004115	11.04	1367.66	525.20	0.66	9.52
Bridge	70	100-yr	10241.00	4993.85	5003.86	5003.86	5005.15	0.004581	12.08	1622.88	532.89	0.71	10.01
Bridge	70	500-yr	15949.00	4993.85	5004.68	5004.68	5006.39	0.005982	14.62	2100.51	598.11	0.82	10.83
Bridge	60	2-yr	1388.00	4993.10	4996.13	4995.11	4996.50	0.002607	4.89	283.87	104.36	0.52	3.03
Bridge	60	5-yr	2849.00	4993.10	4997.44	4996.25	4998.14	0.003091	6.70	425.01	110.07	0.60	4.34
Bridge	60	10-yr	4052.00	4993.10	4998.50	4997.03	4999.36	0.002916	7.45	543.79	114.65	0.60	5.40
Bridge	60	25-yr	6297.00	4993.10	5000.59	4998.27	5001.56	0.002204	7.91	817.48	177.71	0.55	7.49
Bridge	60	50-yr SHWB	6895.00	4993.10	5001.08	4998.57	5002.07	0.002074	8.00	925.87	285.26	0.54	7.98
Bridge	60	50-yr USGS	7958.00	4993.10	5002.12	4999.08	5002.93	0.001530	7.52	1417.08	607.48	0.47	9.02
Bridge	60	100-yr	10241.00	4993.10	5003.99	5000.19	5004.44	0.000785	6.21	2908.39	909.48	0.35	10.88
Bridge	60	500-yr	15949.00	4993.10	5004.92	5003.32	5005.55	0.001078	7.73	3757.03	909.48	0.42	11.82
Bridge	55		Bridge										
Bridge	50	2-yr	1388.00	4993.10	4995.77		4996.24	0.003968	5.51	251.79	106.39	0.63	2.67
Bridge	50	5-yr	2849.00	4993.10	4996.58		4997.67	0.006528	8.38	339.99	111.11	0.84	3.48
Bridge	50	10-yr	4052.00	4993.10	4997.00	4997.00	4998.70	0.008863	10.48	386.66	113.53	1.00	3.90
Bridge	50	25-yr	6297.00	4993.10	4998.20	4998.20	5000.42	0.008297	11.95	526.75	120.49	1.01	5.10
Bridge	50	50-yr SHWB	6895.00	4993.10	4998.50	4998.50	5000.82	0.008110	12.24	563.43	122.25	1.00	5.40
Bridge	50	50-yr USGS	7958.00	4993.10	4999.00	4999.00	5001.51	0.007865	12.71	625.90	125.18	1.00	5.90
Bridge	50	100-yr	10241.00	4993.10	5000.06	5000.06	5002.84	0.007184	13.41	782.24	190.05	0.98	6.96
Bridge	50	500-yr	15949.00	4993.10	5002.52	5002.52	5004.16	0.003309	11.50	2321.47	821.17	0.71	9.42
Bridge	40	2-yr	1388.00	4992.67	4995.23	4995.23	4996.03	0.011666	7.18	193.50	125.77	1.01	2.56
Bridge	40	5-yr	2849.00	4992.67	4996.24	4996.24	4997.44	0.009131	8.84	335.84	156.68	0.97	3.57
Bridge	40	10-yr	4052.00	4992.67	4996.92	4996.92	4998.35	0.008077	9.74	451.61	181.58	0.95	4.25
Bridge	40	25-yr	6297.00	4992.67	4997.94	4997.94	4999.75	0.007386	11.16	664.79	264.55	0.95	5.27
Bridge	40	50-yr SHWB	6895.00	4992.67	4998.44	4998.44	5000.05	0.005788	10.63	807.39	302.83	0.86	5.77
Bridge	40	50-yr USGS	7958.00	4992.67	4998.85	4998.85	5000.52	0.005533	10.98	935.10	331.88	0.85	6.17
Bridge	40	100-yr	10241.00	4992.67	4999.57	4999.57	5001.36	0.005269	11.69	1213.06	432.23	0.85	6.90
Bridge	40	500-yr	15949.00	4992.67	5001.36	5001.36	5002.86	0.003649	11.60	2430.33	818.77	0.74	8.69
Bridge	30	2-yr	1388.00	4986.27	4988.64	4988.64	4989.57	0.011119	7.73	179.59	99.20	1.01	2.37
Bridge	30	5-yr	2849.00	4986.27	4989.77	4989.77	4991.25	0.009334	9.78	292.24	100.83	1.01	3.49
Bridge	30	10-yr	4052.00	4986.27	4990.56	4990.56	4992.41	0.008504	10.94	374.13	107.31	1.00	4.29
Bridge	30	25-yr	6297.00	4986.27	4991.90	4991.90	4994.25	0.007232	12.38	529.11	124.17	0.97	5.63
Bridge	30	50-yr SHWB	6895.00	4986.27	4992.21	4992.21	4994.69	0.007077	12.74	567.86	128.15	0.97	5.93
Bridge	30	50-yr USGS	7958.00	4986.27	4992.79	4992.79	4995.42	0.006559	13.14	645.52	134.65	0.95	6.52
Bridge	30	100-yr	10241.00	4986.27	4993.58	4993.58	4996.88	0.007065	14.81	754.01	146.96	1.00	7.31
Bridge	30	500-yr	15949.00	4986.27	4996.44	4996.44	4999.65	0.004587	15.10	1337.03	253.21	0.86	10.16
Bridge	20	2-yr	1388.00	4982.07	4985.73	4985.73	4986.58	0.011324	7.39	187.90	112.28	1.00	3.66
Bridge	20	5-yr	2849.00	4982.07	4986.79	4986.79	4988.12	0.009305	9.27	312.87	124.04	0.99	4.72
Bridge	20	10-yr	4052.00	4982.07	4987.52	4987.52	4989.15	0.008439	10.33	406.29	132.26	0.98	5.45
Bridge	20	25-yr	6297.00	4982.07	4988.68	4988.68	4990.79	0.007527	11.82	566.69	143.48	0.97	6.61
Bridge	20	50-yr SHWB	6895.00	4982.07	4988.94	4988.94	4991.18	0.007441	12.19	604.83	145.79	0.97	6.87
Bridge	20	50-yr USGS	7958.00	4982.07	4989.43	4989.43	4991.84	0.007103	12.70	677.28	150.09	0.96	7.36
Bridge	20	100-yr	10241.00	4982.07	4990.39	4990.39	4993.15	0.006607	13.66	825.24	158.21	0.96	8.32
Bridge	20	500-yr	15949.00	4982.07	4992.34	4992.34	4995.92	0.006168	15.77	1142.33	168.02	0.97	10.27

Plan: 92ww-mc-SAR-mixF   Laguna Creek   Bridge RS: 55   Profile: 2-yr

E.G. US. (ft)	4996.50	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	4996.13	E.G. Elev (ft)	4996.45	4996.33
Q Total (cfs)	1388.00	W.S. Elev (ft)	4995.96	4995.75
Q Bridge (cfs)	1388.00	Crit W.S. (ft)	4995.18	4995.17
Q Weir (cfs)		Max Chl Dpth (ft)	2.86	2.65
Weir Sta Lft (ft)		Vel Total (ft/s)	5.63	6.08
Weir Sta Rgt (ft)		Flow Area (sq ft)	246.53	228.44
Weir Submerg		Froude # Chl	0.60	0.68
Weir Max Depth (ft)		Specif Force (cu ft)	578.87	550.64
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	2.72	2.52
Min El Prs (ft)	5002.60	W.P. Total (ft)	95.61	95.22
Delta EG (ft)	0.25	Conv. Total (cfs)	22961.6	20277.4
Delta WS (ft)	0.36	Top Width (ft)	90.79	90.79
BR Open Area (sq ft)	753.69	Frctn Loss (ft)	0.12	0.05
BR Open Vel (ft/s)	6.08	C & E Loss (ft)	0.01	0.03
Coef of Q		Shear Total (lb/sq ft)	0.59	0.70
Br Sel Method	Energy only	Power Total (lb/ft s)	-464.62	-464.62

Plan: 92ww-mc-SAR-mixF   Laguna Creek   Bridge RS: 55   Profile: 5-yr

E.G. US. (ft)	4998.14	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	4997.44	E.G. Elev (ft)	4998.12	4997.93
Q Total (cfs)	2849.00	W.S. Elev (ft)	4997.08	4996.39
Q Bridge (cfs)	2849.00	Crit W.S. (ft)	4996.39	4996.39
Q Weir (cfs)		Max Chl Dpth (ft)	3.98	3.29
Weir Sta Lft (ft)		Vel Total (ft/s)	8.18	9.96
Weir Sta Rgt (ft)		Flow Area (sq ft)	348.21	286.02
Weir Submerg		Froude # Chl	0.74	0.99
Weir Max Depth (ft)		Specif Force (cu ft)	1392.72	1333.06
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	3.83	3.15
Min El Prs (ft)	5002.60	W.P. Total (ft)	97.85	96.49
Delta EG (ft)	0.47	Conv. Total (cfs)	40200.1	29233.8
Delta WS (ft)	0.86	Top Width (ft)	91.01	90.93
BR Open Area (sq ft)	753.69	Frctn Loss (ft)		
BR Open Vel (ft/s)	9.96	C & E Loss (ft)		
Coef of Q		Shear Total (lb/sq ft)	1.12	1.76
Br Sel Method	Momentum	Power Total (lb/ft s)	-464.62	-464.62

Plan: 92ww-mc-SAR-mixF   Laguna Creek   Bridge RS: 55   Profile: 10-yr

E.G. US. (ft)	4999.36	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	4998.50	E.G. Elev (ft)	4999.35	4999.17
Q Total (cfs)	4052.00	W.S. Elev (ft)	4997.98	4997.23
Q Bridge (cfs)	4052.00	Crit W.S. (ft)	4997.22	4997.23
Q Weir (cfs)		Max Chl Dpth (ft)	4.88	4.13
Weir Sta Lft (ft)		Vel Total (ft/s)	9.42	11.17
Weir Sta Rgt (ft)		Flow Area (sq ft)	430.28	362.64
Weir Submerg		Froude # Chl	0.76	0.99
Weir Max Depth (ft)		Specif Force (cu ft)	2204.50	2130.84
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	4.72	3.98
Min El Prs (ft)	5002.60	W.P. Total (ft)	99.67	98.18
Delta EG (ft)	0.66	Conv. Total (cfs)	56506.3	42918.0
Delta WS (ft)	1.50	Top Width (ft)	91.19	91.10
BR Open Area (sq ft)	753.69	Frctn Loss (ft)		
BR Open Vel (ft/s)	11.17	C & E Loss (ft)		

Plan: 92ww-mc-SAR-mixF   Laguna Creek   Bridge RS: 55   Profile: 10-yr (Continued)

Coef of Q		Shear Total (lb/sq ft)	1.39	2.06
Br Sel Method	Momentum	Power Total (lb/ft s)	-464.62	-464.62

Plan: 92ww-mc-SAR-mixF   Laguna Creek   Bridge RS: 55   Profile: 25-yr

E.G. US. (ft)	5001.56	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	5000.59	E.G. Elev (ft)	5001.44	5001.19
Q Total (cfs)	6297.00	W.S. Elev (ft)	4999.59	4998.57
Q Bridge (cfs)	6296.65	Crit W.S. (ft)	4998.59	4998.57
Q Weir (cfs)		Max Chl Dpth (ft)	6.49	5.47
Weir Sta Lft (ft)		Vel Total (ft/s)	10.88	12.97
Weir Sta Rgt (ft)		Flow Area (sq ft)	578.66	485.38
Weir Submerg		Froude # Chl	0.76	0.99
Weir Max Depth (ft)		Specif Force (cu ft)	3965.00	3832.14
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	5.95	5.31
Min El Prs (ft)	5002.60	W.P. Total (ft)	108.72	100.89
Delta EG (ft)	1.15	Conv. Total (cfs)	90461.3	68515.4
Delta WS (ft)	2.40	Top Width (ft)	97.30	91.39
BR Open Area (sq ft)	753.69	Frctn Loss (ft)	0.18	0.10
BR Open Vel (ft/s)	12.97	C & E Loss (ft)	0.08	0.12
Coef of Q		Shear Total (lb/sq ft)	1.61	2.54
Br Sel Method	Energy only	Power Total (lb/ft s)	-464.62	-464.62

Plan: 92ww-mc-SAR-mixF   Laguna Creek   Bridge RS: 55   Profile: 50-yr SHWB

E.G. US. (ft)	5002.07	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	5001.08	E.G. Elev (ft)	5001.93	5001.68
Q Total (cfs)	6895.00	W.S. Elev (ft)	4999.96	4998.91
Q Bridge (cfs)	6890.40	Crit W.S. (ft)	4998.91	4998.91
Q Weir (cfs)		Max Chl Dpth (ft)	6.86	5.81
Weir Sta Lft (ft)		Vel Total (ft/s)	11.18	13.35
Weir Sta Rgt (ft)		Flow Area (sq ft)	616.47	516.50
Weir Submerg		Froude # Chl	0.77	0.99
Weir Max Depth (ft)		Specif Force (cu ft)	4465.50	4324.13
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	5.72	5.65
Min El Prs (ft)	5002.60	W.P. Total (ft)	119.95	101.57
Delta EG (ft)	1.24	Conv. Total (cfs)	99043.6	75649.0
Delta WS (ft)	2.58	Top Width (ft)	107.82	91.46
BR Open Area (sq ft)	753.69	Frctn Loss (ft)	0.17	0.10
BR Open Vel (ft/s)	13.34	C & E Loss (ft)	0.08	0.13
Coef of Q		Shear Total (lb/sq ft)	1.56	2.64
Br Sel Method	Energy only	Power Total (lb/ft s)	-464.62	-464.62

Plan: 92ww-mc-SAR-mixF   Laguna Creek   Bridge RS: 55   Profile: 50-yr USGS

E.G. US. (ft)	5002.93	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	5002.12	E.G. Elev (ft)	5002.77	5002.52
Q Total (cfs)	7958.00	W.S. Elev (ft)	5000.63	4999.53
Q Bridge (cfs)	7922.42	Crit W.S. (ft)	4999.49	4999.53
Q Weir (cfs)		Max Chl Dpth (ft)	7.53	6.43
Weir Sta Lft (ft)		Vel Total (ft/s)	11.46	13.80
Weir Sta Rgt (ft)		Flow Area (sq ft)	694.71	576.79
Weir Submerg		Froude # Chl	0.77	0.98
Weir Max Depth (ft)		Specif Force (cu ft)	5388.79	5230.96
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	5.37	5.20
Min El Prs (ft)	5002.60	W.P. Total (ft)	142.71	122.05

Plan: 92ww-mc-SAR-mixF Laguna Creek Bridge RS: 55 Profile: 50-yr USGS (Continued)

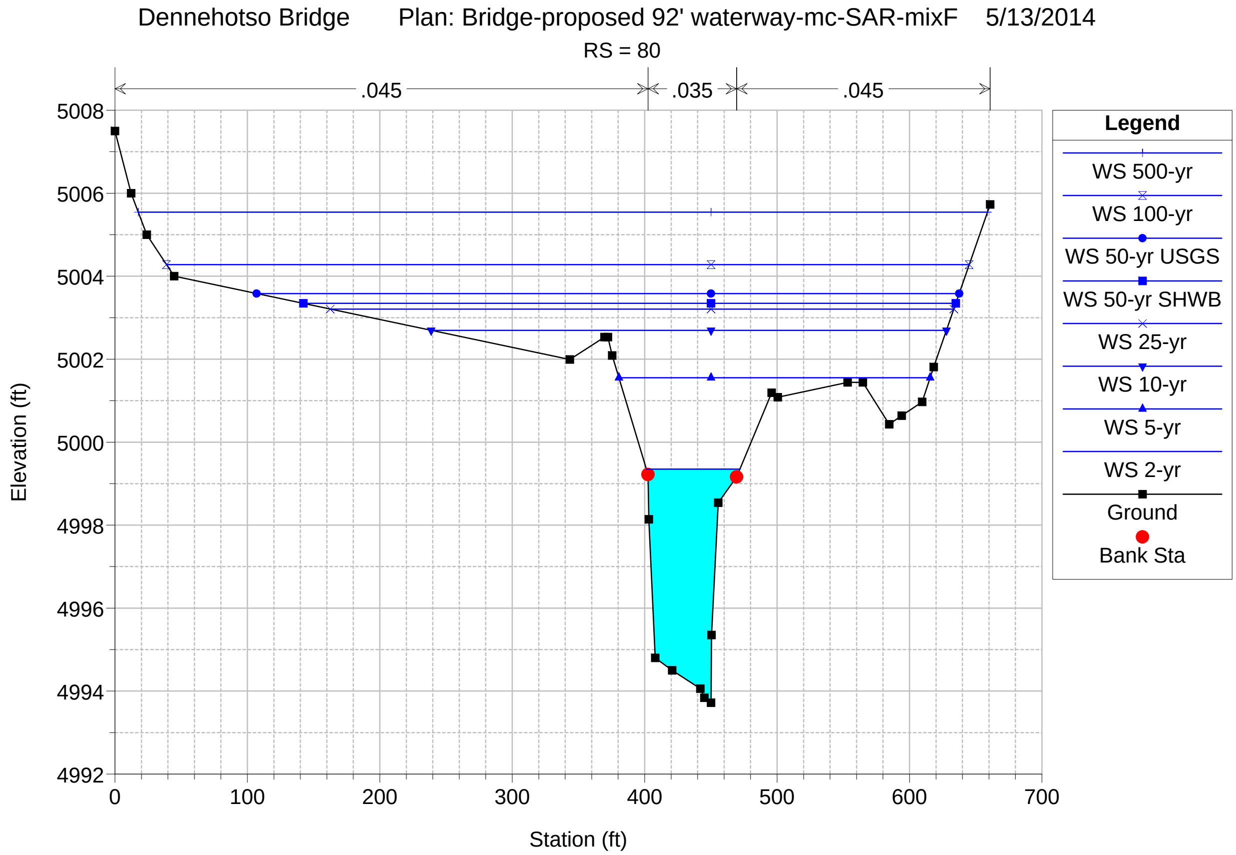
Delta EG (ft)	1.42	Conv. Total (cfs)	115395.6	89150.7
Delta WS (ft)	3.11	Top Width (ft)	129.35	110.82
BR Open Area (sq ft)	753.69	Frctn Loss (ft)	0.17	0.09
BR Open Vel (ft/s)	13.84	C & E Loss (ft)	0.08	0.15
Coef of Q		Shear Total (lb/sq ft)	1.45	2.35
Br Sel Method	Energy only	Power Total (lb/ft s)	-464.62	-464.62

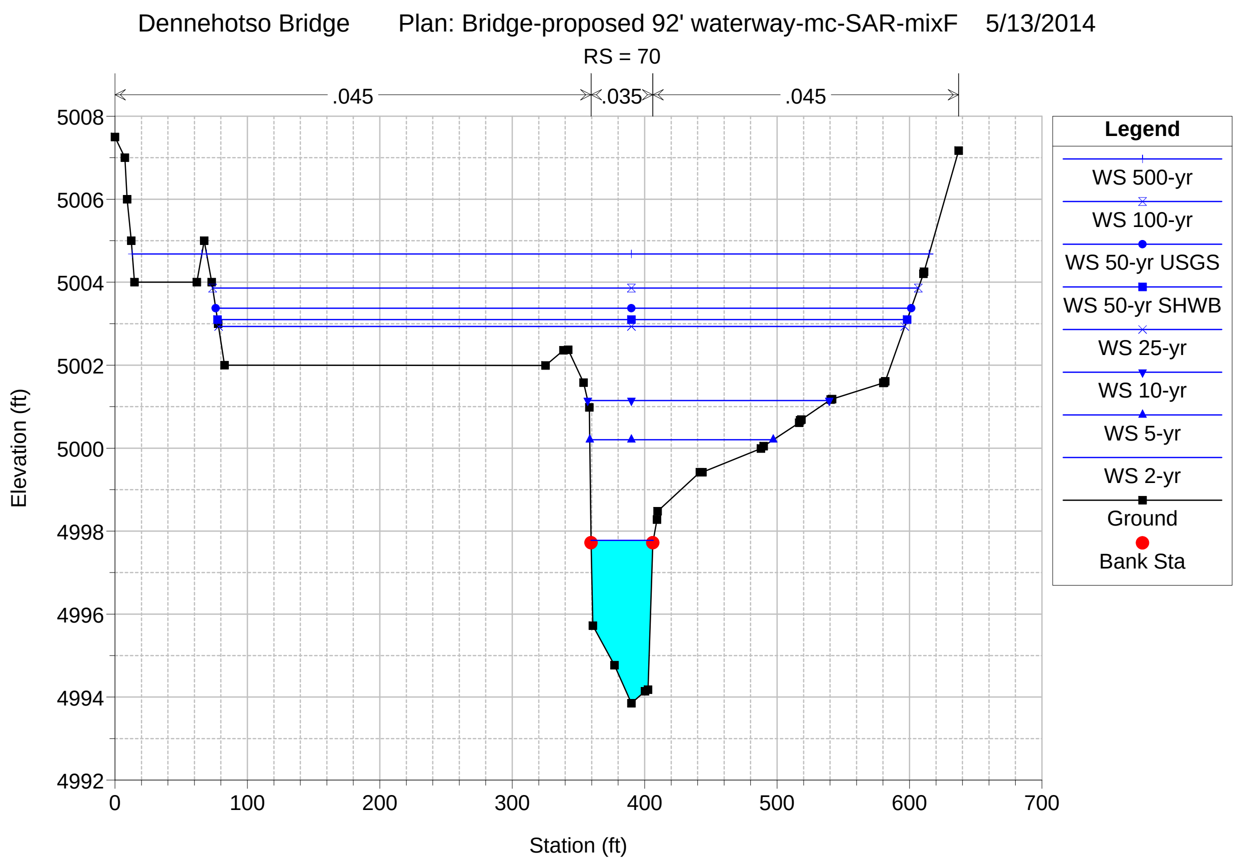
Plan: 92ww-mc-SAR-mixF Laguna Creek Bridge RS: 55 Profile: 100-yr

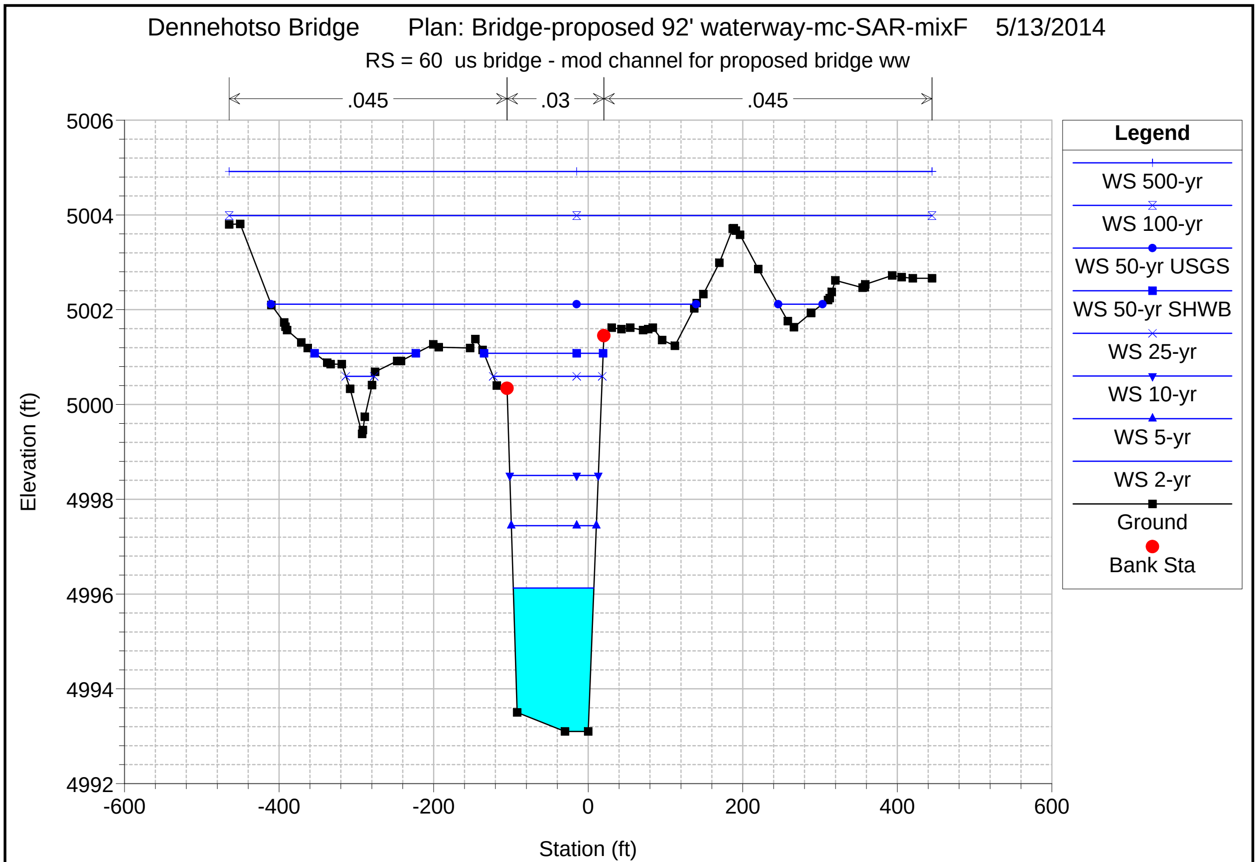
E.G. US. (ft)	5004.44	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	5003.99	E.G. Elev (ft)	5004.19	5003.70
Q Total (cfs)	10241.00	W.S. Elev (ft)	5001.48	5002.01
Q Bridge (cfs)	10025.57	Crit W.S. (ft)	5000.69	5002.01
Q Weir (cfs)		Max Chl Dpth (ft)	8.38	8.90
Weir Sta Lft (ft)		Vel Total (ft/s)	11.84	8.23
Weir Sta Rgt (ft)		Flow Area (sq ft)	864.63	1243.81
Weir Submerg		Froude # Chl	0.82	0.62
Weir Max Depth (ft)		Specif Force (cu ft)	7316.73	7058.72
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	3.39	2.95
Min El Prs (ft)	5002.60	W.P. Total (ft)	270.16	620.46
Delta EG (ft)	1.60	Conv. Total (cfs)	139598.0	108728.3
Delta WS (ft)	3.93	Top Width (ft)	255.23	421.30
BR Open Area (sq ft)	753.69	Frctn Loss (ft)	0.19	0.10
BR Open Vel (ft/s)	13.35	C & E Loss (ft)	0.30	0.11
Coef of Q		Shear Total (lb/sq ft)	1.08	1.11
Br Sel Method	Energy only	Power Total (lb/ft s)	-464.62	-464.62

Plan: 92ww-mc-SAR-mixF Laguna Creek Bridge RS: 55 Profile: 500-yr

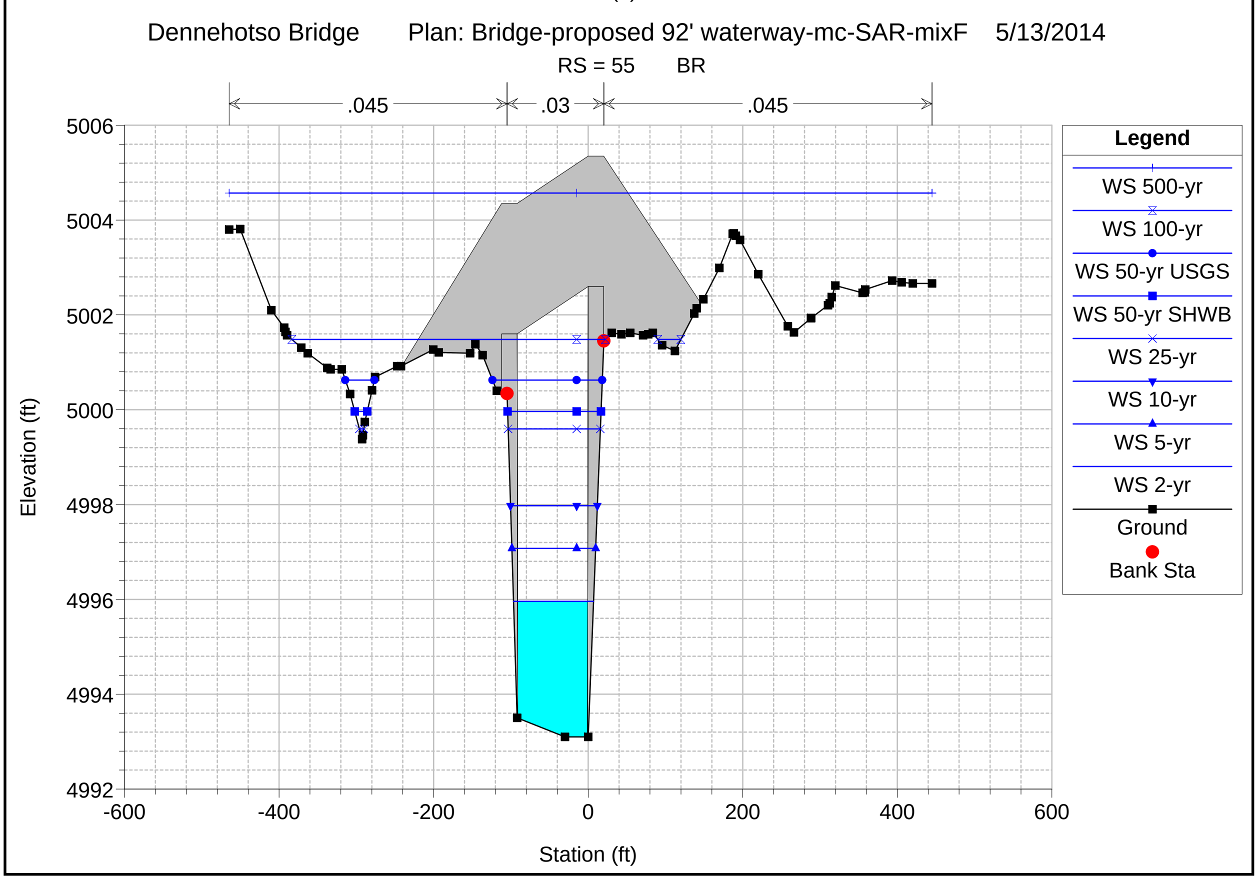
E.G. US. (ft)	5005.55	Element	Inside BR US	Inside BR DS
W.S. US. (ft)	5004.92	E.G. Elev (ft)	5005.49	5004.95
Q Total (cfs)	15949.00	W.S. Elev (ft)	5004.57	5003.67
Q Bridge (cfs)	8276.00	Crit W.S. (ft)	5004.57	5003.67
Q Weir (cfs)		Max Chl Dpth (ft)	11.47	10.56
Weir Sta Lft (ft)		Vel Total (ft/s)	6.46	7.34
Weir Sta Rgt (ft)		Flow Area (sq ft)	2468.26	2172.15
Weir Submerg		Froude # Chl	0.40	0.49
Weir Max Depth (ft)		Specif Force (cu ft)	11437.33	10874.49
Min El Weir Flow (ft)	4999.39	Hydr Depth (ft)	3.14	3.26
Min El Prs (ft)	5002.60	W.P. Total (ft)	988.83	866.36
Delta EG (ft)	1.39	Conv. Total (cfs)	186647.3	168260.0
Delta WS (ft)	2.39	Top Width (ft)	785.90	666.26
BR Open Area (sq ft)	753.69	Frctn Loss (ft)	0.23	0.06
BR Open Vel (ft/s)	10.98	C & E Loss (ft)	0.04	0.03
Coef of Q		Shear Total (lb/sq ft)	1.14	1.41
Br Sel Method	Energy only	Power Total (lb/ft s)	-464.62	-464.62


Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 80
.045
.035
.045
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
5008
5006
5004
5002
5000
4998
4996
4994
4992
0
100
200
300
400
500
600
700

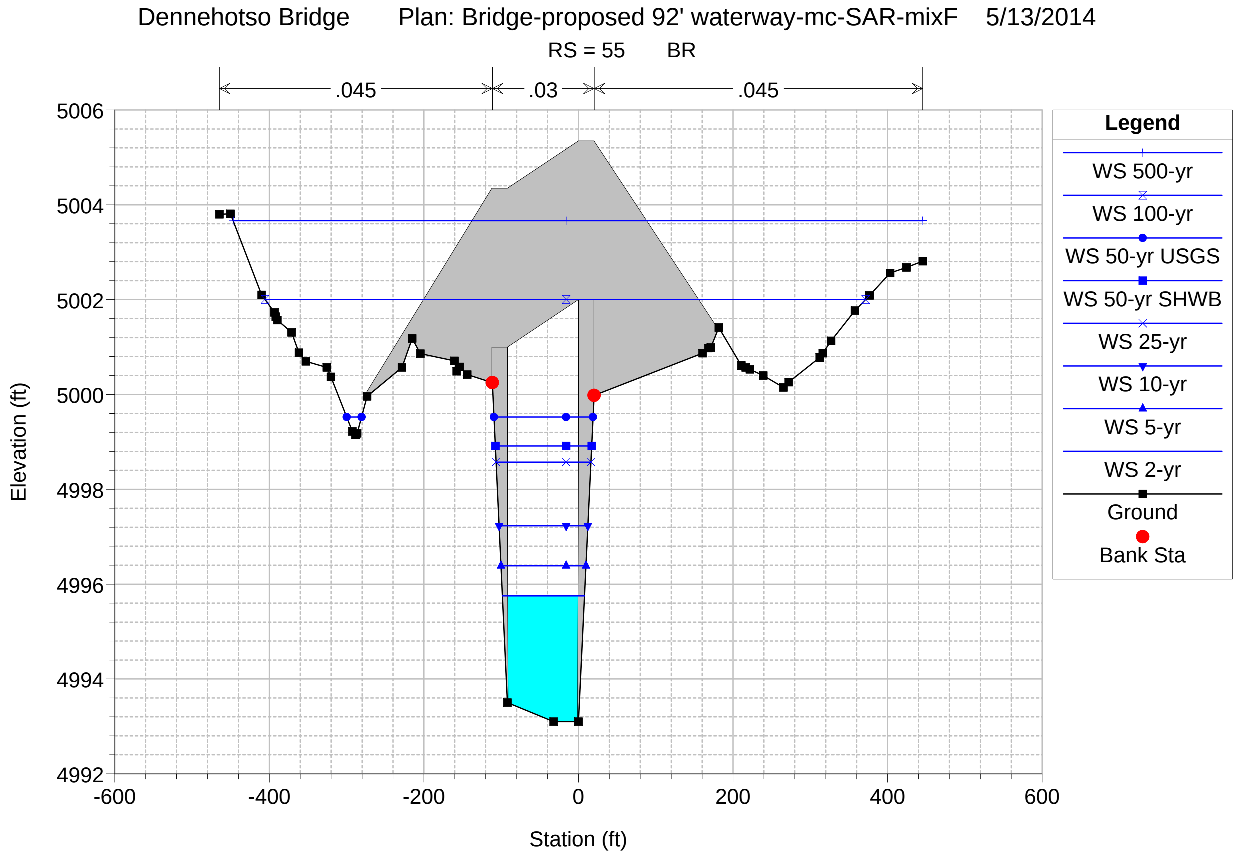

Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 70
.045
.035
.045
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
5008
5006
5004
5002
5000
4998
4996
4994
4992
0
100
200
300
400
500
600
700



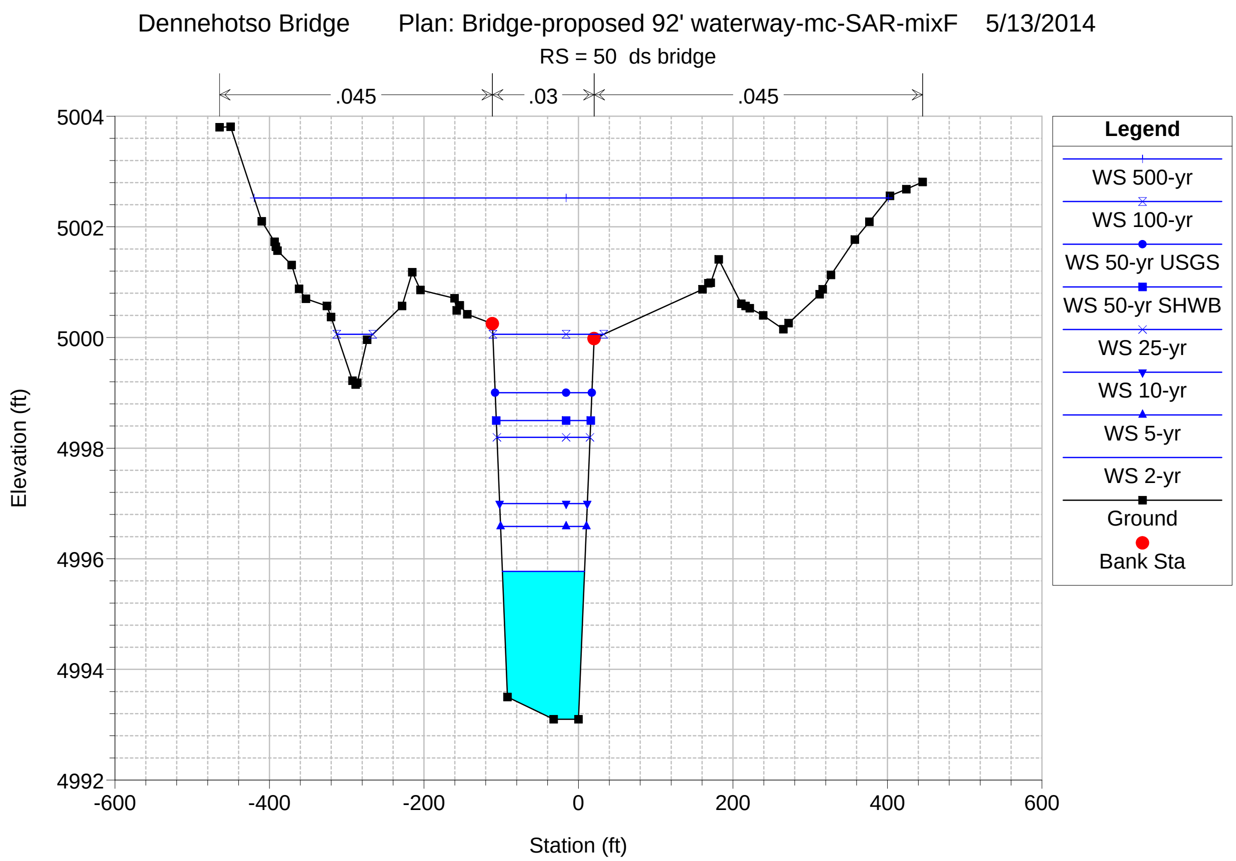
Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 60 us bridge - mod channel for proposed bridge ww
.045
.03
.045
Elevation (ft)
Station (ft)
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta



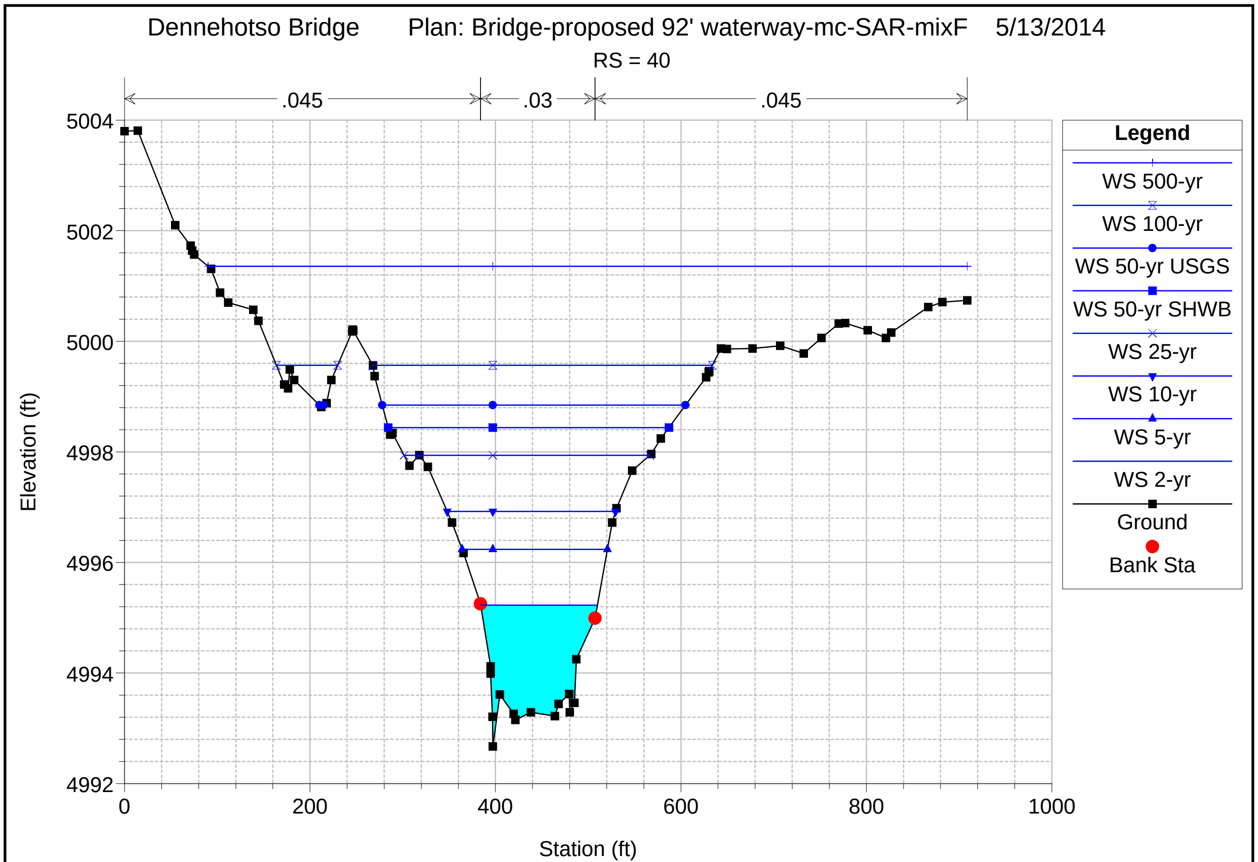
Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 55 BR
.045
.03
.045
Elevation (ft)
Station (ft)
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta

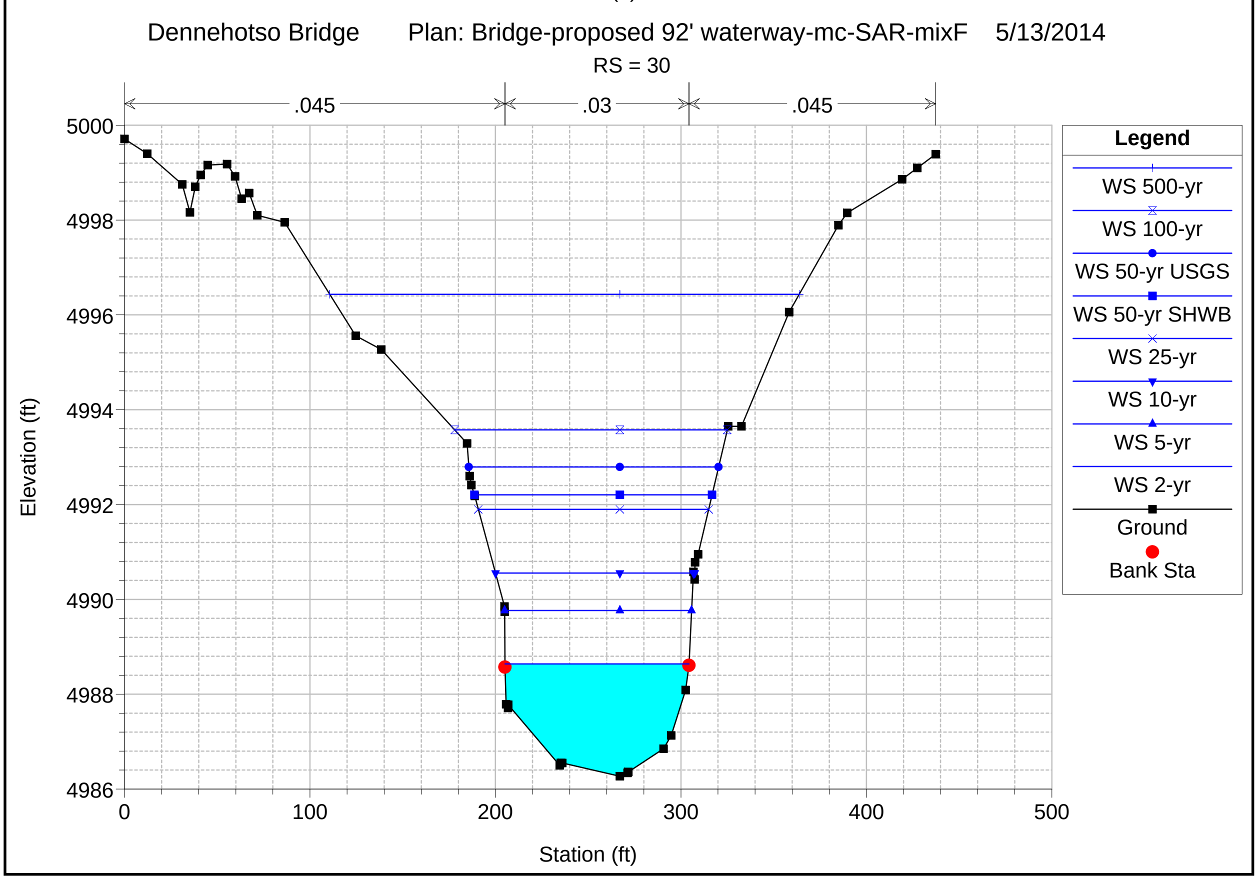


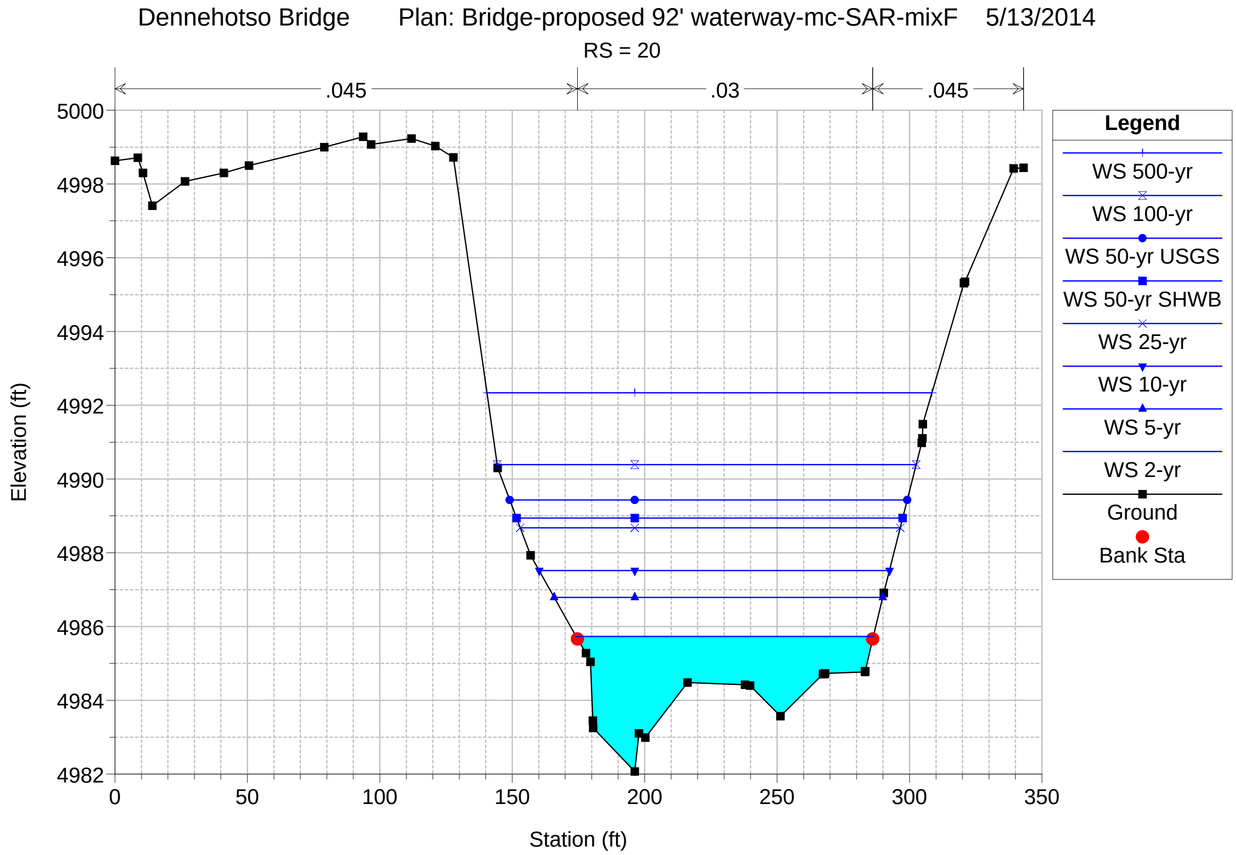
Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 55 BR
.045
.03
.045
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
5006
5004
5002
5000
4998
4996
4994
4992
-600
-400
-200
0
200
400
600



Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 50 ds bridge
.045
.03
.045
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta
Elevation (ft)
Station (ft)
5004
5002
5000
4998
4996
4994
4992
-600
-400
-200
0
200
400
600


Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 40
.045
.03
.045
Elevation (ft)
Station (ft)
5004
5002
5000
4998
4996
4994
4992
0
200
400
600
800
1000
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta


Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 30
.045
.03
.045
Elevation (ft)
Station (ft)
5000
4998
4996
4994
4992
4990
4988
4986
0
100
200
300
400
500
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta

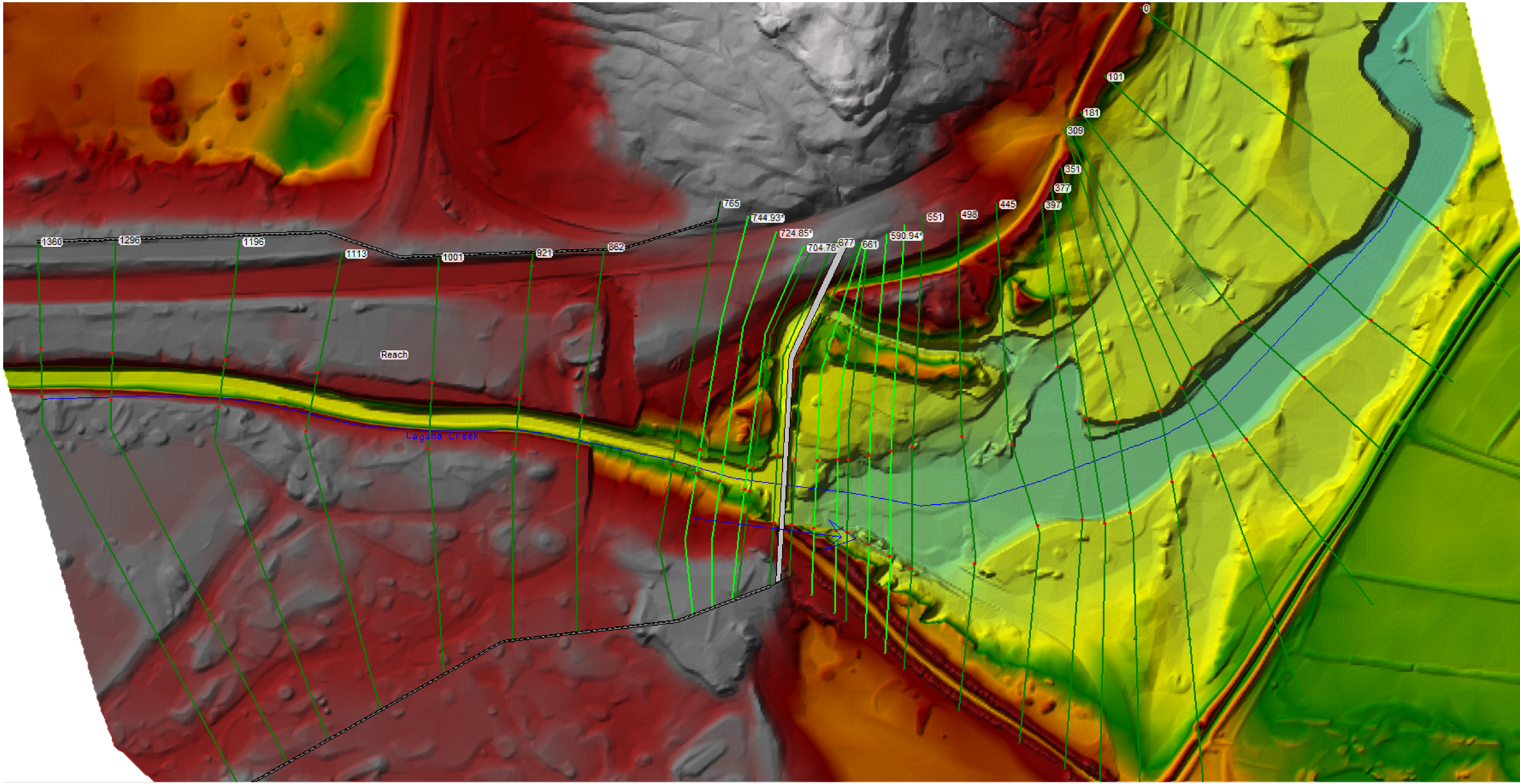


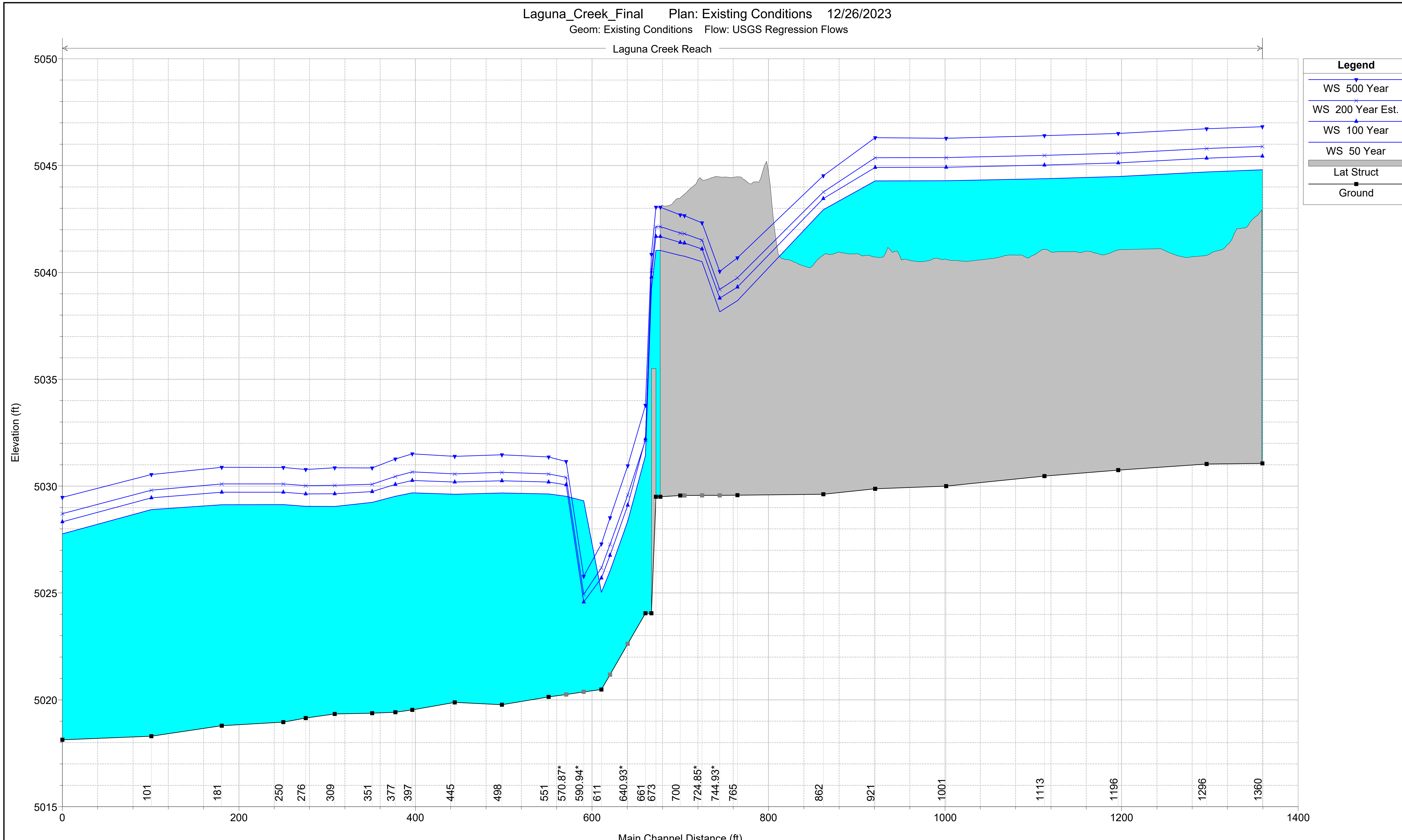
Dennehotso Bridge Plan: Bridge-proposed 92' waterway-mc-SAR-mixF 5/13/2014
RS = 20
.045
.03
.045
Legend
WS 500-yr
WS 100-yr
WS 50-yr USGS
WS 50-yr SHWB
WS 25-yr
WS 10-yr
WS 5-yr
WS 2-yr
Ground
Bank Sta
Elevation (ft)
5000
4998
4996
4994
4992
4990
4988
4986
4984
4982
0
50
100
150
200
250
300
350
Station (ft)

Appendix D Hydraulic Analysis

HEC-RAS CROSS SECTION MAP
LAGUNA CREEK

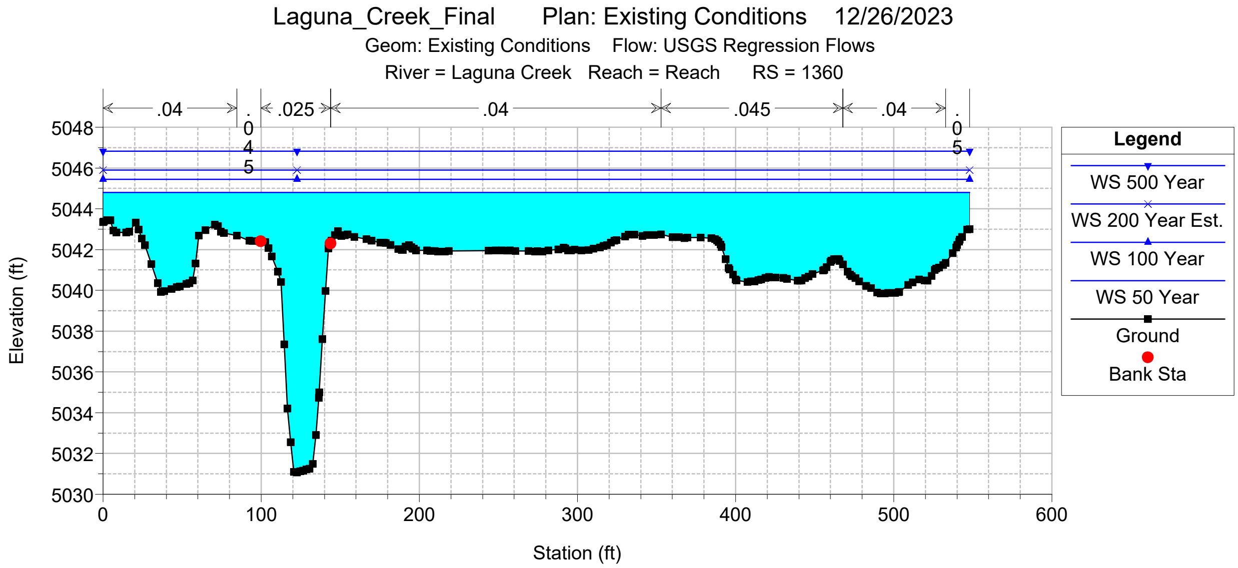
EXISTING CONDITION

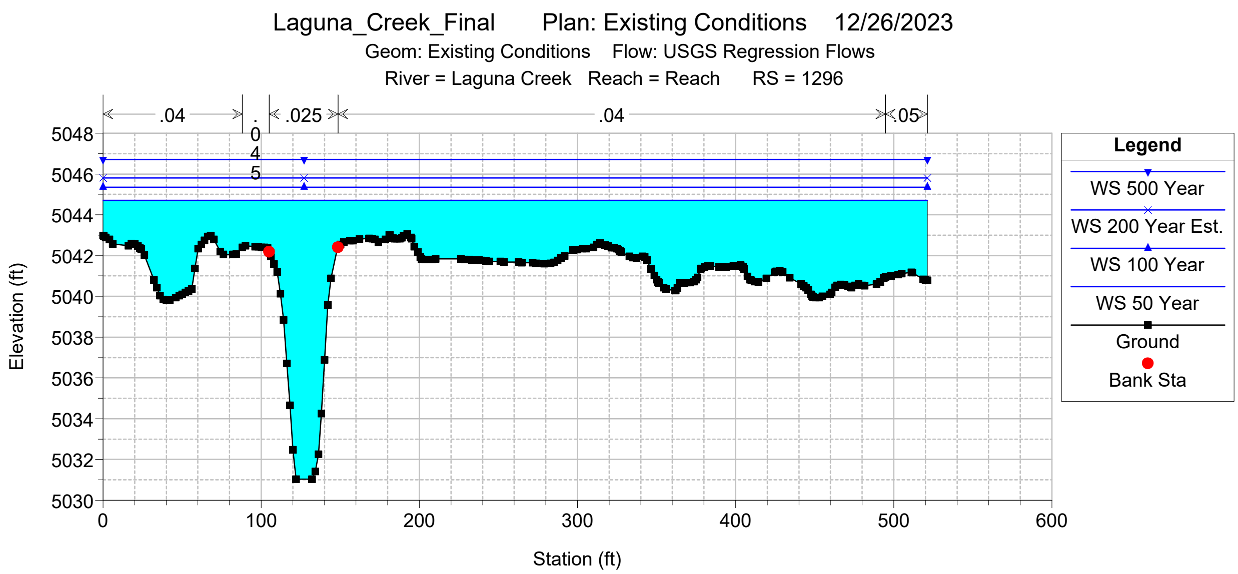


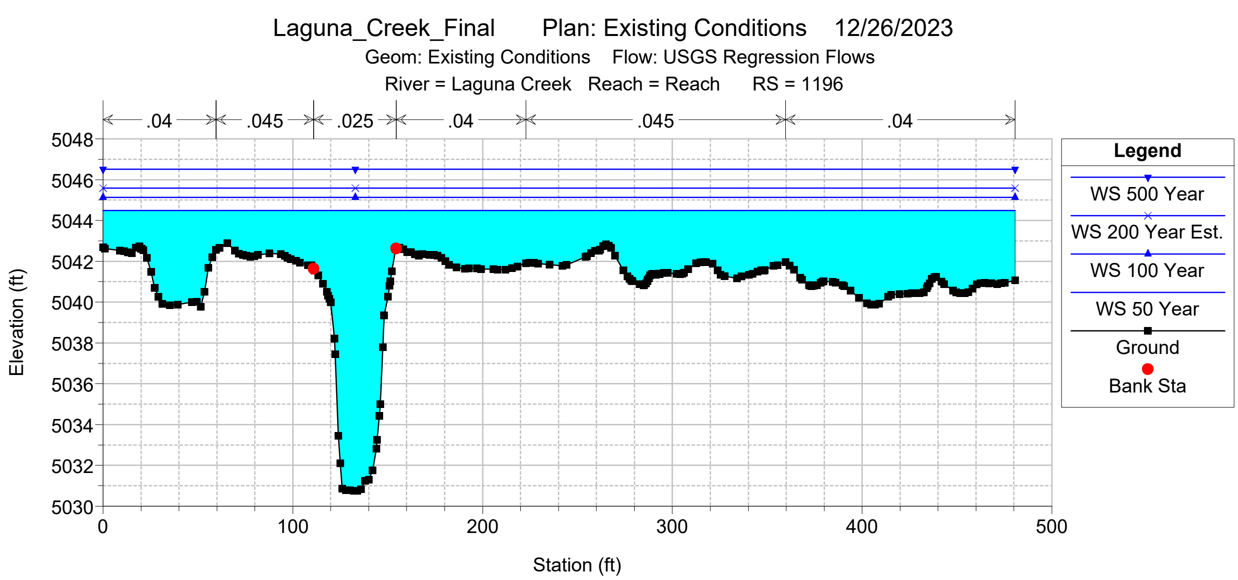

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
Laguna Creek Reach
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Lat Struct
Ground
Elevation (ft)
5015
5020
5025
5030
5035
5040
5045
5050
Main Channel Distance (ft)
0
200
400
600
800
1000
1200
1400
101
181
250
276
309
351
377
397
445
498
551
570.87*
590.94*
611
640.93*
661
673
700
724.85*
744.93*
765
862
921
1001
1113
1196
1296
1360

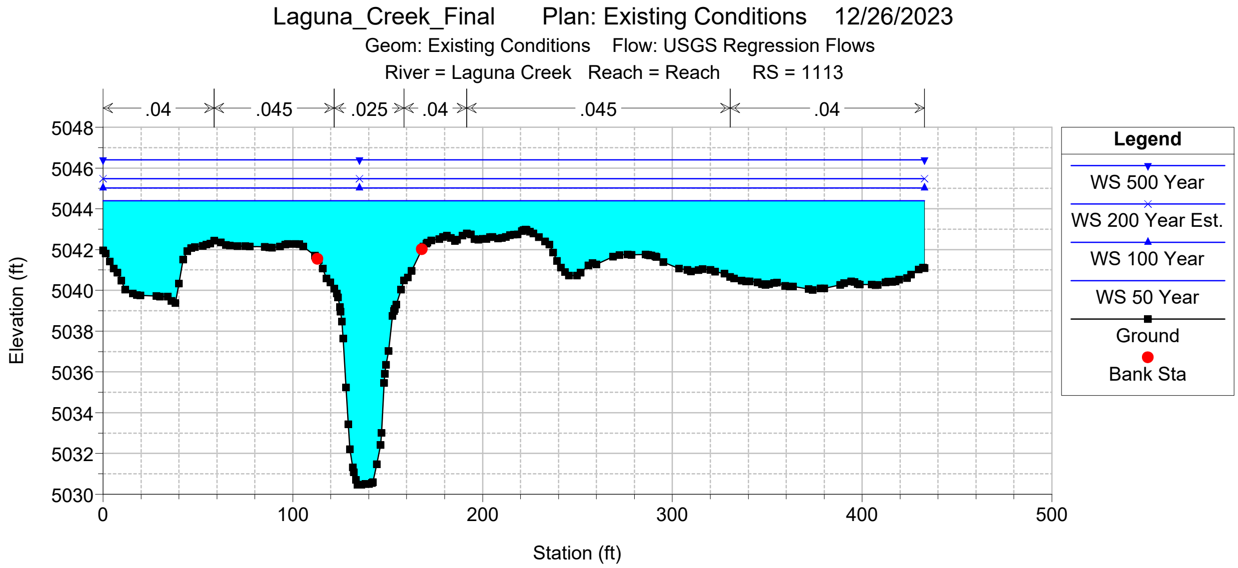
HEC-RAS Plan: Existing   River: Laguna Creek   Reach: Reach

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)	
Reach	1360	50 Year	7958.00	5031.06	5044.80	5043.94	5045.37	0.001623	8.70	1907.45	548.07	0.53
Reach	1360	100 Year	10241.00	5031.06	5045.44	5044.49	5046.05	0.001671	9.27	2257.22	548.07	0.54
Reach	1360	500 Year	15949.00	5031.06	5046.82	5045.36	5047.53	0.001728	10.36	3011.89	548.07	0.57
Reach	1360	200 Year Est.	12000.00	5031.06	5045.90	5044.77	5046.53	0.001692	9.64	2506.64	548.07	0.55
Reach	1359		Lat Struct									
Reach	1358		Lat Struct									
Reach	1296	50 Year	7703.09	5031.03	5044.70		5045.27	0.001475	8.61	1869.96	521.19	0.51
Reach	1296	100 Year	9849.58	5031.03	5045.34		5045.95	0.001515	9.15	2203.34	521.19	0.53
Reach	1296	500 Year	15214.02	5031.03	5046.72		5047.42	0.001568	10.20	2921.50	521.19	0.55
Reach	1296	200 Year Est.	11502.29	5031.03	5045.80		5046.43	0.001533	9.50	2440.78	521.19	0.53
Reach	1196	50 Year	7299.57	5030.75	5044.49		5045.12	0.001575	8.78	1701.93	480.62	0.52
Reach	1196	100 Year	9249.44	5030.75	5045.12		5045.79	0.001612	9.30	2008.65	480.62	0.53
Reach	1196	500 Year	14117.87	5030.75	5046.51		5047.26	0.001655	10.32	2672.32	480.62	0.55
Reach	1196	200 Year Est.	10747.80	5030.75	5045.58		5046.27	0.001624	9.63	2228.78	480.62	0.54
Reach	1113	50 Year	6838.42	5030.47	5044.39		5044.98	0.001452	8.18	1585.47	432.92	0.52
Reach	1113	100 Year	8590.03	5030.47	5045.03		5045.65	0.001502	8.62	1861.54	432.92	0.53
Reach	1113	500 Year	12971.51	5030.47	5046.40		5047.11	0.001576	9.52	2456.59	432.92	0.54
Reach	1113	200 Year Est.	9935.02	5030.47	5045.48		5046.13	0.001525	8.91	2058.77	432.92	0.53
Reach	1001	50 Year	6285.58	5030.00	5044.29		5044.80	0.001236	7.40	1502.41	386.24	0.48
Reach	1001	100 Year	7837.83	5030.00	5044.92		5045.47	0.001296	7.83	1746.07	386.24	0.49
Reach	1001	500 Year	11738.10	5030.00	5046.28		5046.93	0.001400	8.71	2270.54	386.24	0.50
Reach	1001	200 Year Est.	9029.70	5030.00	5045.37		5045.95	0.001329	8.11	1919.76	386.24	0.49
Reach	921	50 Year	5750.05	5029.88	5044.29	5042.77	5044.67	0.001230	6.50	1450.90	358.98	0.38
Reach	921	100 Year	7101.42	5029.88	5044.92	5043.17	5045.33	0.001250	6.86	1669.04	358.98	0.39
Reach	921	500 Year	10518.01	5029.88	5046.30	5043.95	5046.77	0.001222	7.42	2228.21	358.98	0.39
Reach	921	200 Year Est.	8138.98	5029.88	5045.37	5043.43	5045.80	0.001261	7.10	1824.76	358.98	0.39
Reach	862	50 Year	5383.63	5029.62	5042.93	5042.93	5044.45	0.002712	11.48	802.61	356.51	0.68
Reach	862	100 Year	6600.47	5029.62	5043.46	5043.46	5045.10	0.002884	12.30	934.11	356.51	0.71
Reach	862	500 Year	9690.08	5029.62	5044.53	5044.53	5046.51	0.003304	14.15	1202.01	356.51	0.77
Reach	862	200 Year Est.	7541.34	5029.62	5043.76	5043.76	5045.56	0.003114	13.06	1010.51	356.51	0.74
Reach	765	50 Year	5309.74	5029.58	5038.68	5040.02	5043.67	0.009239	21.25	444.60	143.97	1.35
Reach	765	100 Year	6469.75	5029.58	5039.32	5041.07	5044.31	0.008899	21.99	539.49	153.92	1.35
Reach	765	500 Year	9383.64	5029.58	5040.69	5042.28	5045.72	0.008214	23.40	762.72	188.59	1.33
Reach	765	200 Year Est.	7368.03	5029.58	5039.75	5041.46	5044.77	0.008717	22.52	606.63	160.83	1.34
Reach	744.93*	50 Year	5309.74	5029.57	5038.16	5039.95	5043.44	0.010353	21.97	430.52	143.37	1.43
Reach	744.93*	100 Year	6469.75	5029.57	5038.79	5040.60	5044.10	0.009929	22.75	526.69	157.30	1.42
Reach	744.93*	500 Year	9383.64	5029.57	5040.05	5041.81	5045.50	0.009441	24.44	733.81	253.69	1.42
Reach	744.93*	200 Year Est.	7368.03	5029.57	5039.21	5040.99	5044.55	0.009757	23.32	592.69	169.26	1.42
Reach	724.85*	50 Year	5309.74	5029.57	5040.50	5039.14	5041.47	0.001694	10.85	929.00	265.86	0.61
Reach	724.85*	100 Year	6469.75	5029.57	5041.09	5039.86	5042.20	0.001846	11.77	1038.44	273.10	0.64
Reach	724.85*	500 Year	9383.64	5029.57	5042.32	5041.06	5043.78	0.002197	13.83	1272.39	287.51	0.71
Reach	724.85*	200 Year Est.	7368.03	5029.57	5041.52	5040.28	5042.72	0.001945	12.41	1117.99	277.78	0.66
Reach	704.78*	50 Year	5309.74	5029.56	5040.76	5038.04	5041.32	0.000999	8.55	1140.09	260.00	0.47
Reach	704.78*	100 Year	6469.75	5029.56	5041.38	5038.74	5042.04	0.001121	9.41	1256.44	266.69	0.50
Reach	704.78*	500 Year	9383.64	5029.56	5042.66	5040.03	5043.59	0.001394	11.30	1508.56	282.60	0.57
Reach	704.78*	200 Year Est.	7368.03	5029.56	5041.81	5039.24	5042.55	0.001206	10.02	1340.91	271.45	0.52
Reach	700	50 Year	5309.74	5029.56	5040.79		5041.30	0.000913	8.19	1174.75	258.05	0.45
Reach	700	100 Year	6469.75	5029.56	5041.41		5042.02	0.001032	9.05	1290.66	264.80	0.48
Reach	700	500 Year	9383.64	5029.56	5042.70		5043.56	0.001295	10.91	1542.12	280.50	0.55
Reach	700	200 Year Est.	7368.03	5029.56	5041.84		5042.53	0.001114	9.65	1374.89	269.33	0.50
Reach	677	50 Year	5309.74	5029.50	5041.03	5033.56	5041.19	0.000170	3.85	1855.94	264.62	0.20
Reach	677	100 Year	6469.75	5029.50	5041.68	5034.04	5041.89	0.000207	4.41	1983.60	271.35	0.22
Reach	677	500 Year	9383.64	5029.50	5043.05	5035.11	5043.39	0.000298	5.68	2264.65	317.22	0.27
Reach	677	200 Year Est.	7368.03	5029.50	5042.14	5034.37	5042.39	0.000235	4.81	2075.77	280.75	0.24
Reach	673		Inl Struct									
Reach	661	50 Year	5309.74	5024.05	5031.43	5031.43	5033.81	0.006423	12.96	467.23	119.53	0.92
Reach	661	100 Year	6469.75	5024.05	5032.20	5032.20	5034.81	0.006122	13.69	554.75	137.41	0.92
Reach	661	500 Year	9383.64	5024.05	5033.78	5033.78	5036.94	0.005886	15.39	764.12	180.20	0.93
Reach	661	200 Year Est.	7368.03	5024.05	5032.16	5032.16	5035.60	0.008152	15.73	548.91	136.11	1.06
Reach	640.93*	50 Year	5309.74	5022.62	5028.36	5029.92	5033.35	0.017632	18.01	306.03	83.14	1.47
Reach	640.93*	100 Year	6469.75	5022.62	5029.11	5030.98	5034.36	0.015430	18.60	370.99	88.47	1.41
Reach	640.93*	500 Year	9383.64	5022.62	5030.95	5032.77	5036.54	0.011475	19.48	554.06	137.98	1.27
Reach	640.93*	200 Year Est.	7368.03	5022.62	5029.58	5031.38	5035.17	0.014836	19.28	413.10	90.61	1.40

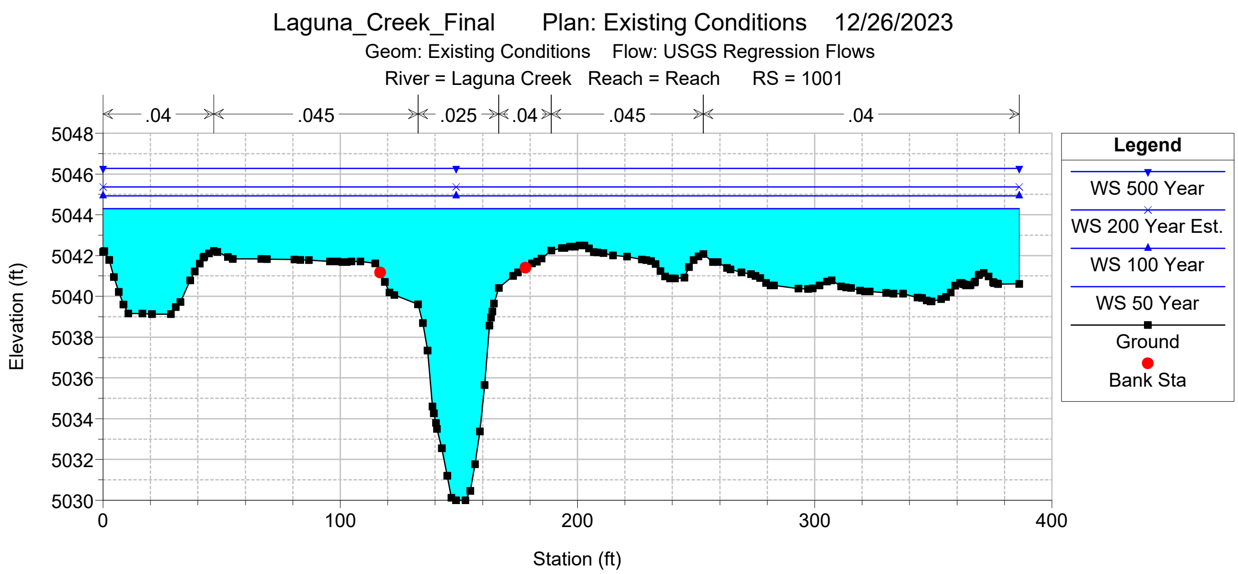

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1360
.04
.045
.025
.04
.045
.04
.05
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1296
.04
.045
.025
.04
.05
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta

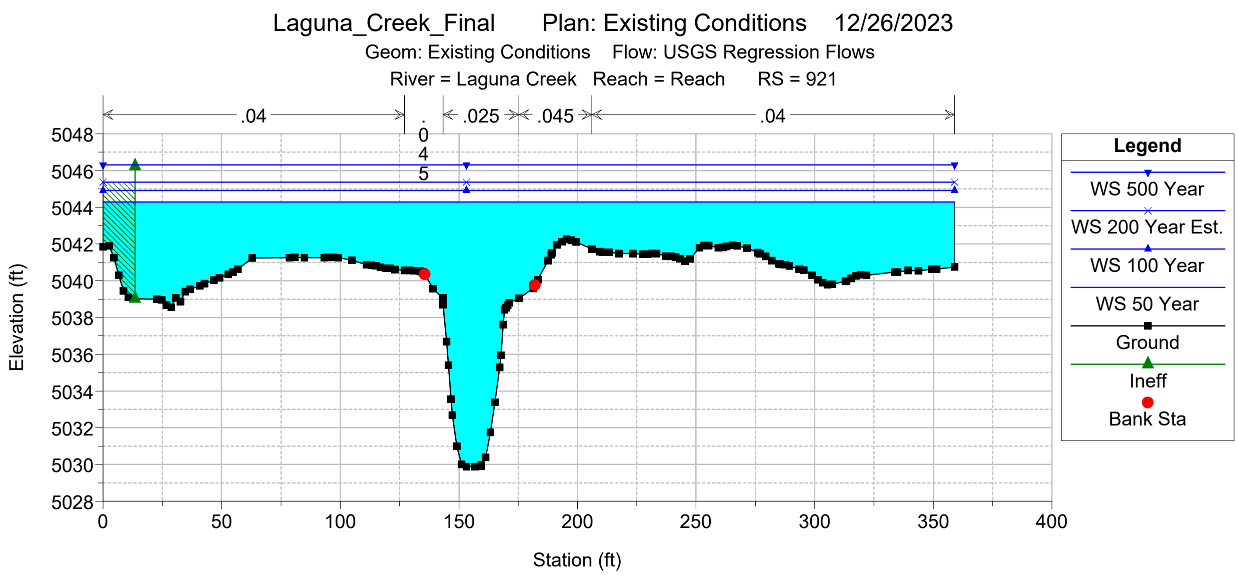

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1196
.04
.045
.025
.04
.045
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta



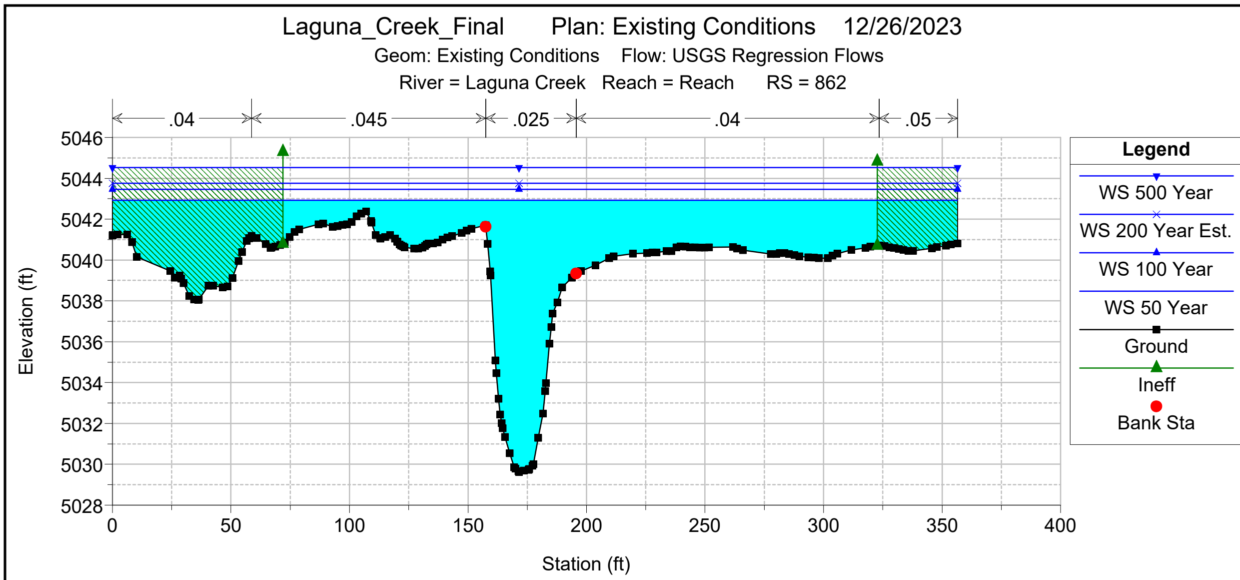
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1113
.04
.045
.025
.04
.045
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta

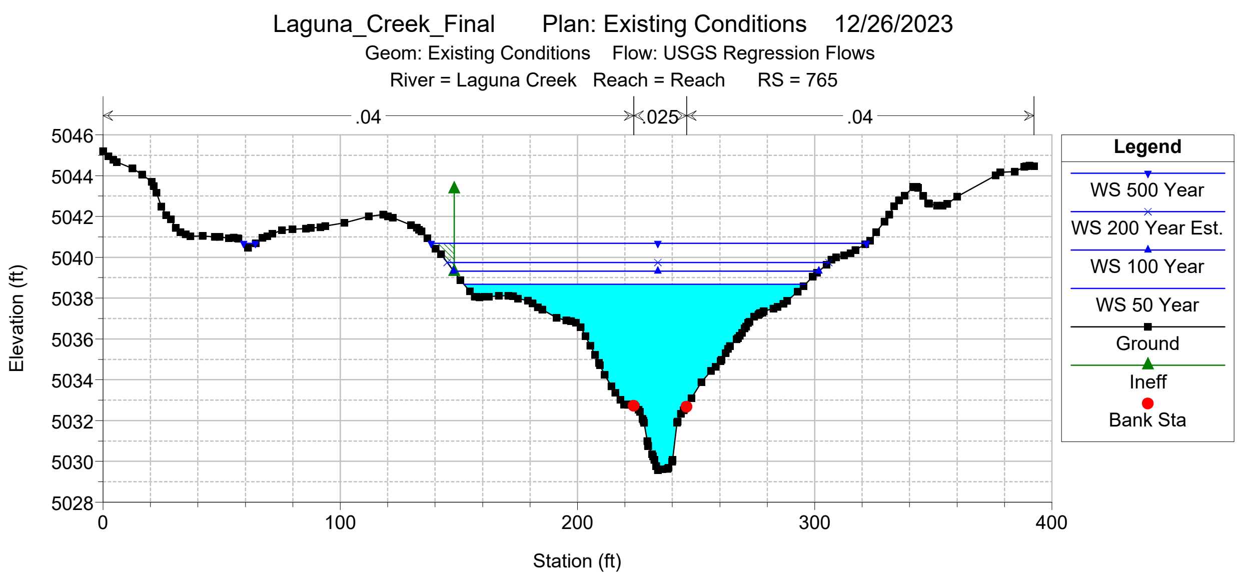


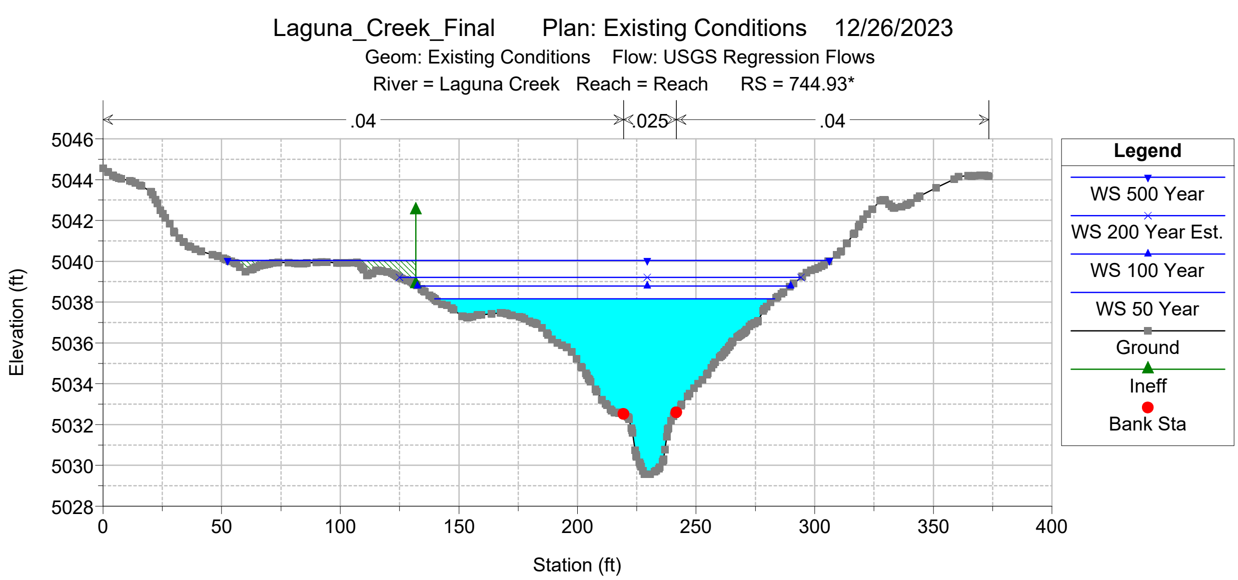
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1001
.04
.045
.025
.04
.045
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta

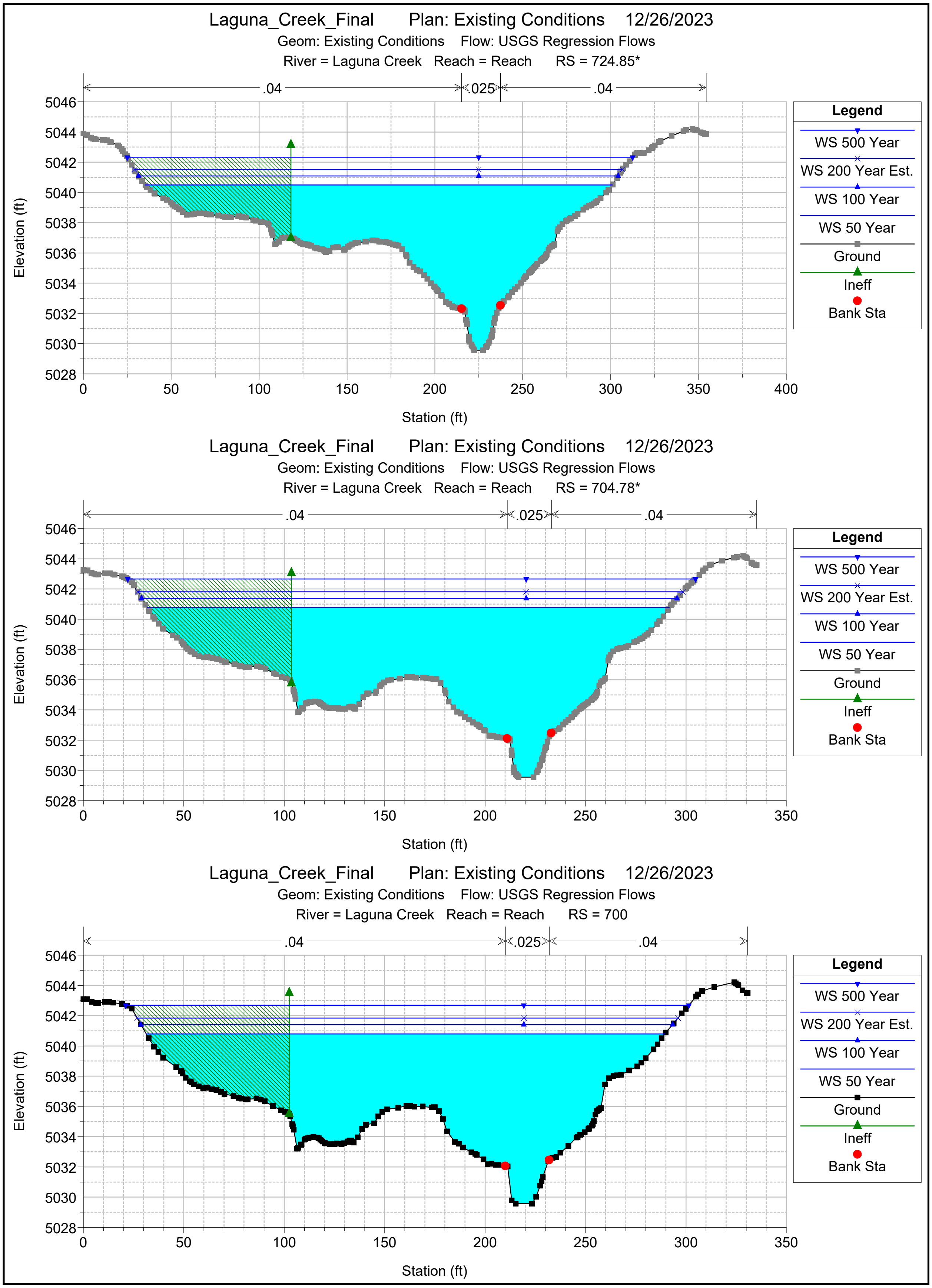


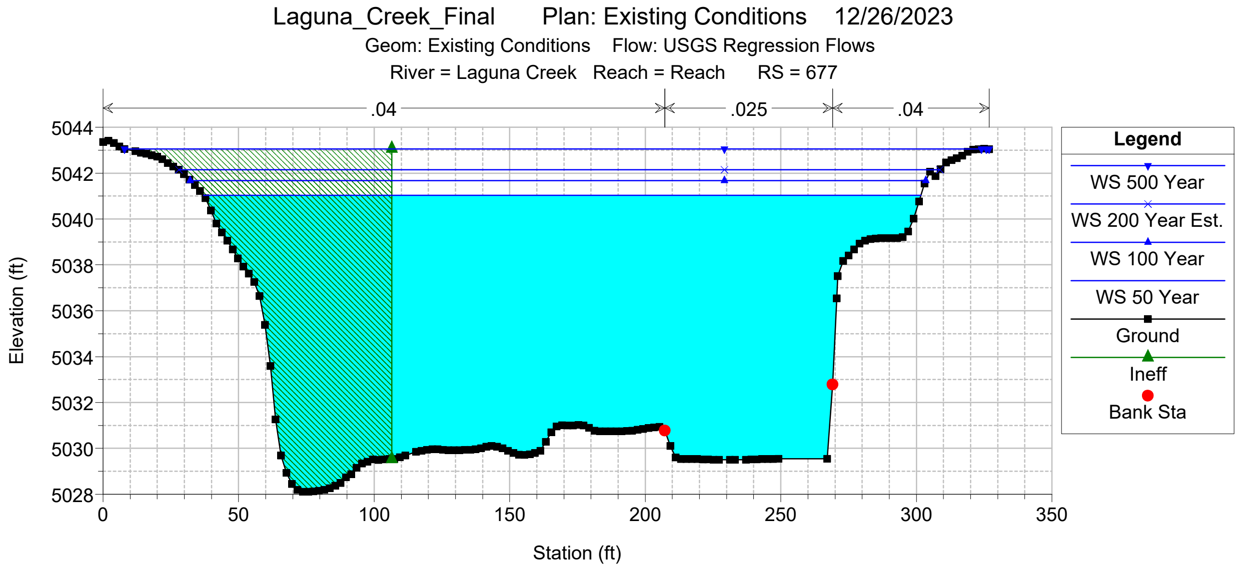
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 921
.04
.045
.025
.045
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 862
.04
.045
.025
.04
.05
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

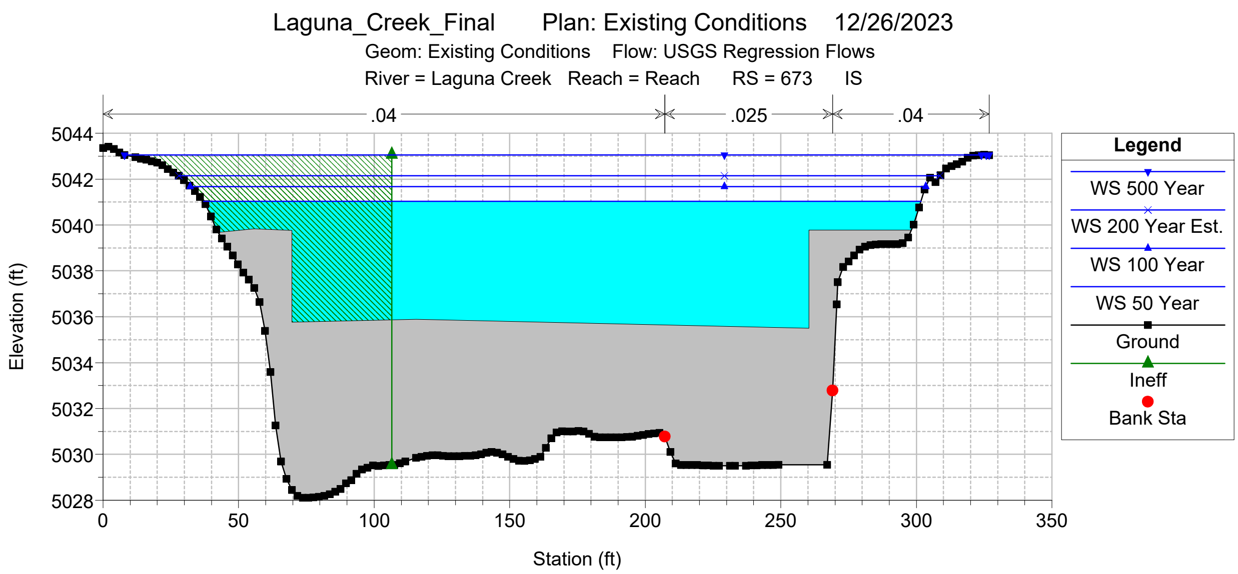

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 765
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 744.93*
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

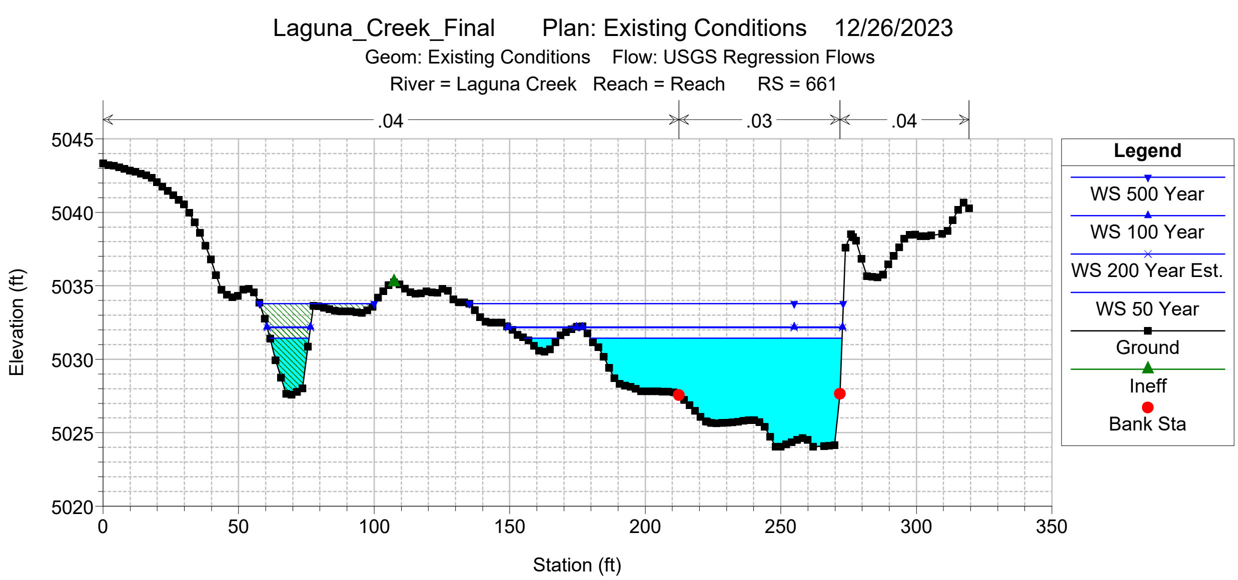

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 724.85*
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 704.78*
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 700
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta



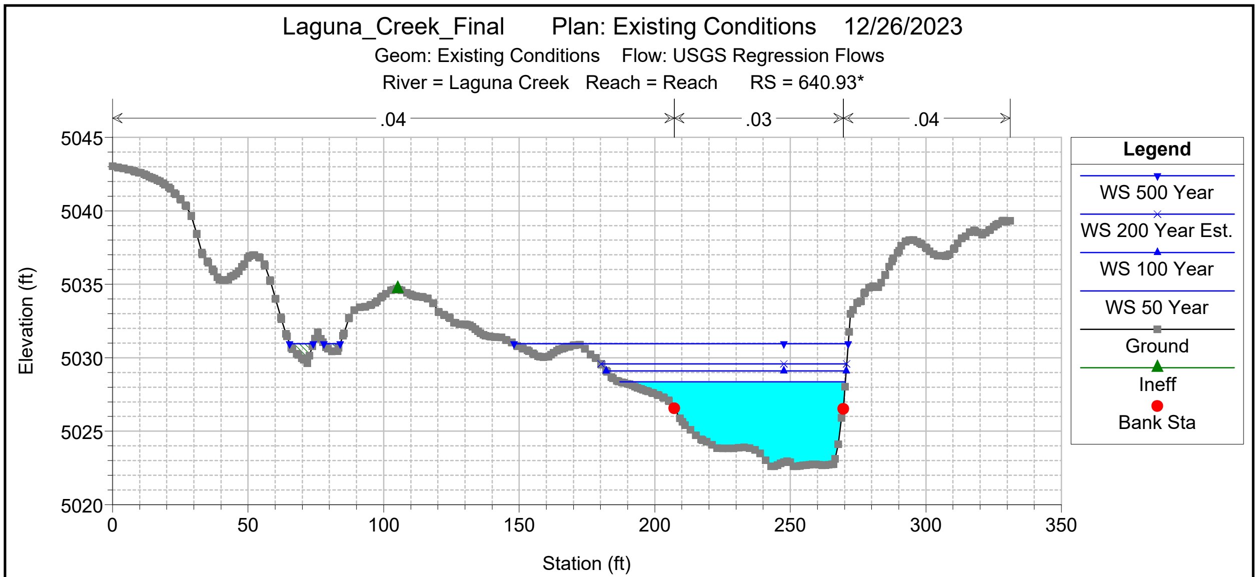
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 677
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

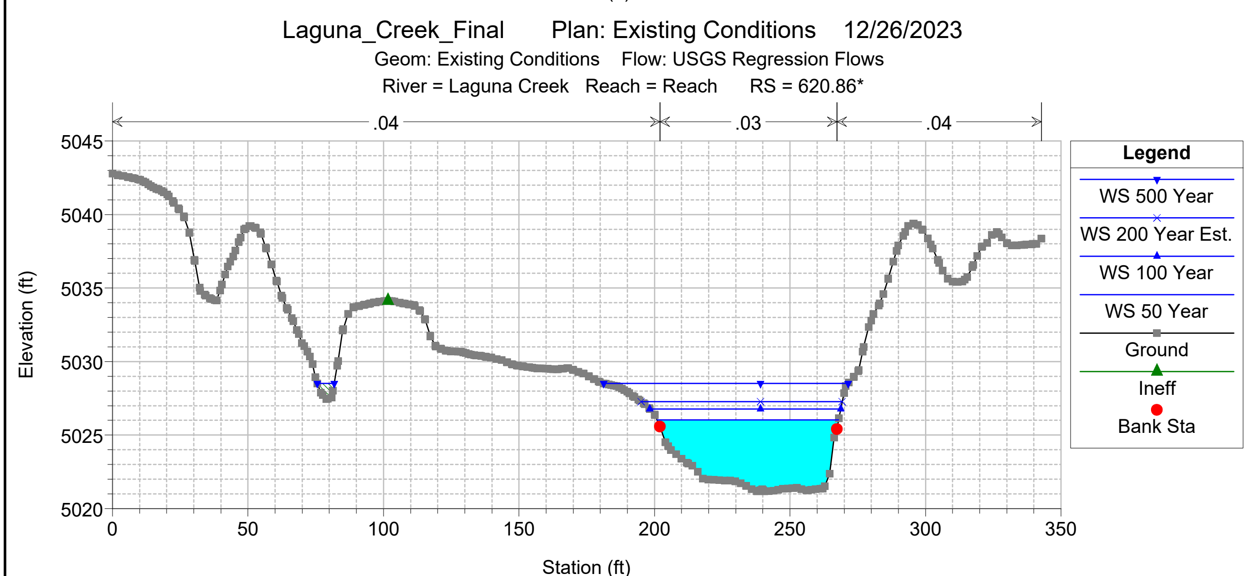


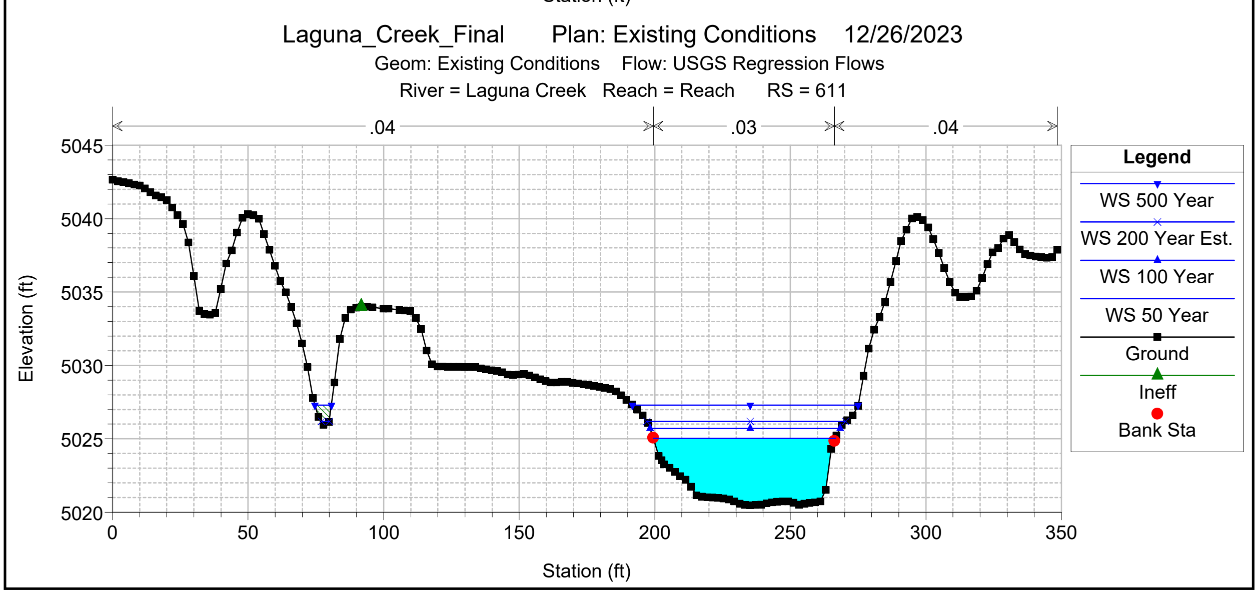
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 673 IS
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

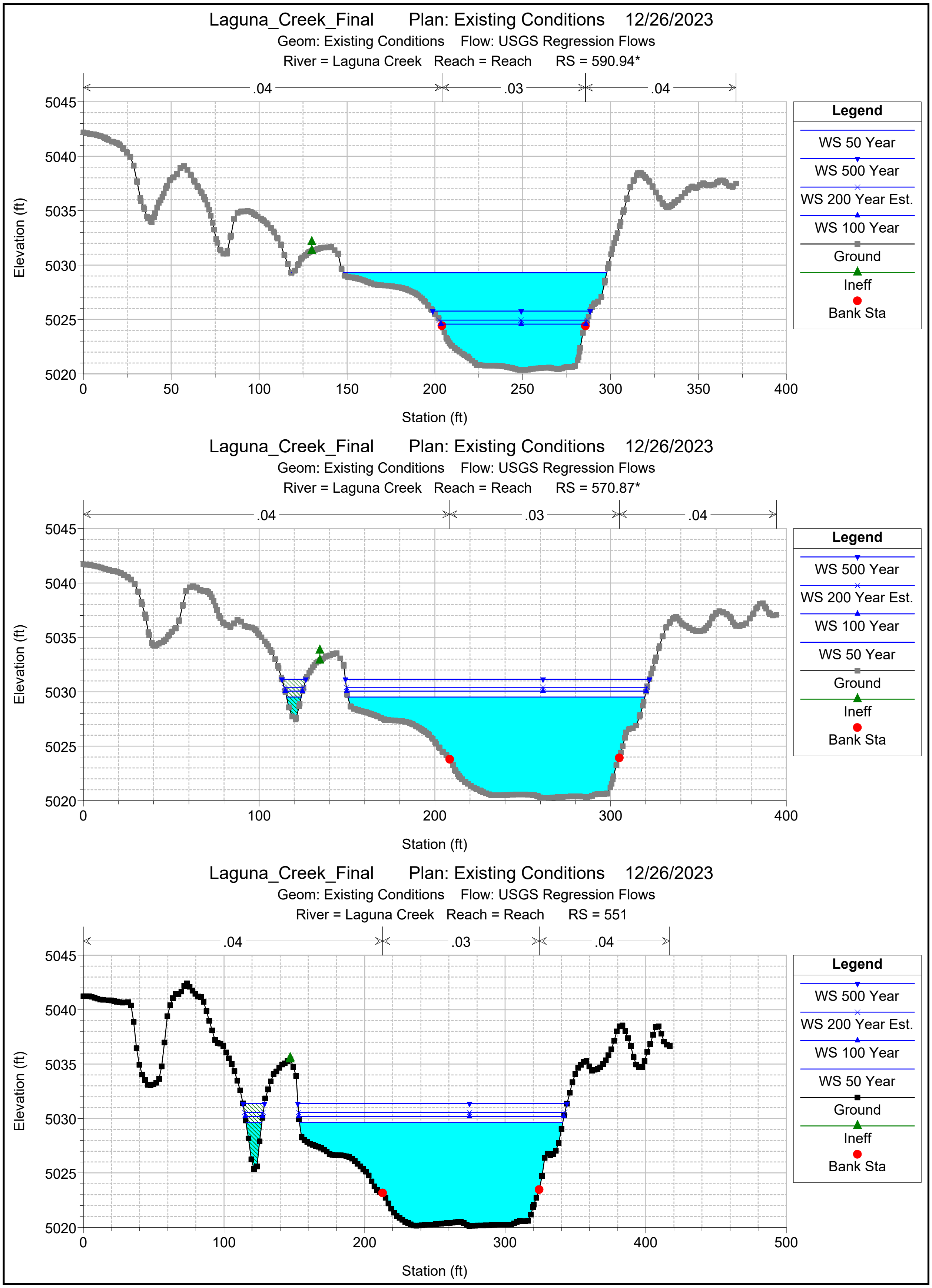


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 661
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 100 Year
WS 200 Year Est.
WS 50 Year
Ground
Ineff
Bank Sta

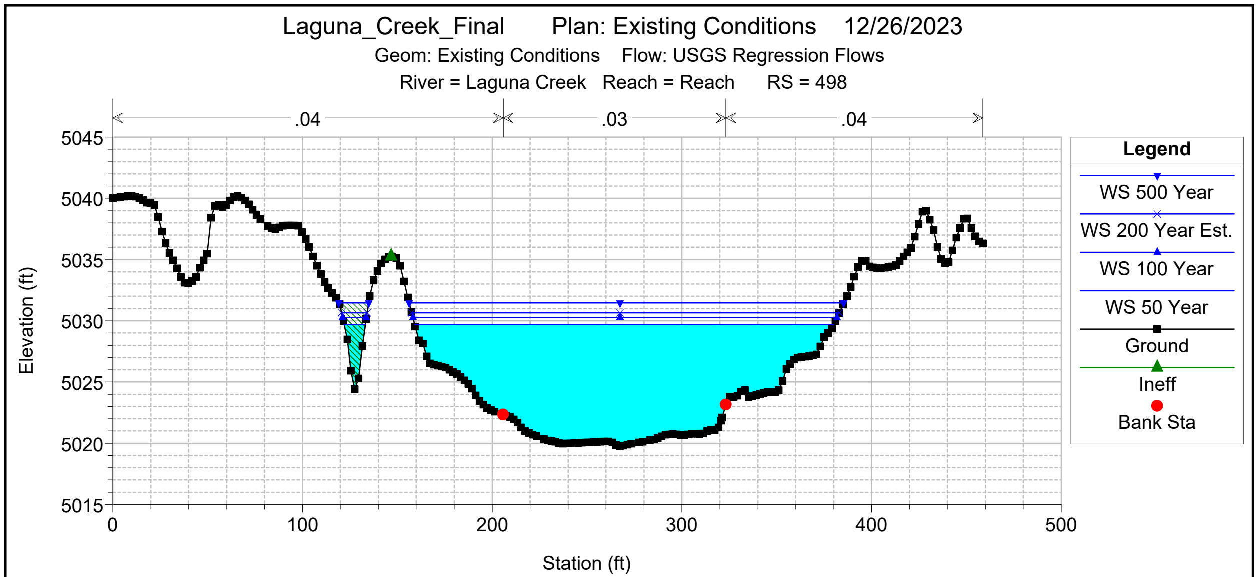

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 640.93*
.04
.03
.04
Elevation (ft)
5045
5040
5035
5030
5025
5020
0
50
100
150
200
250
300
350
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

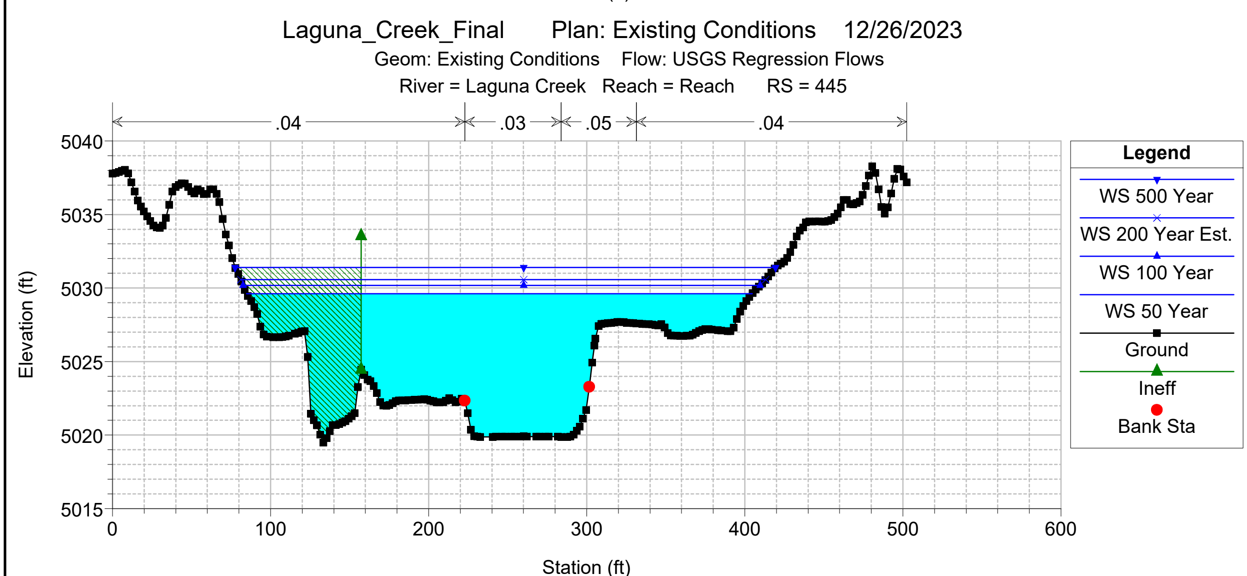

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 620.86*
.04
.03
.04
Elevation (ft)
5045
5040
5035
5030
5025
5020
0
50
100
150
200
250
300
350
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

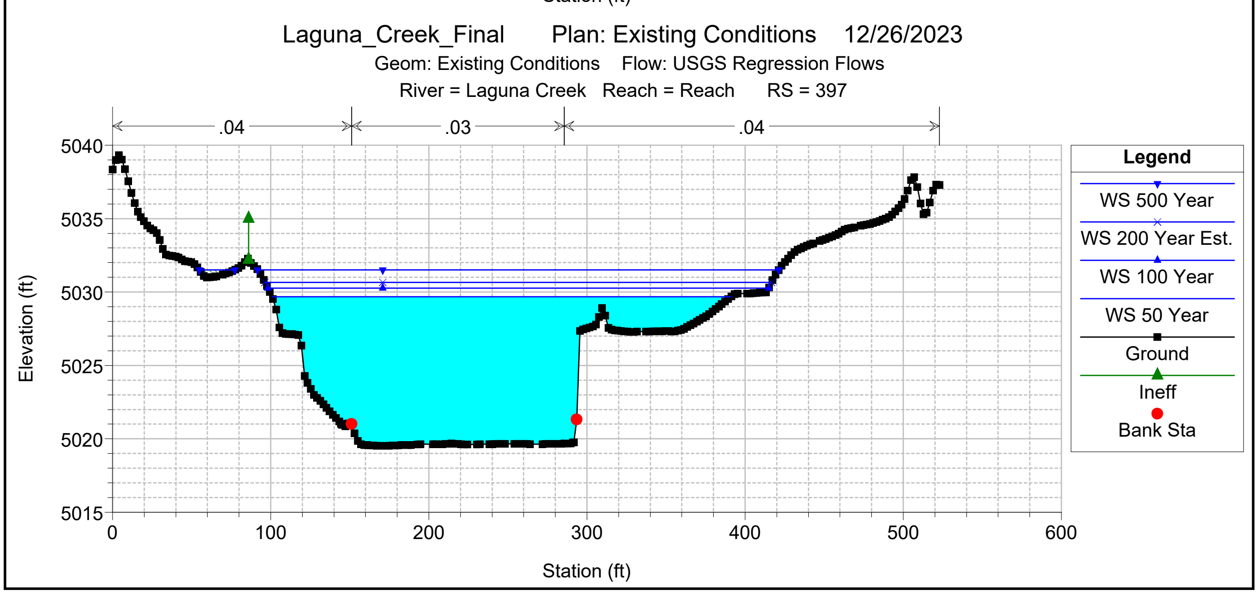

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 611
.04
.03
.04
Elevation (ft)
5045
5040
5035
5030
5025
5020
0
50
100
150
200
250
300
350
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

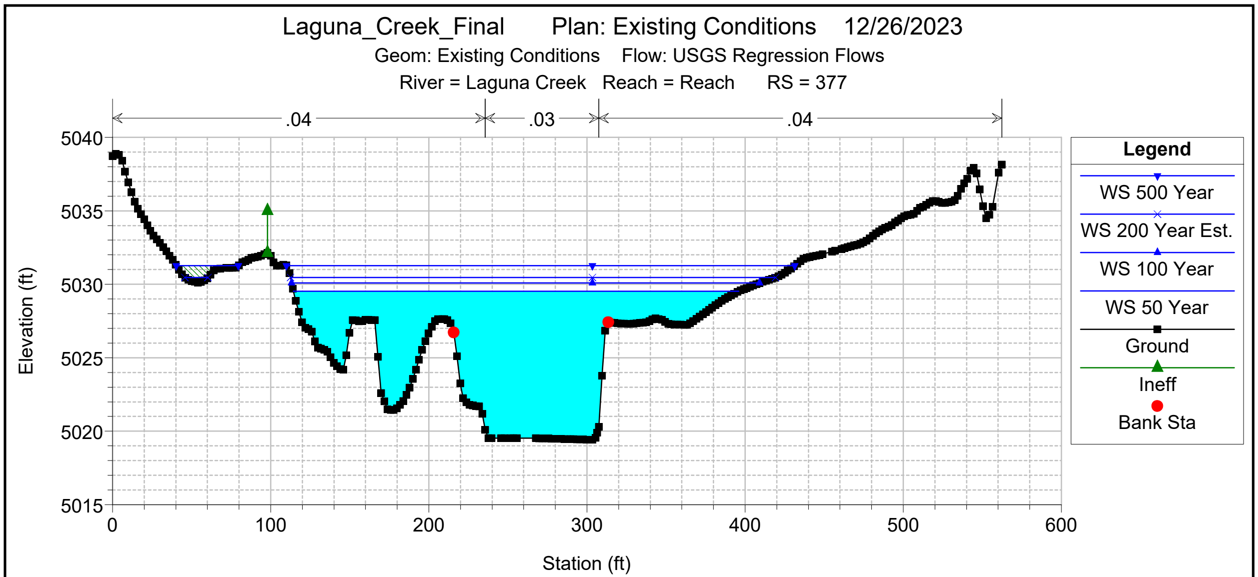


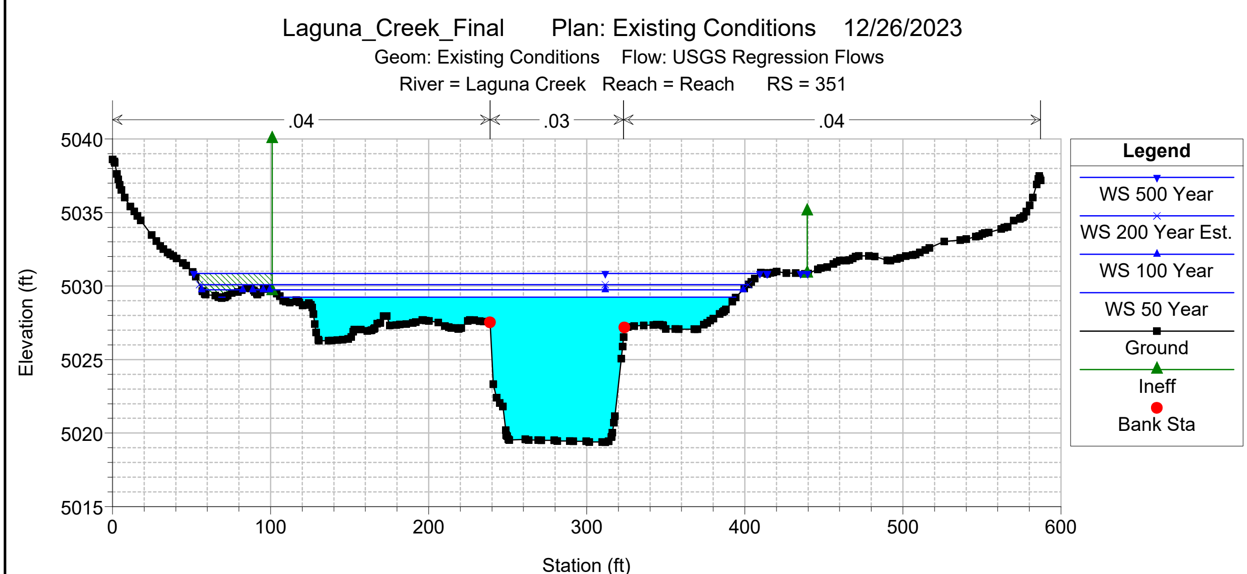
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 590.94*
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 50 Year
WS 500 Year
WS 200 Year Est.
WS 100 Year
Ground
Ineff
Bank Sta
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 570.87*
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta
Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 551
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

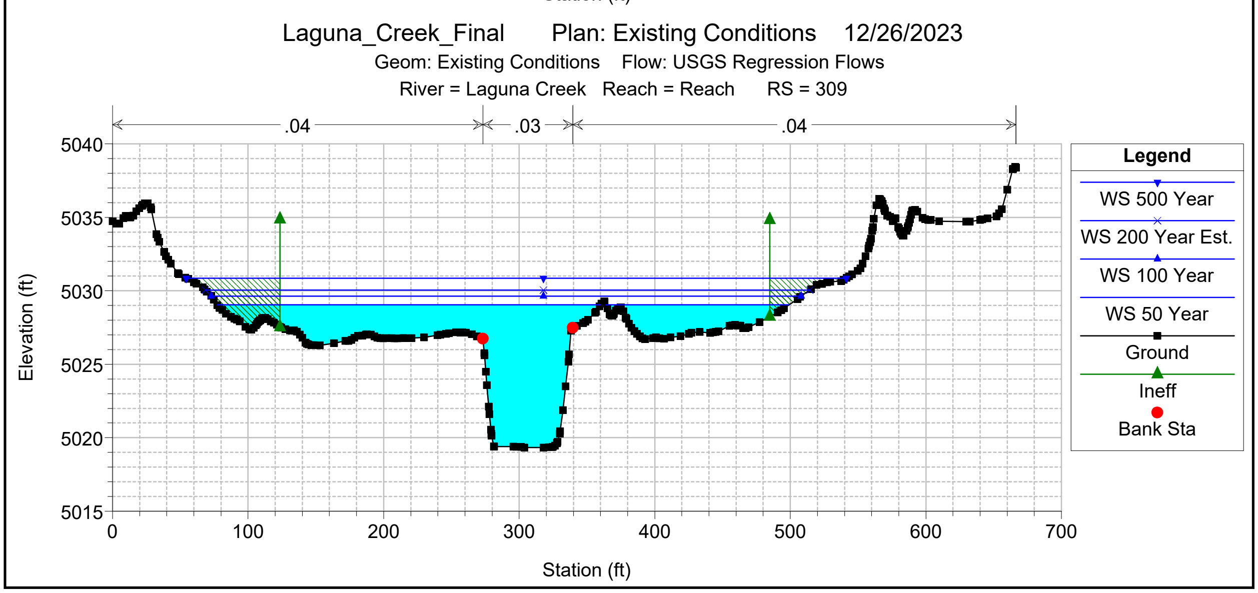

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 498
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

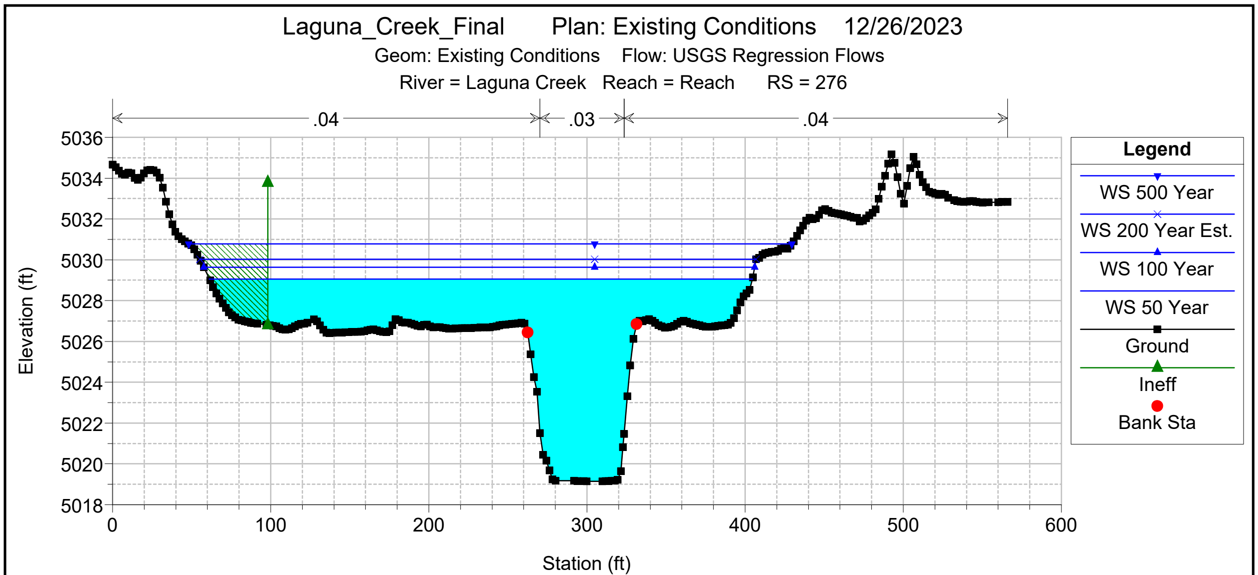

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 445
.04
.03
.05
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

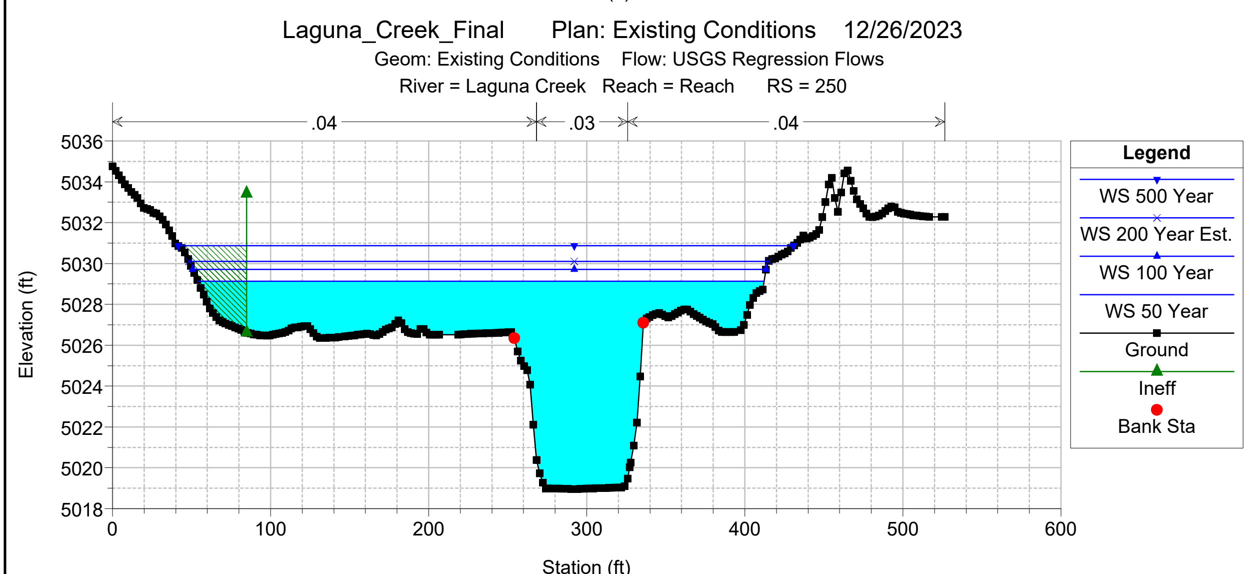

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 397
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

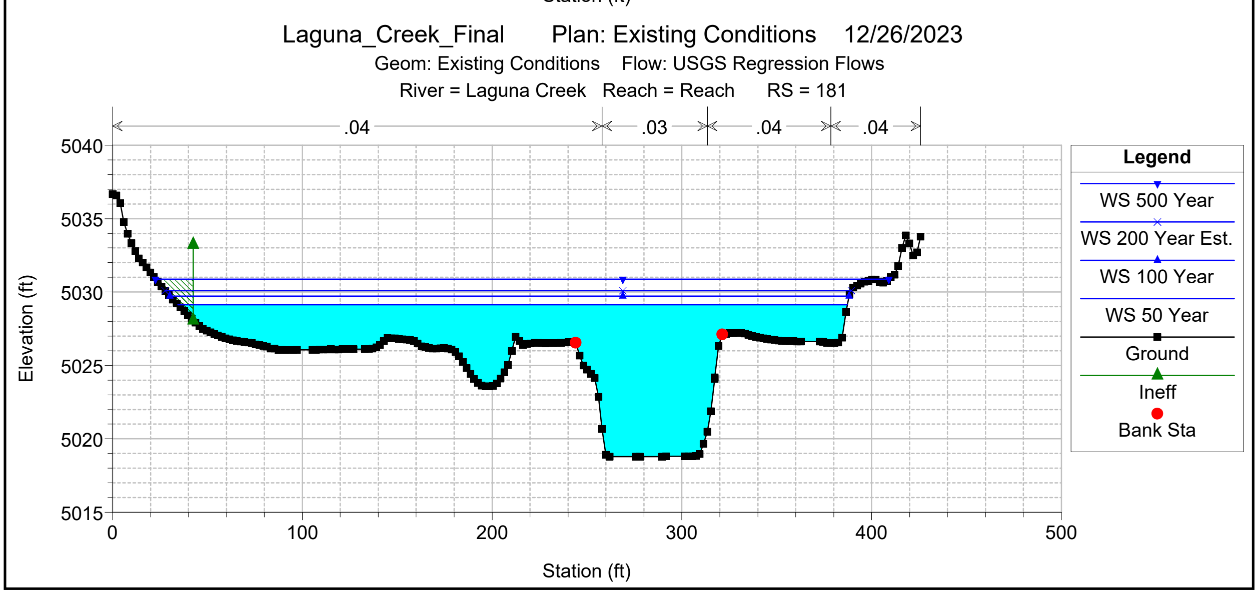

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 377
.04
.03
.04
Elevation (ft)
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
600
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

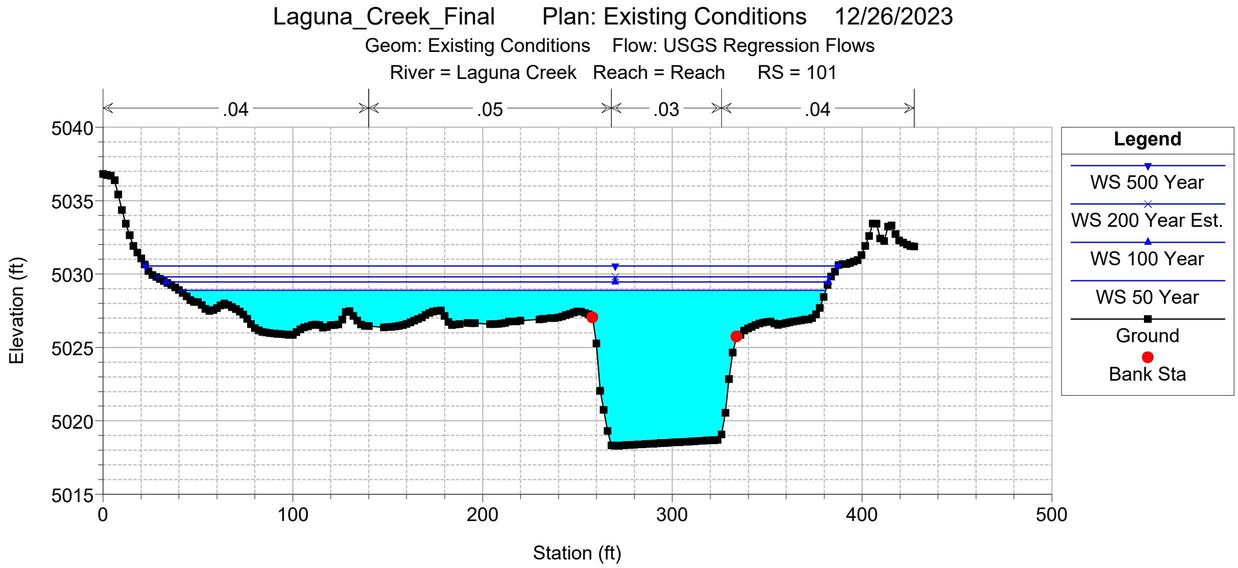

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 351
.04
.03
.04
Elevation (ft)
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
600
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

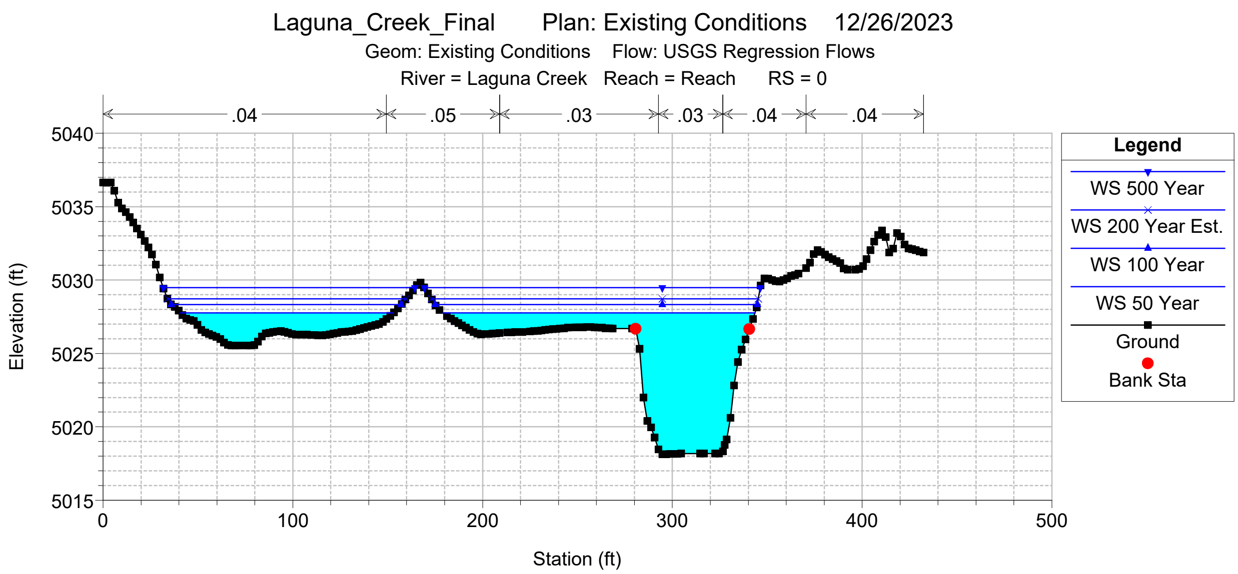

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 309
.04
.03
.04
Elevation (ft)
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
600
700
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 276
.04
.03
.04
Elevation (ft)
5036
5034
5032
5030
5028
5026
5024
5022
5020
5018
0
100
200
300
400
500
600
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 250
.04
.03
.04
Elevation (ft)
5036
5034
5032
5030
5028
5026
5024
5022
5020
5018
0
100
200
300
400
500
600
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 181
.04
.03
.04
.04
Elevation (ft)
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 101
.04
.05
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta

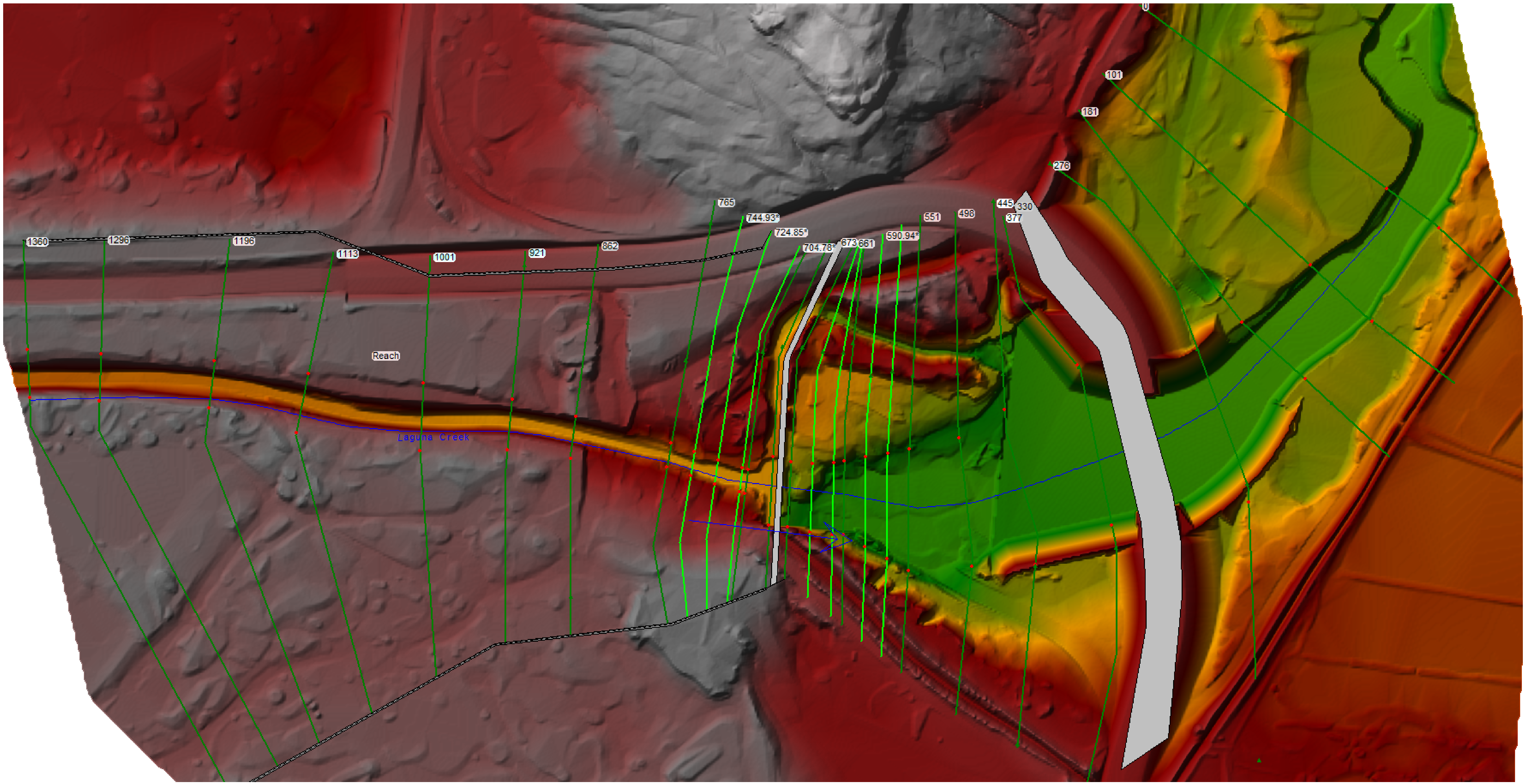

Laguna_Creek_Final Plan: Existing Conditions 12/26/2023
Geom: Existing Conditions Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 0
.04
.05
.03
.03
.04
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta

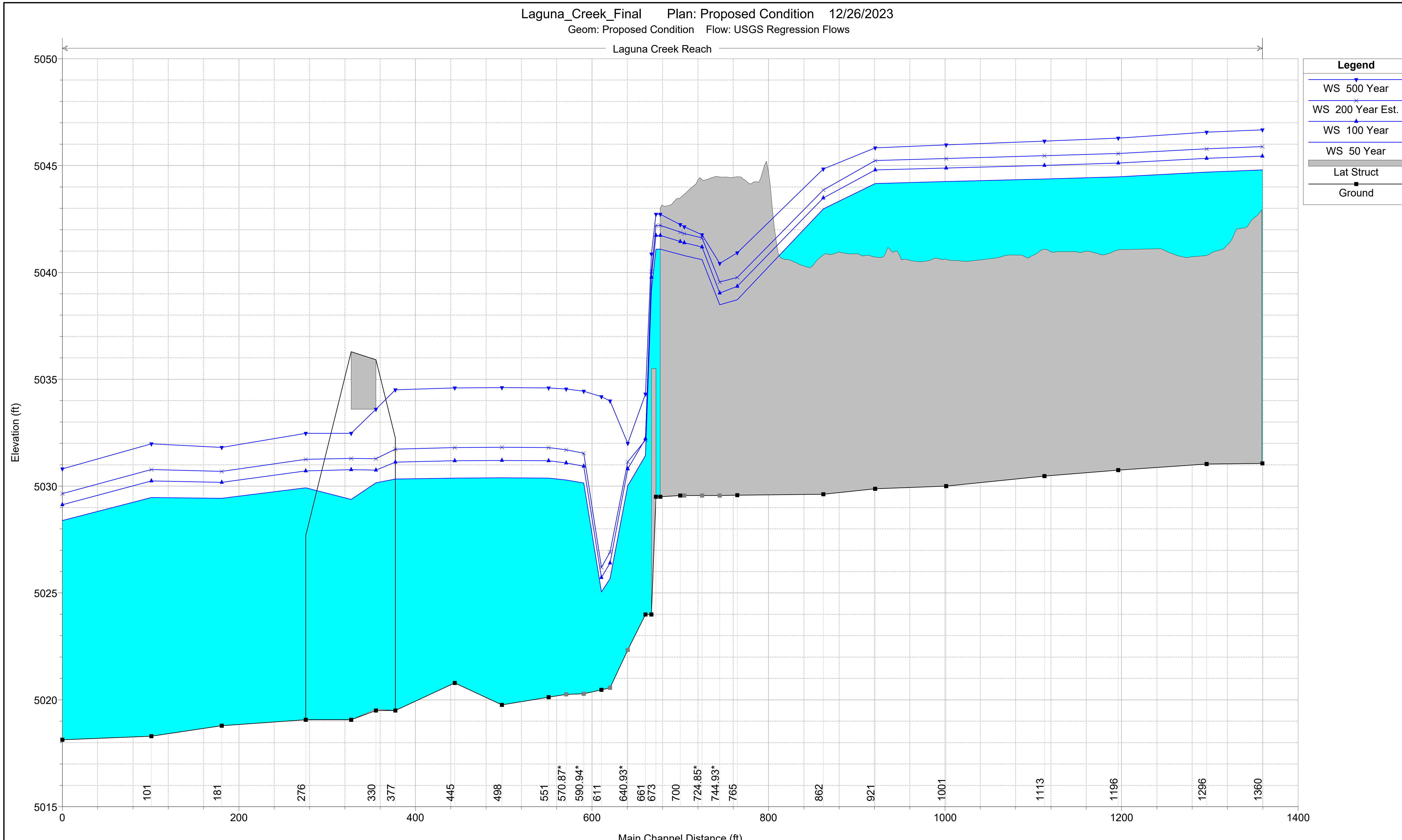
HEC-RAS Plan: Existing River: Laguna Creek Reach: Reach (Continued)

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)	
Reach	620.86*	50 Year	5309.74	5021.18	5026.03	5028.15	5032.73	0.029780	20.76	256.12	67.03	1.85
Reach	620.86*	100 Year	6469.75	5021.18	5026.76	5029.11	5033.80	0.024911	21.29	306.22	70.43	1.74
Reach	620.86*	500 Year	9383.64	5021.18	5028.52	5031.41	5036.06	0.017613	22.16	442.90	96.39	1.54
Reach	620.86*	200 Year Est.	7368.03	5021.18	5027.28	5029.46	5034.63	0.022669	21.78	343.38	74.16	1.69
Reach	611	50 Year	5309.74	5020.48	5025.03	5027.33	5032.35	0.035547	21.70	244.70	67.05	2.00
Reach	611	100 Year	6469.75	5020.48	5025.70	5028.15	5033.46	0.030190	22.35	290.57	70.11	1.89
Reach	611	500 Year	9383.64	5020.48	5027.30	5030.58	5035.77	0.021889	23.46	412.77	89.42	1.70
Reach	611	200 Year Est.	7368.03	5020.48	5026.18	5028.69	5034.30	0.027522	22.88	324.87	76.13	1.84
Reach	590.94*	50 Year	5309.74	5020.37	5029.31	5026.24	5030.16	0.001444	7.55	792.26	150.16	0.46
Reach	590.94*	100 Year	6469.75	5020.37	5024.58	5027.04	5032.71	0.041767	22.87	282.90	82.43	2.17
Reach	590.94*	500 Year	9383.64	5020.37	5025.78	5028.81	5035.16	0.032505	24.59	385.55	89.65	2.01
Reach	590.94*	200 Year Est.	7368.03	5020.37	5024.94	5027.57	5033.60	0.039015	23.61	312.71	84.16	2.13
Reach	570.87*	50 Year	5309.74	5020.25	5029.52	5025.47	5030.03	0.000812	5.91	1023.88	177.37	0.35
Reach	570.87*	100 Year	6469.75	5020.25	5030.06	5026.12	5030.70	0.000959	6.68	1114.32	180.34	0.39
Reach	570.87*	500 Year	9383.64	5020.25	5031.15	5027.79	5032.15	0.001309	8.41	1302.22	186.65	0.46
Reach	570.87*	200 Year Est.	7368.03	5020.25	5030.41	5026.59	5031.16	0.001075	7.26	1174.71	182.33	0.41
Reach	551	50 Year	5309.74	5020.14	5029.63	5024.80	5029.97	0.000512	4.84	1252.78	198.65	0.28
Reach	551	100 Year	6469.75	5020.14	5030.19	5025.38	5030.62	0.000605	5.47	1358.29	201.28	0.31
Reach	551	500 Year	9383.64	5020.14	5031.36	5026.55	5032.03	0.000823	6.89	1580.73	206.77	0.37
Reach	551	200 Year Est.	7368.03	5020.14	5030.57	5025.82	5031.07	0.000678	5.94	1429.59	203.03	0.33
Reach	498	50 Year	5309.74	5019.77	5029.68	5024.65	5029.92	0.000378	4.19	1509.68	231.91	0.24
Reach	498	100 Year	6469.75	5019.77	5030.25	5025.20	5030.56	0.000444	4.73	1637.71	236.10	0.27
Reach	498	500 Year	9383.64	5019.77	5031.47	5026.29	5031.93	0.000596	5.93	1912.27	244.86	0.32
Reach	498	200 Year Est.	7368.03	5019.77	5030.64	5025.59	5031.00	0.000496	5.13	1725.19	238.90	0.28
Reach	445	50 Year	5309.74	5019.88	5029.62	5024.99	5029.89	0.000541	4.69	1446.60	319.82	0.27
Reach	445	100 Year	6469.75	5019.88	5030.19	5025.50	5030.52	0.000628	5.26	1589.02	327.21	0.29
Reach	445	500 Year	9383.64	5019.88	5031.40	5026.65	5031.89	0.000817	6.46	1900.09	341.94	0.34
Reach	445	200 Year Est.	7368.03	5019.88	5030.58	5025.87	5030.96	0.000694	5.67	1687.18	332.04	0.31
Reach	397	50 Year	5309.74	5019.53	5029.69		5029.84	0.000215	3.29	1892.18	290.30	0.18
Reach	397	100 Year	6469.75	5019.53	5030.27		5030.46	0.000258	3.74	2070.52	316.76	0.20
Reach	397	500 Year	9383.64	5019.53	5031.51		5031.81	0.000349	4.69	2471.35	352.14	0.24
Reach	397	200 Year Est.	7368.03	5019.53	5030.67		5030.89	0.000289	4.06	2197.14	320.31	0.22
Reach	377	50 Year	5346.74	5019.42	5029.52		5029.82	0.000647	4.77	1431.92	281.68	0.28
Reach	377	100 Year	6535.75	5019.42	5030.08		5030.44	0.000742	5.31	1593.17	295.94	0.30
Reach	377	500 Year	9536.64	5019.42	5031.27		5031.78	0.000937	6.45	1961.98	360.66	0.35
Reach	377	200 Year Est.	7451.03	5019.42	5030.46		5030.87	0.000813	5.71	1706.81	321.36	0.32
Reach	351	50 Year	5346.74	5019.38	5029.24		5029.77	0.000929	6.20	1126.43	292.10	0.36
Reach	351	100 Year	6535.75	5019.38	5029.75		5030.39	0.001069	6.90	1275.84	332.22	0.39
Reach	351	500 Year	9536.64	5019.38	5030.85		5031.71	0.001331	8.28	1609.66	362.99	0.45
Reach	351	200 Year Est.	7451.03	5019.38	5030.09		5030.81	0.001167	7.38	1379.26	347.32	0.41
Reach	309	50 Year	5346.74	5019.34	5029.05		5029.71	0.001387	7.33	1116.29	417.96	0.44
Reach	309	100 Year	6535.75	5019.34	5029.64		5030.33	0.001405	7.71	1330.41	435.32	0.45
Reach	309	500 Year	9536.64	5019.34	5030.86		5031.62	0.001458	8.53	1769.79	486.80	0.47
Reach	309	200 Year Est.	7451.03	5019.34	5030.04		5030.75	0.001425	7.99	1474.16	445.93	0.45
Reach	276	50 Year	5346.74	5019.15	5029.06		5029.64	0.001439	6.89	1123.15	343.41	0.42
Reach	276	100 Year	6535.75	5019.15	5029.64		5030.27	0.001495	7.34	1301.04	348.40	0.43
Reach	276	500 Year	9536.64	5019.15	5030.78		5031.57	0.001722	8.52	1660.54	381.29	0.47
Reach	276	200 Year Est.	7451.03	5019.15	5030.02		5030.69	0.001550	7.68	1419.66	351.76	0.44
Reach	250	50 Year	5346.74	5018.96	5029.14		5029.56	0.001023	5.82	1280.08	358.20	0.35
Reach	250	100 Year	6535.75	5018.96	5029.72		5030.19	0.001088	6.26	1469.62	362.71	0.36
Reach	250	500 Year	9536.64	5018.96	5030.87		5031.48	0.001272	7.31	1857.44	389.27	0.40
Reach	250	200 Year Est.	7451.03	5018.96	5030.10		5030.61	0.001143	6.59	1596.66	366.70	0.37
Reach	181	50 Year	5346.74	5018.79	5029.13		5029.47	0.000907	5.45	1424.80	352.83	0.33
Reach	181	100 Year	6535.75	5018.79	5029.71		5030.09	0.000953	5.83	1625.89	357.87	0.34
Reach	181	500 Year	9536.64	5018.79	5030.88		5031.36	0.001095	6.76	2033.71	386.36	0.37
Reach	181	200 Year Est.	7451.03	5018.79	5030.10		5030.51	0.000996	6.12	1760.26	361.77	0.35
Reach	101	50 Year	5346.74	5018.30	5028.90		5029.38	0.001116	6.05	1262.40	340.75	0.35
Reach	101	100 Year	6535.75	5018.30	5029.45		5029.99	0.001232	6.60	1450.16	349.16	0.37
Reach	101	500 Year	9536.64	5018.30	5030.55		5031.24	0.001488	7.77	1843.41	364.89	0.41
Reach	101	200 Year Est.	7451.03	5018.30	5029.81		5030.40	0.001321	6.99	1577.86	355.67	0.38
Reach	0	50 Year	5346.74	5018.13	5027.76	5027.60	5029.11	0.003501	9.94	729.41	276.65	0.63
Reach	0	100 Year	6535.75	5018.13	5028.33	5028.15	5029.71	0.003502	10.42	890.22	290.92	0.64
Reach	0	500 Year	9536.64	5018.13	5029.48	5029.15	5030.94	0.003506	11.36	1234.92	309.49	0.65
Reach	0	200 Year Est.	7451.03	5018.13	5028.71	5028.51	5030.12	0.003506	10.74	1002.17	297.71	0.64

HEC-RAS CROSS SECTION MAP
LAGUNA CREEK

PROPOSED CONDITION





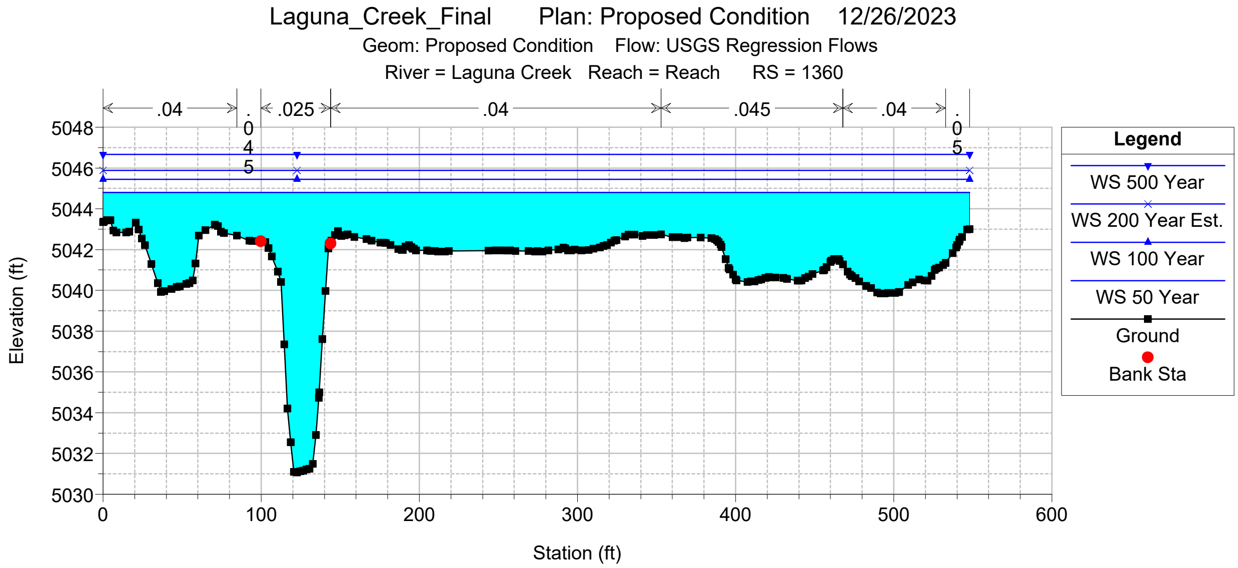
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
Laguna Creek Reach
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Lat Struct
Ground
Elevation (ft)
Main Channel Distance (ft)
5015
5020
5025
5030
5035
5040
5045
5050
0
200
400
600
800
1000
1200
1400
101
181
276
330
377
445
498
551
570.87*
590.94*
611
640.93*
661
673
700
724.85*
744.93*
765
862
921
1001
1113
1196
1296
1360

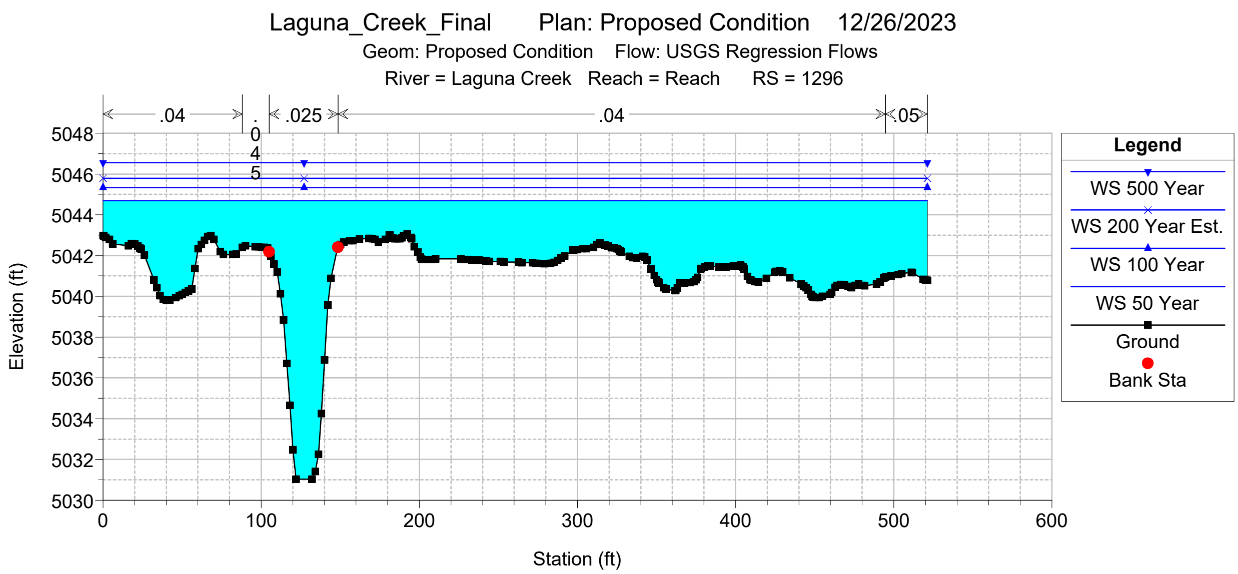
HEC-RAS Plan: Proposed River: Laguna Creek Reach: Reach

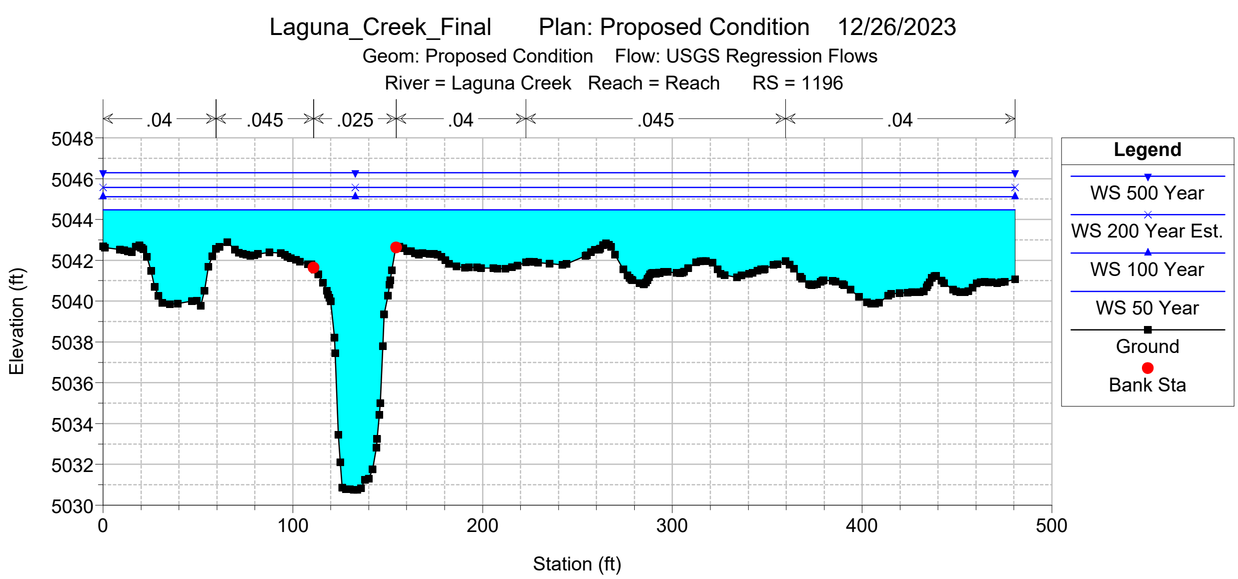
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach	1360	50 Year	7958.00	5031.06	5044.80	5043.94	5045.36	0.001632	8.72	1903.71	548.07	0.53
Reach	1360	100 Year	10241.00	5031.06	5045.44	5044.49	5046.04	0.001675	9.28	2255.35	548.07	0.54
Reach	1360	500 Year	15949.00	5031.06	5046.67	5045.36	5047.43	0.001873	10.69	2932.41	548.07	0.59
Reach	1360	200 Year Est.	12000.00	5031.06	5045.89	5044.77	5046.53	0.001701	9.66	2502.09	548.07	0.55
Reach	1359		Lat Struct									
Reach	1358		Lat Struct									
Reach	1296	50 Year	7704.08	5031.03	5044.70		5045.27	0.001484	8.63	1865.89	521.19	0.52
Reach	1296	100 Year	9851.27	5031.03	5045.34		5045.95	0.001520	9.16	2201.05	521.19	0.53
Reach	1296	500 Year	15251.25	5031.03	5046.56		5047.32	0.001721	10.57	2837.77	521.19	0.57
Reach	1296	200 Year Est.	11506.05	5031.03	5045.79		5046.43	0.001544	9.52	2435.69	521.19	0.54
Reach	1196	50 Year	7303.73	5030.75	5044.47		5045.11	0.001592	8.82	1695.82	480.62	0.52
Reach	1196	100 Year	9254.02	5030.75	5045.12		5045.78	0.001621	9.32	2005.37	480.62	0.53
Reach	1196	500 Year	14220.21	5030.75	5046.29		5047.13	0.001890	10.88	2566.72	480.62	0.59
Reach	1196	200 Year Est.	10757.76	5030.75	5045.57		5046.26	0.001641	9.68	2221.74	480.62	0.54
Reach	1113	50 Year	6855.59	5030.47	5044.37		5044.97	0.001476	8.24	1578.29	432.92	0.53
Reach	1113	100 Year	8607.71	5030.47	5045.01		5045.64	0.001520	8.67	1855.84	432.92	0.53
Reach	1113	500 Year	13162.60	5030.47	5046.15		5046.96	0.001850	10.17	2346.89	432.92	0.59
Reach	1113	200 Year Est.	9961.82	5030.47	5045.46		5046.12	0.001549	8.97	2050.73	432.92	0.54
Reach	1001	50 Year	6346.76	5030.00	5044.26		5044.80	0.001306	7.59	1484.94	386.24	0.49
Reach	1001	100 Year	7905.93	5030.00	5044.89		5045.47	0.001361	8.00	1729.17	386.24	0.50
Reach	1001	500 Year	12081.26	5030.00	5045.97		5046.76	0.001752	9.59	2145.58	386.24	0.56
Reach	1001	200 Year Est.	9116.62	5030.00	5045.33		5045.94	0.001399	8.30	1900.79	386.24	0.50
Reach	921	50 Year	5805.83	5029.88	5044.16	5043.00	5044.70	0.001162	7.62	1386.13	358.98	0.45
Reach	921	100 Year	7153.70	5029.88	5044.80	5043.46	5045.36	0.001191	7.99	1606.12	358.98	0.46
Reach	921	500 Year	10928.38	5029.88	5045.83	5044.41	5046.62	0.001582	9.72	1963.62	358.98	0.53
Reach	921	200 Year Est.	8206.81	5029.88	5045.24	5043.73	5045.83	0.001217	8.27	1759.82	358.98	0.46
Reach	862	50 Year	5476.28	5029.62	5042.97	5042.97	5044.50	0.002729	11.55	812.89	356.51	0.68
Reach	862	100 Year	6695.06	5029.62	5043.49	5043.49	5045.15	0.002914	12.39	941.21	356.51	0.71
Reach	862	500 Year	10140.34	5029.62	5044.84	5044.84	5046.43	0.002739	13.14	1423.87	356.51	0.71
Reach	862	200 Year Est.	7646.42	5029.62	5043.86	5043.86	5045.61	0.003021	12.95	1034.51	356.51	0.73
Reach	765	50 Year	5389.16	5029.58	5038.72	5040.38	5043.71	0.009221	21.31	451.09	144.68	1.35
Reach	765	100 Year	6545.48	5029.58	5039.35	5041.08	5044.36	0.008900	22.06	544.83	154.50	1.35
Reach	765	500 Year	9702.50	5029.58	5040.92	5042.41	5045.70	0.007680	22.99	803.85	205.36	1.29
Reach	765	200 Year Est.	7437.34	5029.58	5039.77	5041.48	5044.82	0.008753	22.60	610.26	161.16	1.35
Reach	744.93*	50 Year	5389.16	5029.56	5038.49	5040.27	5043.51	0.009825	21.57	444.17	171.78	1.39
Reach	744.93*	100 Year	6545.48	5029.56	5039.04	5040.79	5044.16	0.009744	22.52	537.73	183.55	1.40
Reach	744.93*	500 Year	9702.50	5029.56	5040.42	5042.02	5045.50	0.008889	23.93	788.02	203.70	1.38
Reach	744.93*	200 Year Est.	7437.34	5029.56	5039.55	5041.17	5044.63	0.009288	22.92	629.03	191.87	1.39
Reach	724.85*	50 Year	5389.16	5029.56	5040.60	5039.38	5041.50	0.001539	10.53	975.12	231.54	0.58
Reach	724.85*	100 Year	6545.48	5029.56	5041.19	5039.91	5042.22	0.001673	11.40	1086.29	256.10	0.61
Reach	724.85*	500 Year	9702.50	5029.56	5041.76	5041.11	5043.59	0.002821	15.31	1195.27	285.31	0.79
Reach	724.85*	200 Year Est.	7437.34	5029.56	5041.62	5040.30	5042.74	0.001765	12.01	1167.30	278.02	0.63
Reach	704.78*	50 Year	5389.16	5029.56	5040.79	5038.43	5041.39	0.001042	8.87	1132.82	255.51	0.48
Reach	704.78*	100 Year	6545.48	5029.56	5041.39	5039.05	5042.10	0.001165	9.74	1247.88	267.00	0.52
Reach	704.78*	500 Year	9702.50	5029.56	5042.14	5040.29	5043.35	0.001857	12.85	1395.14	286.09	0.66
Reach	704.78*	200 Year Est.	7437.34	5029.56	5041.82	5039.41	5042.61	0.001245	10.33	1332.77	275.77	0.54
Reach	700	50 Year	5389.16	5029.56	5040.84	5037.87	5041.35	0.000918	8.25	1184.25	258.55	0.45
Reach	700	100 Year	6545.48	5029.56	5041.45	5038.53	5042.06	0.001038	9.10	1298.69	269.09	0.48
Reach	700	500 Year	9702.50	5029.56	5042.24	5039.88	5043.30	0.001648	12.01	1452.32	284.81	0.61
Reach	700	200 Year Est.	7437.34	5029.56	5041.89	5039.01	5042.58	0.001115	9.68	1383.31	277.39	0.50
Reach	677	50 Year	5389.16	5029.50	5041.09	5033.46	5041.24	0.000206	3.52	1868.42	265.07	0.18
Reach	677	100 Year	6545.48	5029.50	5041.74	5033.93	5041.93	0.000250	4.02	1995.25	276.18	0.20
Reach	677	500 Year	9702.50	5029.50	5042.72	5035.06	5043.07	0.000416	5.46	2194.72	309.44	0.27
Reach	677	200 Year Est.	7437.34	5029.50	5042.20	5034.24	5042.43	0.000282	4.38	2088.38	291.32	0.22
Reach	673		Inl Struct									
Reach	661	50 Year	5389.16	5023.99	5031.43	5031.43	5033.85	0.006612	13.06	469.84	119.27	0.92
Reach	661	100 Year	6545.48	5023.99	5032.21	5032.21	5034.84	0.006252	13.74	557.68	136.43	0.92
Reach	661	500 Year	9702.50	5023.99	5034.31	5034.31	5037.12	0.004988	14.63	841.35	192.98	0.86
Reach	661	200 Year Est.	7437.34	5023.99	5032.16	5032.16	5035.62	0.008314	15.77	551.17	134.94	1.06
Reach	640.93*	50 Year	5389.16	5022.34	5030.02	5031.35	5033.57	0.011474	15.45	379.47	105.20	1.18
Reach	640.93*	100 Year	6545.48	5022.34	5030.80	5032.11	5034.56	0.010420	16.04	471.89	155.97	1.14
Reach	640.93*	500 Year	9702.50	5022.34	5032.00	5033.44	5036.78	0.011051	18.61	655.71	181.41	1.21
Reach	640.93*	200 Year Est.	7437.34	5022.34	5031.14	5032.50	5035.35	0.011020	17.09	520.21	163.61	1.19

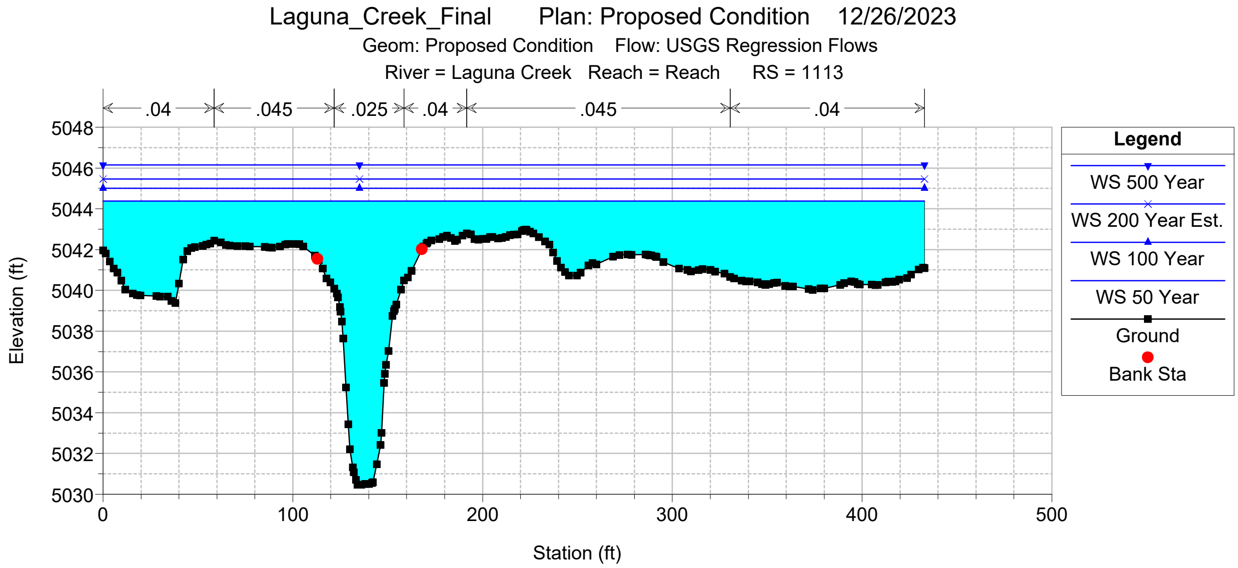
HEC-RAS Plan: Proposed River: Laguna Creek Reach: Reach (Continued)

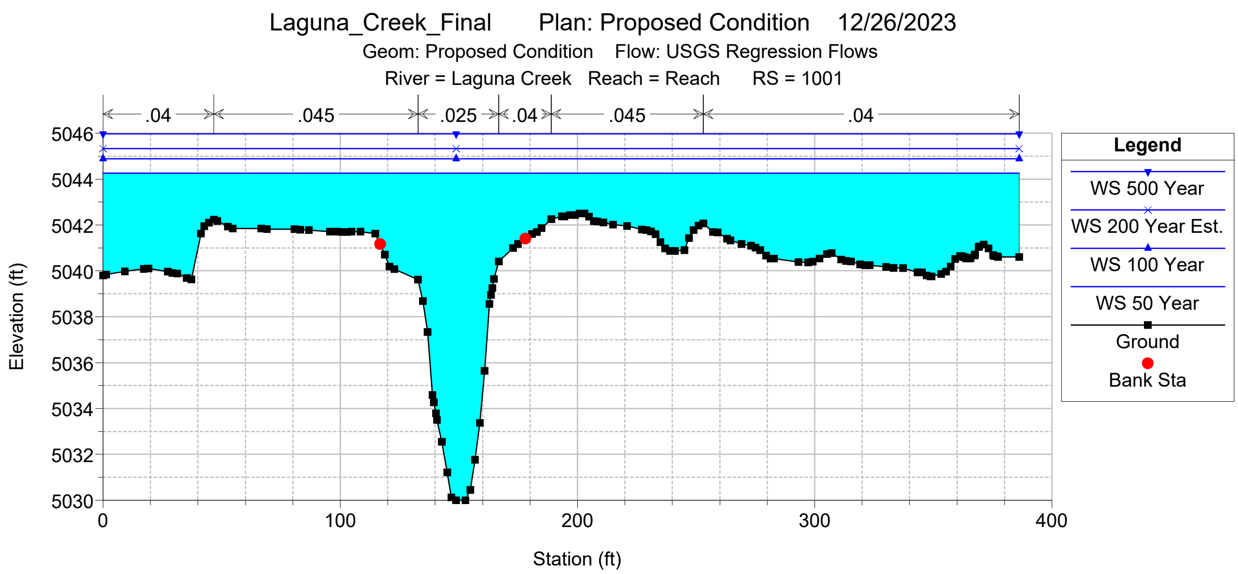
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach	620.86*	50 Year	5389.16	5020.56	5025.67	5027.95	5032.84	0.033595	21.48	250.87	64.70	1.92
Reach	620.86*	100 Year	6545.48	5020.56	5026.40	5028.74	5033.87	0.028146	21.92	299.02	71.85	1.81
Reach	620.86*	500 Year	9702.50	5020.56	5033.99	5031.42	5035.30	0.001584	9.98	1266.80	212.10	0.50
Reach	620.86*	200 Year Est.	7437.34	5020.56	5026.92	5029.49	5034.69	0.025424	22.37	334.58	76.97	1.75
Reach	611	50 Year	5389.16	5020.47	5025.05	5027.37	5032.48	0.036092	21.86	246.51	67.09	2.01
Reach	611	100 Year	6545.48	5020.47	5025.72	5028.19	5033.55	0.030433	22.45	292.56	69.53	1.89
Reach	611	500 Year	9702.50	5020.47	5034.18	5030.77	5035.20	0.001146	8.93	1508.52	226.35	0.44
Reach	611	200 Year Est.	7437.34	5020.47	5026.20	5028.73	5034.39	0.027806	22.98	326.35	76.62	1.84
Reach	590.94*	50 Year	5389.16	5020.28	5030.14	5026.47	5030.79	0.001049	6.74	940.74	180.16	0.40
Reach	590.94*	100 Year	6545.48	5020.28	5030.93	5027.16	5031.67	0.001094	7.28	1073.25	183.86	0.41
Reach	590.94*	500 Year	9702.50	5020.28	5034.44	5029.18	5035.06	0.000663	6.97	1811.99	227.08	0.34
Reach	590.94*	200 Year Est.	7437.34	5020.28	5031.54	5027.93	5032.34	0.001101	7.61	1176.04	187.00	0.42
Reach	570.87*	50 Year	5389.16	5020.26	5030.29	5025.58	5030.71	0.000622	5.44	1161.13	195.94	0.31
Reach	570.87*	100 Year	6545.48	5020.26	5031.09	5026.21	5031.58	0.000664	5.93	1309.72	199.71	0.33
Reach	570.87*	500 Year	9702.50	5020.26	5034.54	5027.97	5035.00	0.000447	5.92	2097.76	240.83	0.28
Reach	570.87*	200 Year Est.	7437.34	5020.26	5031.70	5026.65	5032.24	0.000680	6.24	1424.87	203.03	0.34
Reach	551	50 Year	5389.16	5020.13	5030.38	5024.81	5030.66	0.000391	4.45	1392.83	202.03	0.25
Reach	551	100 Year	6545.48	5020.13	5031.19	5025.38	5031.52	0.000427	4.91	1546.84	205.80	0.27
Reach	551	500 Year	9702.50	5020.13	5034.60	5027.02	5034.97	0.000330	5.20	2214.49	254.78	0.25
Reach	551	200 Year Est.	7437.34	5020.13	5031.81	5025.85	5032.18	0.000445	5.20	1665.70	208.97	0.27
Reach	498	50 Year	5389.16	5019.76	5030.39	5024.61	5030.62	0.000325	4.08	1487.42	237.04	0.23
Reach	498	100 Year	6545.48	5019.76	5031.20	5025.17	5031.49	0.000359	4.53	1633.35	242.59	0.24
Reach	498	500 Year	9702.50	5019.76	5034.61	5026.59	5034.94	0.000291	4.90	2257.35	301.53	0.23
Reach	498	200 Year Est.	7437.34	5019.76	5031.82	5025.58	5032.15	0.000378	4.82	1745.53	248.15	0.25
Reach	445	50 Year	5389.16	5020.79	5030.38	5024.86	5030.60	0.000363	3.95	1438.85	315.96	0.24
Reach	445	100 Year	6545.48	5020.79	5031.19	5025.35	5031.46	0.000402	4.38	1576.13	327.31	0.25
Reach	445	500 Year	9702.50	5020.79	5034.60	5026.51	5034.92	0.000325	4.69	2169.03	379.75	0.24
Reach	445	200 Year Est.	7437.34	5020.79	5031.80	5025.69	5032.12	0.000423	4.66	1681.89	338.20	0.26
Reach	377	50 Year	5426.16	5019.50	5030.33	5024.04	5030.58	0.000336	3.97	1391.82	230.06	0.23
Reach	377	100 Year	6611.48	5019.50	5031.13	5024.63	5031.43	0.000384	4.45	1518.42	321.09	0.25
Reach	377	500 Year	9855.50	5019.50	5034.51	5025.99	5034.88	0.000318	4.92	2074.04	421.53	0.24
Reach	377	200 Year Est.	7520.34	5019.50	5031.73	5025.04	5032.08	0.000407	4.77	1616.39	333.61	0.26
Reach	330		Bridge									
Reach	276	50 Year	5426.16	5019.07	5029.92	5024.48	5030.34	0.000655	5.20	1042.78	332.02	0.31
Reach	276	100 Year	6611.48	5019.07	5030.71	5025.17	5031.24	0.000752	5.80	1139.73	371.70	0.34
Reach	276	500 Year	9855.50	5019.07	5032.47	5026.80	5033.28	0.000984	7.22	1364.52	452.54	0.39
Reach	276	200 Year Est.	7520.34	5019.07	5031.26	5025.68	5031.86	0.000823	6.23	1207.90	385.46	0.36
Reach	181	50 Year	5426.16	5018.79	5029.43	5025.63	5030.16	0.001479	7.11	867.78	355.47	0.42
Reach	181	100 Year	6611.48	5018.79	5030.18	5026.45	5031.04	0.001595	7.79	973.37	362.60	0.44
Reach	181	500 Year	9855.50	5018.79	5031.81	5028.89	5033.03	0.001908	9.44	1203.97	396.98	0.49
Reach	181	200 Year Est.	7520.34	5018.79	5030.69	5027.69	5031.64	0.001682	8.28	1045.34	374.72	0.46
Reach	101	50 Year	5426.16	5018.30	5029.47		5030.00	0.001089	6.21	1100.34	349.53	0.35
Reach	101	100 Year	6611.48	5018.30	5030.25		5030.85	0.001159	6.73	1261.51	362.25	0.36
Reach	101	500 Year	9855.50	5018.30	5031.98		5032.78	0.001330	7.96	1641.41	389.43	0.40
Reach	101	200 Year Est.	7520.34	5018.30	5030.78		5031.44	0.001222	7.13	1373.26	372.58	0.37
Reach	0	50 Year	5426.16	5018.13	5028.39	5026.22	5029.74	0.003500	9.76	682.47	291.99	0.59
Reach	0	100 Year	6611.48	5018.13	5029.13	5028.18	5030.58	0.003503	10.33	810.91	304.45	0.60
Reach	0	500 Year	9855.50	5018.13	5030.81	5029.67	5032.49	0.003504	11.56	1126.26	350.74	0.62
Reach	0	200 Year Est.	7520.34	5018.13	5029.65	5028.65	5031.16	0.003504	10.72	902.03	312.10	0.61

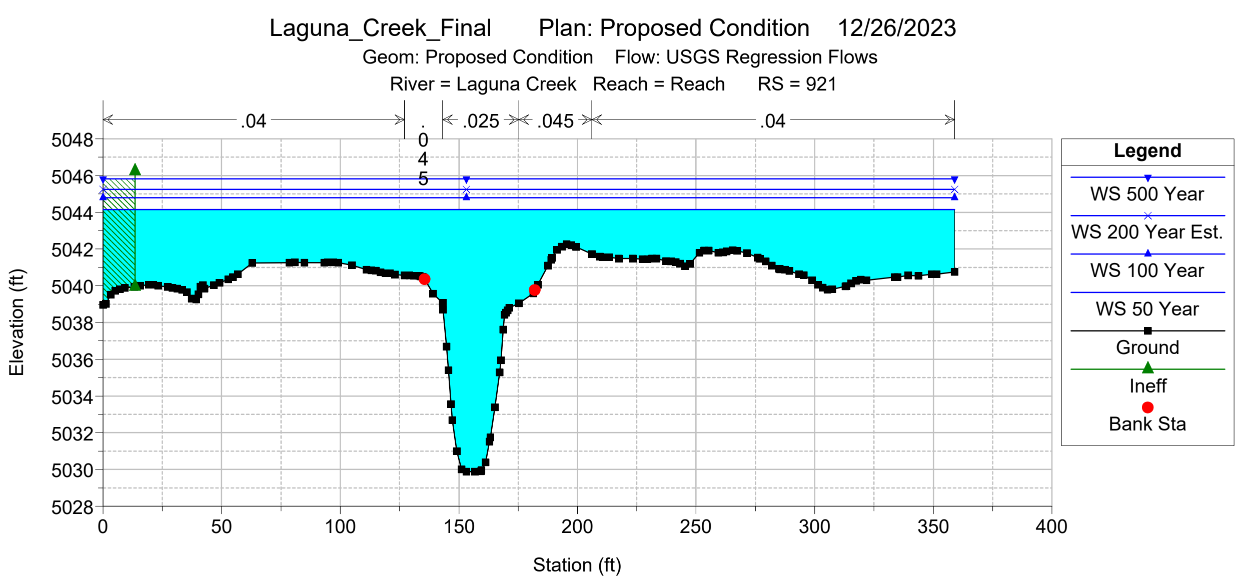

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1360
.04
.045
.025
.04
.045
.04
.05
Elevation (ft)
5048
5046
5044
5042
5040
5038
5036
5034
5032
5030
0
100
200
300
400
500
600
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta

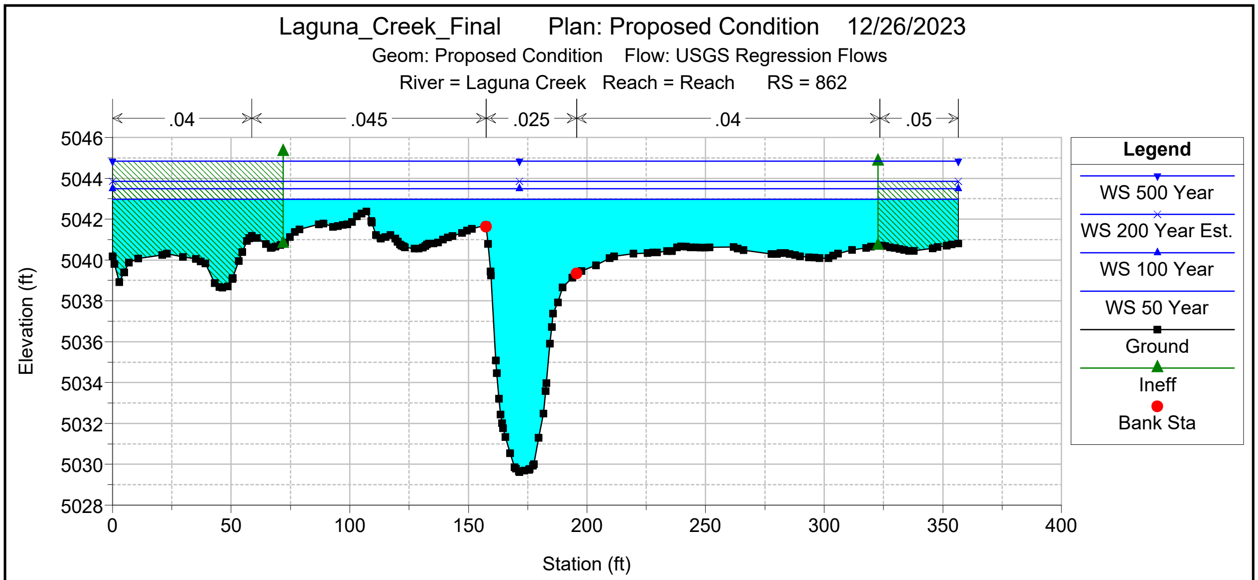

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1296
.04
.045
.025
.04
.05
Elevation (ft)
5048
5046
5044
5042
5040
5038
5036
5034
5032
5030
0
100
200
300
400
500
600
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta


Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1196
.04
.045
.025
.04
.045
.04
Elevation (ft)
5048
5046
5044
5042
5040
5038
5036
5034
5032
5030
0
100
200
300
400
500
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta

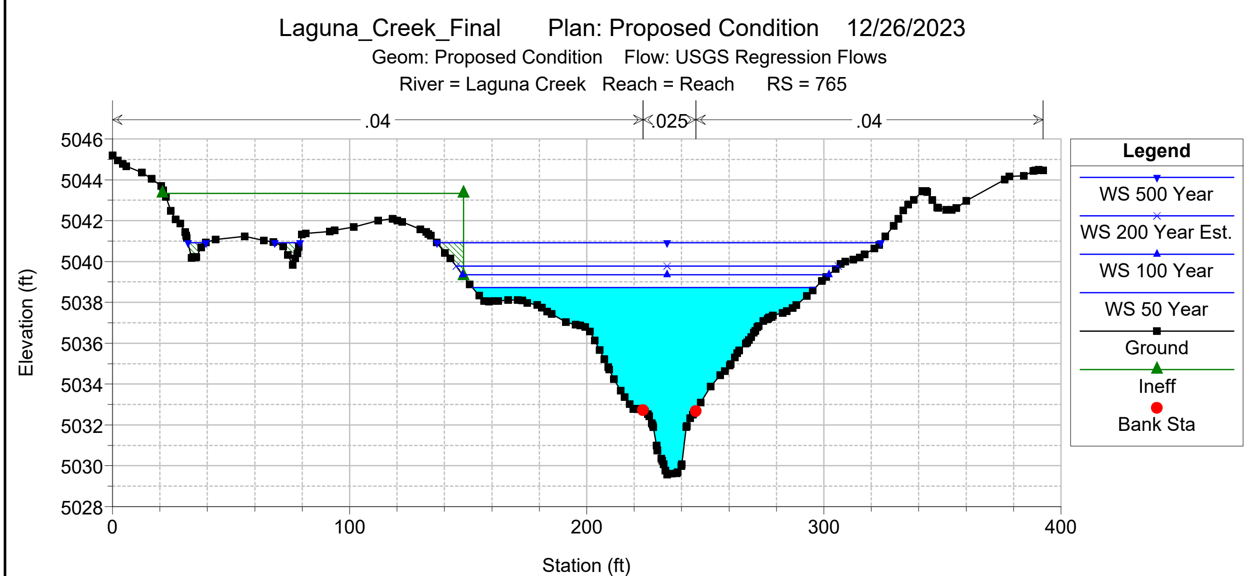

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1113
.04
.045
.025
.04
.045
.04
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta
Elevation (ft)
Station (ft)


Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 1001
.04
.045
.025
.04
.045
.04
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Bank Sta
Elevation (ft)
Station (ft)

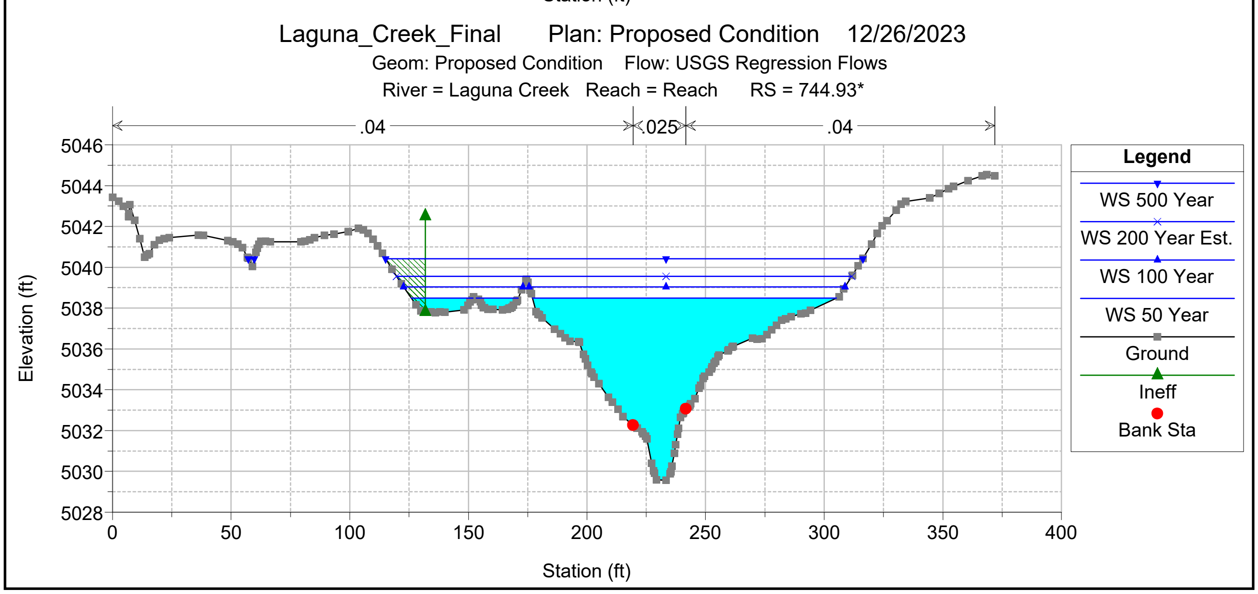

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 921
.04
.045
.025
.045
.04
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta
Elevation (ft)
Station (ft)



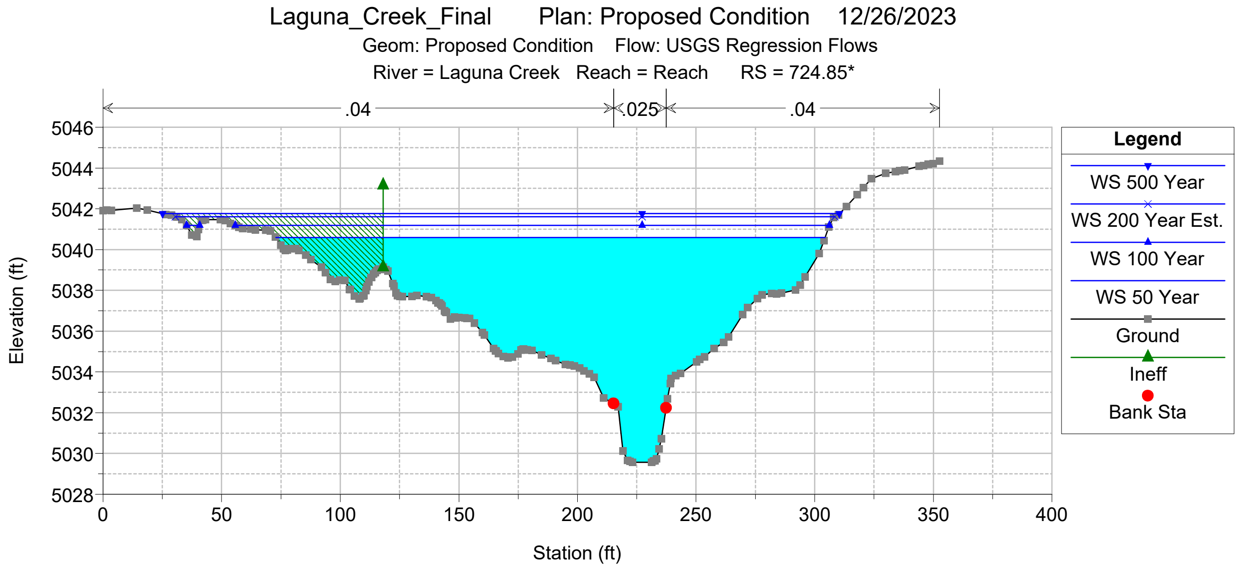
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 862
.04
.045
.025
.04
.05
Elevation (ft)
Station (ft)
5046
5044
5042
5040
5038
5036
5034
5032
5030
5028
0
50
100
150
200
250
300
350
400
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta



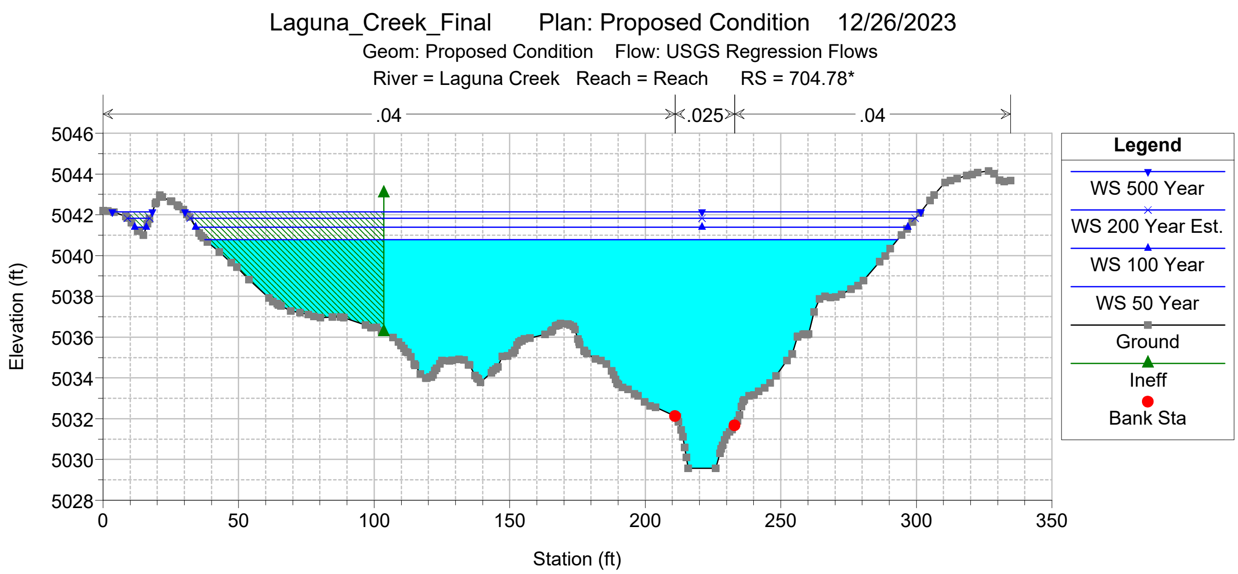
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 765
.04
.025
.04
Elevation (ft)
Station (ft)
5046
5044
5042
5040
5038
5036
5034
5032
5030
5028
0
100
200
300
400
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta



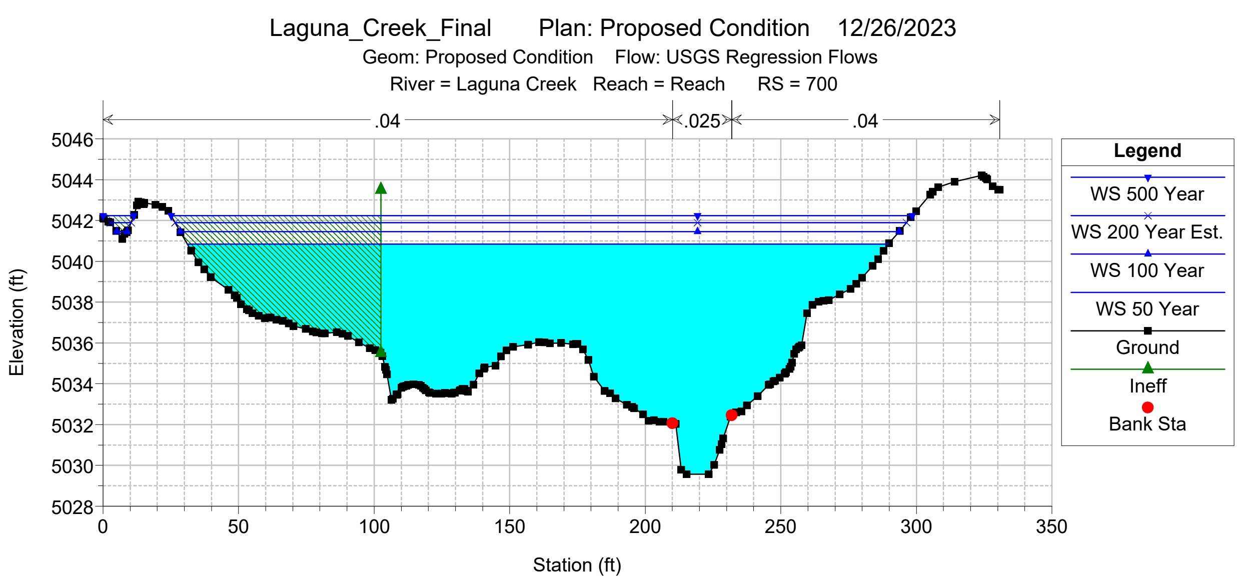
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 744.93*
.04
.025
.04
Elevation (ft)
Station (ft)
5046
5044
5042
5040
5038
5036
5034
5032
5030
5028
0
50
100
150
200
250
300
350
400
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta



Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 724.85*
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

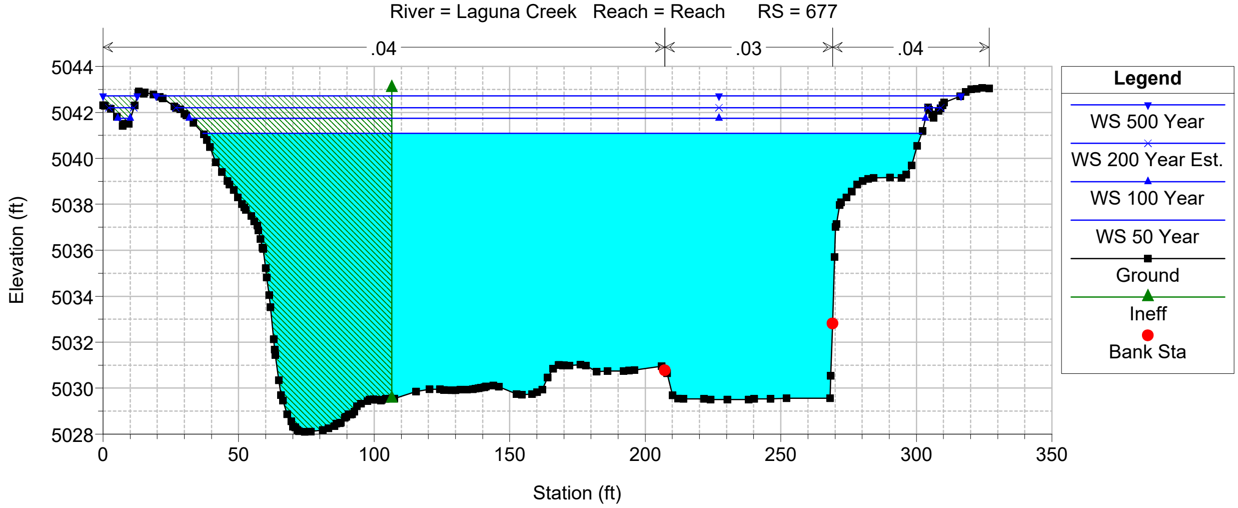


Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 704.78*
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

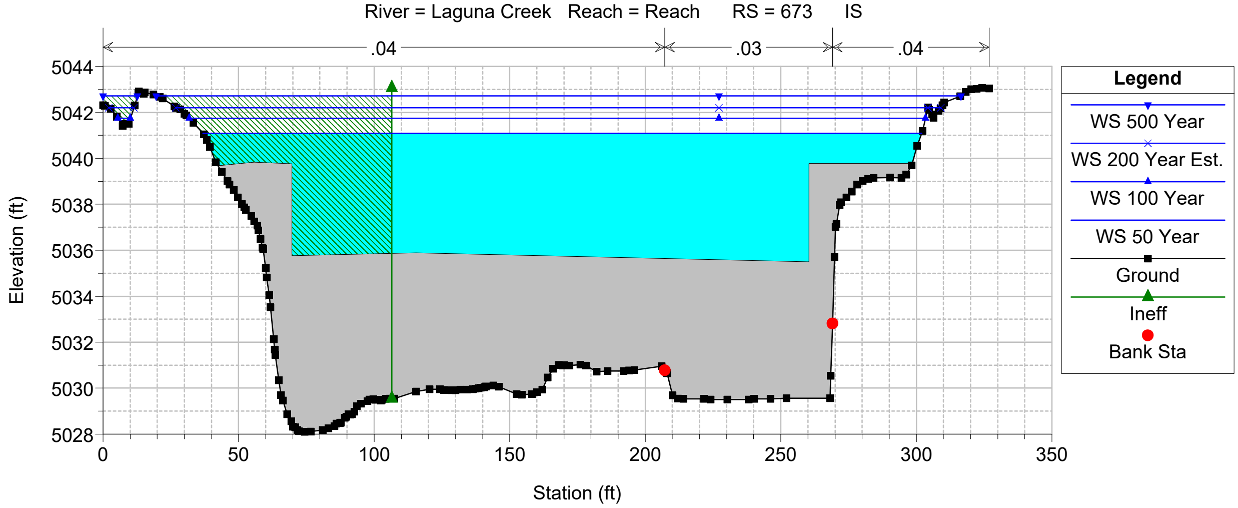


Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 700
.04
.025
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

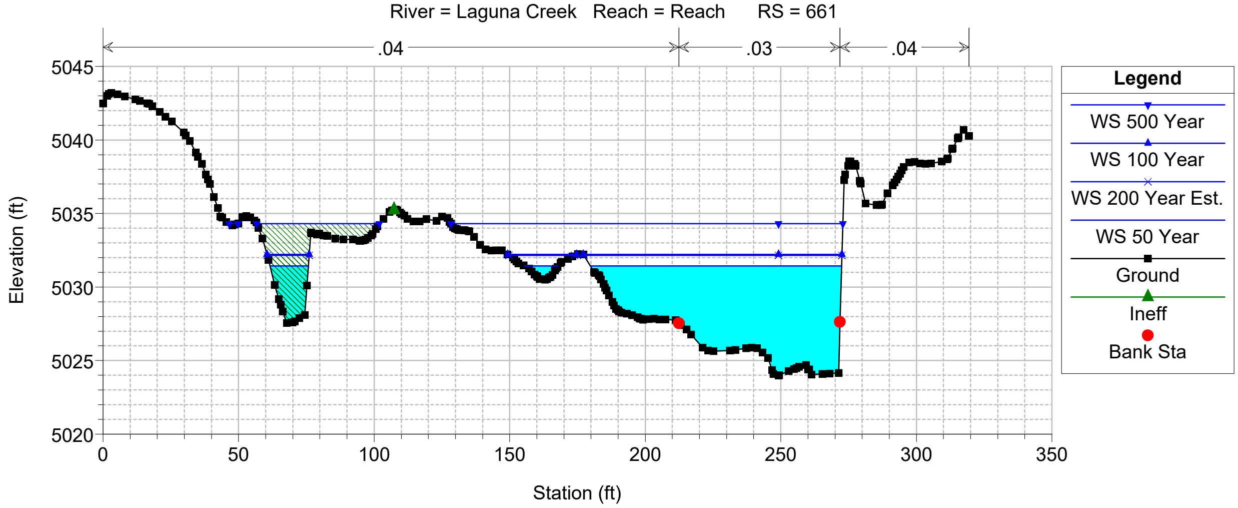
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 677

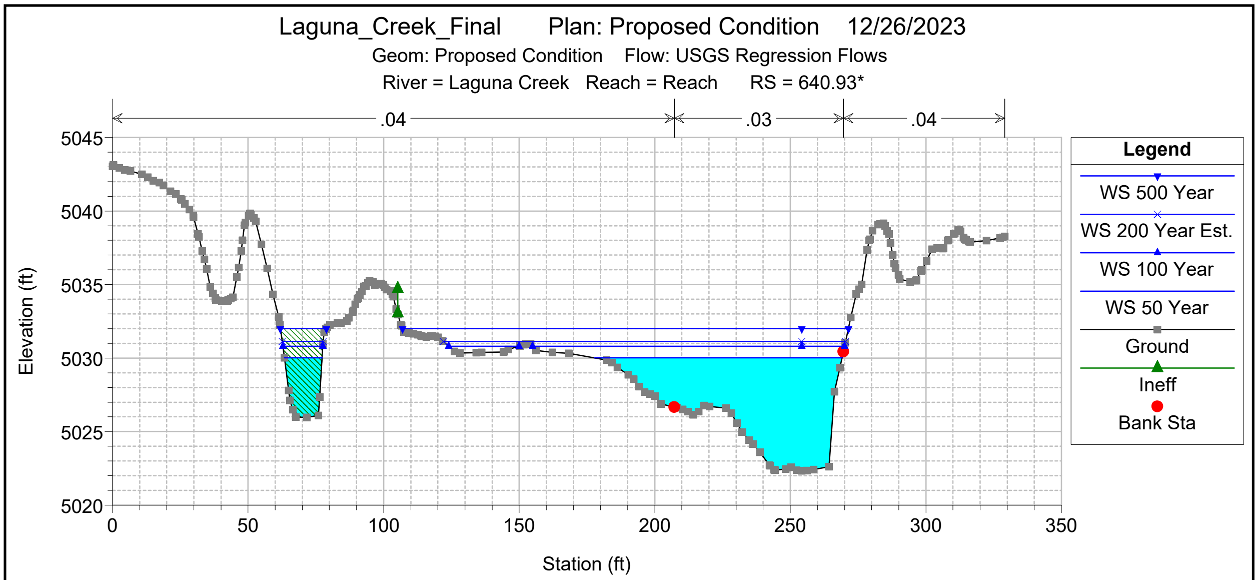


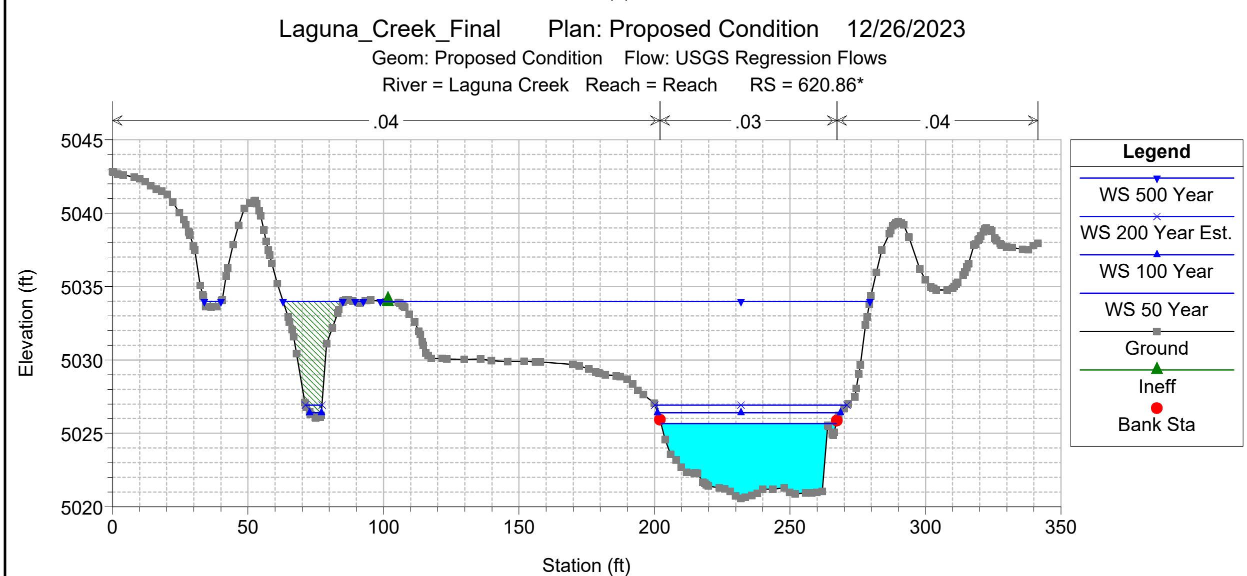
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 673 IS

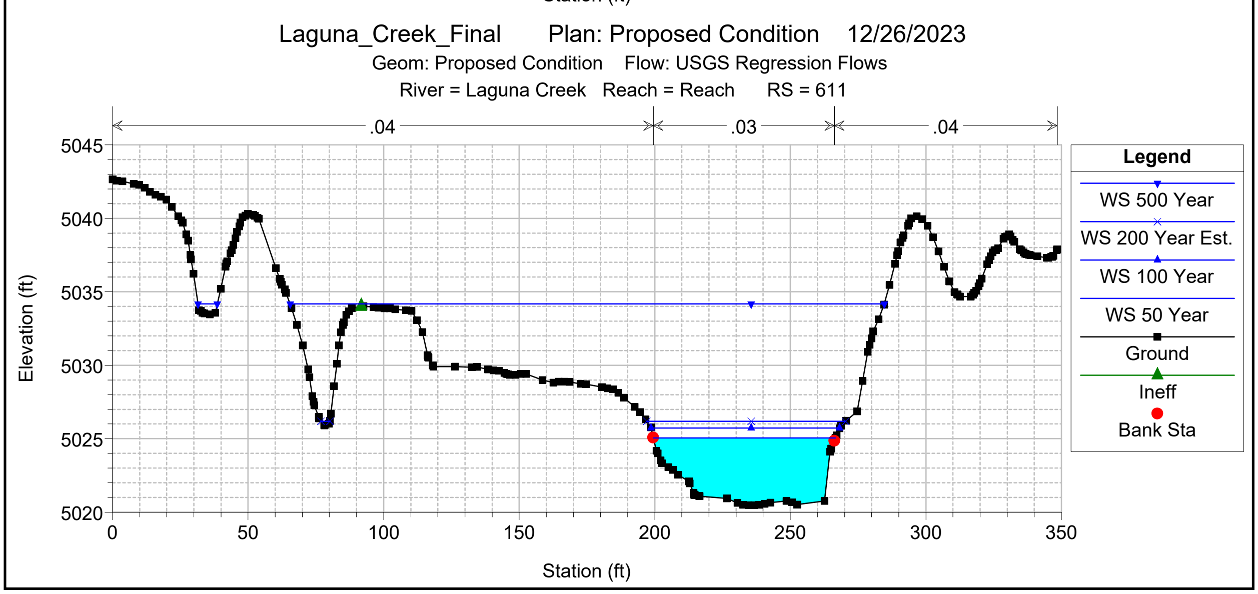


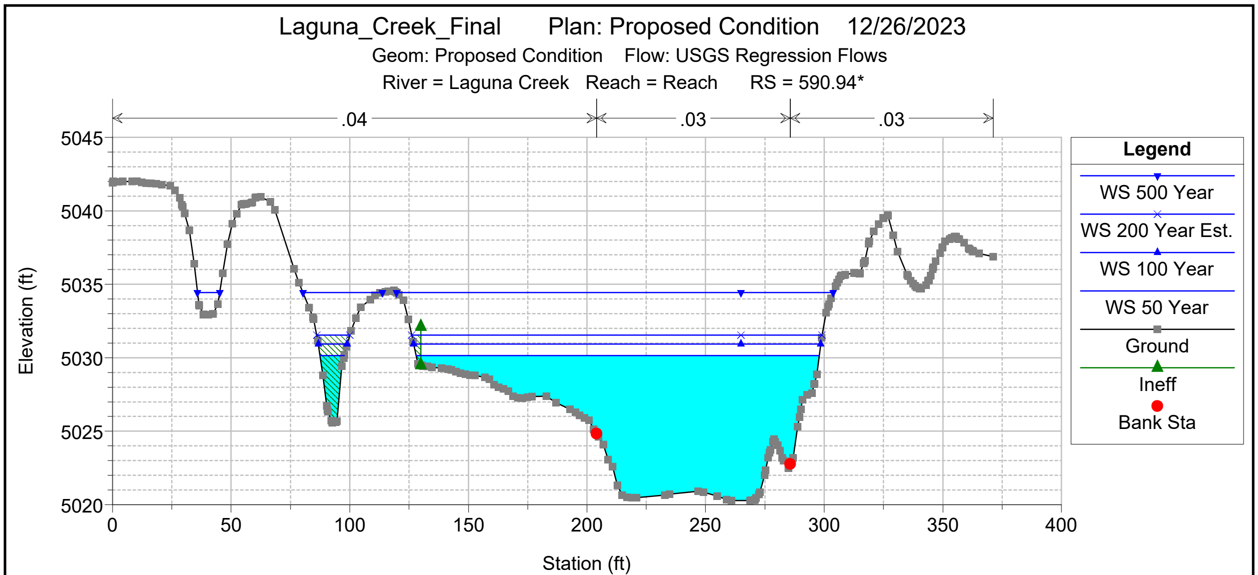
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 661

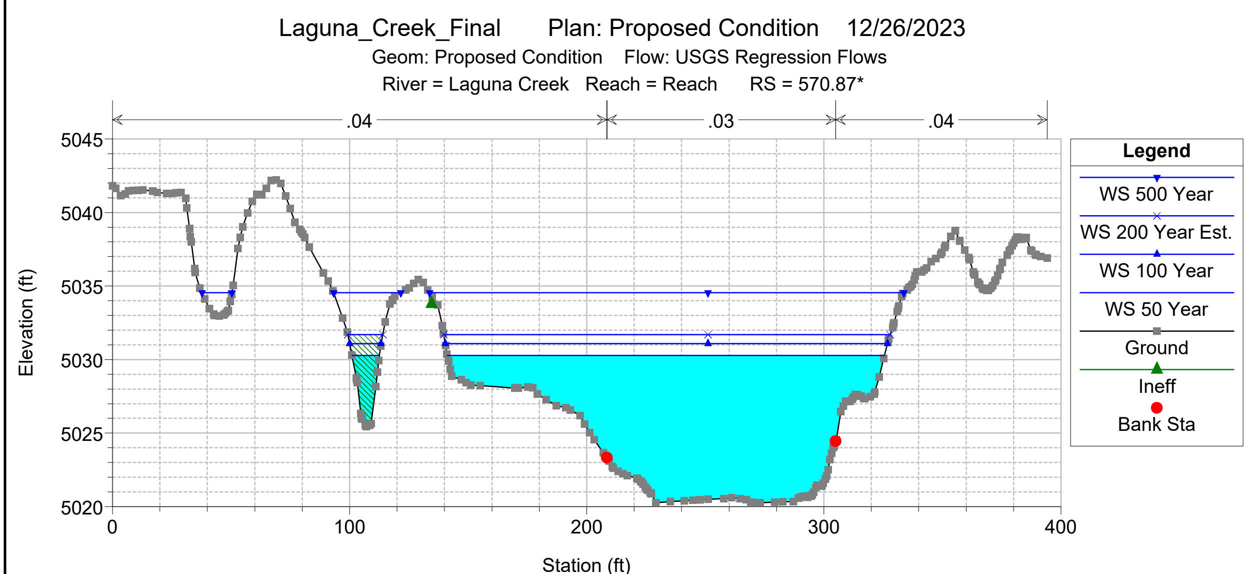


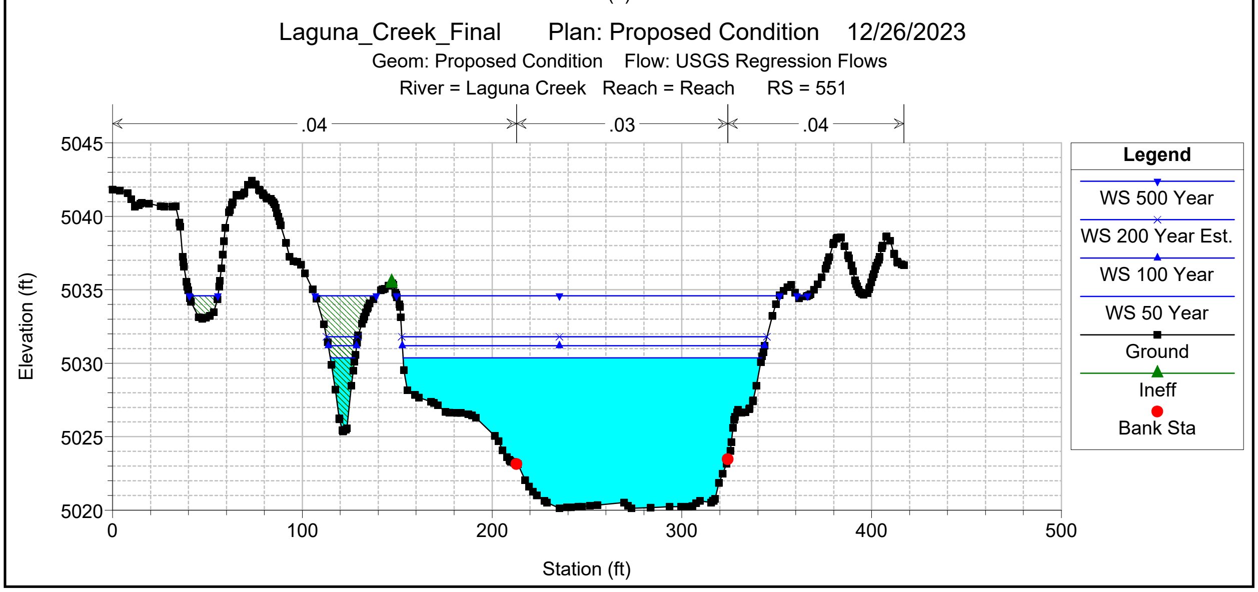

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 640.93*
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

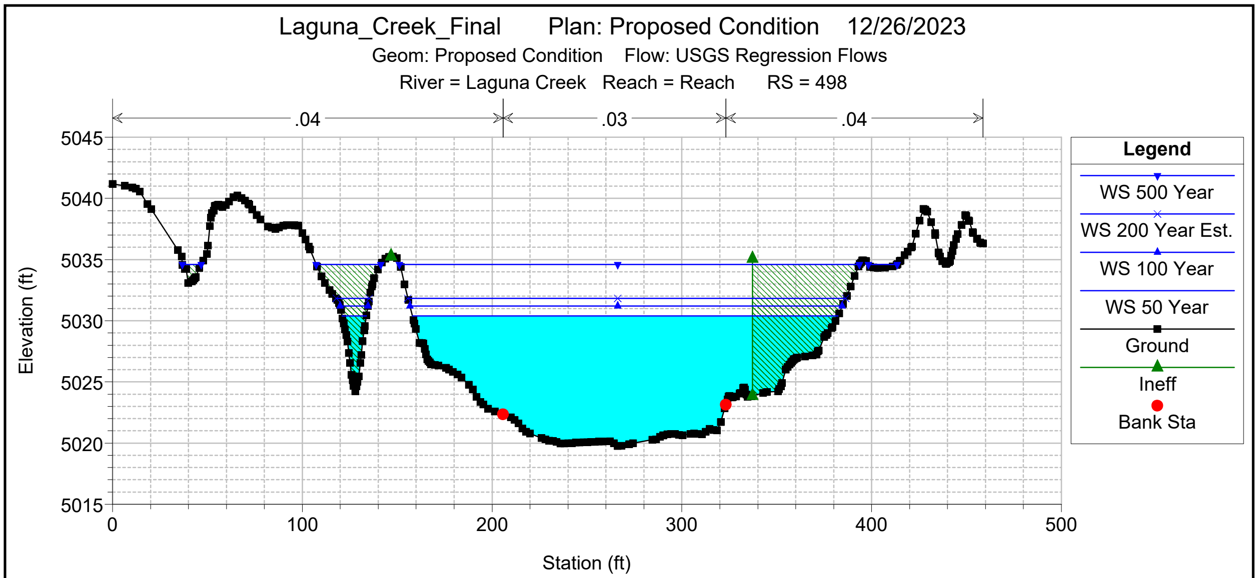

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 620.86*
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

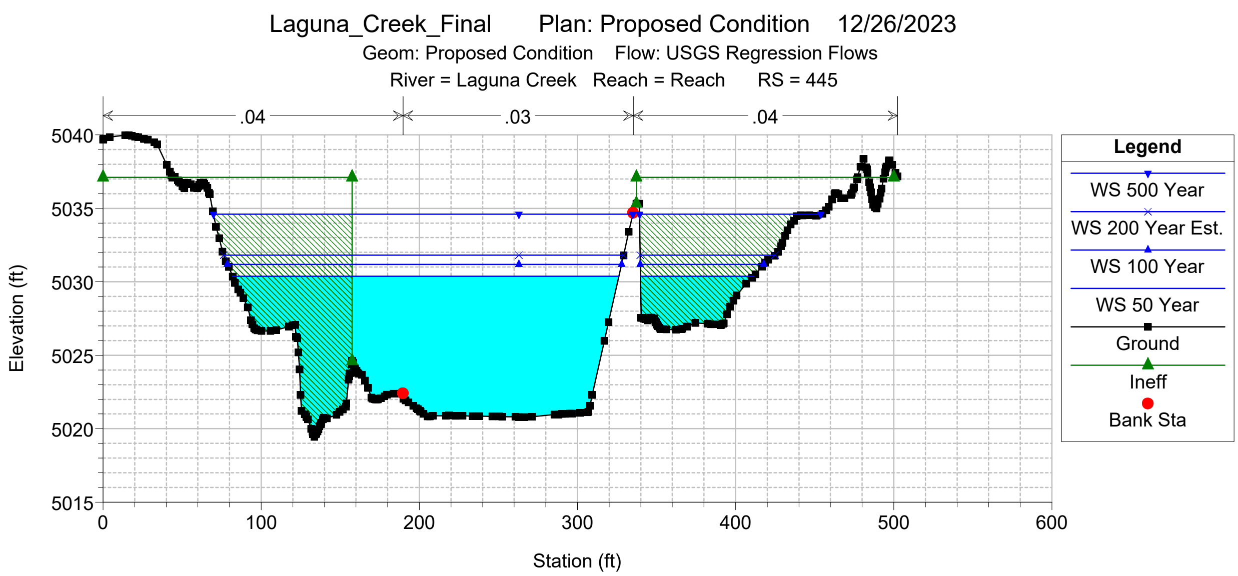

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 611
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

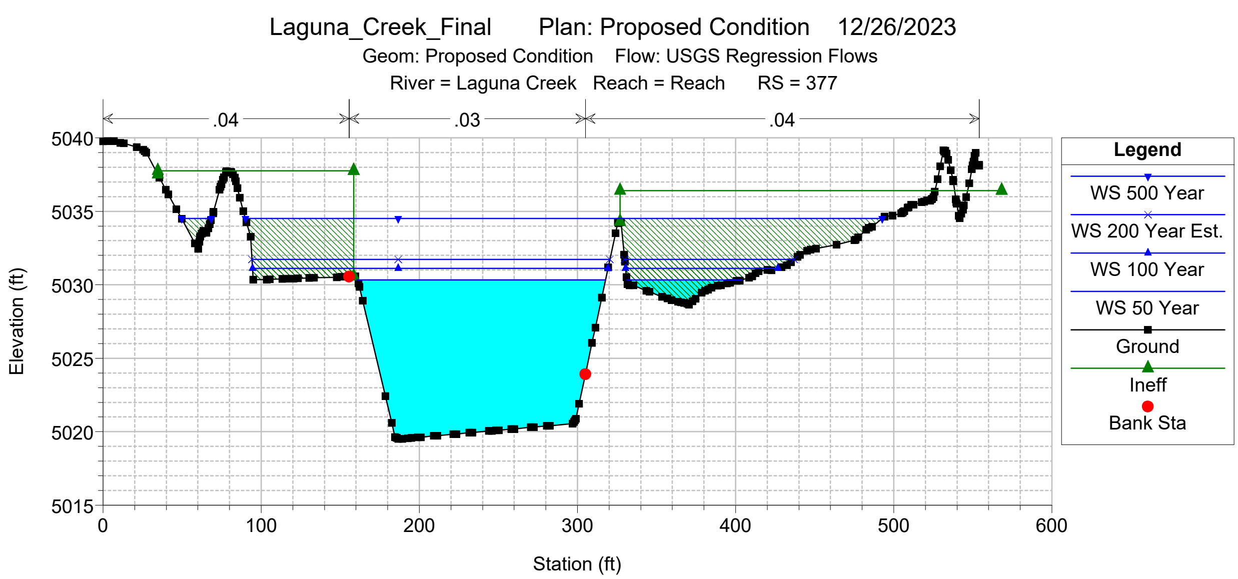

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 590.94*
.04
.03
.03
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

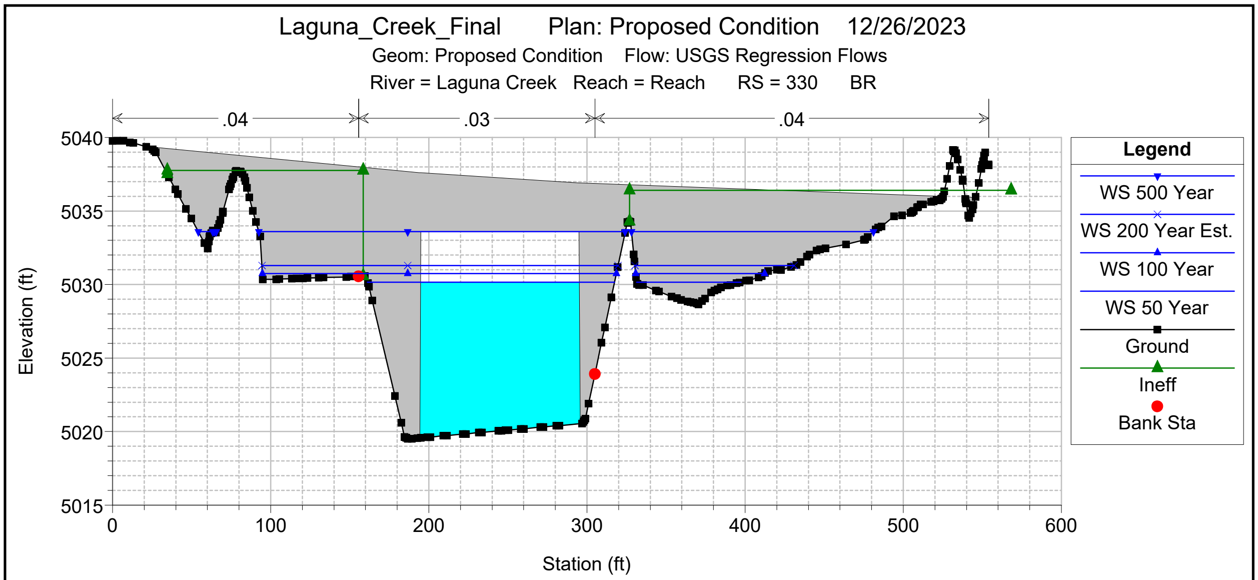

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 570.87*
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

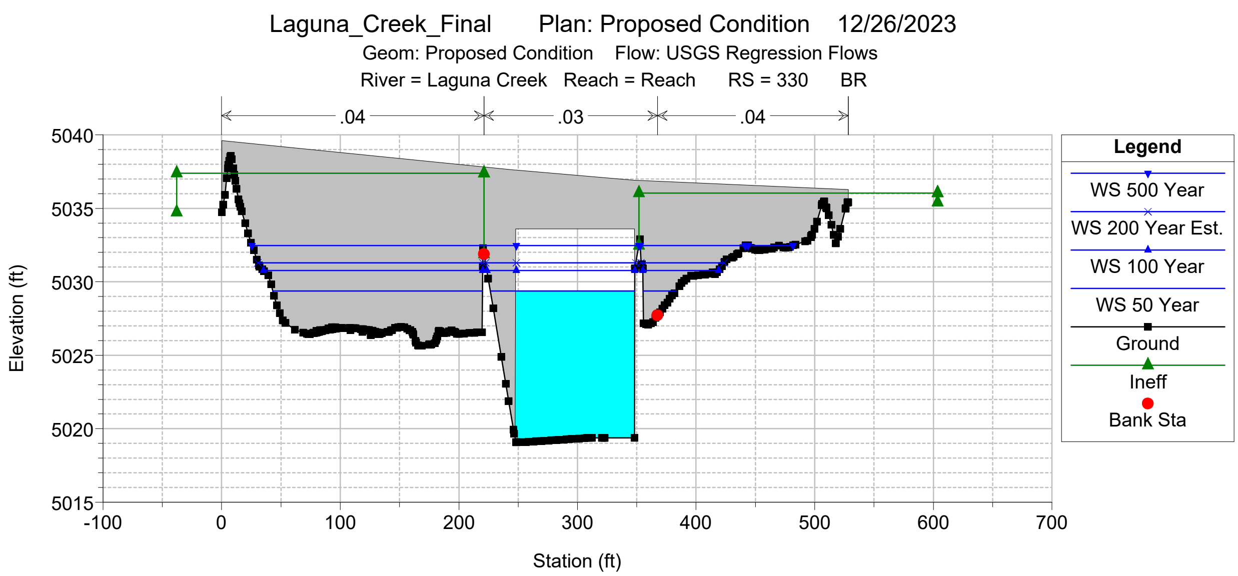

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 551
.04
.03
.04
Elevation (ft)
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

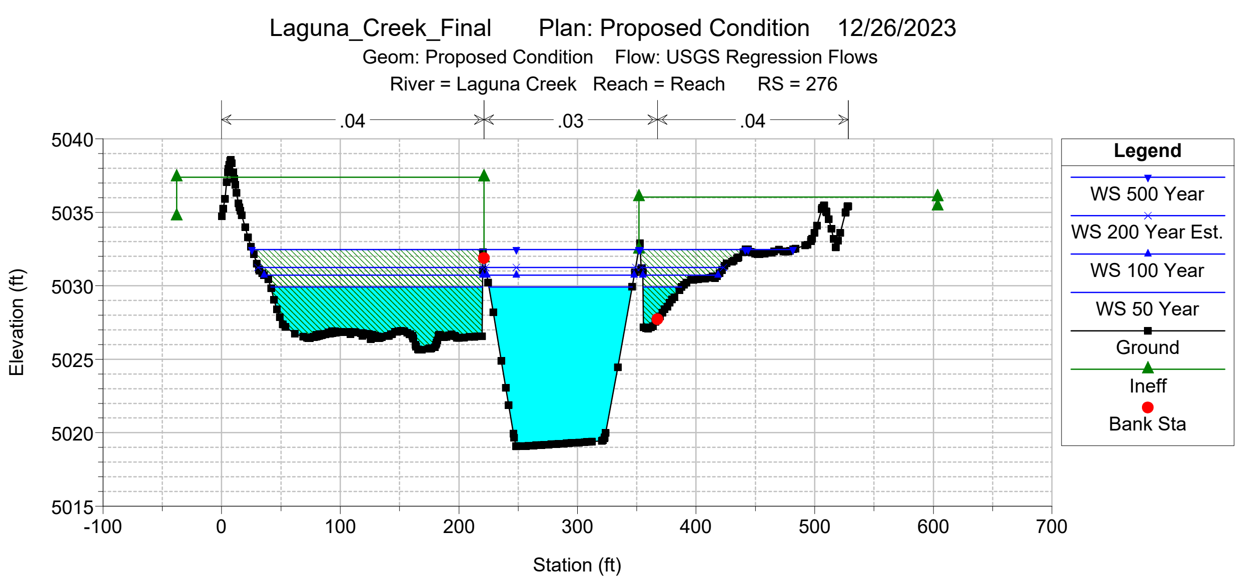

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 498
.04
.03
.04
Elevation (ft)
Station (ft)
5045
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 445
.04
.03
.04
Elevation (ft)
Station (ft)
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
600
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

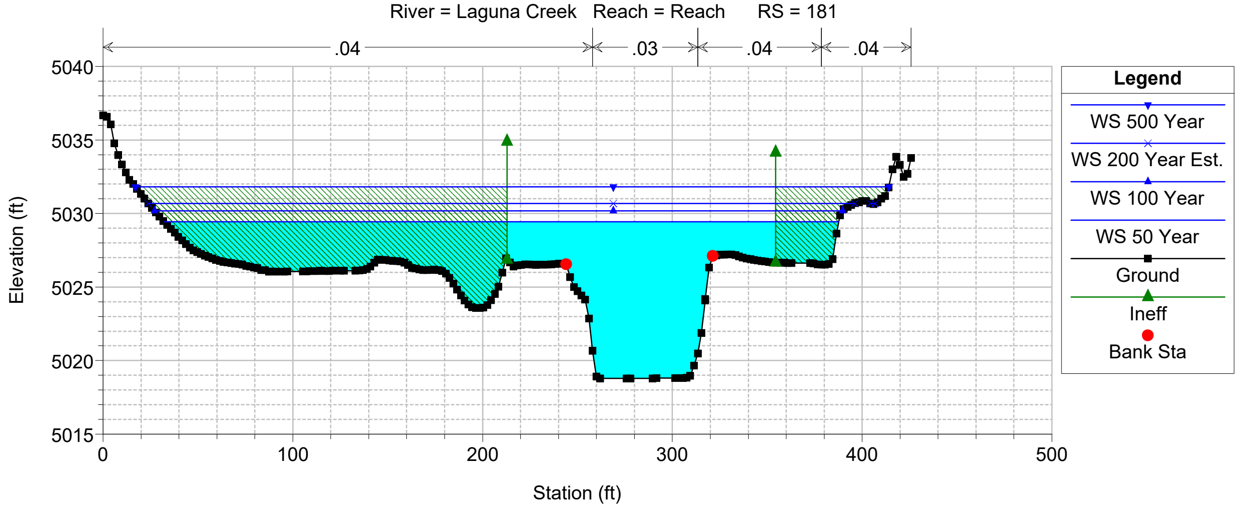

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 377
.04
.03
.04
Elevation (ft)
Station (ft)
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
600
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 330 BR
.04
.03
.04
Elevation (ft)
5040
5035
5030
5025
5020
5015
0
100
200
300
400
500
600
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

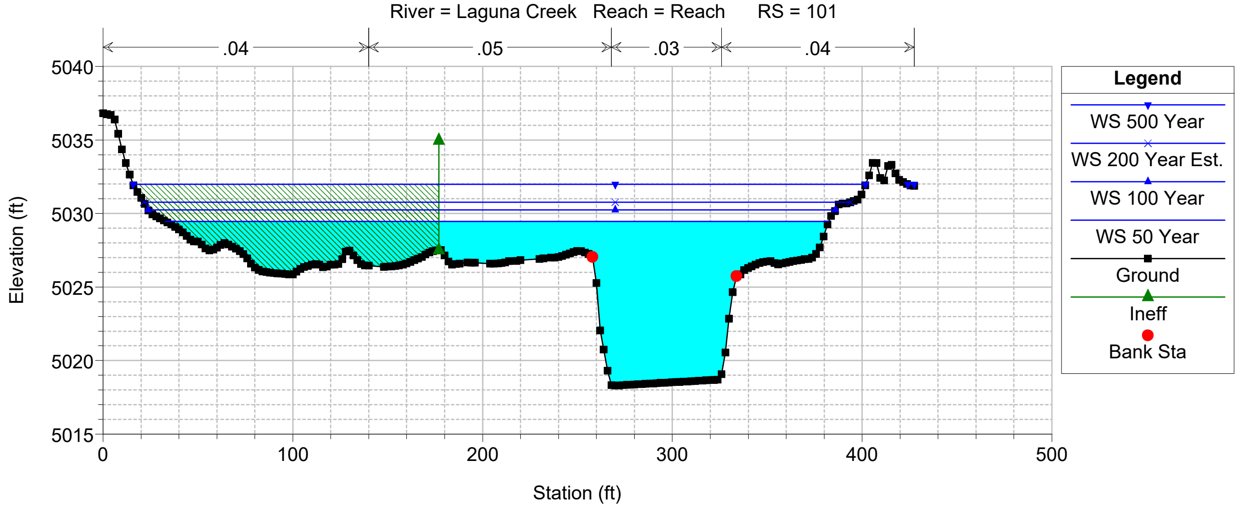

Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 330 BR
.04
.03
.04
Elevation (ft)
5040
5035
5030
5025
5020
5015
-100
0
100
200
300
400
500
600
700
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta


Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 276
.04
.03
.04
Elevation (ft)
5040
5035
5030
5025
5020
5015
-100
0
100
200
300
400
500
600
700
Station (ft)
Legend
WS 500 Year
WS 200 Year Est.
WS 100 Year
WS 50 Year
Ground
Ineff
Bank Sta

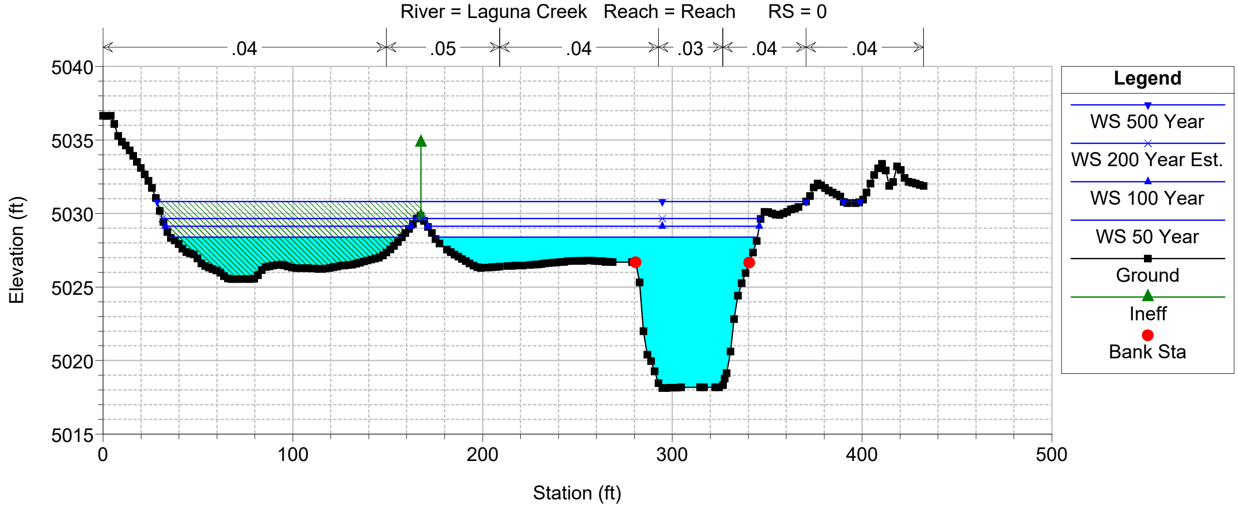
Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 181



Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 101



Laguna_Creek_Final Plan: Proposed Condition 12/26/2023
Geom: Proposed Condition Flow: USGS Regression Flows
River = Laguna Creek Reach = Reach RS = 0



Appendix E Scour Report

DENNESHOTO BRIDGE
SCOUR ANALYSIS

Prepared for:

Dibble Engineering

Dibble Engineering
7878 N. 16th St., Ste. 300
Phoenix, AZ 85020

Prepared by:

PREMIER
ENGINEERING CORPORATION

PREMIER ENGINEERING CORPORATION
6437 W. Chandler Boulevard, Suite 1
Chandler, Arizona 85226
Tel: 480-829-6000
Premier Project Number 2015038

Registered Professional Engineer (Civil)
CERTIFICATE NO.
21560
DENNIS L.
RICHARDS
Date Signed 5/3/18
ARIZONA, U.S.A.
Dennis L. Richards

Expires 3/31/2019

May, 2018

Table of Contents

Tables

Registered Professional Engineer (Civil)
CERTIFICATE NO.
21560
DENNIS L
RICHARDS
Date Signed 5/3/18
ARIZONA U.S.A.

Dennis L Richards

Expires 3/31/2019

1 Introduction

Premier Engineering Corporation, Inc. (Premier), as a subconsultant to Dibble Engineering (Dibble), conducted a bridge scour study for a proposed new bridge crossing of Laguna Creek. The study was performed to establish scour depths at the bridge abutments and in the downstream channel. The proposed crossing of Laguna Creek is located in Navajo County, Dennehotso, Arizona.

Dibble provided hydrologic and hydraulic information for Laguna Creek. The 100-year design discharge in the vicinity of the crossing is 6,545 cubic feet per second (cfs). Hydraulic conditions for the site were established using a HEC-RAS model developed by Dibble.

2 Hydraulics

Representative hydraulic parameters for the 100-year proposed conditions along the project reach of Laguna Creek are summarized in Table 1. Hydraulic parameters listed in the table extend from approximately 330 feet downstream of the proposed bridge to approximately 220 feet upstream of the proposed bridge.

Table 1 – 100-Year Hydraulic Conditions

River Sta.	Discharge (cfs)	Min. Ch El (ft)	W.S. Elev. (ft)	Hydraulic Depth (ft)	Velocity (fps)	Flow Area (ft^2)	Top Width (ft)	Froude No.	E.G. Slope
551	6545	5020.13	5031.20	10.59	4.90	1549.45	205.86	0.27	0.000425
498	6545	5019.76	5031.21	10.66	4.52	1635.73	242.68	0.24	0.000358
445	6545	5020.79	5031.20	9.44	4.37	1578.38	327.50	0.25	0.000400
377	6545	5019.50	5031.15	10.04	4.40	1521.95	321.85	0.24	0.000374
330	Proposed Laguna Creek Bridge								
276	6545	5019.07	5030.67	9.15	5.77	1134.64	370.57	0.34	0.000747
181	6545	5018.79	5030.14	9.73	7.75	967.85	362.18	0.44	0.001598
101	6545	5018.30	5030.21	10.80	6.70	1252.94	361.89	0.36	0.001155
0	6545	5018.13	5029.09	9.11	10.30	804.09	303.86	0.60	0.03503

3 Scour Analysis

3.1 Scour Components

The scour analysis provides the total abutment scour at each bridge abutment calculated for the 100-year design flow event, and total scour. The impacts of the bridge scour components are generally limited to the vicinity of the bridge that causes them; however, they can be significant because abutment scour is frequently many times larger than other components such as long-term or contraction scour. For this project, the scour components considered are local abutment scour within the bridge opening; contraction scour, bed form scour, and bend scour for the channel reach downstream of the bridge. Abutment and contraction scour were calculated based on the procedures of the Federal Highway Administration's (FHWA) Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges," Fifth Edition, April, 2012. Bend scour was calculated using the bend scour equation from the Arizona Department of Water Resources (ADWR) "Design Manual for Engineering Analysis of Fluvial Systems", and bed-form scour was based on equations from the Flood Control District of Maricopa County, "Design Manual for Maricopa County, Hydraulics."

3.1.1 *Contraction Scour*

Contraction scour occurs when the flow area of a river or wash is reduced by a natural contraction in the channel, a bridge, or another structure that restricts the flow. At a contraction, several different factors can contribute to the occurrence of contraction scour. These factors may include natural channel contraction; the presence of road embankments at the approach to the bridge; bridge abutments projecting into the main channel; bridge piers blocking a significant portion of the flow area; or a drop in the downstream tailwater, which causes increased velocities inside the bridge. There are two forms of contraction scour that can occur and are a function of the quantity of bed material being transported upstream of the contraction reach: live-bed contraction scour and clear-water contraction scour. Live-bed contraction scour occurs when sediment-laden water flows into the contracted section, while clear-water contraction scour occurs when sediment transport upstream of the contraction is negligible.

Contraction scour was calculated for live-bed conditions. FHWA HEC-18 recommends using a modified version of Laursen's (1960) live-bed contraction scour equation given by:

$$\frac{y_2}{y_1} = \left[\left(\frac{Q_2}{Q_1} \right)^{6/7} \left(\frac{W_1}{W_2} \right)^{K_1} \right]$$

$$y_s = y_2 - y_0$$

y_s is average depth of contraction scour (ft), y_2 is average depth after scour in the contraction (ft), y_1 is the average depth in the main channel (ft), y_0 is the average depth in the at the contracted section before scour (ft), Q_1 is the flow in the main channel which is transporting sediment (cfs), Q_2 is the flow in the main channel in the contracted section which is transporting sediment (cfs), W_1 is the bottom width in the main channel (ft) which is approximated as the top width of the active flow area in HEC-RAS, W_2 is the bottom width of the main channel in the contracted section less pier widths (ft), approximated as the top width of the active flow area, and k_1 is the exponent (0.64) for mode of bed material transport.

The hydraulic parameters used for the contraction scour analyses are the main channel conditions at the upstream section (RS 445) and the section immediately upstream of the bridge (RS 330). Table 2 lists the parameters for estimating contraction scour for the 100-year event.

Table 2 – Contraction Scour

Upstream (RS 445)			Contraction (RS 330)				Scour
Q_1 (cfs)	W_1 (ft)	y_1 (ft)	Q_2 (cfs)	W_2 (ft)	y_2 (ft)	y_0 (ft)	y_s (ft)
5708	138.3	9.4	6545	100.3	13.0	10.93	2.1

3.1.2 *Local Scour at Abutments*

Abutment scour occurs when the abutment and roadway embankment obstruct the flow. The flow obstructed accelerates and often forms a vortex starting at the upstream end of the abutment and running along the toe of the abutment. Generally a wake vortex forms at the downstream end of the abutment which is similar to the wake vortex that forms downstream of a pier. Abutment scour depth depends on abutment shape, discharge in the main channel at the abutment (especially the flow depth in the main channel and depth of the overbank flow at the abutment), sediment characteristics, cross-sectional shape of the main channel abutment, and alignment.

The NCHRP 24-20 Equation was applied to establish abutment scour. The equation uses contraction scour as the starting calculation for abutment scour and applies a factor to account for large scale turbulence that develops in the vicinity of the abutment. The equations for live bed conditions are:

$$y_{max} = \alpha_A \, y_c$$

$$y_c = y_1 (q_2/q_1)^{6/7}$$

$$y_s = y_{max} - y_0$$

where y_{max} is maximum flow depth resulting from abutment scour (ft), y_c is flow depth including contraction scour (ft), α_A is amplification factor for live-bed conditions (Figure 8.9, HEC-18), y_s is abutment scour depth (ft), and y_0 is flow depth prior to scour. Abutment scour was calculated for hydraulic conditions of the north abutment. Table 3 provides the hydraulic parameters for calculating abutment scour at the north abutment for the 100-year event.

Table 3 – Abutment Scour

Upstream River Station	q_1 (cfs/ft)	q_2 (cfs/ft)	y_1 (ft)	y_c (ft)	α_A	y_{max} (ft)	y_0 (ft)	y_s (ft)
551	51.9	65.3	10.6	12.9	1.7	21.9	10.93	11.0

3.1.3 Bed-form Scour

For natural channels with sand beds, bed-forms may form in the channel. Bed-forms result from the interaction of the flowing water and the bed material in the stream. The bed-forms can deform a channel bed and potentially undermine bank protection or other structures in the channel and significantly change the hydraulic characteristics of a channel in terms of its hydraulic roughness and sediment transport capability. Dunes may form in lower regime flow and antidunes in transitional or upper regime flow. Flow in the vicinity of the proposed crossing is lower regime. Therefore, bed-form scour was evaluated using the Zanke Equation given as:

$$0.015 < d_h/y_h < 0.3$$

$$y_s = 0.5 \, d_h$$

where y_s is the bed-form depth measured below the original bed (ft) and y_h is the hydraulic depth of flow (ft), and dh is the dune height (ft). Table 4 provides the bed-form scour depth for the 100-year event.

Table 4 – Bed-form Scour

Upstream River Station	Y_h (ft)	y_s (ft)
445	9.44	3.0

3.1.4 *Bend Scour*

Bends induce transverse or "secondary" currents which will scour sediment from the outside of a bend and cause it to be deposited along the inside of the bend. There are a number of theoretical relationships that have been developed to predict the amount of scour through a river bend. The equation applied to estimate bend scour was the Zeller Equation was applied which is given as:

$$y_{bs} = [0.0685\ y_{max}\ V^{0.8} / (y_h^{0.4}\ S_e^{0.3})]\ [2.1(\mathrm{Sin}^2(\alpha/2) / \mathrm{Cos}\ \alpha)^{0.2} - 1]$$

y_{bs} is the bend scour depth (ft), y_{max} the maximum depth of upstream flow, (ft), y_h the hydraulic depth of upstream flow (ft), V the mean velocity of upstream flow (ft/s), S_e the upstream energy slope (ft/ft), and α the angle formed by projection of channel centerline from point of curvature to a point which meets a line tangent to the outer bank of channel (degrees). In addition,

$$r_c / W = (\mathrm{Cos}\ \alpha) / (4\ (\mathrm{Sin}^2(\alpha/2))$$

where r_c is the radius of curvature to centerline of channel (ft) and W the channel topwidth (ft).

Table 5 – Bend Scour

Upstream River Station	y_{max} (ft)	V (fps)	y_h (ft)	S_e (ft/ft)	α (degrees)	W (ft)	r_c (ft)	y_{bs} (ft)
445	11.77	4.37	9.44	0.00040	28.0	138.2	521.6	2.5

3.1.5 *Long-term Degradation*

Long-term degradation is the lowering of the stream invert occurring over a long reach and over a long period of time. The primary causes for long-term degradation of a channel are reductions in upstream sediment supply, changes in river geomorphology, and man-induced effects. Bank failure can occur in a degrading channel. Long-term degradation is based on the channel forming discharge, usually a 5 to 10-year event in the arid southwest. Assessment of the potential for long-term degradation usually involves consideration of historical trends and engineering analysis using available qualitative and quantitative relationships to estimate the stream behavior in reaction to various scenarios or future conditions. Although long-term degradation was not determined to a major contributing component, a long-term component of 1.0 foot was used in establishing total scour in the downstream channel.

3.2 Estimated Scour Depths

The depth, velocity, and other hydraulic parameters required for the scour analyses were obtained from HEC-RAS modeling results Scour analyses were performed for a 100-year design discharge of 6,545 cfs. Contraction scour and abutment scour depths were calculated using the equations of FHWA HEC-18. Bend scour was calculated using the equation provided in the Arizona Department of Water Resources "Design Manual for Engineering Analysis of Fluvial Systems."

Table 6 provides a summary of the scour components evaluated for Laguna Creek for the Denneshoto crossing.

Table 6 - 100-Year Scour Depths

Contraction Scour (ft)	Abutment Scour (ft)	Bed-form Scour (ft)	Bend Scour (ft)	Long-term Degradation (ft)
2.1	11.0	3.0	2.5	1.0

4 Recommendations

The total scour depth at a given location is determined by adding the individual scour components that are present within the given channel section. For the Denneshoto crossing, total scour was determined at two sections: the bridge crossing and the channel section downstream of the crossing. The total abutment scour depth recommended for design is the sum of the abutment scour component and long-term degradation. Although long-term degradation was determined to be minimal, it is recommended one foot of long-term degradation be included in the estimate. The total scour depth recommended for the channel section downstream of the crossing is the sum of contraction scour, bed-form scour, bend scour, and long-term degradation components.

Table 7 provides a summary of the recommended total scour depths for the proposed Denneshoto Creek crossing.

Table 7 - Total Scour Depths

Location	Total Scour Depth (ft)
Bridge Abutments	12.0
Downstream Channel	8.6

5 References

1. Arneson, L.A., Zevenbergen, L.W., Lagasse, P.F., and Clopper, P.E., 2012, "Evaluating Scour at Bridges," Federal Highway Administration, Hydraulic Engineering Circular No. 18, U.S. Department of Transportation, Washington, D.C.

2. Simons, Li & Associates, 1985, Design Manual for Engineering Analysis of Fluvial Systems, Arizona Department of Water Resources, Phoenix, AZ.

3. __________, 2013, Drainage Design Manual for Maricopa County, Hydraulics, Chapter 11, Flood Control District of Maricopa County, Phoenix, AZ 85009.

DIBBLE

Laguna Creek Bridge Check Scour Calculations

101411.01

DES: JEP

DATE: 2023-1215

Q_{100}= 6611 cfs **Q_{200}= 7520 cfs**

Abutment Scour

NCHRP Equation - Live-Bed

$$\boxed{y_c = y_1(q_{2c}/q_1)^{6/7}} \quad \boxed{y_{max} = \alpha_A y_c} \quad \boxed{y_s = y_{max} - y_o}$$

Station	Event	V_1 [fps]	y_1 [ft]	q_1 [cfs/ft]	V_{2c} [cfs]	y_o [ft]	q_{2c} [cfs/ft]	q_{2c}/q_1 [ft]	y_c [ft]	α [Fig. 8.9]	y_{max} [ft]	y_o [ft]	y_s [ft]
551	100-year	**4.9**	10.6	51.9	**6.1**	10.8	65.9	1.27	12.97	**1.70**	22.1	10.8	11.3
551	200-year	**5.2**	11.1	58.3	**6.6**	11.3	75.0	1.29	13.81	**1.70**	23.5	11.3	12.2

Contraction Scour

$$\frac{y_2}{y_1} = \left[\left(\frac{Q_2}{Q_1}\right)^{6/7}\left(\frac{W_1}{W_2}\right)^{K_1}\right] \qquad y_s = y_2 - y_0$$

Station	Event	Q_2 [cfs]	W_2 [ft]	Q_1 [cfs]	y_1 [ft]	W_1 [ft]	k1	y_2 [ft]	y_0 [ft]	y_s [ft]	V_1 [fps]	V_{2c} [cfs]
445	100-year	**6611**	**100**	**5708**	9.4	**138**	0.64	13.1	10.8	2.4	**4.38**	**6.1**
445	200-year	**7520**	**100**	**6471**	10.0	**139**	0.64	14.0	11.3	2.7	**4.66**	**6.6**

Laguna Creek Bridge
Check Scour Calculations

Bend Scour Calculations - Zeller Bend Scour Equation

* Methodology from ADWR, "Engineering Analysis of Fluvial Systems", 1985*

Zeller Bend Scour Equation:

$$Z_{bend} = \frac{0.0685 y V_a^{0.8}}{y_h^{0.4} S_e^{0.3}}\left[2.1\left(\frac{\sin^2(\alpha/2)}{\cos(\alpha)}\right)^{0.2} - 1\right]$$

Where:

Z_{bend}= Scour Depth Below Streambed (ft)
r_c = centerline channel radius (ft)
T= channel top width (ft)
V_a= average velocity (ft/s)
y= maximum depth of flow (ft)
y_h= hydraulic depth (ft)
Se= energy slope (ft/ft)
α= angle formed by the projection of the channel centerline from the point of curvature to a point which meets a line tangent to the outer bank of the the channel, (°)

Storm	River Sta	Q Total	Max Chl Dpth	Vel Chnl	Hydr Depth	E.G. Slope	Top Width	CL Radius	α	Z_{bend}
100 Yr	445	6545	11.75	4.38	9.43	0.000402	327.31	521.6	28	2.5
200 Yr	445	7437	12.37	4.66	9.96	0.000423	338.20	521.6	28	2.6

Storm	River Sta	Q Total	Max Chl Dpth	Vel Chnl	Hydr Depth	E.G. Slope	Top Width	CL Radius	α	Z_{bend}
100 Yr	276	6611	11.64	5.80	9.18	0.000752	371.70	521.6	28	**2.6**
200 Yr	276	7520	12.19	6.23	9.55	0.000823	385.46	521.6	28	**2.7**

Storm	River Sta	Q Total	Max Chl Dpth	Vel Chnl	Hydr Depth	E.G. Slope	Top Width	CL Radius	α	Z_{bend}
100 Yr	181	6611	11.39	7.79	9.43	0.001595	362.60	521.6	28	2.5
200 Yr	181	7520	11.90	8.28	10.28	0.001682	374.72	521.6	28	2.6

Laguna Creek Bridge
Check Scour Calculations

Dune and Anti-Dune Scour Height Calculations

* Methodology from Zanke, 1976 and Simons, Li & Associates, 1982, "Engineering Analysis of Fluvial Systems"*

Dune Height Equation

dh= 0.3Yh

Anti-Dune Height Equation

dh= $0.027V^2$

Where:

dh= Dune Height, in feet
Yh= Hydraulic depth of flow, in feet
V= Average Channel Velocity
Fr= Froude Number

Scour Component Equation

if Anti-Dune is controlling (Fr≥0.7):

ds= 0.5(Anti-Dune Height)

if Dune is controlling (Fr≤0.7):

ds= 0.5(Dune Height)

Storm	River Station	Yh ft	V ft/s	Fr	Controlling:	Dune Height ft	Anti-Dune Height ft	Scour ft
100 Yr	445	9.43	4.38	0.25	Dune	2.8	0.5	1.4
200 Yr	445	9.96	4.66	0.26	Dune	3.0	0.6	1.5

Storm	River Station	Yh ft	V ft/s	Fr	Controlling:	Dune Height ft	Anti-Dune Height ft	Scour ft
100 Yr	276	9.18	5.80	0.34	Dune	2.8	0.9	1.4
200 Yr	276	9.55	6.23	0.36	Dune	2.9	1.0	1.4

Storm	River Station	Yh ft	V ft/s	Fr	Controlling:	Dune Height ft	Anti-Dune Height ft	Scour ft
100 Yr	181	9.43	7.79	0.44	Dune	2.8	1.6	**1.4**
200 Yr	181	10.28	8.28	0.46	Dune	3.1	1.9	**1.5**

DIBBLE

Laguna Creek Bridge Check Scour Summary

101411.01

DES: JEP

DATE: 2023-1215

Abutment Scour	100-Year Discharge			200-Year Discharge			
	Calculated Scour [ft]	Factor of Safety	Design Scour [ft]	Calculated Scour [ft]	Factor of Safety	Design Scour [ft]	
Long-term scour	1.0	1.0	1.0	1.0	1.0	1.0	
Abutment scour	11.3	1.0	11.3	12.2	1.0	12.2	
Total Abutment Scour			12.3			**13.2**	**Use 13.2'**

Wash Scour	100-Year Discharge			200-Year Discharge			
	Calculated Scour [ft]	Factor of Safety	Design Scour [ft]	Calculated Scour [ft]	Factor of Safety	Design Scour [ft]	
Long-term scour	1.0	1.0	1.0	1.0	1.0	1.0	
Contraction scour	2.4	1.0	2.4	2.7	1.0	2.7	
Bend scour	2.6	1.0	2.6	2.7	1.0	2.7	
Bedform scour	1.4	1.0	1.4	1.5	1.0	1.5	
Total Wash Scour			7.3			**8.0**	**Use 9.0'**