Basis of Design Report

Merced River Restoration Project - Phase 3

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MERCED RIVER RESTORATION PROJECT TEAM

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Summary

A research team led by the University of California Santa Barbara (UCSB) has previously designed and assisted the National Park Service (NPS) in the implementation of a set of site-specific riparian restoration projects along the Merced River through Yosemite Valley, with four projects constructed between 2016 and 2019. This Basis of Design Report represents a comprehensive presentation by the UCSB team of design analysis and recommendations for the next phase of restoration work in the Merced River, specifically focused on the reaches immediately downstream and upstream of Sugar Pine Bridge, to mitigate for the localized impacts associated with the bridge.

The river in the vicinity of Sugar Pine Bridge is over-widened, locally confined within its banks by riprap, and largely disconnected from its once-active floodplain. Since the sediment supply to the Merced River through Yosemite Valley is limited, restoration that relies primarily on natural processes to rebuild a natural channel will be hindered by extended recovery times. To accelerate the pace of restoration, four broad categories of active restoration approaches have been identified for implementation: (1) reconstruction, replanting, and protection of the riparian zone; (2) encouragement of more frequent overbank flooding and off-channel flows; (3) restoration of dynamic river and tributary channels; and (4) creation of more complex in-channel habitat.

In alignment with these restoration approaches, the following actions have been identified as having the best opportunity to correct the critical impacts in the vicinity of Sugar Pine Bridge:

- Revegetation of the riparian zone
- Revegetation of channel banks
- Riprap removal
- Flow redirection
- Increasing in-channel roughness and narrowing widened channel reaches
- Floodplain regrading
- Engineered log jam installations along banks

The actions were evaluated for their ability to achieve several restoration objectives. A hydraulic model was developed to quantitatively predict the achievement of restoration objectives based on the effects of these actions on hydraulic and geomorphic conditions. Indicators of performance were also developed to permit the evaluation of future effects on streambank and vegetation conditions.

The evaluation of modeled and anticipated future conditions has resulted in four alternatives consisting of different combinations of the above-bulleted restoration actions, which provide different levels of restoration benefits. A cost-benefit analysis was then performed by weighing the restoration benefits and estimated construction costs of each alternative, and also considering the risks and recommended mitigations for the design elements that make up the alternatives. After conducting this analysis, we have selected one alternative as our Recommended Action, whose multiple components constitute the project that we recommend for final design and construction. We also provide evaluation criteria for monitoring the project success after construction, in order to evaluate the long-term effects of a mitigated Sugar Pine Bridge on the biological and hydrological Outstandingly Remarkable Values of the Merced River through Yosemite Valley.

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1 Introduction

1.1 Project Background

Despite more than a century of human modifications, the Merced River through Yosemite Valley benefits from having a largely undisturbed watershed, wholly contained within Yosemite National Park and protected in perpetuity by its wilderness status. The river itself is not unimpacted, but the watershed processes that support it are intact. Where impacts have occurred only from local manipulation of and to the channel, however, then reversing those local effects is the correct fundamental approach to restoration. This overarching principle—reversing past damage to the river itself to allow natural watershed processes to reassert their influence—constitutes the fundamental guidance for the restoration of the Merced River in Yosemite Valley.

The Merced River Plan (NPS 2014, hereafter abbreviated "MRP") has guided the development of this restoration plan, particularly its focus on improving the Outstandingly Remarkable Values (ESA 2012) of the river through Yosemite Valley:

> "The overall goal of the Final Merced River Plan/EIS is to provide for public use and enjoyment of the river resource while protecting and enhancing the values for which the Merced River was designated a Wild and Scenic River," values that include "the river's free-flowing condition, water quality, and outstandingly remarkable values, collectively referred to as river values." Such rivers and their immediate environments are to be protected for the benefit and enjoyment of present and future generations. (MRP, pp. ES-1 and 1-3).

The current project arose during development of a final preferred alternative of the MRP. Although earlier draft versions of the MRP recommended removal of one or more of the historic stone bridges to improve the natural function of the Merced River, the preferred alternative specified that all historic bridges would be retained for the near-term. It went on to state that for Sugar Pine Bridge in particular:

> "Additional study will be conducted by a third party to determine the hydrologic impacts of the historic bridges. Develop criteria for bridge removal (prior to study) that establishes quantitative conditions related to altered flow velocity (speed and direction) attributed to [Sugar Pine Bridge], both upstream and downstream" (MRP, p. 8-199).

The Merced River Restoration Project Team, a collaboration of University of California Santa Barbara (UCSB) (the project lead), UC Davis, and California State University Sacramento, began work on this project in 2015 under a Cooperative Agreement with the National Park Service (NPS). This report, together with a separate 50% design plan set of the restoration actions that are described below, constitute the final product of this effort.

Completed outcomes of this project include the characterization of the physical, biological, and social dimensions of the reach; engagement of key stakeholders in the scope, timeline, and anticipated products of the work; guidance on riparian restoration projects planned for implementation within the reach; and preparation for a variety of monitoring efforts to be conducted opportunistically by the NPS during any high-flow event that might occur during this or subsequent years. The UCSB-led team has already designed and assisted the NPS in the implementation of site-specific riparian restoration projects, with four projects constructed between 2016 and 2019. This Basis of Design Report represents a comprehensive presentation by the UCSB team of design recommendations and analysis of the next phase of restoration work along the river, addressing a study component specifically called for in the final MRP, namely restoration actions in the reach that includes Sugar Pine Bridge (Figure 1-1).

Figure 1-1 Sugar Pine Bridge, looking downstream from the left bank gravel bar. The eponymous sugar pine is visible through the bridge opening (shown with the white arrow), protected by a rocked bank.

1.2 Key Findings from the Project

Conditions within the watershed and along the Merced River through the Study Area (Figure 1-2) have direct consequences for the impacts that have occurred, and they provide significant implications for reversing those effects through active restoration. The following findings are summarized from Booth et al. 2018):

1. The river is largely disconnected from its once-active floodplain, such that adjacent upland areas that once flooded almost annually now require significantly larger, less frequent flows to be occupied. This has the dual effects of altering the biota of the floodplain, affecting both vegetation communities and water-dependent biota, and amplifying erosive forces within the channel by confining flows within its banks. The underlying causes are most likely the historical de-snagging the river of its logs, tree trunks, and other large woody debris, reducing roughness and so enhancing the efficiency of flows to transport sediment; and historical gravel mining of the bed of the river, poorly documented but noted by prior studies. An additional factor may be long-term changes in climate patterns that have increased the relative frequency of high-magnitude winter rain-on-snow floods relative to more moderate (and less competent) snowmelt-dominated floods.
2. The channel has widened substantially during the historical period, with increases averaging more than 25% throughout much of the Valley. The locations of greatest widening align well with areas of high visitor access and use; more pervasive channel expansion likely results from the increased in-channel containment of high flows resulting from incision (see #1 above). The only exceptions to this pattern are the localized constrictions of the channel in the immediate vicinity of the stone bridges.
3. The sediment supply to the Merced River through Yosemite Valley is limited by the river profile upstream and through Nevada and Vernal Falls, which trap virtually all coarse sediment from the upper watershed. The load transported through the Valley is limited to that delivered downstream of these sediment blockages by Illilouette Creek and local rockfalls, supplemented by bank erosion

from channel widening (see #2 above). Comparison of the historical loss of coarse sediment (from incision and channel erosion) with the modern flux of coarse sediment through the reach suggest that more than a century of natural sediment delivery would be required to fully recover the losses that have occurred. Thus, restoration that relied primarily on natural processes to rebuild a natural channel form would require great patience.

Figure 1-2 Overview map of the Study Area, highlighting the bridges within this part of the Merced River. Numbers reference the individual "reaches" into which the river has been subdivided; this Basis of Design report addresses Reaches 6 and 7, straddling Sugar Pine Bridge.

1.3 Restoration Objectives

Four broad categories of restoration approach stand out as having the best opportunity to correct the critical impacts to the Merced River through Yosemite Valley. They are listed in overall priority ranking for implementation, in recognition that direct impacts to the riparian zone and channel banks are not only the most pervasive throughout the Valley but also the most easily and (relatively) inexpensively corrected. Those restoration approaches that require more extensive in-channel work, or that require extensive modifications to adjacent floodplain areas, will demand a higher level of engineering design support and impose greater (albeit temporary) disturbance to both the landscape and visitors alike. Table 1-1 shows the four categories of restoration approach, and some examples of the types of actions that are commonly used to achieve their goals.

Table 1-1 Restoration approaches and potential actions.

Restoration approaches	Potential actions
1. Restoration of the riparian zone	a) Revegetate riparian zone to increase channel roughness, induce sediment deposition, and promote the natural succession of native species b) Fence off or otherwise impede access to bank areas vulnerable to trampling, and direct visitor usage to more resilient portions of the river c) Remove unnecessary riprap, or failed riprap that causes increased erosion d) Redirect flows to minimize bank erosion caused or exacerbated by bridges
2. Encouragement of more frequent overbank flooding and off-channel flows	a) Increase in-channel roughness; narrow excessively widened channel reaches through riparian restoration and bank structures b) Restore ditched and graded meadows, and remove structures diverting groundwater c) Enhance existing or abandoned side channels to encourage more frequent reoccupation d) Regrade selected floodplain areas to permit floodwater access at lower discharges
3. Restoration of dynamic river and tributary channels	a) Remove riprap in non-essential locations, and/or replace with bioengineered bank protection structures b) Place large wood structures along channel bank to reestablish a more natural channel width, limit bank erosion, and promote revegetation c) Revegetate banks d) Add large wood or engineered large wood structures to the river channel e) Redirect flows near bridges
4. Creation of more complex in-channel habitat	a) Retain large wood that naturally falls into the river; reposition, but not remove, wood between Clarks Bridge and Sentinel Beach where recreational rafting occurs b) Add large wood or engineered large wood structures in the mainstem Merced River channel to increase habitat complexity and induce localized scour and sediment deposition c) Revegetate the riparian and near-channel zone

In the vicinity of Sugar Pine Bridge, the most suitable and potentially effective opportunities for restoration include:

- Restoration and revegetation of denuded and/or eroded channel banks
- Revegetation of the broader riparian zone
- Riprap removal
- Flow redirection
- Increasing in-channel roughness and narrowing widened channel reaches
- Floodplain reactivation and regrading
- Engineered log jam (ELJ) installations along banks
- ELJ placement in the channel

2 Methods

2.1 Design Approach

The overarching goal of restoration of the Merced River is to protect and enhance the values for which the Merced River was designated a Wild and Scenic River (for which the Geological and Hydrological Outstandingly Remarkable Values are most relevant for this effort), while providing for present and future public use and enjoyment of those river values. Given its intact watershed setting, restoration of the river through Yosemite Valley should focus on the local impediments to reach-scale hydrologic and geomorphic processes. These reach-scale processes include:

- The localized erosion, transportation, and deposition of sediment, and the expression of these processes in the form and shape of the river channel itself;
- The input, transport, and retention of organic material, particularly large wood;
- The lateral inputs of water and sediment from upland runoff and tributary streams; and
- The hydrologic and sedimentologic interactions between the channel and its adjacent floodplain, in the form of overbank flows and side-channel occupation.

Because the restoration designs that are the subject of this report are specifically intended to address the influence of Sugar Pine Bridge, not every one of these reach-scale processes are equally relevant to this effort. Our emphasis here is on mitigating (1) localized channel modifications resulting from flow confinement and artificially high flow velocities; (2) constraints imposed by the bridge on dynamic channel behavior; and (3) loss of channel–floodplain interactions resulting from both incision and confinement.

Following the guidance of the MRP, a wide range of potential actions were developed within each of the four restoration categories of Table 1-1 (i.e., riparian zone restoration, increased overbank flows, restoration of dynamic channels, and more complex in-channel habitat). They were evaluated for their ability to improve riverine processes and to meet quantitative criteria, as available, that would demonstrate their ability to mitigate for the retention of Sugar Pine Bridge. The indicators of performance, and their criteria for success, are listed in Table 2-1 (see Section 4.2 for a complete discussion of these measures).

Table 2-1 Indicators of performance; criteria for evaluation of success.

Type	Indicator	Evaluation criterion*	Restoration actions (and approaches**)
Hydraulic performance	Floodplain connection	Increase activation at 2-year flood	Revegetation of riparian zone (1,3) Flow redirection (1,3) Floodplain regrading (2)
	Active channel width	Reduce wetted width at baseflow	Increasing in-channel roughness (2)
	Velocity at Sugar Pine Bridge (from MRP)	Reduce velocity to match no-bridge conditions	Flow redirection (1,3)
Streambank conditions	Length of barren and compacted soils***	Reduction in length	Decompaction and revegetation of banks (1,3,4)
	Length of riprap-stabilized bank face	Reduction in length	Riprap removal (1,3) Revegetation of banks (1,3,4)
Vegetation conditions within riparian corridor	Area of invasive plant species	Reduction in area per field monitoring	Revegetation of riparian zone (1,3,4) Revegetation of banks (1,3,4)
	Vertical complexity	Improvement per CRAM attributes (vertical biotic structure and number of plant layers)	
	Species richness	Improvement in number of co-dominant species per field monitoring	
	Native woody riparian regeneration	Improvement in abundance and spatial distribution of native woody riparian regeneration per field monitoring	

*“Reductions” and “Improvements” are considered relative to pre-restoration monitoring. Quantitative targets for defining success will require statistical analysis of pre-restoration variability to define minimum magnitude(s) of significance and comparison with a reference reach (discussed further in Section 4.2).

**See Table 1-1 for reference to restoration approaches (1 = Restoration of the riparian zone, 2 = Encouragement of more frequent overbank flooding and off-channel flows, 3 = Restoration of dynamic river and tributary channels, 4 = Creation of more complex in-channel habitat).

*** Not intended to include active, unvegetated gravel bars or vertical cut banks at the outside of river bends (i.e., naturally unvegetated areas along a river channel).

Characterizing the potential effects of restoration measures, and quantitative evaluation of their success at mitigating for bridge retention, has required the development and application of a hydraulic model (described in the section below) through the Project Area (i.e., Reaches 6 and 7 of the overall Study Area that extends from above Happy Isles Bridge to Sentinel Bridge). An earlier model was previously developed for the reach including Sugar Pine Bridge (Minear and Wright 2013), but subsequent advances in computing power and additional opportunities for its application beyond the immediate vicinity of the bridge has motivated our development of a new model of substantially greater extent and accuracy. A comparison of the two models’ output, where comparable, is provided in the discussion below.

Modeling of various design alternatives, together with more qualitative assessments of the relative benefits of potential restoration actions, led to a set of prospective design elements grouped into a range of alternatives. Based on subsequent assessment of hydraulic, geomorphic, and ecological benefits, a final set of design elements constitutes our recommended restoration actions (Section 4).

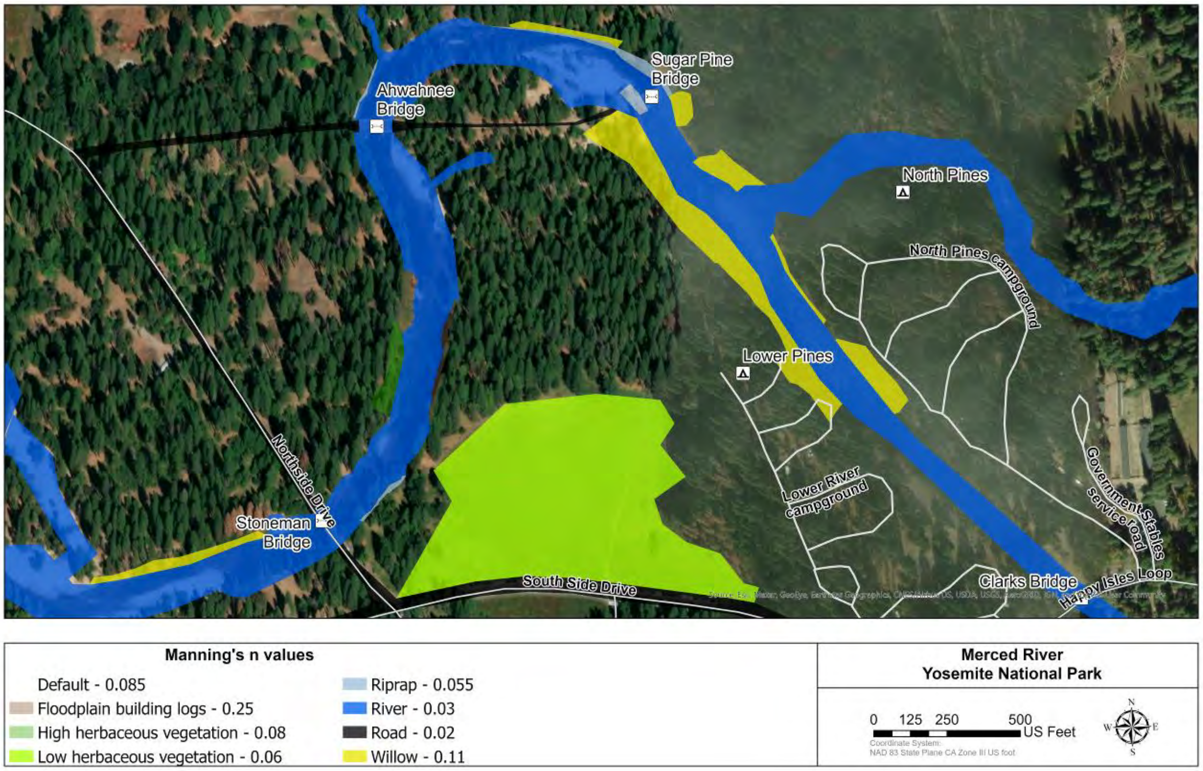
2.2 Hydraulic Modeling

2.2.1 Existing Conditions Model Development

A two-dimensional (2D) hydraulic model was developed for the Project Area using the U.S. Army Corps of Engineers' (USACE's) Hydrologic Engineering Center Hydraulic River Analysis System (HEC-RAS) version 5.0.7. Given the nature of complex hydraulics within the Merced River system, a 2D model that employs the full momentum equations to describe a moving fluid was selected to reasonably simulate abrupt expansions and contractions within the channel (associated with sinuosity and bridges) as well as overbank flow patterns over a wide and relatively flat floodplain.

The main elements of the hydraulic model consist of a Digital Terrain Model (DTM), a roughness layer, and upstream and downstream boundary conditions at the limits of the Study Area. A composite DTM was constructed that integrates elevation data from light detection and ranging (LiDAR) data flown in 2010 (NCALM, 2011), bathymetric survey data collected in 2007 (Minear and Wright 2013), and topographic surveys conducted by Yosemite National Park (YNP) and Cardno from 2009-2019. The model terrain is in the North American Datum of 1983 California State Plane Coordinate System, Zone 3 (US feet). The vertical datum of the model terrain is the North American Vertical Datum of 1988.

An unstructured mesh reads elevation data from the underlying DTM and Manning's n values from the underlying roughness layer. The mesh consists of cells with up to eight sides that vary in size (approximately 8 feet by 8 feet in the channel and 20 feet by 20 feet in the floodplain). The individual cell faces each act as a detailed cross-section; data are read continuously along the edge of the cell face (instead of being reduced to a single value per cell). Manning's roughness values (Figure 2-1) were assigned using GPS data collected by Cardno during a 2011 riparian corridor vegetation survey and 2017 aerial imagery from Google Earth Pro (2020).

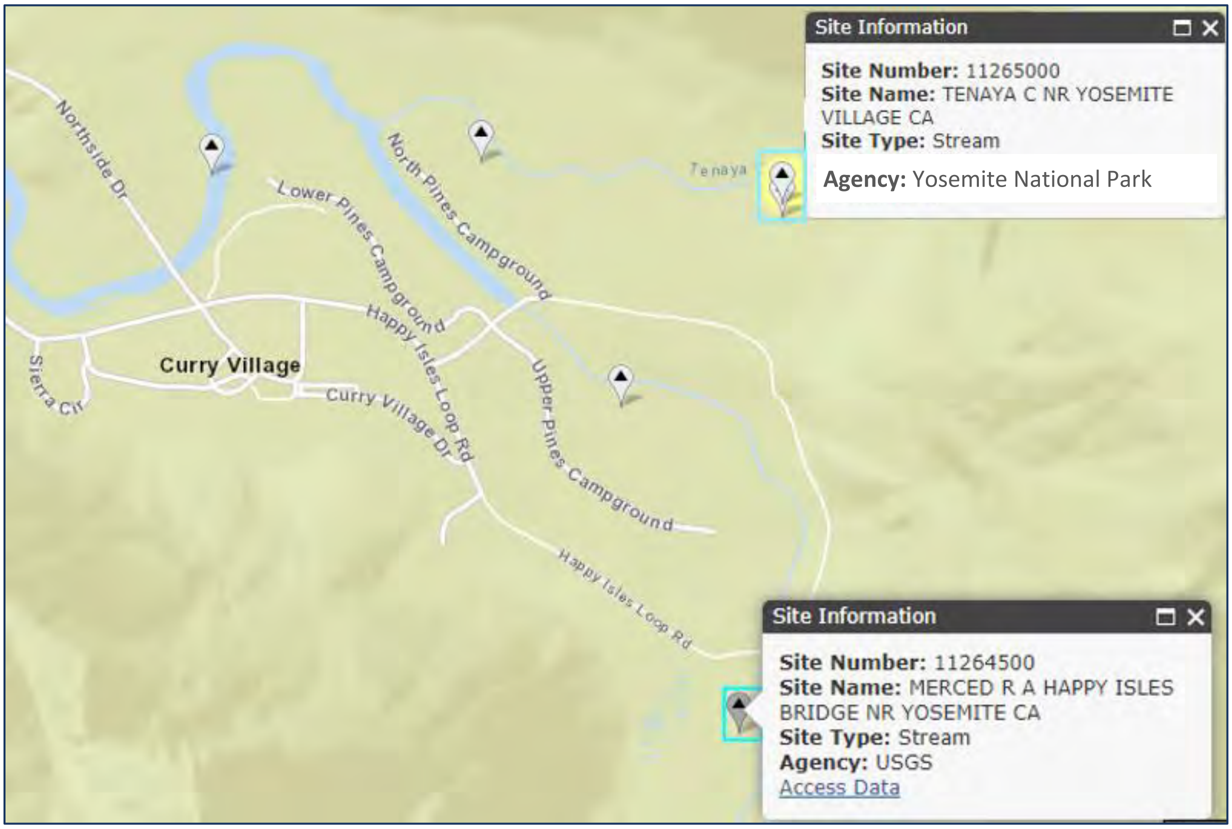


Note: Areas not covered with a shaded polygon were assigned a default Manning's n value of 0.085, representative of conifer forest

Figure 2-1 Manning's n values for the existing conditions model.

Boundary conditions for the model consist of inflow hydrographs at the upstream end of the model extents, and the elevation of the water surface at the calculated normal depth at the downstream end of the model extents (normal depth is calculated in HEC-RAS using the Manning's equation; a friction slope of 0.002, approximated from the slope of the bed at the downstream boundary location, was entered in HEC-RAS to calculate the normal depth). Inflow hydrographs were generated using available data from stream gage records. Referenced stream gages include the USGS 11264500 Merced River at Happy Isles Bridge gage (1916–present), the USGS 1126500 Tenaya Creek gage (1912–1958), and the YNP Tenaya Creek gage (2006–2018).

Figure 2-2 shows the locations of the USGS gages upstream of the modeled reach. All gages are located less than one mile upstream of the model extents. Calibration flows in the Merced River were derived directly from the USGS gage records, and calibration flows in Tenaya Creek were derived from the YNP gage record. At those times when measured flow data were unavailable, Tenaya Creek flows were estimated as a fraction of Merced River flows.



Site Number: 11265000
Site Name: TENAYA C NR YOSEMITE VILLAGE CA
Site Type: Stream
Agency: Yosemite National Park

Site Number: 11264500
Site Name: MERCED R A HAPPY ISLES BRIDGE NR YOSEMITE CA
Site Type: Stream
Agency: USGS

Figure 2-2 **Stream gage locations upstream of the Project Area.**

Three flow magnitudes were selected to evaluate design criteria: summertime baseflow, the 2-year flood event, and the 25-year flood event. Summertime baseflow was determined by calculating the median of the average daily flows during the months of July, August, and September over the period of record for Happy Isles Bridge gage. Annual exceedance probabilities (AEPs) of flood flows within the Merced River and Tenaya Creek were calculated using USGS and YNP gage data and Bulletin 17B methodology (USGS 1982). Design flows for Merced River and Tenaya Creek are summarized in Table 2-2.

Table 2-2 Design flows for hydraulic modeling.

Flow magnitude	Merced (cfs)	Tenaya (cfs)	Total flow (cfs)
Summertime baseflow	65	3.7	68.7
2-year AEP	2,678	981	3,659
25-year AEP	7,021	3,553	10,574

2.2.2 Existing Conditions Model Calibration

The existing conditions model was calibrated using stage-discharge equations derived from bridge tape-down measurements of water surface elevations (WSEs) collected by YNP for flows ranging from 193 to 4,266 cfs (see Figure A.1, Figure A.2, and Figure A.3 in Appendix A). Simulated WSEs at various flows within the calibration range were compared with the calculated stage derived from the stage-discharge equations at six locations—upstream and downstream of Sugar Pine, Ahwahnee, and Stoneman bridges. (Table A.1, Table A.2, and Table A.3 in Appendix A). On average, the difference in simulated minus calculated WSEs is approximately 0.0 feet at Sugar Pine Bridge, 0.3 feet at Ahwahnee Bridge, and 0.7 feet at Stoneman Bridge. In order to achieve these model results, the initial bed roughness was reduced from a Manning’s n of 0.035 to a Manning’s n of 0.030; all other roughness values were unchanged from the initial assumption.

The calibrated model was further evaluated using surveyed WSE points from topographic surveys conducted by YNP and Cardno during low-flow events (137 to 1,070 cfs) and Global Positioning System (GPS) high-water-mark surveys conducted by YNP for high-flow events in April 2018 (8,060 cfs) and January 1997 (10,100 cfs). When compared with the topographic survey data, simulated WSEs are higher than measured WSEs, with divergence increasing in the downstream direction (up to an average of 0.8 feet) (Table A.4, Table A.5, and Table A.6 in Appendix A).

When comparing the model results with the 2018 surveyed high-water marks (Figure A.4, Appendix A), simulated WSEs are generally higher than observed high-water marks by approximately one foot. When comparing the model results with the 1997 surveyed high-water marks (Figure A.5, Appendix A), simulated WSEs are generally higher than observed high-water marks by approximately two-tenths of a foot. Due to the lack of calibration data available for the high-flow events, the model is considered well-calibrated for flows up to the five-year event, and validated (see Section 2.2.3) for flows up to the 100-year event.

Tenaya Creek gage data were unavailable for the calibration events. High-water-mark surveys were conducted with GPS, which are accurate horizontally within about one meter, but vertical (elevation) data were not collected. Thus, high-water elevations were extracted from the topographic surface used for modeling at the location of the GPS survey.

2.2.3 Existing Conditions Model Validation

YNP has collected acoustic Doppler current profiler (ADCP) data at multiple bridges along the Merced River. In order to validate the velocity component of the calibrated existing conditions model results, ADCP data were compared to model predictions from two cross-sections of the Merced River—upstream and downstream of Sugar Pine Bridge (see Figure A.6 and Figure A.7 in Appendix A for cross-section locations).

Teledyne RD Instruments WinRiver II application (2019) was used to post-process raw ADCP data. The ADCP data provide discrete velocity measurements—both vertically, along the water column; and horizontally, across the cross-section. Because the simulated velocity results do not vary with depth (an intrinsic limitation of a 2D model), it was necessary to process the measured velocity data in order to make comparisons with the simulated results. Measured velocity values were averaged over each “column” of velocities from the water surface elevation to the maximum flow depth, at increments along the length of the cross-section for which data were collected. Average and maximum values were then calculated from average velocities for each depth column across the cross-section. The ADCP is unable to measure velocities near the riverbed due to streambed interference with the acoustic signal. Although the data collection program is able to estimate velocities in this area near the riverbed, data used for this analysis were limited only to the measured data. Therefore, this approximation, together with estimated locations and extents of the cross-sections in the model based on photographs and field measurements from the bridge, leaves considerable room for error when interpreting results. Figure A.9 in Appendix A shows a graphical representation of the measured velocities and associated spatial velocity distribution as well as the area where data were not collected.

From the 10 days that flows were measured during the spring months in 2016 and 2017, the two days with the highest flows were selected for analysis. These days corresponded most closely to the calibration flows for the existing conditions model, and this flow range (the 2-year event) is a primary consideration for design. A calibration hydrograph (a synthesized hydrograph containing gaged flow data coinciding with the dates and times of events when calibration data were collected) was utilized to compare model output with the measured data.

Upstream of Sugar Pine Bridge, the utilized data consisted of flows and velocities on May 25, 2017. Table A.7 in Appendix A lists the gaged flows and measured velocities on this date, with flows ranging from 2,960 to 4,380 cfs. The average measured flow was 3,707 cfs, and a simulated flow of 3,718 cfs was utilized for comparison. At this upstream location, simulated velocities closely match the measured velocity distribution—in that higher velocities are located at the thalweg of the river and lower velocities are on the right bank of the river (Figure A.9, Appendix A). Table 2-3 shows the average and maximum velocities for the measured and simulated flows at the cross-section upstream of Sugar Pine Bridge. The simulated average velocity over the total length of the cross-section is 1.0 ft/s less than the measured average velocity, and the simulated maximum velocity is 1.8 ft/s less than the measured maximum velocity.

Table 2-3 Simulated and measured velocities upstream of Sugar Pine Bridge.

	Flow (cfs)	Average Velocity (ft/s)	Maximum Velocity (ft/s)
Measured	3,707	6.8	9.8
Simulated	3,718	5.8	8.0
Difference (simulated minus measured)	11	-1.0	-1.8

Downstream of Sugar Pine Bridge, the utilized data consisted of measured flows and velocities on May 10 and 25, 2017. Table A.8 in Appendix A lists the measured flows and velocities on these dates, with flows ranging from 3,352 and 4,505 cfs. The average measured flow was 3,824 cfs, and a simulated flow of 3,870 cfs was utilized for comparison. At this downstream location, simulated velocities match measured velocity distribution on the right bank but not on the left bank (Figure A.10, Appendix A). Table 2-4 shows the average and maximum velocities for the measured and simulated flows at the cross-section downstream of Sugar Pine Bridge. The simulated average velocity is 1.2 ft/s less than the measured average velocity, and the simulated maximum velocity is 1.9 ft/s less than the measured maximum velocity.

Table 2-4 Simulated and measured velocities downstream of Sugar Pine Bridge.

	Flow (cfs)	Average Velocity (ft/s)	Maximum Velocity (ft/s)
Measured	3,824	7.0	10.6
Simulated	3,870	5.9	8.7
Difference (simulated minus measured)	46	-1.2	-1.9

The following conclusions were drawn from this validation exercise:

- On average, the measured velocities are about 1 ft/s higher than the simulated velocities.
- In some instances, the measured velocities were less than or equal to the simulated velocities.
- The maximum measured velocities are about 2 ft/s higher than the simulated velocities.

These results suggest the value of incorporating a factor-of-safety of 2 ft/s as an addition to simulated velocities for subsequent use in project designs. This should provide a conservative (i.e., high) estimate of velocity for design purposes in order to compensate for a paucity of near-bed measurements, local differences, and extrapolation of measured data to higher flows.

2.2.4 Comparison of Current and Previous Hydraulic Models

An earlier hydraulic and geomorphic study of the Merced River, from upstream of the Tenaya Creek confluence to below Housekeeping Bridge, was previously executed (Minear and Wright 2013). The present effort now provides an opportunity to compare the results of two independently prepared hydraulic models. Historical conditions, present-day conditions, and planning scenarios, including the potential removal of Sugar Pine Bridge and Ahwahnee Bridge, were investigated as part of that earlier study. The USGS FaSTMECH model was used to assess the hydraulic effects (i.e., flow widths, depths, and velocities) for several existing and proposed scenarios. The study found that, historically, a large portion of the floodplain between Reach 7 and Reach 5 was inundated during the 2-year event and that in-channel velocities were lower using the 1919 channel topography than at present. It also noted that the maximum velocities in the Study Area are associated with flow through Stoneman Bridge and Sugar Pine Bridge.

Table 2-5 below summarizes the differences between the models. The FaSTMECH model was not made available for use in our present study, but the same bathymetric data used in the FaSTMECH model, from the Tenaya Creek confluence to upstream of Ahwahnee Bridge (i.e., Reaches 7 and 6), were available and were incorporated into the HEC-RAS model developed for our study. Reflecting improvements in computational speed and power since the work of Minear and Wright (2013), the HEC-RAS model applied here uses the full momentum equation for its computations, which account for the acceleration term in those equations and allow for the approximation of rapidly varied flow associated with abrupt expansions, contractions, and drops. In contrast, FaSTMECH neglects terms in the equations of motion in order to decrease model run times. The HEC-RAS model uses an unstructured grid, with sub-grid capabilities, which allow each grid cell to have up to eight detailed cell faces which each represent continuous cross-sections of elevations, whereas FaSTMECH is an unstructured curvilinear grid, which only allows for a single elevation per grid cell. However, the FaSTMECH grid is finer (3.3 feet throughout the model domain) vs. that of the HEC-RAS model (2 to 6 times coarser, within the channel and on the floodplain). The HEC-RAS model utilizes more recent LiDAR and ground-surveyed topography than the FaSTMECH model; and the HEC-RAS model simulates a wider range of flows, from baseflows to the 100-year event, whereas FaSTMECH simulated flows only in the range of the 2-year to 20-year events.

Table 2-5 Comparison of the current and previous hydraulic models.

Model Element	Current model (this study)	Previous model (Minear and Wright 2013)
Model	HEC-RAS	FaSTMECH
Computational grid type	Unstructured sub-grid (up to 8 cell faces per grid cell, with each cell representing a detailed cross-section)	Structured curvilinear (single elevation per grid cell)
Grid size	Varies 8 ft x 8 ft in river, 20 ft x 20 ft in floodplain	1 m x 1 m (3.3 ft x 3.3 ft)
Numerical methodology	Unsteady, full momentum equations	Quasi-steady (i.e., discharge varies, but unsteady terms are neglected in the equations of motion)
LiDAR survey	2010	2007
Ground survey	2007-2019	2007-2010
Simulated flows	Baseflows to 100-year	2- to 20-year

Figure 2-3 and Figure 2-4 show simulated velocities during the 2- to 25-year flow event in the FaSTMECH and HEC-RAS models, respectively. Both models display relatively high velocities at Stoneman and

Ahwahnee bridges under existing (present-day) conditions. However, the HEC-RAS model extends the high-velocity zone farther upstream than the FaSTMECH model, and higher velocities (in the range of 8-12 ft/s) are simulated within the river throughout Reach 7 as well. Both models find limited floodplain inundation during the 2-year event. In the HEC-RAS model, however, somewhat more extensive floodplain inundation is predicted during lower recurrences than the FaSTMECH model, although by the 10-year event such differences are minimal as to extent, and only modest as to predicted velocity.

Table 2-6 compares the average and maximum velocities at Sugar Pine Bridge as simulated in the FaSTMECH and HEC-RAS models. The HEC-RAS model simulates higher average and maximum velocities than the FaSTMECH model for the 2-year and 25-year events, which are more in line with measured average and maximum velocities (Section 2.2.3).

Table 2-6 Velocities at Sugar Pine Bridge as simulated in FaSTMECH and HEC-RAS models.

Simulated velocity for existing conditions (ft/s)	FaSTMECH	HEC-RAS
2-yr discharge		
Maximum velocity	7.9	9.4
Average velocity	4.5	4.9
20-yr discharge (FaSTMECH) or 25-yr discharge (HEC-RAS)		
Maximum velocity	9.1	10.3
Average velocity	5.2	5.9

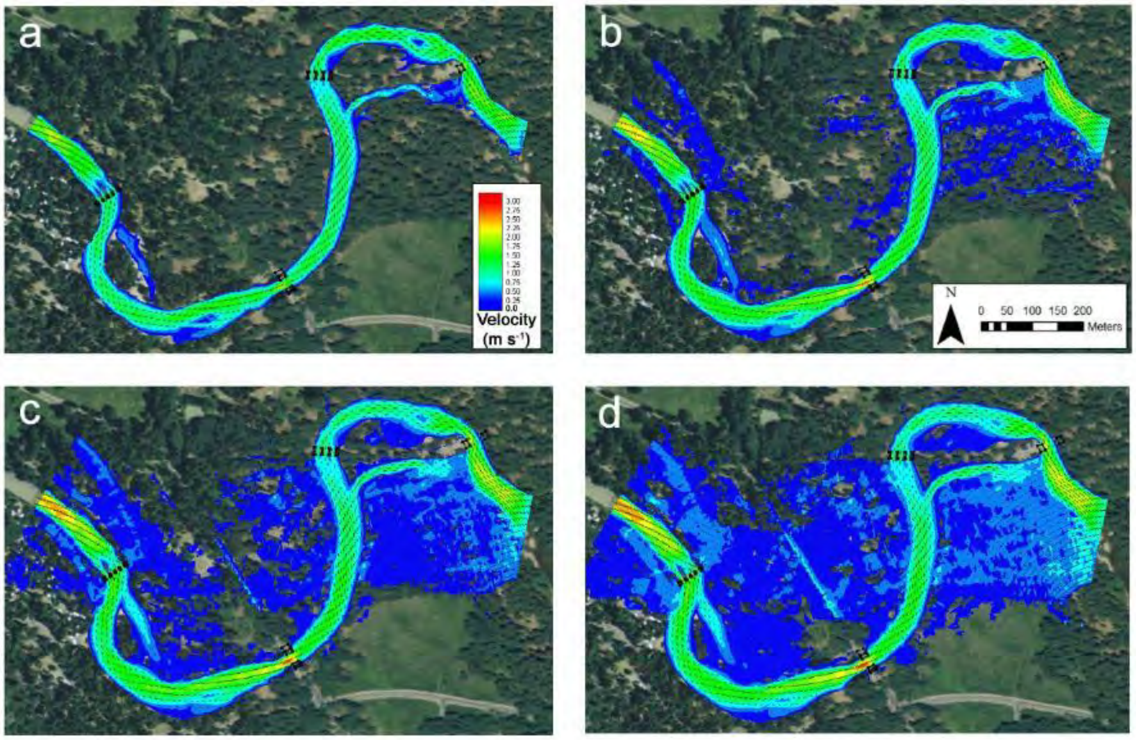


Figure 2-3 FaSTMECH simulated present-day velocities (meters/sec) for 2-year, 5-year, 10-year, and 20-year events (panels a-d, respectively).

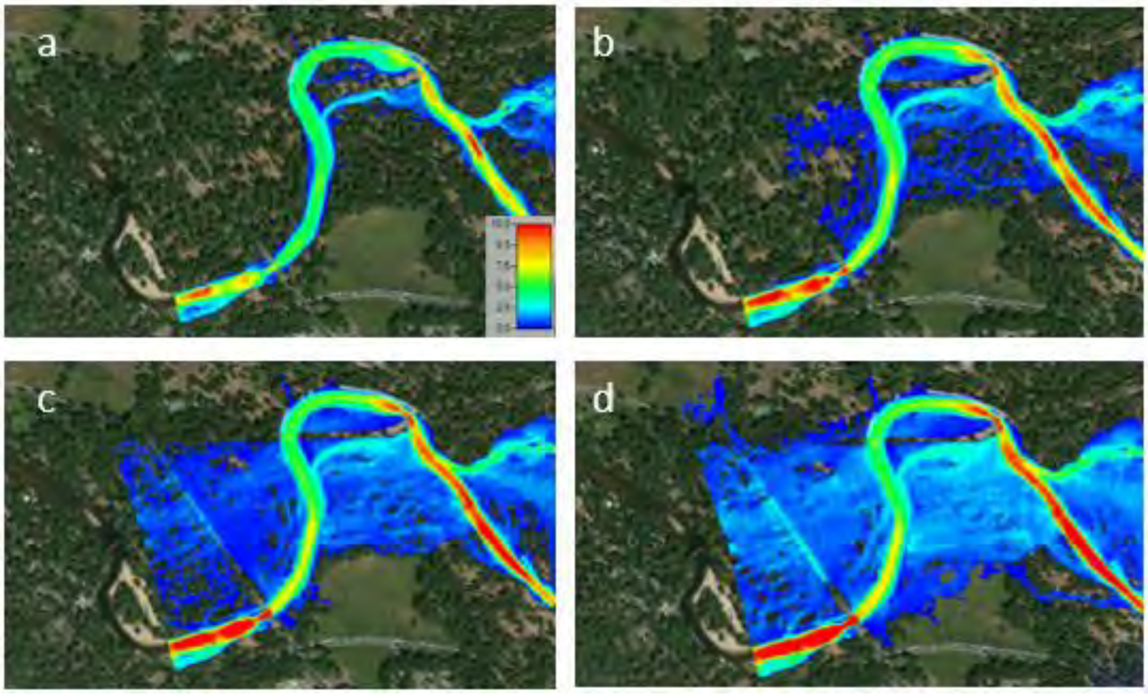


Figure 2-4 HEC-RAS simulated velocities (ft/s) for present-day conditions with for 2-year, 5-year, 10-year, and 25-year events (a-d, respectively). Color ramp is equivalent for both Figures 2-3 and 2-4, despite the change in measurement units.

Between Ahwahnee Bridge and Sugar Pine Bridge is a berm—about 800 feet long and 65 to 115 feet wide at its base—supporting a paved bicycle/pedestrian path that is locally about 5 to 14 feet above the surrounding floodplain (Figure 2-5). Both models simulated the removal of both Sugar Pine Bridge and this berm. In order to be consistent with the assumptions in the FaSTMECH model, the removal of Sugar Pine Bridge was graded equivalently in HEC-RAS. Figure 2-6 shows cross-sections of the existing and proposed topography at Sugar Pine Bridge from the FaSTMECH model (top) and the HEC-RAS model (bottom). Note that the cross-section in Minear and Wright (2013) did not extend to show where the proposed topography meets the existing topography on the left bank. However, the cross-section for the HEC-RAS model was graded to a similar slope as in the FaSTMECH model, and so the overall geometry was assumed to be equivalent.

Source: Google Earth Pro 2020

Figure 2-5 **Aerial image of berm (marked by the paved path) between Ahwahnee Bridge and Sugar Pine Bridge.**

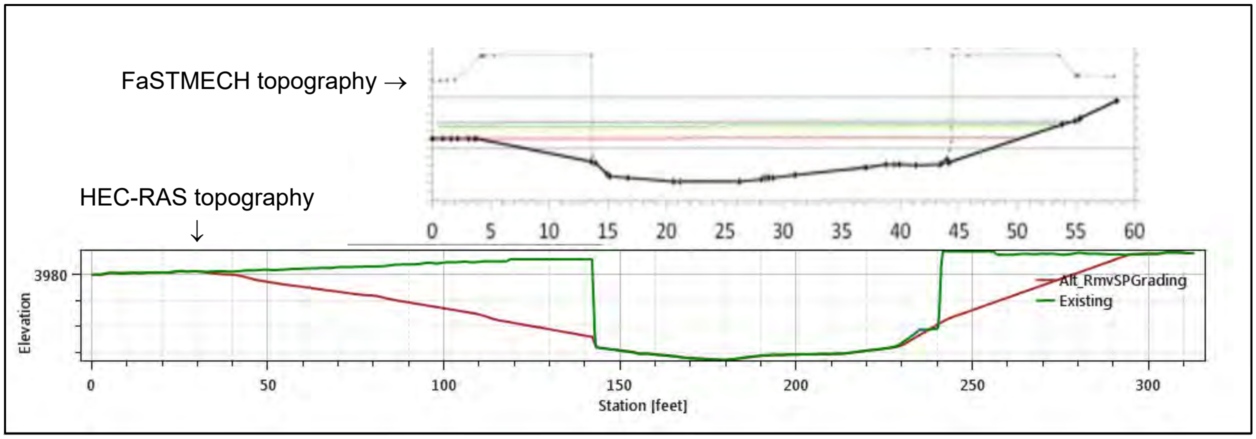


Figure 2-6 **Comparable cross-sections of the existing and proposed topography at Sugar Pine Bridge from the FaSTMECH model (top; horizontal scale in meters) and the HEC-RAS model (bottom; horizontal scale in feet).**

Table 2-7 compares the velocity reductions from the removal of Sugar Pine Bridge and berm as they are simulated in the FaSTMECH and HEC-RAS models. For the 2-year event, the FaSTMECH model simulates less reduction in maximum velocity and greater reduction in average velocity than the HEC-RAS model. For the 25-year event, the FaSTMECH model simulates the same reduction in maximum velocity and less reduction in average velocity than the HEC-RAS model.

Table 2-7 Reduction in maximum and average velocities at Sugar Pine Bridge, as simulated in FaSTMECH and HEC-RAS models.

Simulated velocity for existing conditions (ft/s)	FaSTMECH	HEC-RAS
2-yr discharge		
Reduction in maximum velocity	5%	12%
Reduction in average velocity	36%	16%
20-yr discharge (FaSTMECH) or 25-yr discharge (HEC-RAS)		
Reduction in maximum velocity	9%	9%
Reduction in average velocity	30%	41%

We have used this scenario—removal of Sugar Pine Bridge, and the partial removal of the berm between Sugar Pine Bridge and Ahwahnee Bridge—to provide a “Baseline” for evaluating the likely success of alternative restoration designs, consistent with the guidance of the MRP (which requires evaluation of the “quantitative conditions related to altered flow velocity (speed and direction) attributed to the bridge, both upstream and downstream” [MRP, p. 8-199]). In the analysis of alternatives that follows (Section 3), all velocities are consistently predicted and compared to one another using our updated HEC-RAS model to minimize any of the biases or inaccuracies inherent in any model. Although the validation suggests that absolute values may diverge from actual conditions by up to 2 ft/sec, we expect that comparisons between modeled velocities for the various alternatives will have much less potential error.

2.3 Design Elements

To address the combined influences of heavy visitor traffic, bridge-confined channel dimensions, and riprap-limited channel positions, the following design elements for restoration of Reaches 6 and 7 were identified and analyzed (Figure 2-7):

a) Floodplain reactivation

- Floodplain reactivation consists of reconstructing the banks immediately upstream of Sugar Pine Bridge to smooth hydraulic transitions, especially on left bank, and opening up multiple relict side channels across the left-bank peninsula upstream of Sugar Pine Bridge to allow more frequent, larger flows to reactivate the floodplain. The locations and alignments of the side channels were designed to minimize excavation volume. The depths (approximately 2 feet) of the side channels were designed to be the minimum depth that would allow for flow activation within the side channels during the 2-year AEP. The dimensions (approximately 10-foot bottom width and 3H:1V side slopes) were designed to mimic sections of abandoned relict side channels. Grading is only required at the upstream ends of the side channels, as they all connect downgradient to existing side channels. The three downstream side channels converge into a single outlet that discharges to Reach 5 just downstream of Ahwahnee Bridge.

  The inlets of the side channels will be widened and, in the case of the two most downstream side channels, the entire bank will be lowered at the mouths of the side channels to direct overbank flows into the channels. An example graphic (Figure B.6) and example detail (Figure B.7) are provided in Appendix B. Figure 2-7 below shows the location and extents of the proposed side channels in teal (on the “Design Element Locations and Extent” panel) as well as the elevation difference from the existing topography. The net excavation required for the proposed side channels is estimated to be 6,150 cubic yards.

b) Selective riprap removal

- Selective riprap removal consists of selectively removing riprap and revegetating the right bank riparian zone downstream of Sugar Pine Bridge where cultural resources would not be impacted, together with associated control of visitor access. Selective riprap removal will take place in areas where the simulated velocity is less than the permissible velocity for vegetative bank stabilization and where the simulated shear is less than the permissible shear for vegetative bank stabilization (Fischenich 2001). An example graphic (Figure B.8), detail (Figure B.9), and photographs (Figure

B.10) are provided in Appendix B. Figure 2-7 below shows the location and extents of the selective riprap removal in yellow.

c) Berm removal

   - Berm removal consists of removing the berm between Ahwahnee Bridge and Sugar Pine Bridge. The existing paved trail at the elevation of Ahwahnee Bridge will transition to a gravel trail at the floodplain elevation at a slope of no greater than 10 percent. An example detail (Figure B.11) is provided in Appendix B. Figure 2-7 below shows the location and extents of the berm removal in green.

d) Flow-deflecting ELJ

   - Installing one (or potentially more) flow-deflecting ELJ consists of constructing a triangular-shaped engineered log jam or jams on the left bank in Reach 7 immediately downstream of the Tenaya Creek confluence. The upstream face of the ELJ is oriented perpendicular to Merced River flows and parallel to Tenaya Creek flows to deflect flows away from the right bank of Reach 7 and towards the reactivated floodplain. An example photograph (Figure B.12) is provided in Appendix B. Figure 2-7 above shows the location and approximate extent of the flow-deflecting ELJ in purple.

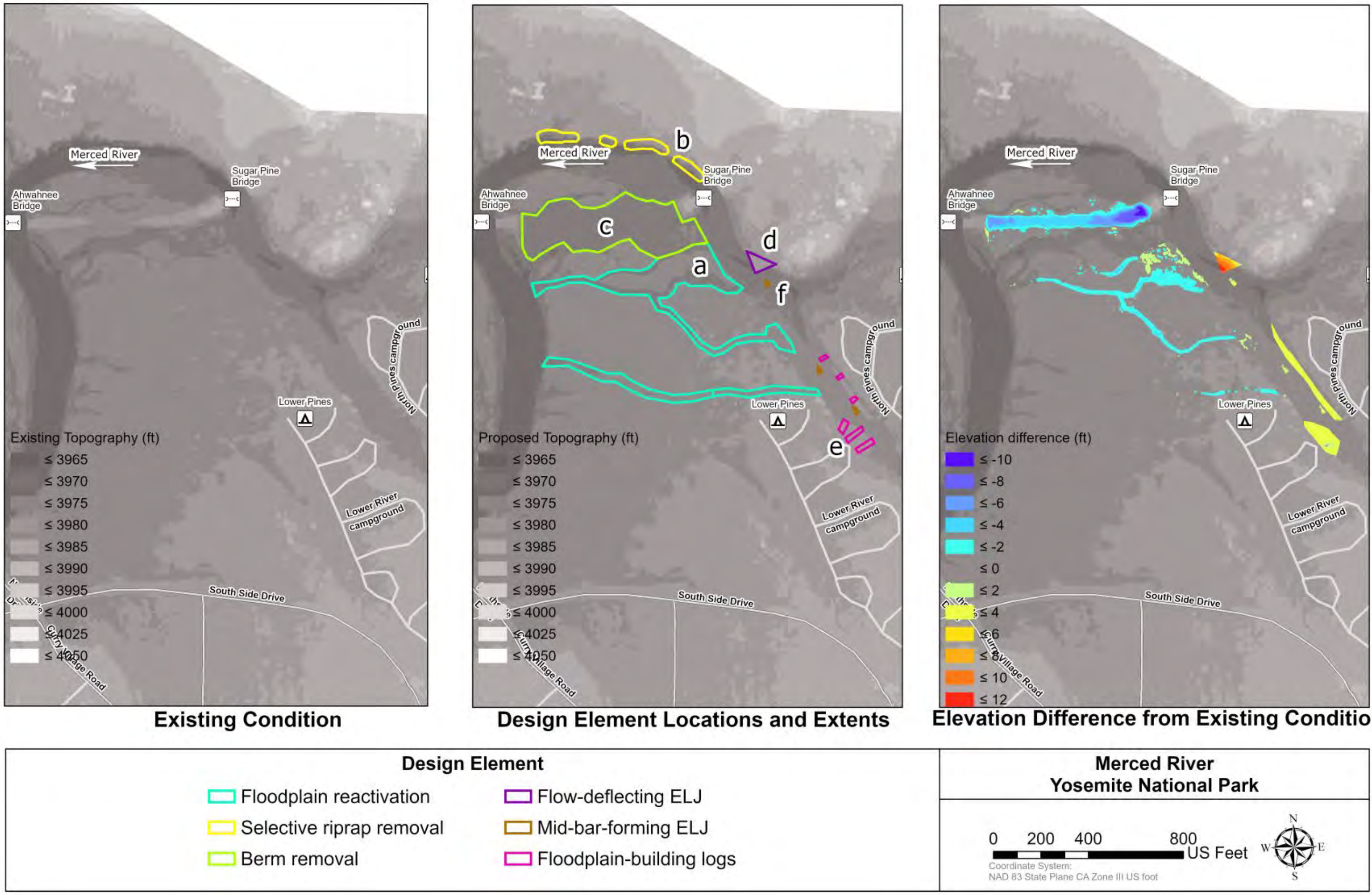
e) Floodplain-building logs

   - Installing floodplain-building logs consists of installing riparian log treatments at locations within Reach 7 to narrow the channel to more natural dimensions and create a meandering planform via riparian reconstruction on alternate banks in the 500 yards upstream of Sugar Pine Bridge. The locations of the floodplain-building logs were selected to create a meandering planform that would direct flows into and help maintain the newly reactivated side channels (first element above), as well as improve the flow alignment through the opening provided by Sugar Pine Bridge. An example graphic (Figure B.13), detail (Figure B.14), and photographs (Figure B.15) are provided in Appendix B. Figure 2-7 above shows the location proposed log locations in pink (on the “Design Element Locations and Extent” panel); the final, filled extents of the floodplain-building logs are shown in yellow on the “Elevation Difference From Existing Condition” panel.

f) Mid-bar-forming ELJs

   - Installing mid-bar-forming ELJs consists of constructing multiple (currently three are proposed) ELJs mid-way between the banks in Reach 7 to increase in-channel roughness upstream of Sugar Pine Bridge, raise overall channel/flood elevations, and allow better access of moderate and high flows to overbank areas. The ELJs are designed such that the logs are nearly parallel to river flows with the rootwad in the upstream direction. The roughened obstruction slows velocities immediately downstream of the ELJ, which encourages sediment deposition within the channel. Flows are deflected to either side of the ELJ. The two upstream ELJs are located adjacent to the proposed floodplain-building log treatments, which protect the right bank from increased velocities, and instead direct forces downward, scouring the riverbed and providing vertical complexity. Increased velocities on the left banks are desirable to maintain proposed (reactivated floodplain) side channel inlets. The downstream mid-bar-forming ELJ is located just upstream of the proposed flow-deflecting ELJ to aid in flow deflection. An example graphic (Figure B.16) and photograph (Figure B.17) are provided in Appendix B. Figure 2-7 above shows the three proposed locations of the mid-bar-forming ELJ in brown (on the “Design Element Locations and Extent” panel).

To analyze the alternatives in the hydraulic model, rough grading for the different elements (including ELJs) was incorporated using Autodesk Civil 3D 2019, and model runs were developed for each alternative HEC-RAS. For each alternative, a composite terrain surface was generated by beginning with the existing surface as the base surface and overriding the existing surface in the locations of the design elements with the proposed rough grading surfaces specific to each alternative. Similarly, existing Manning’s n values were overridden in proposed grading locations and updated with proposed roughness values representing the final, maturely revegetated condition. Figure B.1 through Figure B.5 in Appendix B show the proposed topographic and roughness changes for each alternative compared with existing conditions.



Existing Condition

Design Element Locations and Extents

Elevation Difference from Existing Condition

Figure 2-7 Existing topography (left panel), locations of identified design elements (center), and elevation difference associated with design elements (right) within Reach 6 and Reach 7 (Reach 5, downstream of Ahwahnee Bridge, would also be affected indirectly by several of these actions).

3 Alternatives Analysis

To determine the recommended actions within the Project Area (Reaches 6 and 7), alternatives consisting of various combinations of the design elements summarized in the previous section were developed, and a cost-benefit analysis was performed. Restoration benefits were measured by analyzing simulated geomorphic and hydraulic performance, and by estimating potential changes in streambank and vegetation conditions. Construction cost estimates were developed for each alternative. Additional design considerations independent of restoration benefits or construction costs were also characterized and incorporated into the assessment of alternatives.

Table 3-1 lists the various modelling scenarios including the existing condition, the “Baseline scenario” condition (summarized in Section 2.2.4), and four alternatives for design conditions.

Table 3-1 Description of alternatives.

Scenario	Description
Existing condition	Current configuration of channel, floodplain, and bridges
Baseline scenario	Existing condition with Sugar Pine Bridge removed and partial berm removal (existing condition with Sugar Pine Bridge removed and limited grading around existing abutments also analyzed but not reported in output tables)
Alternative 1	Existing condition with the following: • Selective riprap removal and planting within Reach 6 • Reactivate historic swale connections (in floodplain between Reach 7 and Reach 5), lower banks at swale entrances (within Reach 7), and planting • Install ELJ at Tenaya Creek confluence • Install filled floodplain-building log treatments with planting at locations within Reach 7 • Berm Removal
Alternative 2	Alternative 1, minus berm removal
Alternative 3	Alternative 1, minus berm removal, plus unfilled floodplain-building log treatments
Alternative 4	Alternative 1, plus mid bar-forming ELJs within Reach 7

3.1 Benefits

The benefits of the proposed restoration actions were evaluated using the indicators of success and design criteria table (Table 2-1). Only the hydraulic indicators, however, are amenable to rigorous quantitative prediction prior to implementation. Several other indicators can be inferred on the basis of planned actions and their assumed success; and still others are wholly dependent on future ecological recovery that can only be measured as post-implementation outcomes compared to pre-construction and/or reference-reach ecological conditions.

3.1.1 Hydraulic Performance

The hydraulic performance indicators comprise the degree of floodplain activation, active channel width, and velocity through Sugar Pine Bridge. Results from the hydraulic model allow prediction of the first and third indicators in this category; the second (active channel width) was simply scaled off of the preliminary design drawings relative to existing channel measurements. For each alternative, a successful outcome should match or improve the performance under the Baseline scenario, which reflects the hypothetical condition for which the recommended actions should mitigate (as specified by Alternative 5 of the MRP).

The first indicator of success for geomorphic and hydraulic performance is floodplain activation. Figure 3-1 shows plan views of the simulated inundation extents (and velocities) during a 2-year event. Inspection of these simulation results shows relatively modest expansion of floodplain activation under the Baseline scenario, primarily in the area of the removed berm adjacent to Sugar Pine Bridge. In contrast, dramatic (and only minimally different) outcomes are predicted under each of the alternatives, particularly those that include full removal of the berm between Ahwahnee Bridge and Sugar Pine Bridge (Alternatives 1 and 4).

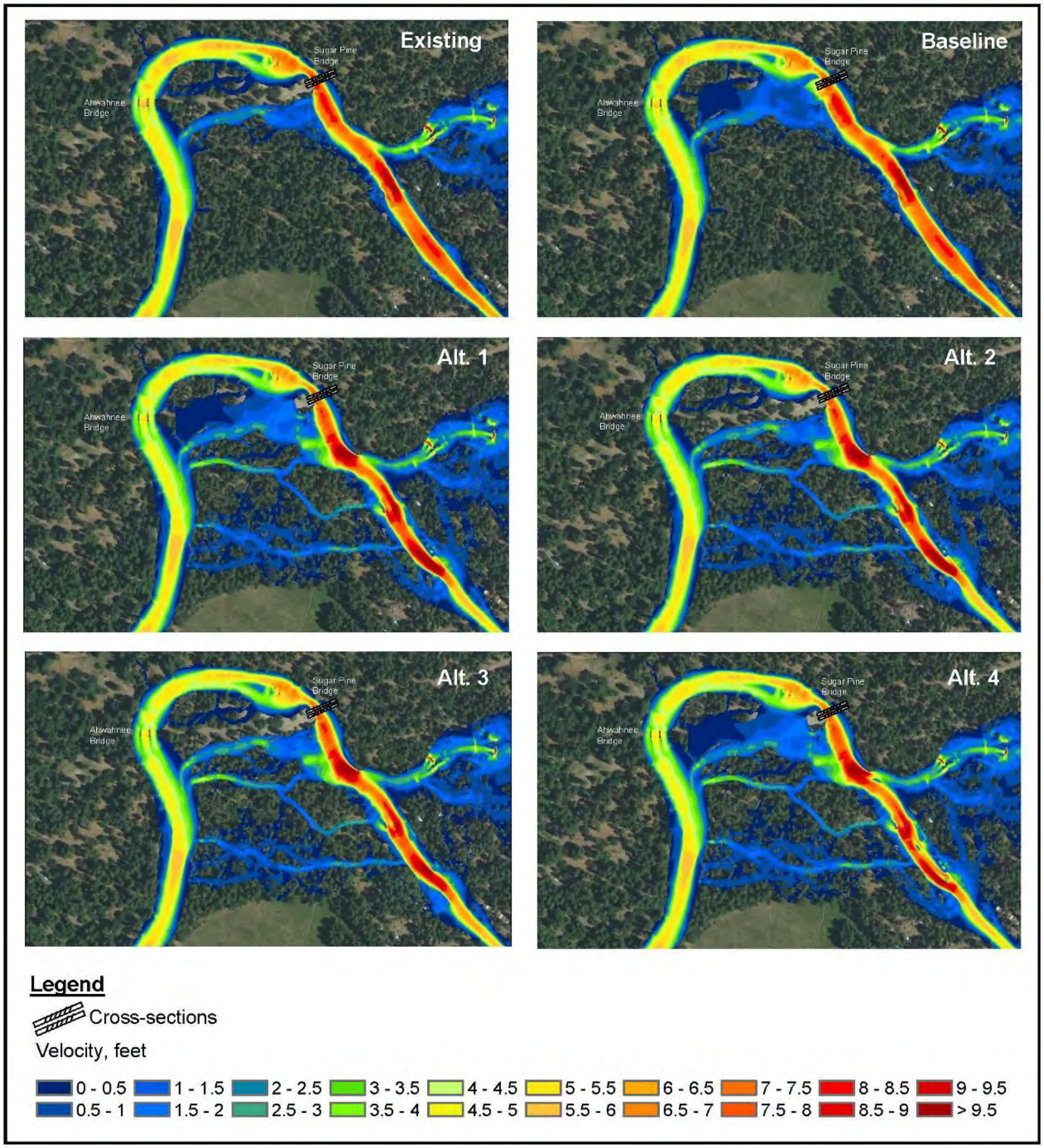


Figure 3-1 Simulated inundation areas and depth-averaged velocities for a 2-year event under the six modeled scenarios. The marked cross-sections (at Sugar Pine Bridge) identify where each alternative's flow velocities were evaluated.

A decrease in the magnitude of the modeled flow through Sugar Pine Bridge corresponds to an increase in flow through the left bank floodplain upstream of Sugar Pine Bridge. Thus, the *least* flow through the cross-section of channel that includes Sugar Pine Bridge represents the greatest restoration benefit with respect to floodplain activation. Table 3-2 shows the results of this analysis. Alternative 4 results in the most substantial benefits, with 15% less flow through Sugar Pine Bridge than under existing conditions, followed fairly closely by the other alternatives. The Baseline scenario offers virtually no benefit by this criterion. An alternative to full berm removal (as in Alternatives 1 and 4), namely the installation of one or more culverts beneath the berm, was evaluated but abandoned as a meaningful alternative, providing no significant area of floodplain activation while only modestly reducing flow through the bridge opening.

Table 3-2 Floodplain activation analysis.

Scenario	2-year flow through bridge opening (cfs)	Difference from existing (cfs)	Percent difference from existing
Existing	3,271	N/A	N/A
Baseline	3,333	62	2%
Alternative 1	2,805	466	14%
Alternative 2	2,917	354	11%
Alternative 3	2,929	342	10%
Alternative 4	2,785	486	15%

The second indicator of success for hydraulic performance is active channel width. In order to evaluate geomorphic and hydraulic performance, the wetted widths of the channel during baseflow conditions, averaged at multiple cross-sections upstream of Sugar Pine Bridge for each scenario, were compared. There is no difference between any of the four alternatives, and all result in a significantly narrower channel then either the existing condition or Baseline scenario as a result of the bank-side log treatments common to all. Although Alternative 3 explores the consequences of leaving those log structures unfilled with sediment (relying instead on natural sedimentation processes), observations of the existing structures previously installed downstream of Ahwahnee Bridge demonstrate that the “active channel” is constrained once the structures are constructed, regardless of whether or not they are also filled with sediment immediately upon construction.

The third indicator of success for hydraulic performance is velocity at Sugar Pine Bridge. Average and maximum velocities were calculated for the 2- and 25-year events for each alternative, both *at* Sugar Pine Bridge (Table 3-3, following the approach of Minear and Wright 2013) and in Reach 6 immediately downstream of Sugar Pine Bridge (Table 3-4, matching where the calibration velocity data were collected). These results are also displayed graphically in Figure 3-2. Overall, Alternative 4 results in the most improvement from existing conditions, although the Baseline scenario is marginally best at reducing average velocities at Sugar Pine Bridge. By every other metric, however, it provides less benefit than one or more (and in several cases, all) alternatives (note that the potential underestimation of flow velocities noted in Section 2.2.4 applies equally to all modeled scenarios and so does not change these comparative findings). Alternatives 1 and 4, differing only in the placement of upstream ELJs, are quite similar in velocity effects at and downstream of the bridge; similarly, the effects of Alternatives 2 and 3 (i.e., filled vs. unfilled riparian log structures) are virtually indistinguishable by this criterion.

Table 3-3 Simulated maximum and average velocities at Sugar Pine Bridge.

Scenario	Maximum velocity (ft/s)	Difference from existing (ft/s)	Change from existing	Average velocity (ft/s)	Difference from existing (ft/s)	Change from existing
2-yr discharge						
Existing	9.4	N/A	N/A	4.9	N/A	N/A
Baseline	8.3	-1.1	-12%	4.1	-0.8	-16%
Alternative 1	8.1	-1.3	-14%	4.3	-0.6	-12%
Alternative 2	8.3	-1.1	-12%	4.5	-0.4	-8%
Alternative 3	8.3	-1.1	-12%	4.5	-0.4	-8%
Alternative 4	8.1	-1.4	-14%	4.2	-0.6	-13%
25-yr discharge						
Existing	10.3	N/A	N/A	5.9	N/A	N/A
Baseline	9.4	-0.9	-9%	3.5	-2.4	-41%
Alternative 1	8.3	-2	-19%	3.8	-2.2	-36%
Alternative 2	9.6	-0.7	-7%	5	-0.9	-15%
Alternative 3	9.6	-0.7	-7%	5	-0.9	-15%
Alternative 4	8.1	-2.3	-22%	3.8	-2.2	-36%

Table 3-4 Simulated maximum and average velocities downstream of Sugar Pine Bridge.

Scenario	Maximum velocity (ft/s)	Difference from existing (ft/s)	Change from existing	Average velocity (ft/s)	Difference from existing (ft/s)	Change from existing
2-yr discharge						
Existing	8.5	N/A	N/A	4.5	N/A	N/A
Baseline	8.4	-0.1	-1%	4.6	0.1	3%
Alternative 1	7.7	-0.9	-10%	3.9	-0.6	-13%
Alternative 2	7.8	-0.7	-8%	4.1	-0.4	-9%
Alternative 3	7.9	-0.7	-8%	4.1	-0.4	-8%
Alternative 4	7.6	-0.9	-10%	3.9	-0.6	-14%
25-yr discharge						
Existing	10.2	N/A	N/A	5.8	N/A	N/A
Baseline	9.5	-0.7	-6%	4.2	-1.6	-27%
Alternative 1	7.5	-2.7	-27%	3	-2.9	-49%
Alternative 2	8.9	-1.3	-13%	4.4	-1.5	-25%
Alternative 3	8.9	-1.3	-13%	4.4	-1.5	-25%
Alternative 4	7.4	-2.8	-28%	3	-2.9	-49%

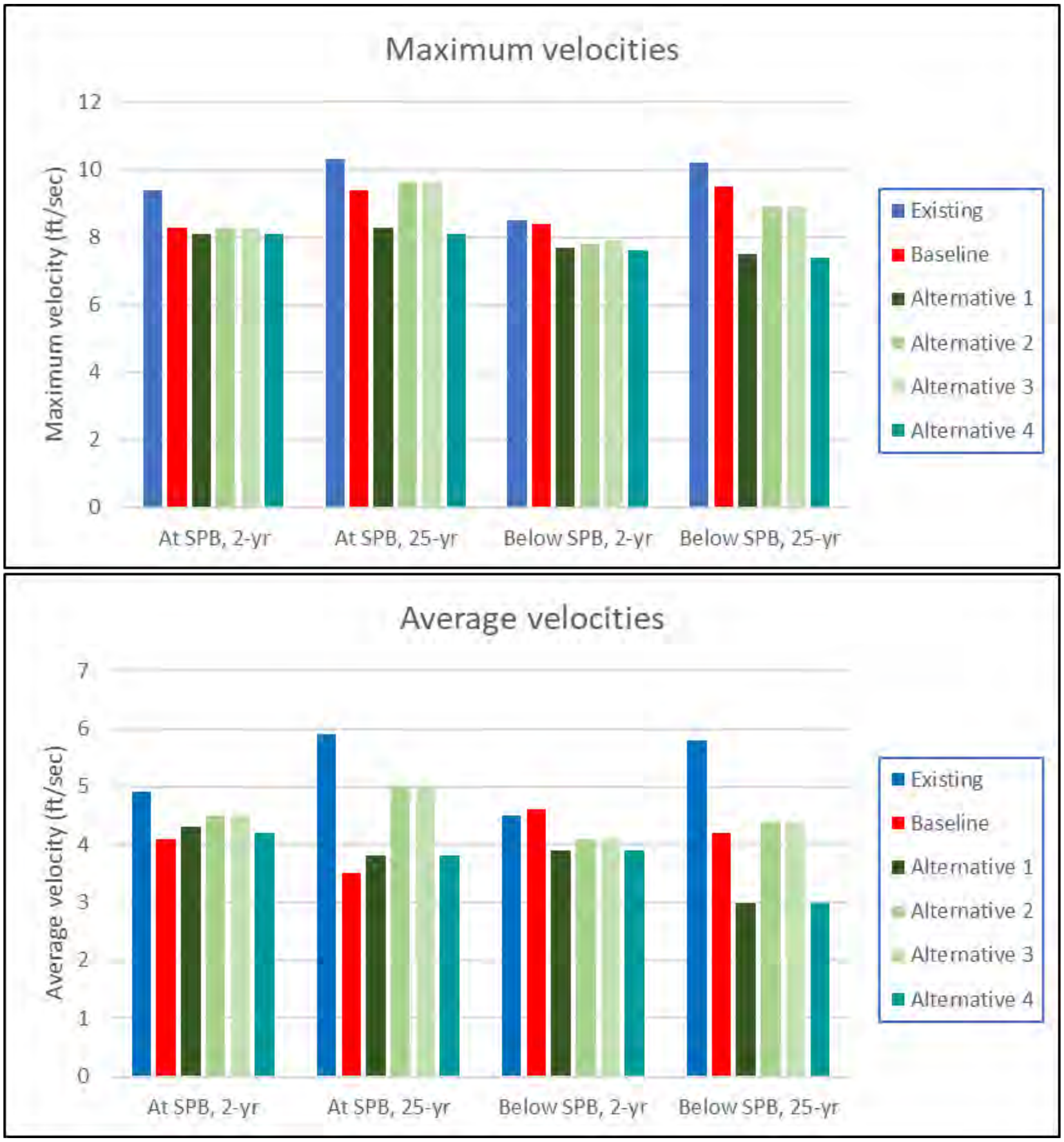
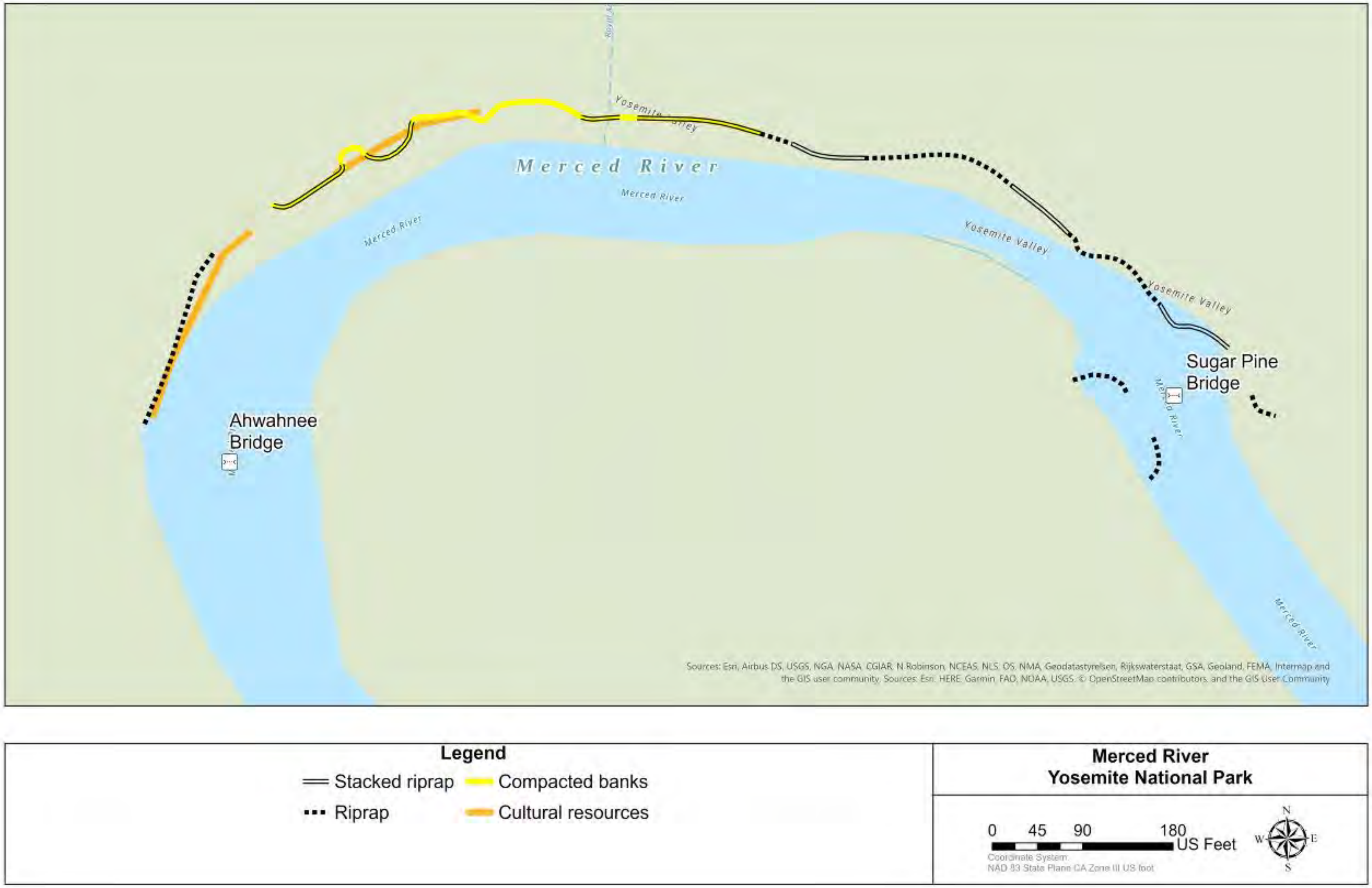


Figure 3-2 Graphs of simulated maximum and average velocities, plotted from the data in Table 3-3 and Table 3-4.

3.1.2 Streambank Conditions

In addition to increases in floodplain activation provided by all of the alternatives over the current condition, direct actions to improve streambank conditions are incorporated into all of the alternatives (except the Baseline scenario, which includes no action except removal of Sugar Pine Bridge). These actions include riprap removal and revegetation. Additional opportunities to reduce the extent of riprap, already accomplished in other locations along the river through multiple projects since 2016, are most prominent in the Project Area along the outside bank of Reach 6, but only in those locations where neither bank stability nor cultural resources are compromised (Figure 3-3).



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community. Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 3-3 **Locations of riprap and areas of cultural resources within Reaches 6 and 7.**

Restoring streambanks and the floodplain to a natural state provide benefits to both geomorphic and ecological processes. Replacing armored banks with less rigid materials, particularly vegetation, allows for a return to more natural rates of channel evolution, including the morphological responses to both large floods and more frequent high-water events as a potential consequence of future climate change. Rebuilding and revegetating trampled banks can create more normative, self-sustaining channel dimensions and patterns of sediment transport and deposition. These indirect results of streambank improvements are commonly difficult to quantify, but achieving these outcomes depend fundamentally on the state of the channel margins. The benefits associated with each of the alternatives are therefore non-quantified, but they are nonetheless substantial and can be compared on the basis of their respective lengths and/or proportions of affected channel margins.

Indicators of success for bank conditions include reductions in the lengths of streambanks with armored banks and/or barren and compacted soils. Presently, bank armoring within Reaches 6 and 7 includes a combination of rounded or angular riprap and stacked riprap along the north streambank (Figure 3-3; note that except for the upstream Sugar Pine Bridge abutments, no riprap is present in Reach 7). The soils along the north streambank are compacted. Table 3-5 shows a comparison of the length of riprap between the existing condition and as anticipated under the Baseline scenario and Alternatives. Under the Baseline scenario, all the riprap is left in place and no planting or soil decompaction would occur, except that the non-stacked riprap at the bridge abutments would be removed and planted. The length of riprap within Reaches 6 and 7 would be reduced by 11 percent compared to the existing condition. Under all Alternatives 1 through 4, rounded or angular riprap would be removed and planting would occur in selected sections along the north streambank. Planting with soil decompaction would also be implemented along selected areas of the north streambank. Under Alternatives 1 through 4 the length of riprapped bank face would be reduced by about 40 percent, and planting with soil decompaction would be implemented along approximately 22 percent of the streambanks with barren and compacted soils, compared to the existing and Baseline scenarios.

Locations where revegetation is recommended are shown on (Figure 3-4). Overall, Alternatives 1-4 will result in greater improvement in streambank conditions compared to the Baseline scenario and the existing condition.

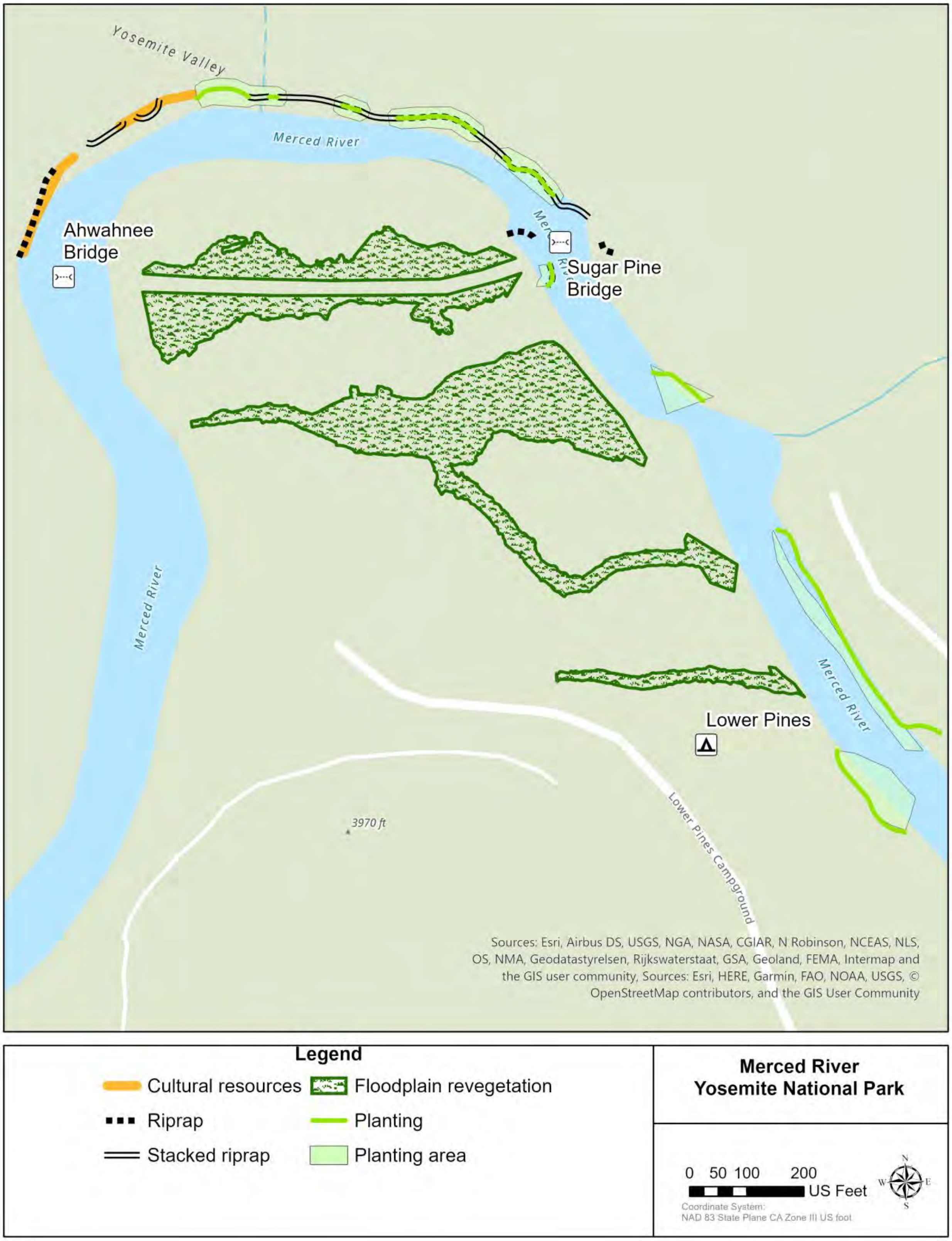
Table 3-5 Bank conditions within Reaches 6 and 7.

Scenario	Length of Armored Bank Face (feet)	Change from Existing	Length of Barren and Compacted Soils (feet)	Change from Existing
Existing	1,191	--	555	--
Baseline	1,060	-11%	Same as Existing	0%
Alternatives 1-4	691	-42%	433	-22%

3.1.3 Vegetation Conditions

The benefits of a restored riparian vegetation community, whether following riprap removal, as part of a structural bank treatment or floodplain reconnection, or as a direct response to barren soil, are difficult to quantify but substantial in nature. These benefits, which ultimately accrue to the riverine processes that support a healthy ecological river, include maintenance of normal rates of stream evolution, riparian succession, sedimentation, habitat maintenance, and biological community interactions (e.g., Fischenich, 2003).

Given the temporary ground disturbance that accompanies project construction, revegetation is a key component of the installation of floodplain-building log structures, the expansion of side channels between Reaches 5 and 7, and selective riprap removal. It is also a stand-alone action in its own right where barren soil is a consequence of excessive human traffic. The recommended areas for revegetation are shown in Figure 3-4. The areas recommended for revegetation are located where engineered design elements may be constructed, riprap may be removed and vegetation is required to maintain stable banks, and/or the ground has been disturbed during construction. Specifically, as part of the floodplain-building log structures, *Salix* sp. (willow) poles or salvaged willow shrubs, and *Carex* (sedge) species



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 3-4 **Recommended areas for revegetation under Alternatives 1 through 4.**

should be planted at the lower elevations between the log structures, transitioning to riparian shrubs and trees, such as willows and *Populus trichocarpa* (black cottonwood) to higher riparian and upland species, such as *Cornus nuttallii* (mountain dogwood), *Acer macrophyllum* (big leaf maple), *Populus tremuloides* (quaking aspen), and *Rhododendron occidentale* (western azalea), with greater height above and distance from the main channel. Figure B.14 in Appendix B shows a detail with planting within the floodplain-building structures. Similarly, in areas where selective riprap would be implemented, wetland species should be planted nearest the channel, transitioning to riparian, and upper riparian-upland species higher on the banks. Sections of the bank where riprap removal may be removed are steep and planting survival may be challenging. In these locations, denser planting and supplemental irrigation may need to be considered. Figure B.9 in Appendix B shows a detail with planting in areas with selective riprap removal. Revegetation within the reactivated floodplain should involve a combination of wetland plantings in low-lying areas near the channels and clumps of willow pole plantings along the banks similar to natural side channels. Native riparian trees, such as black cottonwood, should also be planted on higher surfaces. It is also anticipated that conifer removal or thinning will be needed in the reactivated floodplain—which will provide the opportunity to plant native upland species, such as mountain dogwood, western azalea, and big leaf maple that would add structural and compositional complexity to the floodplain forest. The potential benefits from riparian restoration can be anticipated by the sheer length of riverbank or area of floodplain slated for restoration, which can provide a basis to compare the relative benefits of different alternatives.Table 3-6 compares the lengths and areas that are recommended for revegetation under the existing condition, Baseline scenario, and Alternative 1–4 scenarios. Under the Baseline scenario, the streambanks with non-stacked riprap immediately upstream and downstream of Sugar Pine Bridge would be planted (about 235 feet of bank). Under Alternatives 1-4, planting is recommended along approximately 1,326 feet of streambank with approximately 1.14 acres of revegetated banks. Alternatives 1-4 and the Baseline scenario also include components for re-connecting the floodplain either through floodplain reactivation between Reaches 7 and 5 (Alternatives 1-4) or longitudinal connectivity by removal of the berm between Reaches 7 and 6 (Alternatives 1 and 4 and the Baseline scenario). Restoration of these processes will promote natural riparian recruitment and improve the overall health and functionality of the riparian community.

Under Alternatives 2 and 3, revegetation and natural fluvial geomorphic floodplain processes would be restored to approximately 2.76 acres of floodplain between Reaches 7 and 5, for a total of approximately 3.9 acres of revegetated streambanks and floodplain. Under the Baseline scenario, removal of the berm and the Sugar Pine Bridge would restore approximately 1.57 acres of floodplain, for a total of approximately 1.86 acres of revegetation streambanks and floodplain. Under Alternative 1 and 4, floodplain reactivation and removal of the berm with revegetation will restore fluvial geomorphic processes and connectivity to approximately 4.33 acres of floodplain along Reaches 7, 6, and 5. The greatest improvement in the riparian vegetation conditions would occur under Alternatives 1 and 4 (approximately 5.47 acres in total), with a combination of planting along the streambanks and restoration of lateral and longitudinal floodplain connectivity and associated fluvial geomorphic processes.

Once constructed, a variety of indicators can be applied to evaluate the performance of these actions in comparison to pre-construction conditions or conditions in a reference reach over time, and to confirm that they are yielding tangible improvements over what had previously existed (see Section 4.2.3).

Table 3-6 Proposed revegetation within Reaches 6 and 7.

Scenario	Length of Planted Streambank (feet)	Area of Planted Streambank (acres)	Area of Revegetated Floodplain (acres)
Existing	--	--	--
Baseline	235	0.29	1.57
Alternative 1	1,326	1.14	4.33
Alternative 2	1,326	1.14	2.76
Alternative 3	1,326	1.14	2.76
Alternative 4	1,326	1.14	4.33

3.2 Costs

For comparative purposes we developed concept-level cost estimates for each alternative. Each alternative has two cost components: the construction cost of its specific design elements (Table 3-7), and the non-construction costs associated with site preparation (construction staking, staging and access, dewatering and diversion, or erosion control); mobilization and demobilization; permitting; design; and contingency costs. The total estimated cost of implementing each alternative (Table 3-8) is the sum of the construction costs for each alternative's constituent design elements plus the non-construction costs associated with that alternative (i.e., site preparation, mobilization, etc.).

Construction costs vary widely among the design elements. Overall, the berm removal is estimated to be the most expensive design element ($357,000), followed by the bank lowering and floodplain reactivation element ($213,000). The remaining design elements are estimated to be less than $100,000 each, with the least expensive design element estimated to be the unfilled floodplain-building logs. The estimated construction cost of Sugar Pine Bridge removal ($316,000) is also included in Table 3-7 for comparison.

Implementation costs for Alternatives 1 and 4 are substantially higher than those for Alternatives 2 and 3 because of the construction costs associated with the berm removal design element. Alternatives 2 and 3 are similar in costs, with Alternative 2 being slightly higher because of the additional construction cost associated with filling the floodplain-building logs. Alternative 4 includes the full suite of design elements and so is the most expensive alternative ($1,485,000), followed by Alternative 1 ($1,414,000) and Alternative 2 ($792,000). Alternative 3 is least expensive at $777,000. The estimated implementation cost of the Baseline scenario ($1,274,700) is also included in Table 3-8 for comparison.

Table 3-7 Estimated construction costs for design elements.

Design Element	Letter in Figure 2-7	Construction cost
Sugar Pine Bridge removal	n/a	$ 316,000
Floodplain reactivation	a	$ 213,000
Riprap removal	b	$ 57,000
Berm removal	c	$ 357,000
Flow-deflecting ELJ	d	$ 83,000
Floodplain-building logs – filled	e	$ 43,000
Floodplain-building logs – unfilled	e	$ 34,000
Mid-bar-forming ELJs	f	$ 40,000

Table 3-8 Estimated implementation costs for each alternative.

Alternative	Total cost
Baseline	$ 1,274,700
Alternative 1	$ 1,414,000
Alternative 2	$ 792,000
Alternative 3	$ 777,000
Alternative 4	$ 1,485,000

3.3 Cost-Benefit Analysis

Table 3-9 provides a summary and relative comparison of the restoration benefits and costs of each alternative. All alternatives restore the riparian zone, restore dynamic river processes, and encourage more frequent overbank flooding. Alternative 4 provides the additional benefit of restoring in-channel habitat (because of complexity associated with the mid-bar-forming ELJs). Alternatives 1 and 4 show additional benefits in restoring riparian zone vegetation (because of increase in riparian area associated with the removal of the berm) and redirecting flow (because of the reduction of flows and velocities through Sugar Pine Bridge associated with the removal of the berm [Section 4.2.1]). Alternative 4 also shows additional benefits in increasing in-channel roughness (because of the roughness associated with the mid-bar-forming ELJs).

Alternatives 2 and 3 are the least expensive alternatives, because they do not include removal of the berm between Ahwahnee Bridge and Sugar Pine Bridge.

Restoration benefits and costs for the Baseline scenario have been included in Table 3-9 for comparison.

Table 3-9 Restoration benefits and cost of each alternative.

RESTO-RATION . ACTIONS:	Reveg of the riparian zone	Reveg of banks	Riprap removal	Flow re-direction	ELJ placement in banks	Increase in-channel roughness (narrow over-widened channel)	Floodplain regrading	ELJ placement in channel	Construc-tion costs
Restoration Approach (see Table 1-1):	**1. Restoration of the riparian zone**					**2. Encouragement of more frequent overbank flooding & off-channel flows**		**4. Complex in-channe habitat**	
	3. Restoration of dynamic river and tributary channels								
Baseline	+	+		+			+		--
Alternative 1	++	+	+	++	+	+	+		- -
Alternative 2	+	+	+	+	+	+	+		-
Alternative 3	+	+	+	+	+	+	+		-
Alternative 4	++	+	+	++	+	++	+	+	- -

3.4 Additional Design Considerations

This section summarizes additional design considerations that have not been previously described. Table 3-10 lists the potential risks associated with each design element as well as potential mitigating strategies. For all design elements, there is a risk that the features will not perform as intended or will fail. To mitigate this risk, output from the calibrated hydraulic model should be used to lead and follow design iterations. For example, simulated water-surface elevations for a target flow event should be used to determine swale invert elevations for floodplain reactivation; simulated velocity and shear outputs for a target event should be used to determine the allowable extents of riprap removal to prevent bank erosion; and simulated water-surface elevations and velocities should be used to calculate sliding, rotational, and buoyant forces acting on the ELJs. The design should be attuned to counteract these forces. An inherent risk with ELJ design is dislodgement of individual logs during flooding events. To mitigate this occurrence, a maintenance plan should be developed to facilitate the prompt removal of hazard logs. Large wood is also naturally present in the Merced River and could accumulate, as it has done in the past, on the left bank of the river upstream of Sugar Pine Bridge in the vicinity of the proposed bank lowering area, thereby blocking the proposed swale entrances. Such conditions would not be likely following typical, annual floods; but larger decadal events would have a moderate probability of rearranging large logs, which in turn would have the potential to produce a range of undesired consequences for either recreation or floodplain activation. Long-term, the movement of large woody debris is a natural fluvial process that should require no management intervention, but given the legacy effects of bank armoring and channel incision some actions may be advisable. In any such case, the large wood would need to be repositioned to ensure proper functioning of the swales. Developing a maintenance plan to reposition naturally accumulating large wood in undesirable locations is also recommended, with the expectation that it would require no more frequent action than is currently provided to maintain recreational access and boater safety.

An inherent risk with construction activities involving bank disturbance is erosion. If a large flood event occurs prior to vegetation establishment, bank erosion could occur. To mitigate this risk, temporary erosion control measures, such as an erosion blanket, jute netting, turf reinforcement mat, or sediment logs, should be implemented to stabilize the banks until vegetation becomes established.

Regarding the berm removal design element, culturally sensitive resources may exist in the proposed disturbance area. Currently, identified zones of cultural resources (Figure 3-3) on the right bank of the river in Reach 6 just upstream of Ahwahnee Bridge will require additional archeological study, which may include identifying the extent of the archaeology site, a subsurface survey to identify cultural materials, and development of protection measures. Archeological monitoring during construction may also be required.

Currently, there is a paved pedestrian, bicycle, and emergency vehicle path along the top of the berm connecting Ahwahnee Bridge and Sugar Pine Bridge. If the berm is removed and the paved path is reconstructed, the path will be exposed to instability associated with undermining at the edges of the path and cracking and potential uplift associated with seasonal rise in the water table, swelling soils, and freeze-thaw cycles. At a minimum, the profile and cross-section of the path will need to be designed to shed water; and if the replacement path is paved, it should be designed with underdrains. An alternative flexible surface type (gravel or small cobble) designed to withstand the simulated hydraulic shear forces along the path alignment may be considered to decrease capital and maintenance costs.

We also considered the implications of leaving the floodplain-building logs unfilled. The purpose of the floodplain-building logs is to trap sediment between the logs over time, eventually forming a new channel bank at the river-facing ends of the logs, and to narrow the river. Because of the lack of sediment supply in the system (Section 1.2), this process could take at least several decades to be completed naturally. Leaving the floodplain-building logs unfilled increases the risk of local scour at each log that could potentially undermine the logs and reduce the stability of the logs. Filling the floodplain-building logs would accelerate the bank- and floodplain-building process and would provide an additional matrix for planting between logs, which would increase bank stability in the near term.

Table 3-10 Additional design considerations: risks and mitigations.

Design Element	Site (Figure 2-7)	Design Risk	Mitigation
Bank lowering and floodplain reactivation	a	Swales not activated frequently	Target swale inlet elevations for activation and target swale dimensions to move sediment
		Swales inlets become blocked by large woody debris (LWD)	Include maintenance plan and funding for LWD removal
Riprap removal	b	Bank erosion due to excessive riprap removal	Use simulated velocity and shear output and bank armoring guidelines to determine removal limits; employ factor-of-safety recommended in model velocity validation process
		Planting does not establish prior to erosive flood event	Install temporary erosion control measures
		Culturally sensitive resources potentially affected	May require additional archeological study
Berm removal	c	Culturally sensitive resources potentially affected	May require additional archeological study
		Damage to paved pedestrian and vehicle path from flooding	Consider rerouting or alternative path material; include maintenance plan and funding for re-grading and re-paving
Bank ELJ(s)	d	Structural failure of ELJ due to buoyancy and hydraulic forces; dislodged wood features could block downstream bridge openings	Perform engineering calculations for LWD design and include factor-of-safety
Floodplain-building logs – filled	e	Planting does not establish prior to erosive flood event	Install temporary erosion control measures
		Planting mortality due to water-stress or trampling	Temporary watering after planting and exclusion areas and signage
Floodplain-building logs – unfilled	e	Planting does not establish prior to erosive flood event	Install temporary erosion control measures
		Planting mortality due to water-stress or trampling	Temporary watering after planting and exclusion areas and signage
		May take time to fill due to lack of sediment supply	Fill floodplain-building logs
Mid bar-forming ELJs	f	Structural failure of ELJ due to buoyancy and hydraulic forces; dislodged wood features could block downstream bridge openings	Perform engineering calculations for LWD design and include adequate factor-of-safety

3.5 Summary

To determine the suite of recommended actions within Reaches 6 and 7, a cost-benefit analysis was performed by weighing the restoration benefits and estimated construction costs for each alternative. Additional design considerations, independent of restoration benefits or construction costs were also analyzed.

From a qualitative cost-benefit perspective, the alternatives are well-matched: increasing benefits are associated with monotonically greater costs. This analysis does highlight the greatest trade-off—that of the increased costs and benefits associated with removing most of the berm between Ahwahnee and Sugar Pine Bridges. This cost constitutes nearly half of the total base cost of the most expensive alternative (Alternative 4), whereas its quantifiable benefits with respect to reductions in flows are mainly expressed only during large floods (Figure 3-2), and it carries the likelihood of increased maintenance costs following any floodplain-overtopping discharge. However, it also provides a substantial increase in the area of restored floodplain and removes one of the major impediments to the reestablishment of natural riverine processes along this entire reach of the river.

4 Recommendations

This section described the recommended restoration actions that have the best opportunity to correct the critical impacts in the vicinity of Sugar Pine Bridge and recommendations for monitoring the success of failure of the implemented actions.

4.1 Recommended Actions

After conducting a cost-benefit analysis for the alternatives and considering the risks and mitigations for the design elements that make up the alternatives, we recommend Alternative 4 as our Recommended Action. It includes the following components (letters in parentheses identify locations on Figure 4-1):

a) Floodplain reactivation (in floodplain between Reach 7 and Reach 5), with lower banks at swale entrances (within Reach 7)

b) Selective riprap removal with follow-up revegetation, within Reach 6

c) Berm removal between Ahwahnee Bridge and Sugar Pine Bridge

d) Flow-deflecting ELJ at Tenaya Creek confluence

e) Floodplain-building logs (filled) with planting at specific locations within Reach 7

f) Mid-bar-forming ELJs within Reach 7

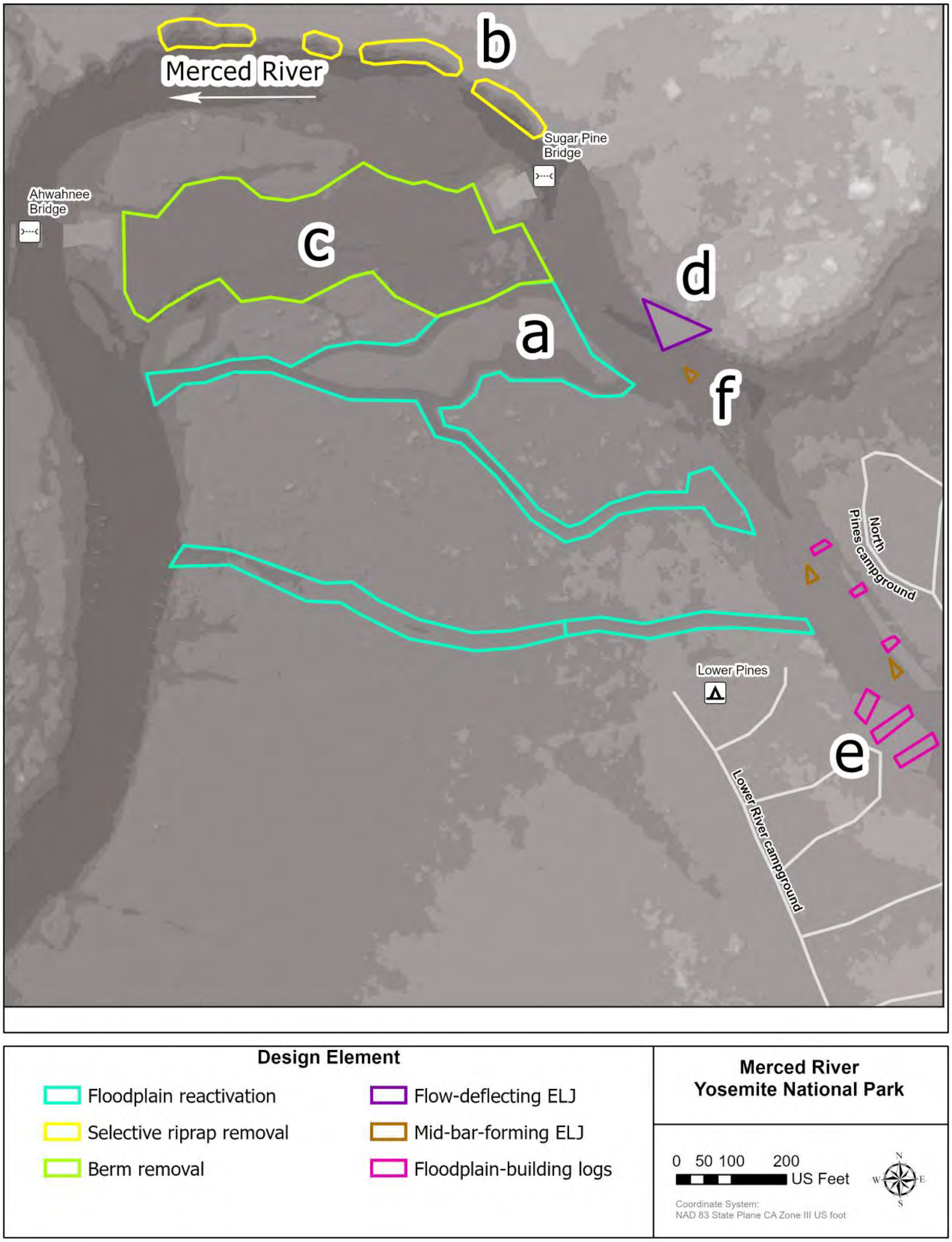


Figure 4-1 **Locations of the components of the Recommended Actions.**

This list of recommendations incorporates the full suite of actions considered. This reflects the demonstrated value of the most intensive actions to mitigate for the hydraulic effects of Sugar Pine Bridge (actions a, c, and d), the additional benefits that accrue from riparian treatments (b and e), and the ancillary benefits of further in-channel work (f) that appear to be well-matched by the modest additional cost.

The four sets of alternatives (Table 3-1) divide naturally into the two that include removal of the berm between Ahwahnee Bridge and Sugar Pine Bridge (Alternatives 1 and 4) and the two that do not (Alternatives 2 and 3). All reduce velocities through Sugar Pine Bridge relative to current conditions (and nearly all, for maximum velocities, relative to the Baseline scenario; Figure 3-2) because of the release of some flows through the floodplain reactivation channels upstream of the bridge. Differences in the performance of the alternatives, however, become particularly distinct during large floods—the removal of the berm provides a large additional area for flows to bypass the opening of Sugar Pine Bridge, reducing velocities at and immediately downstream of the bridge. During a 2-year event the differences between alternatives are not substantial, but even here they are expressed by modeling and would result in a greater area of floodplain inundation (Figure 3-1). Insofar as velocity increases and limited floodplain activation are the primary impacts resulting from the retention of Sugar Pine Bridge, this implementation of a maximum feasible set of measures consistent with bridge retention meets the fundamental goal of the restoration program.

From a hydraulic perspective, Alternatives 1 and 4 are not well discriminated. Average and maximum velocities at and below Sugar Pine Bridge are virtually identical. Similarly, direct benefits to floodplain reactivation or revegetation are essentially identical, and so other criteria are needed to determine whether the additional cost of the mid-channel jam (of Alternative 4) is balanced by the benefit that it provides. What it does address is the extreme degree of in-channel simplification that presently exists between Clarks Bridge and Sugar Pine Bridge (Figure 4-2), a condition that reflects over a century of close human proximity and past management practices, particularly with respect to the removal or repositioning of large logs that have fallen into the river or carried downstream from farther upvalley. Although a single jam (or even multiple jams) cannot fully replace the loss of dynamic geomorphic processes and resulting in-channel diversity that would typify unimpacted mid-elevation forested rivers, even one such structure can reinitiate such processes and provide a basis for evaluating the potential benefits of increasing their numbers over time.

Figure 4-2 View downstream of about 1,000 feet of the homogenous channel of the Merced River along Reach 7, between Clarks Bridge (about 400 feet upstream of the foreground channel) and Sugar Pine Bridge (about 1,900 feet downstream of the camera).

4.2 Recommendations for Monitoring Success or Failure of the Implemented Recommendations

In addition to providing the overall direction for this restoration effort, the MRP (NPS, 2014) called for “A list of measurable attributes that quantify impacts, as well as thresholds (criteria) for those attributes that define mitigation success” (p. 8-215). More broadly based guidance has also been offered by Palmer et al. (2005), with principles for the design, implementation, and monitoring of ecological restoration efforts:

> “We propose five criteria for measuring success, with emphasis on an ecological perspective. First, the design of an ecological river restoration project should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site. Secondly, the river’s ecological condition must be measurably improved. Thirdly, the river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed. Fourthly, during the construction phase, no lasting harm should be inflicted on the ecosystem. Fifthly, both pre- and post-assessment must be completed and data made publicly available…Determining if these five criteria have been met for a particular project requires development of an assessment protocol” (p. 208).

With this overarching framework, the following monitoring activities are recommended (Table 4-1):

Table 4-1 Indicators of performance; criteria for evaluation of success.

Type	Indicator	Evaluation criterion	Location	Duration
Hydraulic performance	Floodplain connection	Increase activation at 2-year flood relative to current or Baseline scenario	Floodplain b/w Reaches 5 and 7	Modeling results, plus 3-5 years data
	Active channel width	Reduce wetted width at baseflow (63 cfs, = median flow for July-Aug-Sept) relative to current conditions	Reach 7	
	Velocity at Sugar Pine Bridge (criterion specified by MRP)	Reduce velocity to match Baseline (i.e., no-bridge) scenario	Sugar Pine Bridge	
Streambank conditions	Length of barren and compacted soils	Reduction in length	Reaches 6 and 7 (primarily right bank)	Post-implementation
	Length of riprap-stabilized bank face	Reduction in length	Reach 6	
Vegetation conditions within riparian corridor	Area of invasive plant species	Reduction in area per field monitoring; comparison to reference reach[1]	Reaches 6 & 7, and floodplain between Reaches 5 & 7	Baseline (prior to construction), initial (3-5 years), long-term (10 years)
	Vertical complexity	Improvement per CRAM attributes (vertical biotic structure and number of plant layers); comparison to reference reach		
	Species richness and percent cover	Improvement in number of co-dominant species per field monitoring and/or improvement in percent cover of native species; comparison to reference reach		
	Native woody riparian regeneration	Improvement in abundance and spatial distribution of native woody riparian regeneration per field monitoring; comparison to reference reach		

[1] The comparisons to a reference reach should be made along the river upstream of Clarks Bridge (see Figure 4-3).

In general, the evaluation criteria are framed in terms of quantitative improvement over existing conditions (in the case of streambank and vegetation indicators) or over predicted conditions in the absence of Sugar Pine Bridge (i.e., the Baseline scenario). In addition, appeal to a reference reach (Figure 4-3) is judged to be a useful basis of comparison for the vegetation indicators, based on that reach’s relatively high geomorphic quality and limited direct human interventions.

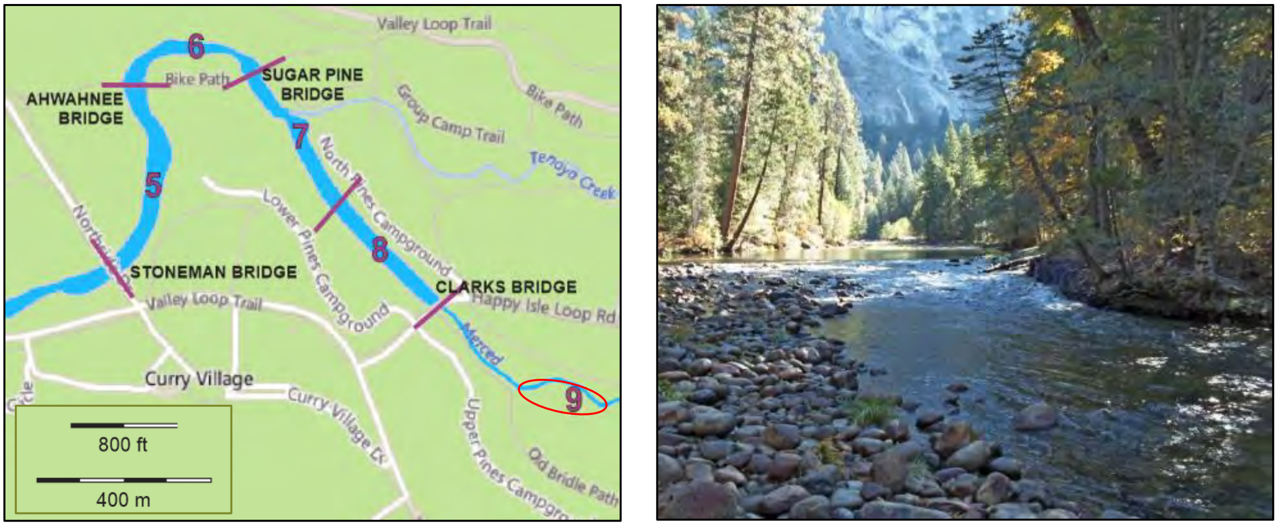


Figure 4-3 Recommended reference reach for evaluating future project performance. Left, red circled area above Clarks Bridge in Reach 9 indicates area; right, view upstream near the lower end of the circled area.

4.2.1 <u>Hydraulic Performance</u>

Three indicators (frequency and extent of floodplain connection during high-flow events, active channel width at baseflow, and flow velocities at Sugar Pine Bridge during high-flow events) have all been predicted by hydraulic modeling (see Section 2.2). The goal for monitoring these indicators, therefore, is to confirm those model predictions and evaluate whether additional measures may be needed to achieve their anticipated outcomes. We recommend a monitoring duration sufficient to experience at least two flows of 2-year recurrence (about 2500 cfs at the Happy Isles Bridge gage; USGS 11264500) or greater, with at least one set of those measurements occurring at or near the time of the 2-year discharge (regardless of the ultimate peak flow). This will likely take a monitoring program of 3 years' (50-50 chance) to 5 years' (~80% chance) duration to meet these objectives.

<u>Floodplain activation</u>: The criterion for success should be a degree of floodplain inundation generally equivalent to that shown in Figure 3-1. More precise quantification could be achieved by comparing the measured discharge at the upstream end of Reach 7 with the discharge flowing through Sugar Pine Bridge (less the flow contribution from Tenaya Creek). However, these measurements may be difficult to accomplish simultaneously, and (for the instream measurements) likely infeasible during flood flows. Alternatively, flow measurements made at Sugar Pine Bridge, Clarks Bridge, and the Tenaya Creek crossing of the trail out of North Pines Campground would provide a reasonable basis for estimating the discharge across the floodplain between Reaches 7 and 5. Model results predict a value of 2,785 cfs under the Recommended Action at the 2-year flow; the actual discharge is expected to lie within 20% of this value, with greater divergences (particularly shortfalls) motivating a review of whether additional actions are needed.

<u>Active channel width</u>: This measurement should be made during summertime low flow at multiple locations in Reach 7 upstream of Sugar Pine Bridge. Results will be meaningful only after all bank treatments have been completed in this reach; results should approximate the expected "natural" conditions for this river, which range between about 100 and 120 feet on the basis of scaled measurements off the 1919 topographic map as reported by Madej et al. (1991, their Figure 17).

<u>Sugar Pine Bridge flow velocities</u>: Measurements should be made at Sugar Pine Bridge during at least two high-flow events as described above for floodplain activation. The validation of the hydraulic model indicated that simulated peak flows could be nearly 2 ft/sec lower than measured, and so the appropriate evaluation criterion is the *measured* pre-project velocity through the bridge, with the expectation that restoration actions upstream under the Recommended Alternative will reduce average velocities by

approximately 13 percent. The measurements made as part of this report (Table 2-3 in Section 2.2.3) provide one such comparison; ideally, at least one pre-implementation measurement during a high-flow event will be added as a basis for future post-project comparison. A reduction of the maximum velocity of at least 12 percent at the bridge and 6 percent downstream of the bridge during the 2-year AEP should be considered a successful outcome, as these are the simulated velocity reductions for the Baseline (Sugar Pine Bridge and berm removal) condition (Table 3-3 and Table 3-4).

4.2.2 Streambank Conditions

Two indicators of success (length of streambanks with riprap and length of streambanks with barren and compacted soils) should be monitored to document a successful outcome.

Length of streambank with riprap: One of the objectives of this restoration project is to reduce the extent of riprap within the restoration reach. Depending on the alternative selected, stability modeling results, and implementation, the amount of riprap removal will vary. A reduction in the length of riprap within the reach of at least 40 percent compared to the existing condition should be considered a successful outcome. This indicator is based on the approximate length of riprap to be removed under the Alternatives compared to existing conditions (Table 3-5).

Length of barren and compacted soils: This involves mapping the location and extent of barren and compacted soils within the restoration reach. We recommend baseline mapping the summer of the fall construction to document the conditions immediately before the construction is implemented, an initial monitoring 3-5 years after construction, and a total monitoring duration (at least 10 years) during which several high flows of sufficient magnitude to scour banks and inundate the floodplain have occurred. Results will be most meaningful after all bank treatments have been completed in the restoration reach. However, if treatment elements are implemented in a phased approach, it is recommended that the monitoring is initiated immediately following the first phase. A reduction in the length of barren and compacted soils within the reach of at least 25 percent compared to the existing condition should be considered a successful outcome. This indicator is based on the approximate length of banks mapped as barren/compacted (Booth et al. 2019) along which revegetation is recommended. This indicator could be modified if pre-construction baseline surveys indicate that bank conditions have changed.

4.2.3 Vegetation Conditions

Four attributes of the adjacent riparian corridor have been identified to evaluate success of the performance of the restoration: improvement in vertical complexity, native species richness and percent cover, and regeneration of native woody riparian species; and reduction in the area of invasive plant species. The goal of the monitoring is to assess improvements in key vegetation attributes of the riparian corridor that indicate a healthy and functioning riparian community with diverse community composition, native woody riparian regeneration, and vertical structural complexity.

The approach for monitoring riparian condition over time is to build upon and expand ongoing monitoring efforts by the NPS (NPS 2014, 2018) that use the California Rapid Assessment Method (CRAM) (CWMW, 2013a). The intent is to use data already being collected in assessment areas for the ongoing CRAM surveys, with specific refinements for the purposes of monitoring the success of this restoration effort that are outlined below:

- Establish additional assessment areas to continuously survey both streambanks within the entire restoration reach.
- Document and map all invasive plant species identified within each assessment area, regardless of total cover within a plant layer within an assessment area.
- Document all plant species identified within each assessment area, regardless of total cover within a plant layer within the assessment area.
- Collect additional data on native woody riparian regeneration within each assessment area.

We recommend an initial vegetation monitoring (baseline) the summer of the planned fall construction, an initial monitoring 3-5 years after construction, and a total monitoring duration (of at least 10 years) during which several high flows of sufficient magnitude have occurred to laterally and longitudinally reconnect the floodplain between Reaches 5, 6, and 7 and to inundate the floodplain-building treatments. Flows of this magnitude would be expected to rejuvenate natural riparian recruitment processes along the banks and floodplain within the restored reaches.

The field survey methods and analyses for comparison over time and to the reference reach for the four attributes are described below.

Area of invasive plant species: Document and map all invasive plant species identified within each assessment area. Data for each invasive plant population documented should include: species, location, area (SF), and level of infestation (categorized as LOW [<5 percent cover], MOD [6–25 percent cover], and HIGH [>25 percent cover]). The number of invasive plant species and area of invasive plants by level of infestation can be compared within the restoration reach, over time, and to the reference reach.

Vertical biotic structural complexity of and number of plant layers in the riparian corridor: Vertical biotic structure monitoring is a CRAM attribute that assesses “the degree of overlap among plant layers” (CWMW, 2013b). Collect data on the vertical biotic structure and the number of plant layers consistent with the methods defined in the California Rapid Assessment Method for Wetlands: Riverine Wetland Field Book (CWMW, 2013b), or more recent version. For these attributes, only layers with at least 5 percent cover within the assessment area that is suitable for that layer are to be counted. The CRAM ratings (A, B, C, or D) can be compared over time and to the reference reach.

Native species richness and percent cover: Tally all plant species that are encountered within each assessment area. Estimate percent cover of all species. Species richness (number of species per area), the number of co-dominant species (species with greater than 10 percent cover within an assessment area), and percent cover by species can be compared within the restoration reach, over time, and to the reference reach.

Native woody riparian regeneration[1]: Estimate the area (polygon) of each regenerating native woody riparian species within each assessment area. For each polygon, estimate the percent cover by size classes of willows (*Salix* spp.), alders (*Alnus* spp.), and cottonwood (*Populus* spp.). For shrubs, regeneration size classes are: (1) sprout/seedling: 1 stem; (2) young: 2 to 10 stems; (3) > 10 stems (mature). For trees, the regeneration size classes are: (1) seedling: stem < 4.5 feet tall; < 1-inch diameter at breast height (dbh); (2) young: stem ≥ 4.5 feet tall; 1 to 5 inch dbh; and (3) mature: ≥ 5 inch dbh (Winward 2000; Burton et al. 2008). Within each area in which recruitment is documented, collect information on the physical characteristics of the area, including: substrate, physiographical setting, and distance from and elevation above the base flow channel. By species, the presence of regeneration, number of age classes present, and number and size of polygons with recent regeneration can be related to the physical characteristics and compared within the restoration reach, over time, and to the reference reach.

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[1] This metric uses a modified approach from Winward (2000) and Burton et al. (2008).

5 Conclusions

In order to accelerate the natural process of restoration Reaches 6 and 7 of the Merced River, a list of restoration actions was developed to (1) restore of the riparian zone; (2) encourage more frequent overbank flooding and off-channel flows; (3) restore the dynamic river and tributary channels and (4) create more complex in-channel habitat. These restoration actions consist of:

- Revegetation of riparian zone
- Revegetation of banks
- Riprap removal
- Flow redirection
- Increasing in-channel roughness/narrowing widened channel reaches
- Floodplain regrading
- ELJ placement in banks

The actions were evaluated for their ability to achieve several restoration objectives. Hydraulic model outputs provided a quantitative evaluation of the achievement of restoration objectives relating to the design elements' effects on hydraulic and geomorphic conditions. The assessment of indicators of performance provided a qualitative evaluation the achievement of restoration objectives relating to the design elements' effects on streambank and vegetation conditions.

From this analysis, four alternatives were developed consisting of different combinations of the above-bulleted restoration actions, which provide different levels of restoration benefits. After performing a cost-benefit analysis and considering the risks and mitigations for the design elements, we have selected Alternative 4 as our Recommended Action. We recommend this project for design and construction because it achieves all of the restoration objectives and provides additional restoration benefits beyond those of the other alternatives. The Recommended Action includes the following design elements:

- Remove and regrade the berm between Ahwahnee Bridge and Sugar Pine Bridge.
- Reactivate historic swale connections (in floodplain between Reach 7 and Reach 5), with lower banks at swale entrances (within Reach 7).
- Selectively remove riprap, with follow-up revegetation, within Reach 6.
- Install ELJ at Tenaya Creek confluence.
- Install filled floodplain-building log treatments with planting at specific locations within Reach 7.
- Install three mid bar-forming ELJs within Reach 7.

A suite of monitoring activities that span a range of moderate-to-large floods are outlined that should provide sufficient information over a 5- to 10-year period following the implementation of restoration activities to evaluate the success of these mitigation measures. This monitoring program is "…designed to evaluate the efficacy, durability, and long-term costs of mitigation management" (MRP, p. 8-215), and it should provide the basis to evaluate the long-term effects of a mitigated Sugar Pine Bridge on the biological and hydrological Outstandingly Remarkable Values (ESA 2012) of the Merced River through Yosemite Valley.

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6 References

Booth, D.B., Ross-Smith, K., Larsen, E., Mahacek, V., Haddon, E., Dunne, T. 2019. Restoration of the Merced River through Yosemite Valley, Yosemite National Park. Internal report to Yosemite National Park, June 2019, 52 pp.

Burton, T.A., S.J. Smith and E.R. Cowley. 2008. Monitoring Stream Channels and Riparian Vegetation – Multiple Indicators. Version 5.0, April 2008. Interagency Technical Bulletin. BLM/ID/GI-08/001+1150.

California Wetlands Monitoring Workgroup. 2013a. California Rapid Assessment Method (CRAM) for Wetlands and Riparian Areas: User's Manual, Version 6.1. April 2013. Available at: http://www.cramwetlands.org/documents#field+books+and+sops.

California Wetlands Monitoring Workgroup. 2013b. California Rapid Assessment Method for Wetlands: Riverine Wetland Field Book, Version 6.1. January 2013. Available at: http://www.cramwetlands.org/documents#field+books+and+sops.

ESA, Inc. 2012. Merced Wild and Scenic River Values, Final Baseline Conditions Report. Prepared by ESA for the National Park Service, Yosemite National Park, September 2012, 155 pp.

Fischenich, J.C. 2003. Effects of riprap on riverine and riparian ecosystems. ERDC/EL TR-03-4, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 53 pp.

_________ 2001. Stability Thresholds for Stream Restoration Materials.

Google Earth Pro 7.3.2.577. 2020. Yosemite National Park 37°44'40.28"N 119°34'16.72"W.

Minear, J. Toby, and Wright, Scott A. 2013. *Hydraulic and Geomorphic Assessment of the Merced River and Historic* Bridges *in Eastern Yosemite Valley, Yosemite National Park, California*. U.S. Department of the Interior, U.S. Geological Survey, Sacramento, California, Open-File Report 2013-1016, 74 pp.

NCALM. Yosemite National Park LiDAR Mapping Project Report. Feb 1, 2011.

National Park Service (NPS). 2014. Merced Wild and Scenic River Final Comprehensive Management Plan and Environmental Impacts Statement. Yosemite National Park. February 2014.

National Park Service, 2014. Indicator 2 – Status of Riparian Habitat for ORV 2, Merced Wild and Scenic River: Final Comprehensive Management Plan and Environmental Impact Statement. February 2014, pp. 5-43 to 5-46.

National Park Service, 2018. Indicator 2 – Status of Riparian Habitat for ORV 2, Merced Wild and Scenic River: Final Comprehensive Management Plan and Environmental Impact Statement.

Palmer, M.A., Bernhardt, E.S., Allan, J.D., Lake, P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C.N., Follstad Shah, J., Galat, D.L., Loss, S.G., Goodwin, P., Hart, D.D., Hassett, B., Jenkinson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Sudduth, E. 2005. Standards for ecologically successful river restoration. Journal of Applied Ecology, 42 (2), pp. 208-217.

USGS. 1982. Guidelines for Determining Flood Flow Frequency.

Winward, A.H. 2000. Monitoring the Vegetation Resources in Riparian Areas. General Technical Report RMRS-GTR-46. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Merced River Restoration Project - Phase 3

A

Calibration and Validation Data and Model Results

APPENDIX A Calibration and Validation Data and Model Results

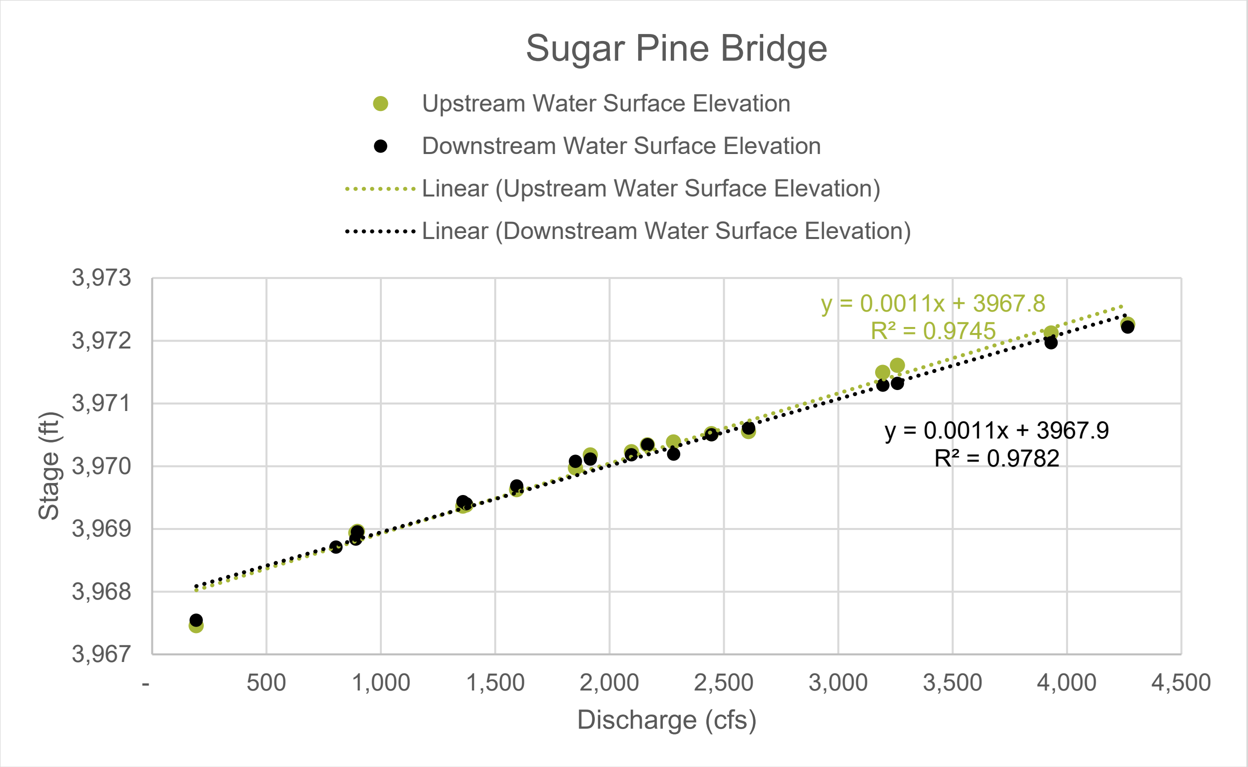


Figure A.1 Stage-discharge equation for Sugar Pine Bridge.

Table A.1 Simulated vs calculated water surface elevations at Sugar Pine Bridge.

Simulated Flow through Bridge (cfs)	Simulated Upstream Water Surface Elevation (ft)	Simulated Downstream Water Surface Elevation (ft)	Calculated Upstream Water Surface Elevation (ft)	Calculated Downstream Water Surface Elevation (ft)	Difference in Upstream Water Surface Elevations (ft)	Difference in Downstream Water Surface Elevations (ft)
191	3,967.46	3,967.46	3,968.01	3,968.11	-0.55	-0.65
461	3,968.23	3,968.21	3,968.31	3,968.41	-0.08	-0.20
527	3,968.38	3,968.36	3,968.38	3,968.48	0.00	-0.12
1,284	3,969.47	3,969.41	3,969.21	3,969.31	0.26	0.10
1,377	3,969.58	3,969.52	3,969.31	3,969.41	0.27	0.11
2,737	3,970.87	3,970.77	3,970.81	3,970.91	0.06	-0.14
2,895	3,971.10	3,971.00	3,970.98	3,971.08	0.12	-0.08
3,622	3,971.89	3,971.75	3,971.78	3,971.88	0.11	-0.13
3,677	3,972.02	3,971.89	3,971.84	3,971.94	0.18	-0.05

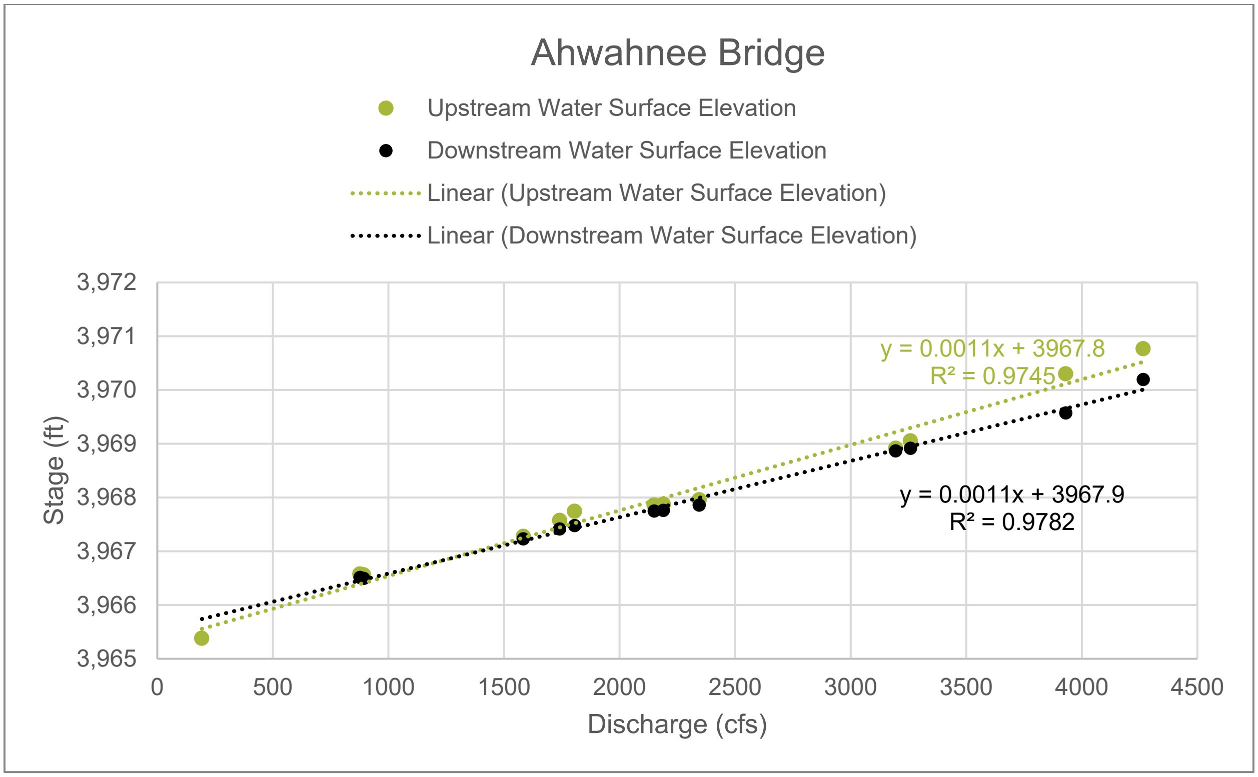


Figure A.2 Stage-discharge equation for Ahwahnee Bridge.

Table A.2 Simulated vs calculated water surface elevations at Ahwahnee Bridge.

Simulated Flow through Bridge (cfs)	Simulated Upstream Water Surface Elevation (ft)	Simulated Downstream Water Surface Elevation (ft)	Calculated Upstream Water Surface Elevation (ft)	Calculated Downstream Water Surface Elevation (ft)	Difference in Upstream Water Surface Elevations (ft)	Difference in Downstream Water Surface Elevations (ft)
191	3,965.05	3,964.95	3,965.53	3,965.69	-0.48	-0.74
461	3,965.71	3,965.57	3,965.85	3,965.96	-0.14	-0.39
527	3,965.91	3,965.77	3,965.93	3,966.03	-0.02	-0.26
1,284	3,967.03	3,968.80	3,966.84	3,966.78	0.19	2.02
1,377	3,967.31	3,967.07	3,966.95	3,966.88	0.36	0.19
2,737	3,968.98	3,968.66	3,968.58	3,968.24	0.40	0.42
2,895	3,969.40	3,969.09	3,968.77	3,968.40	0.63	0.69
3,622	3,970.22	3,969.89	3,969.65	3,969.12	0.57	0.77
3,677	3,970.42	3,970.09	3,969.71	3,969.18	0.71	0.91

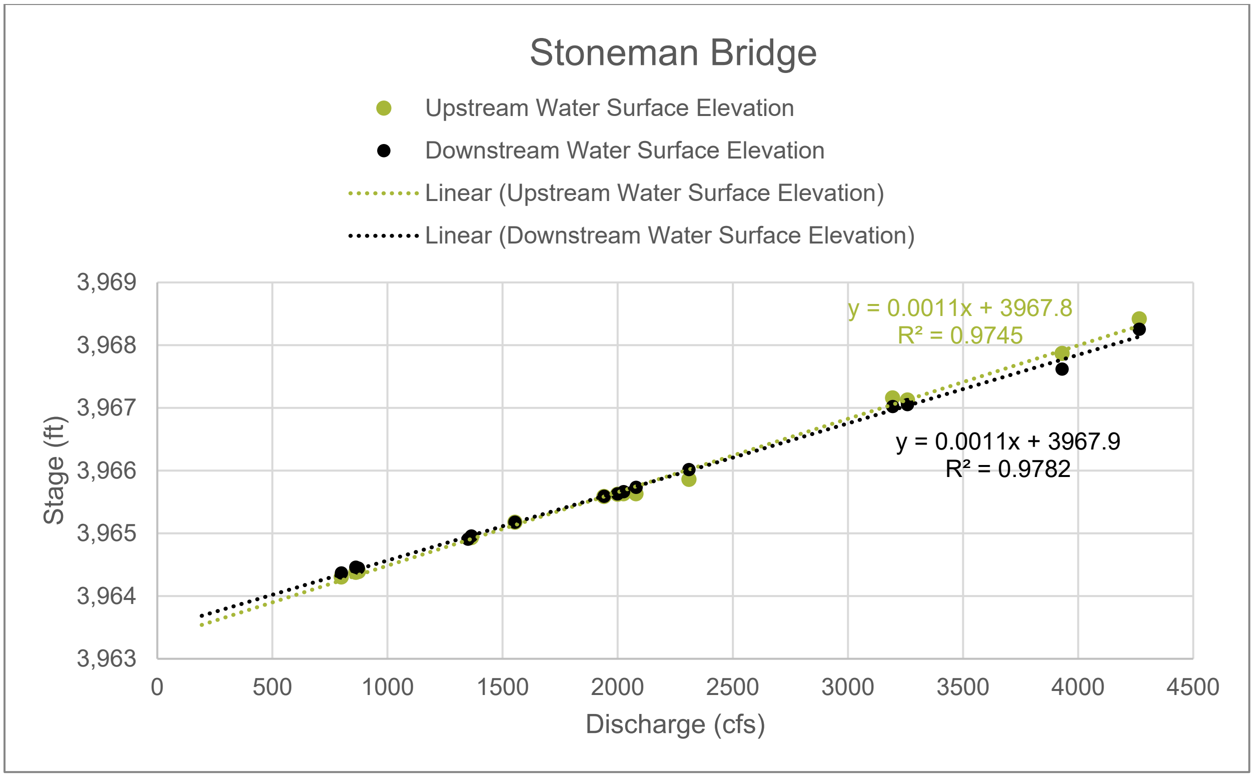


Figure A.3 Stage-discharge equation for Stoneman Bridge.

Table A.3 Simulated vs calculated water surface elevations at Stoneman Bridge.

Simulated Flow through Bridge (cfs)	Simulated Upstream Water Surface Elevation (ft)	Simulated Downstream Water Surface Elevation (ft)	Calculated Upstream Water Surface Elevation (ft)	Calculated Downstream Water Surface Elevation (ft)	Difference in Upstream Water Surface Elevations (ft)	Difference in Downstream Water Surface Elevations (ft)
191	3,964.07	3,964.06	3,963.53	3,963.71	0.54	0.35
461	3,964.52	3,964.52	3,963.85	3,964.01	0.67	0.51
527	3,964.77	3,964.76	3,963.93	3,964.08	0.84	0.68
1,284	3,965.67	3,965.61	3,964.84	3,964.91	0.83	0.70
1,377	3,965.99	3,965.91	3,964.95	3,965.01	1.04	0.90
2,737	3,967.31	3,967.11	3,966.58	3,966.51	0.73	0.60
2,895	3,967.70	3,967.44	3,966.77	3,966.68	0.93	0.76
3,622	3,968.33	3,967.94	3,967.65	3,967.48	0.68	0.46
3,677	3,968.50	3,968.07	3,967.71	3,967.54	0.79	0.53

Table A.4 Surveyed and simulated water surface elevations for 137 cfs flow event[1].

Location	Survey Point Name	Surveyed Water Surface Elevation (ft)	Simulated Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
Upstream of Ahwahnee Bridge	XSa12	3,965.15	3,965.14	-0.01
Upstream of Ahwahnee Bridge	XSa5	3,965.35	3,965.16	-0.19
Ahwahnee Bridge at Upstream End	ABUS16	3,965.85	3,965.00	-0.85
Ahwahnee Bridge at Downstream End	ABUS2	3,965.14	3,965.00	-0.14
Ahwahnee Bridge at Upstream End	ABDS1	3,965.46	3,964.99	-0.47
	SBUS32	3,963.72	3,964.10	0.38
	SBDS2	3,963.46	3,964.08	0.62

1. Measured flow on October 26, 2016 at Happy Isles gage (USGS Gage No. 11264500)

Table A.5 Surveyed and simulated water surface elevations for 350 cfs flow event[1].

Location	Survey Point Name	Surveyed Water Surface Elevation (ft)	Simulated Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
Downstream of Ahwahnee Bridge	Sch50	3,964.97	3,965.40	0
	Sch48	3,965.17	3,965.21	0.04
	Sch25	3,964.41	3,965.21	0.08
	Sch24	3,965.03	3,965.21	0.18
	Sch21	3,965.05	3,965.13	0.43
	Sch20	3,965.12	3,965.12	0.61
	RLPrj67	3,964.29	3,964.90	0.61
	RLPrj68	3,964.30	3,964.91	0.73
	RLPrj69	3,964.15	3,964.90	0.75
	RLPrj70	3,964.16	3,964.89	0.8
	RLPrj71	3,964.08	3,964.89	0.81

1. Measured flow on November 2, 2016 at Happy Isles gage (USGS Gage No. 11264500)

Table A.6 Surveyed and simulated water surface elevations for 1,070 cfs flow event[1].

Location	Survey Point Name	Surveyed Water Surface Elevation (ft)	Simulated Water Surface Elevation (ft)	Difference in Water Surface Elevation (ft)
Upstream of Stoneman Bridge	EOW1	3,965.41	3,966.27	0.86
	EOW2	3,965.47	3,966.23	0.76
	EOW3	3,965.32	3,966.21	0.89
	EOW4	3,965.26	3,966.18	0.92
	EOW5	3,965.32	3,966.18	0.86
	EOW6	3,965.45	3,966.18	0.73
	EOW7	3,965.28	3,966.07	0.79
	EOW8	3,965.24	3,966.07	0.83
	EOW17	3,965.31	3,966.07	0.76
	EOW10	3,965.30	3,966.04	0.74
	EOW11	3,965.21	3,966.04	0.83
	EOW12	3,965.23	3,966.04	0.81
	EOW13	3,965.13	3,966.04	0.91
	EOW14	3,965.12	3,966.01	0.89
	EOW15	3,965.16	3,966.01	0.85
	EOW16	3,964.99	3,966.01	1.02

1. Measured flow on October 31, 2016 at Happy Isles gage (USGS Gage No. 11264500)

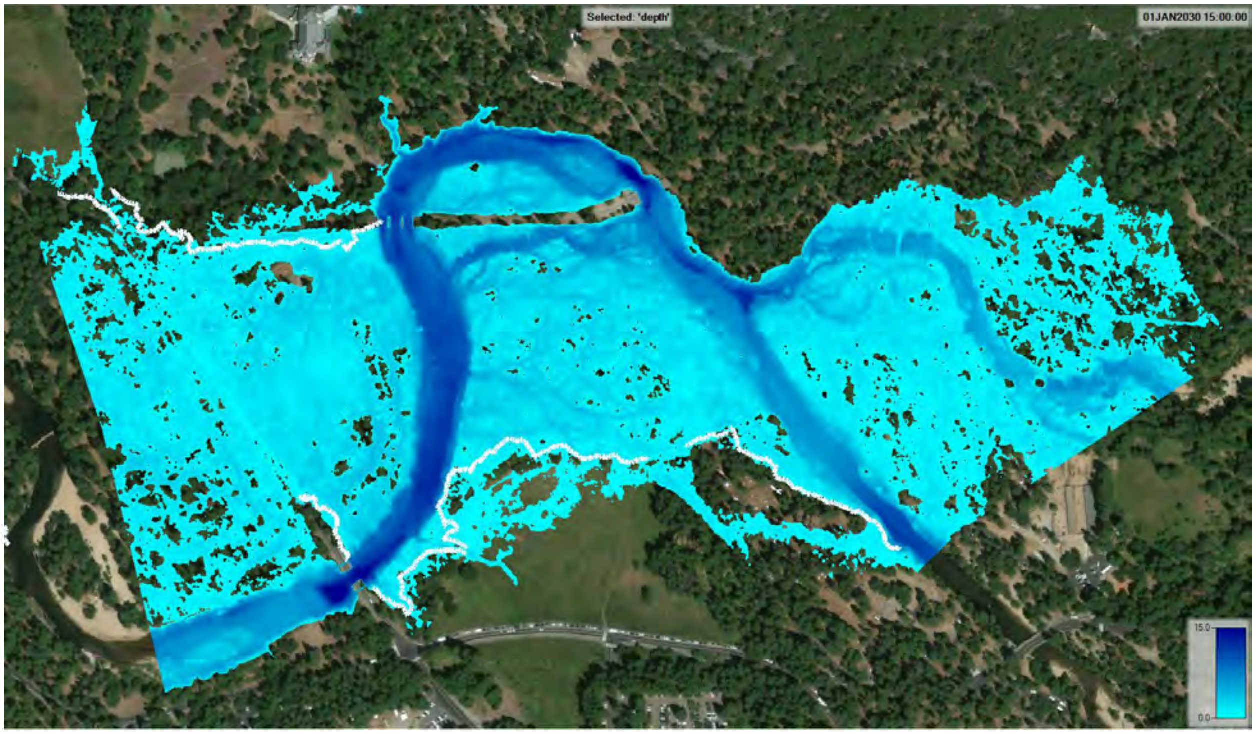


Figure A.4 **Surveyed high-water-mark (white polyline) event and simulated inundation extents (colored shading) for April 2018 calibration event.**

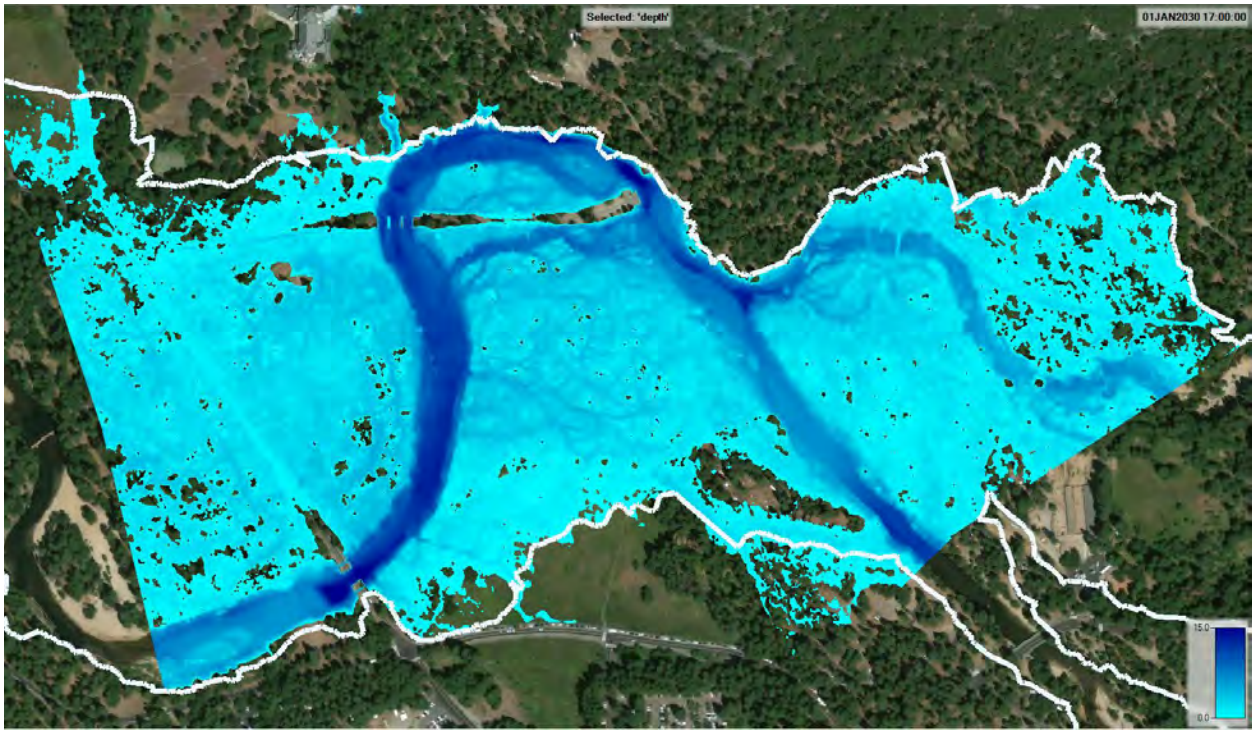


Figure A.5 **Surveyed high-water-mark (white polyline) event and simulated inundation extents (colored shading) for January 1997 calibration event.**

Table A.7 Measured flow and velocity data for selected flow range at cross-section upstream of Sugar Pine Bridge.

Date	Measured Flow (cfs)	Measured Velocity	
		Average (ft/s)	Maximum (ft/s)
20170525	3,783	7.1	11.0
	3,566	6.4	8.9
	4,134	7.3	10.2
	3,630	6.2	9.1
	3,827	6.9	10.5
	2,960	6.2	9.7
	3,606	8.1	10.9
	4,380	5.8	8.3
	3,643	8.0	10.9
	3,539	5.9	8.4

Notes:

In the photo above, the “line” is the orange line nearly parallel to the bridge, and the “tether” (not shown) is the orange line extending perpendicularly from the “line.” At this cross-section, the right bank line distance upstream of the bridge was 18 feet and left bank line distance upstream of the bridge was 21.2 feet. The tether length was 1 foot.

Figure A.6 Cross-Section location (orange line) upstream of Sugar Pine Bridge where velocity measurements were collected.

Table A.8 Measured flow and velocity data for selected flow range downstream of Sugar Pine Bridge.

Date	Measured Flow (cfs)	Measured Velocity		Measured Velocity (Right Side of Transect)	
		Average (ft/s)	Maximum (ft/s)	Average (ft/s)	Maximum (ft/s)
20170510	3,899	7.2	10.7	5.1	6.6
20170510	3,424	7.1	10.4	4.9	6.8
20170510	3,352	7.2	10.4	5.0	6.6
20170510	3,938	7.2	10.2	5.0	6.4
20170525	4,505	6.5	11.3	4.7	7.0

Notes:

In the photo above, the “line” is the orange line nearly parallel to the bridge, and the “tether” is the orange line extending perpendicularly from the “line.” At this cross-section, the right bank line distance downstream of the bridge was 2.5 feet and left bank line distance downstream of the bridge was 2 feet. On 5/10/17, Tether length was 13.6 feet. Measurements ended 3.5 feet from the left edge of water and 12 feet from the right edge of water. On 5/25/17, The tether length was 13.4 feet.

Figure A.7 Cross-Section location downstream of Sugar Pine Bridge where velocity measurements were collected.

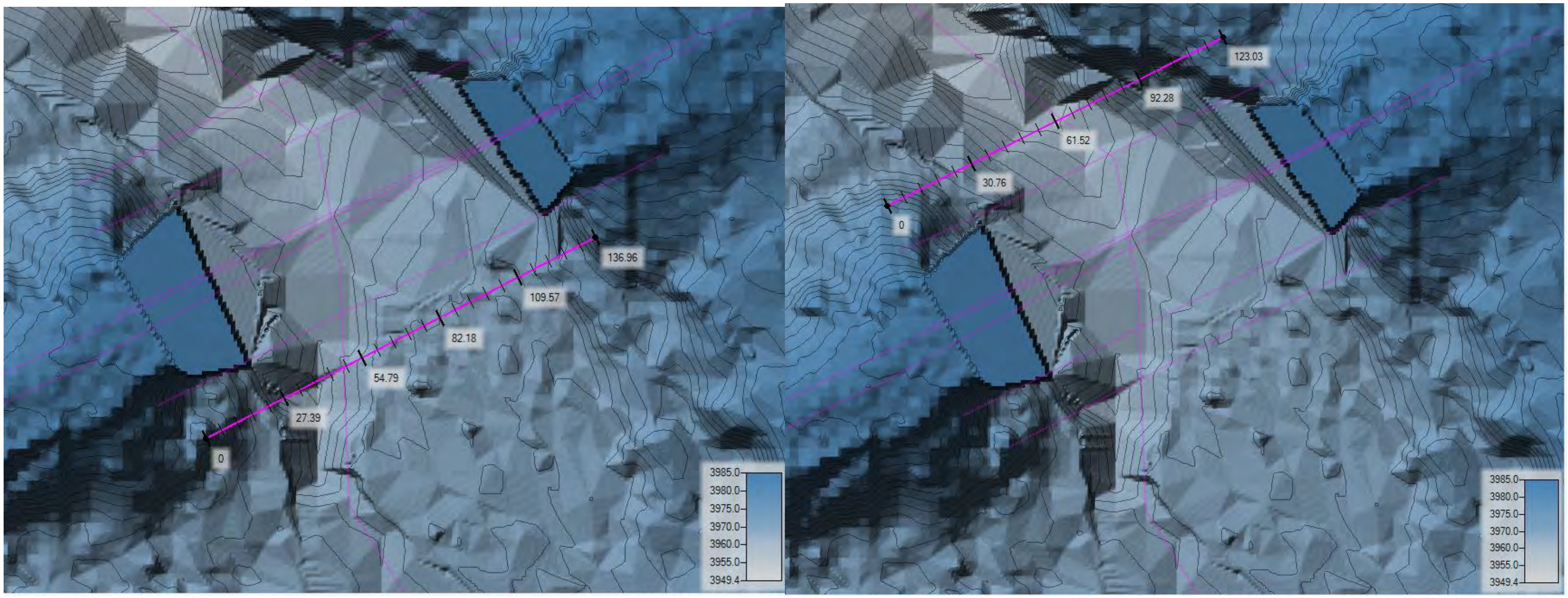
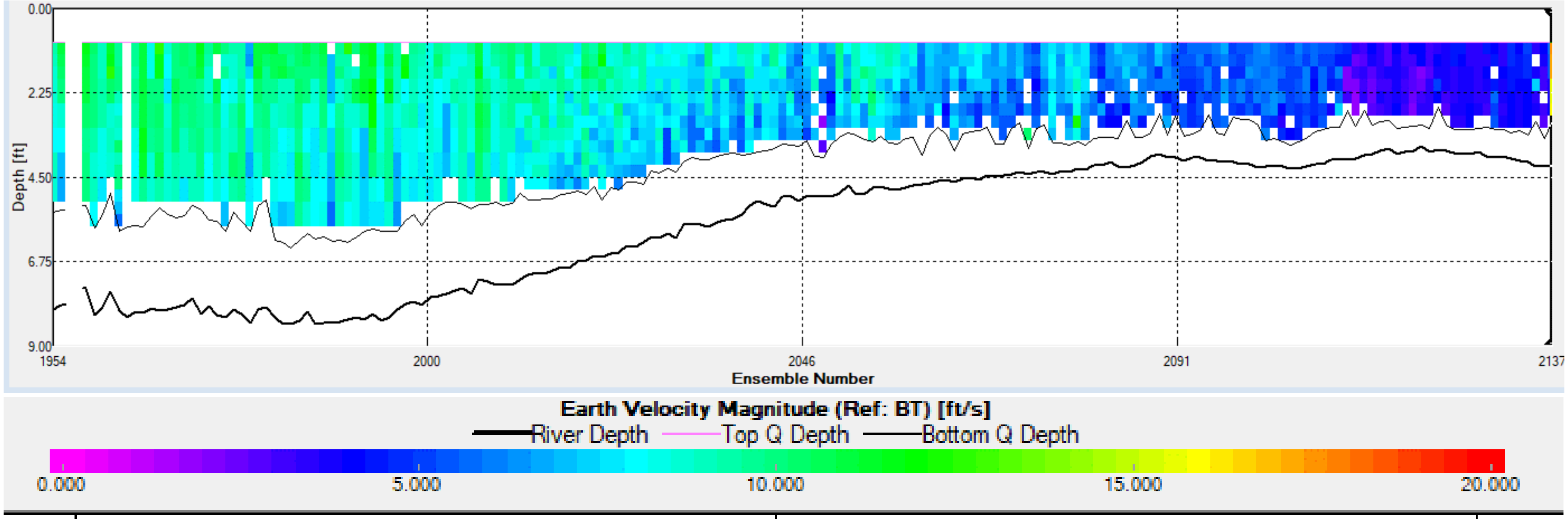
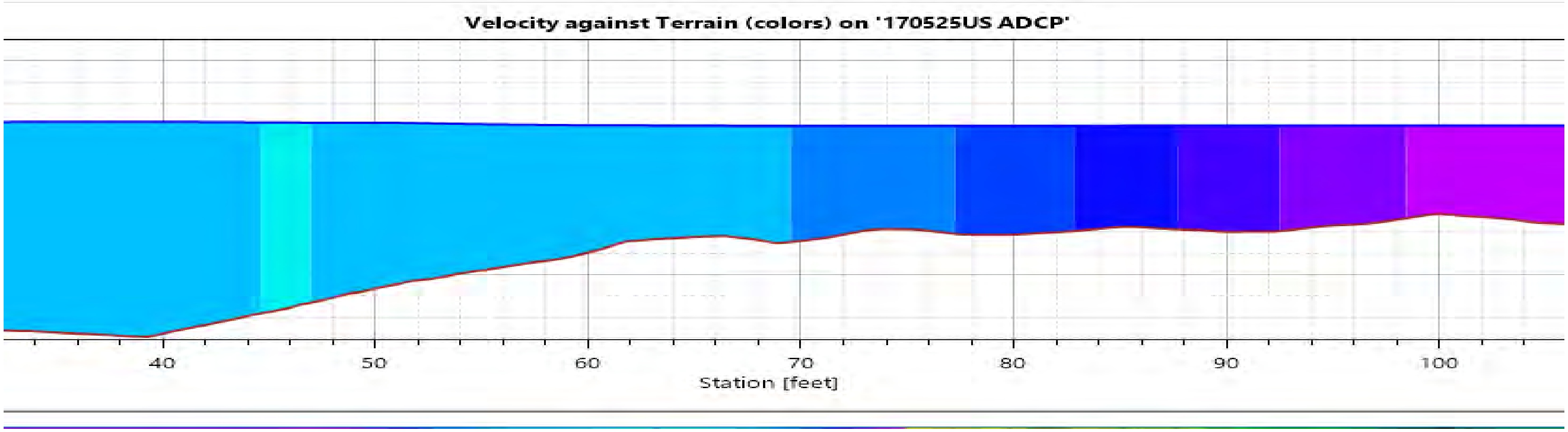


Figure A.8 **Cross-section location upstream (left) and downstream (right) of Sugar Pine Bridge where simulated velocities were extracted.**

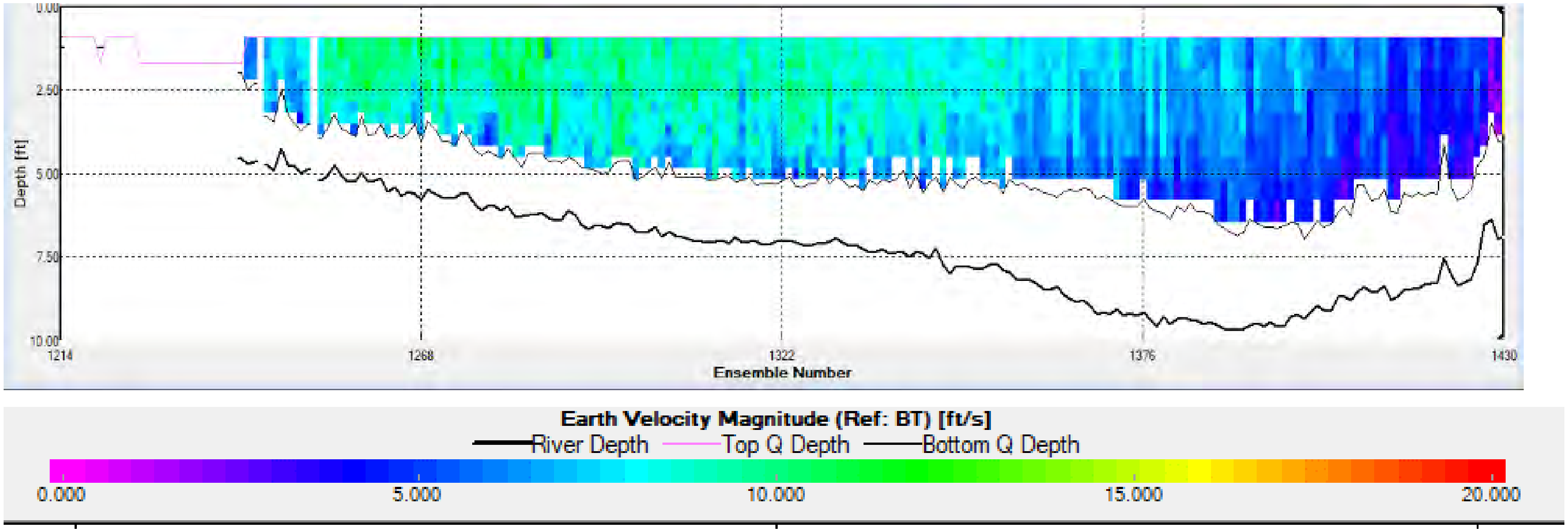


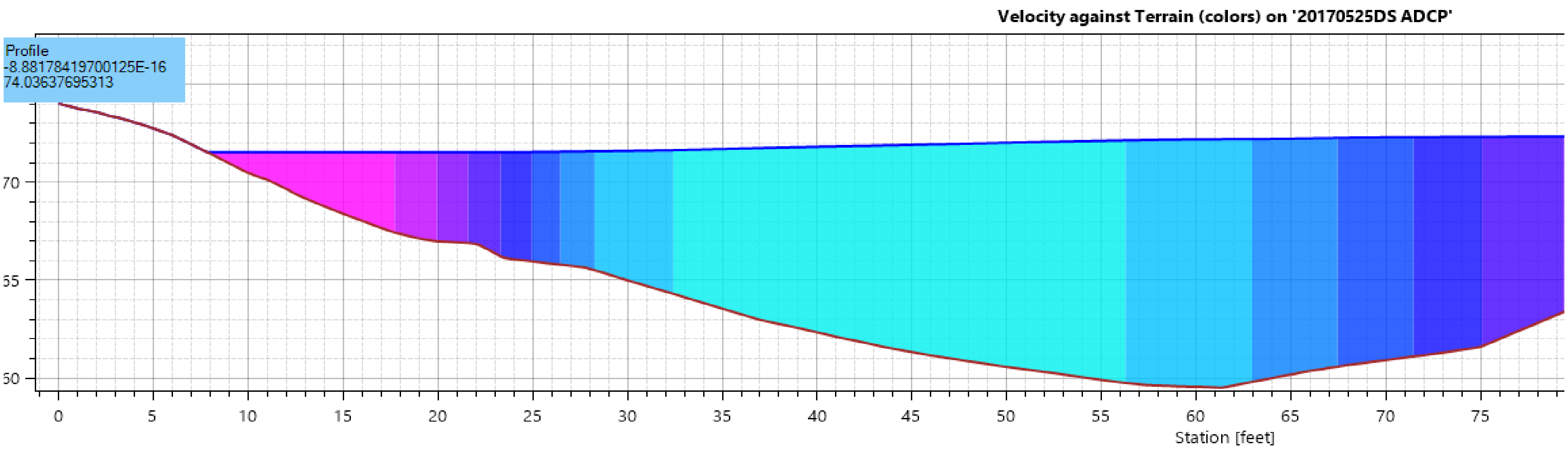


Notes: Legend applied to both measured and modeled cross-sections. See Figure A.6 for photograph of measured cross-section location and

Figure A.8 for plan view of modeled cross-section location.

Figure A.9 **Raw ADCP velocity data at cross-section upstream of Sugar Pine Bridge (top) and model output showing simulated velocities at cross-section upstream of Sugar Pine Bridge (bottom)**





Notes: Legend applied to both measured and modeled cross-sections. See Figure A.7 for photograph of measured cross-section location and

Figure A.8 for plan view of modeled cross-section location.

Figure A.10 Raw ADCP velocity data at cross-section downstream of Sugar Pine Bridge (top) and model output showing simulated velocities at cross-section upstream of Sugar Pine Bridge (bottom).

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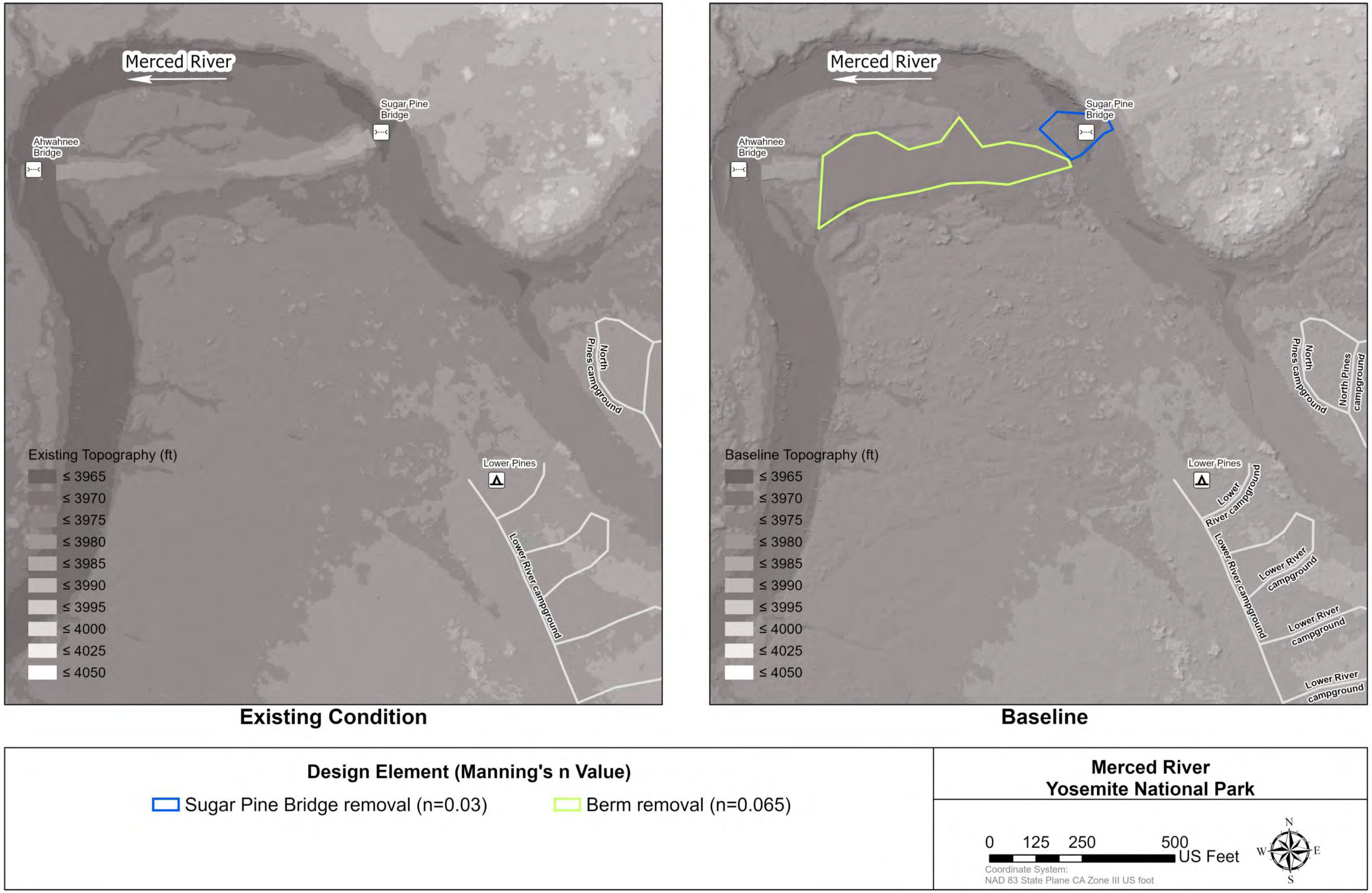
Merced River Restoration
Project - Phase 3

APPENDIX
B

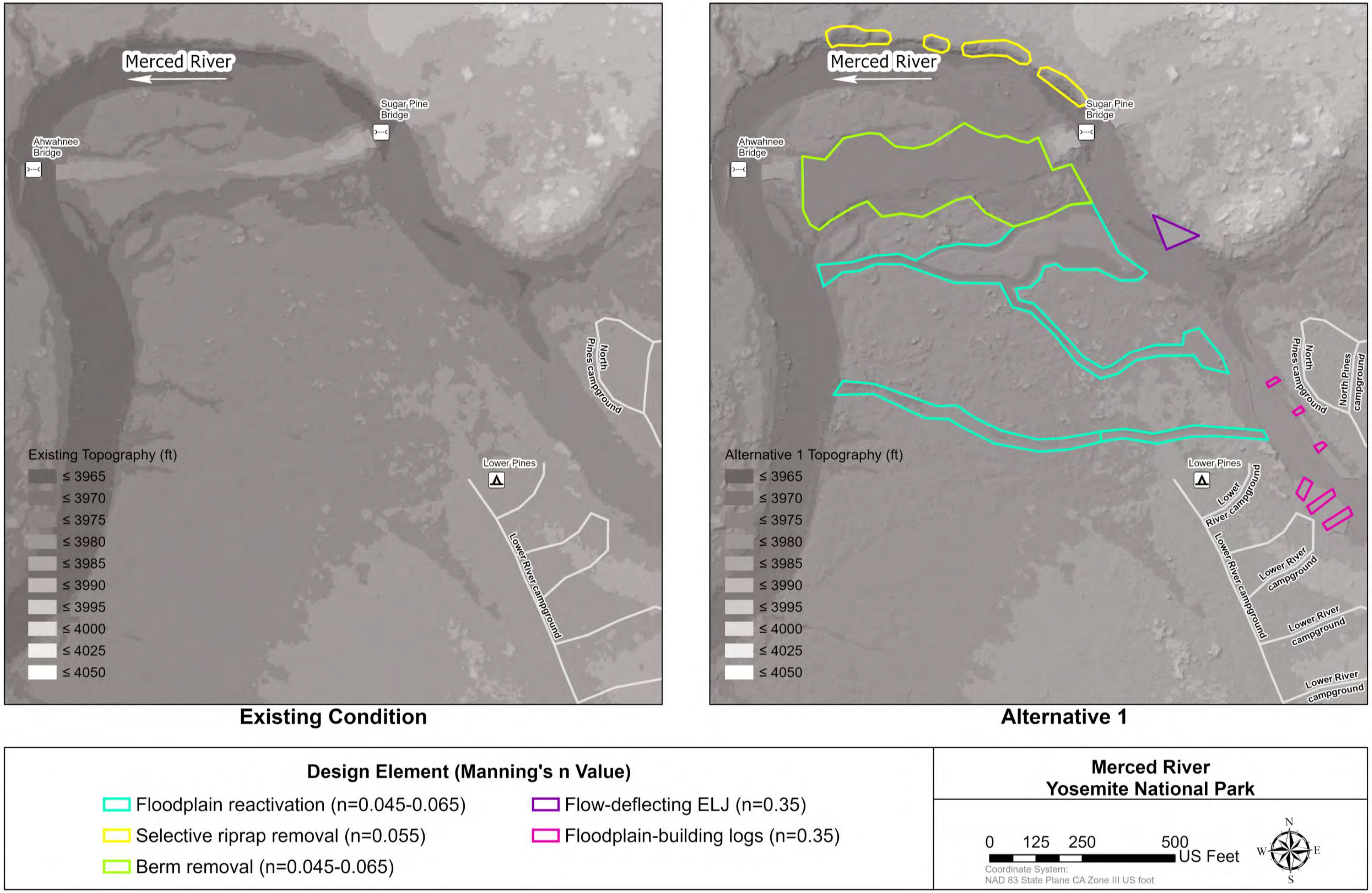
Modeled Alternatives and Examples of Project Elements

APPENDIX B Modeled Alternatives and Examples of Project Elements


Existing Condition

Baseline

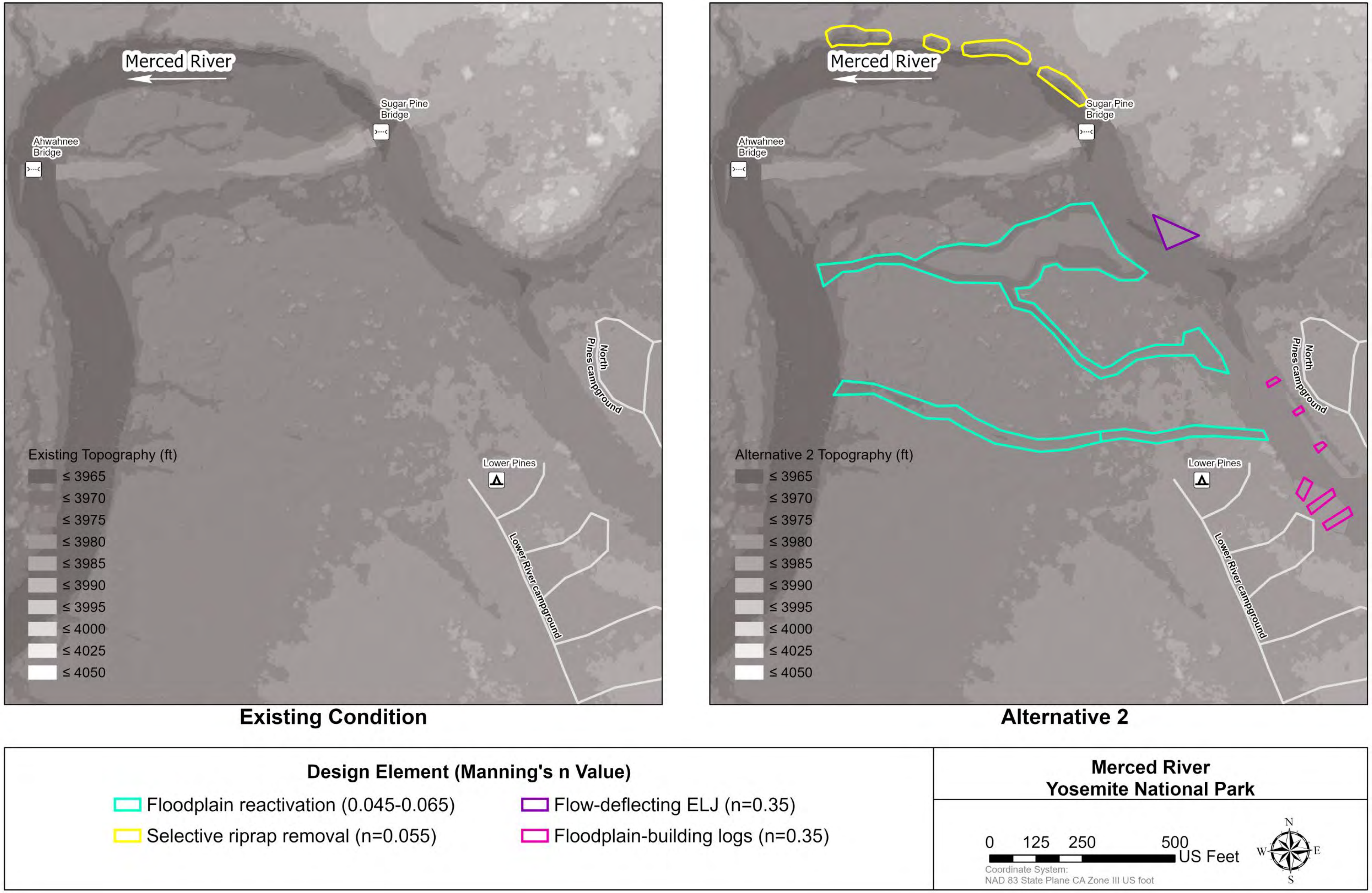
Figure B.1 Comparison of existing conditions Baseline topography, design elements, and roughness.



Existing Condition

Alternative 1

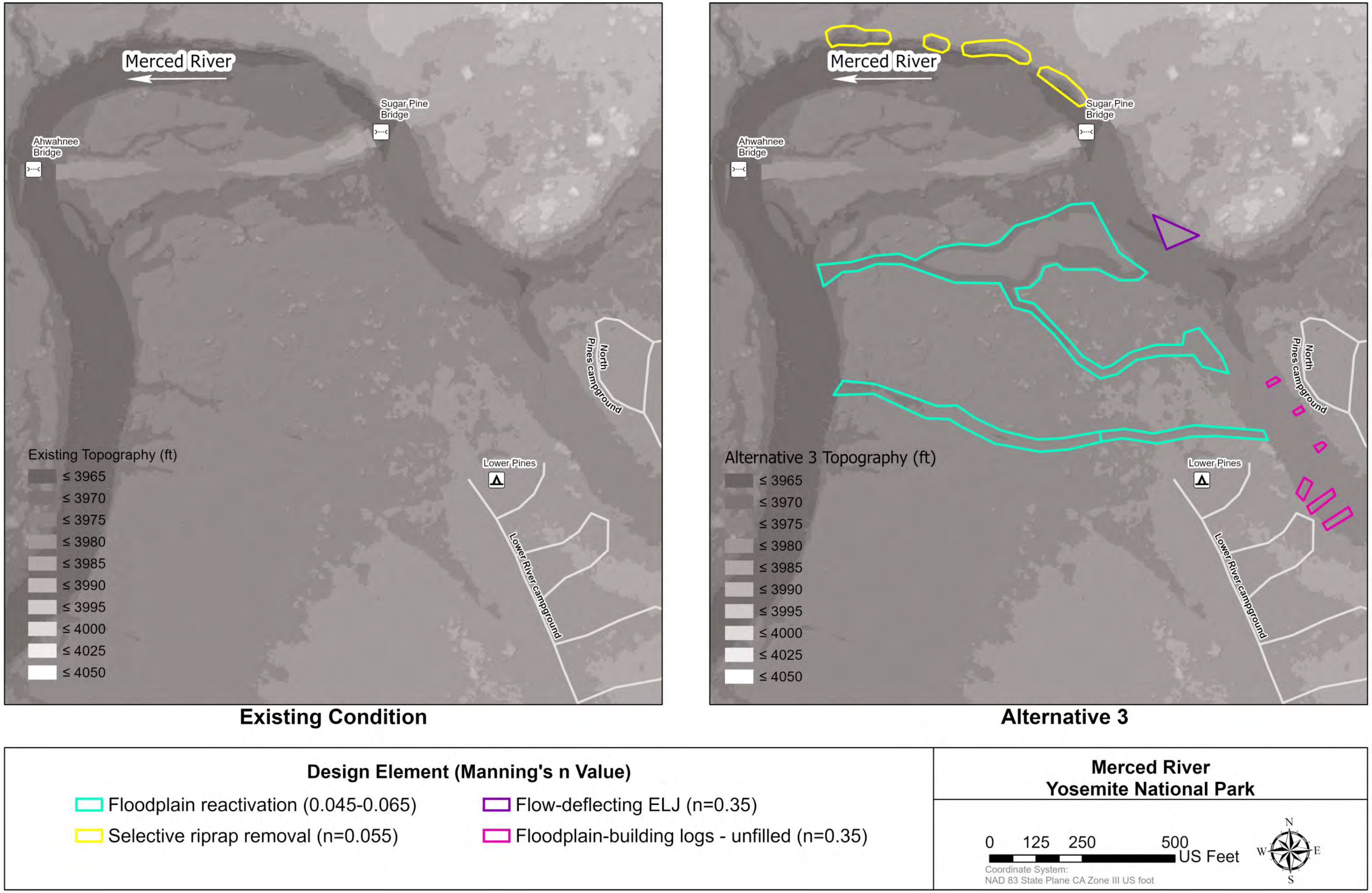
Figure B.2 Comparison of existing conditions Alternative 1 topography, design elements, and roughness.



Existing Condition

Alternative 2

Figure B.3 Comparison of existing conditions Alternative 2 topography, design elements, and roughnes.



Existing Condition

Alternative 3

Figure B.4 Comparison of existing conditions Alternative 3 topography, design elements, and roughness.

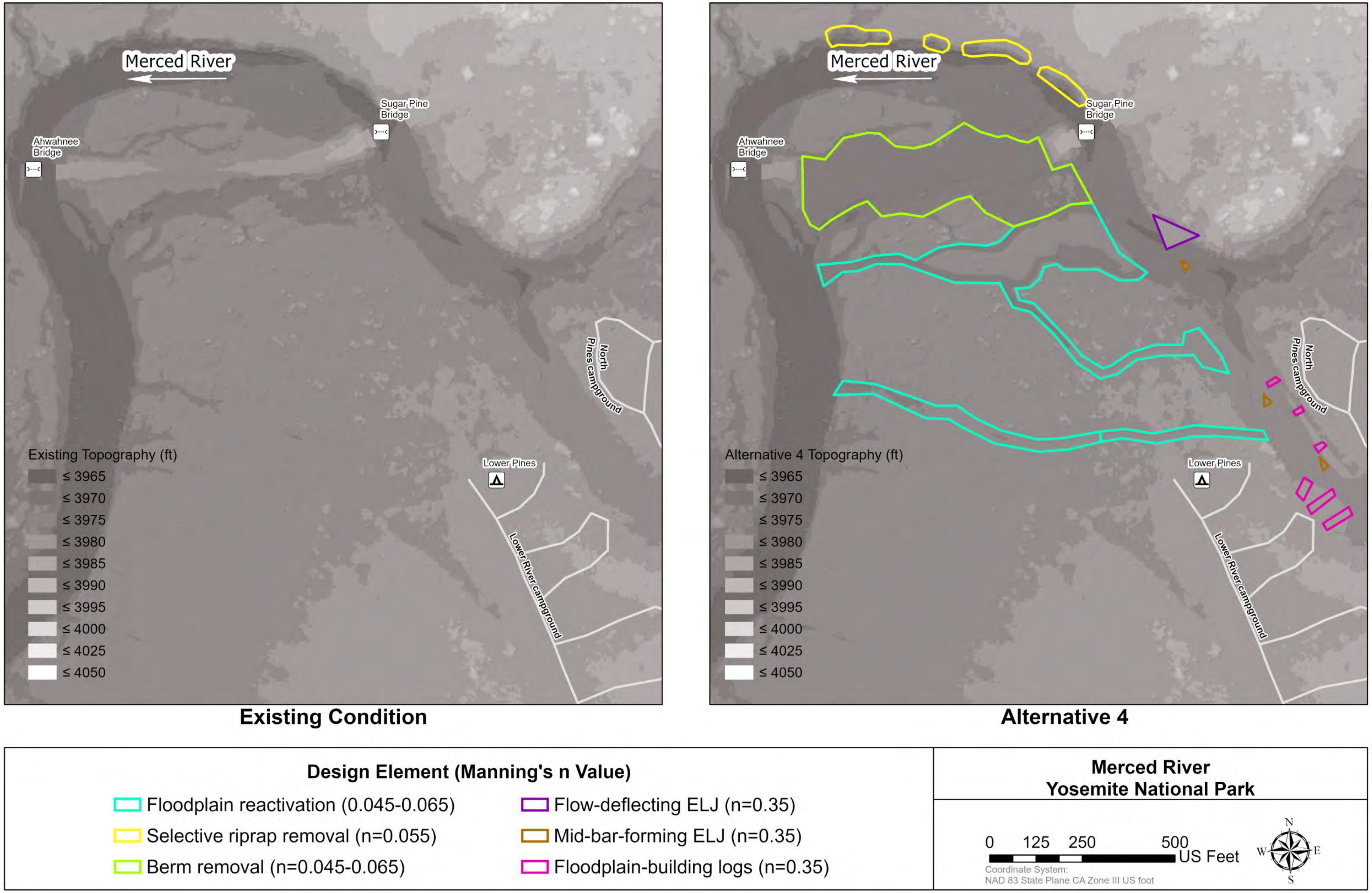


Figure B.5 Comparison of existing conditions Alternative 4 topography, design elements, and roughness.

Floodplain Reactivation Examples

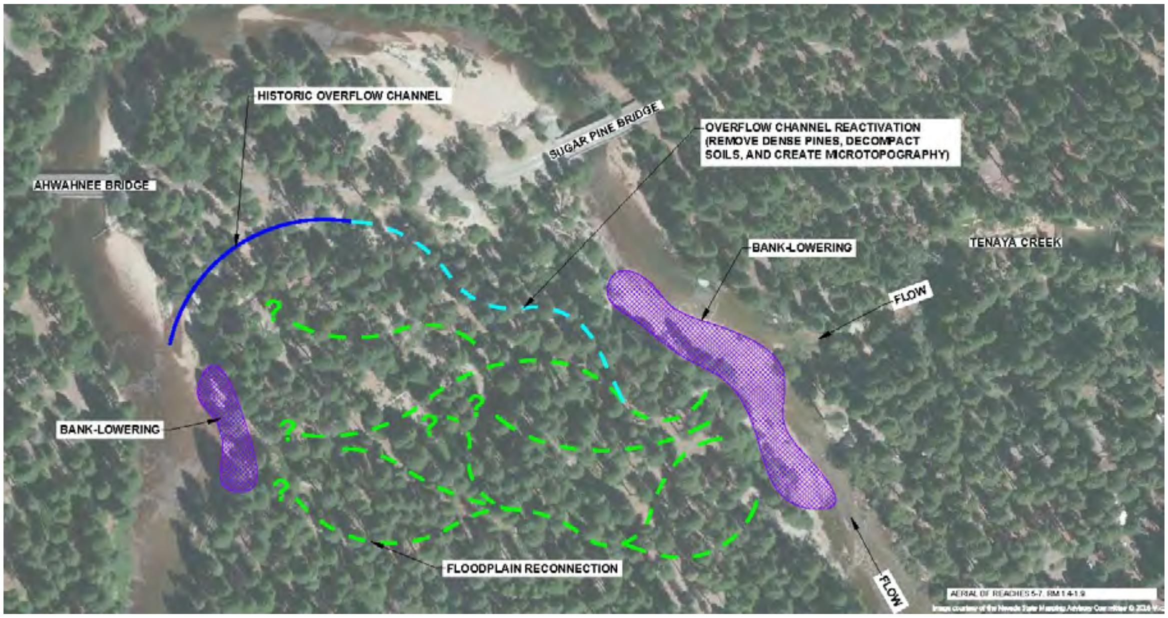


Figure B.6 Example graphic of floodplain reactivation and revegation.

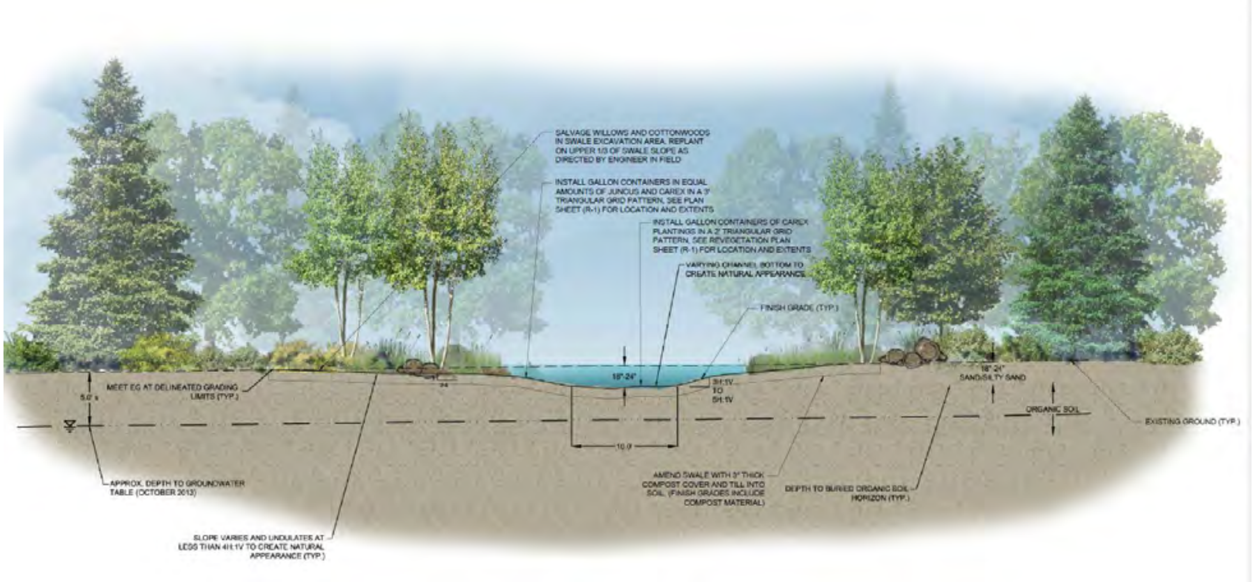
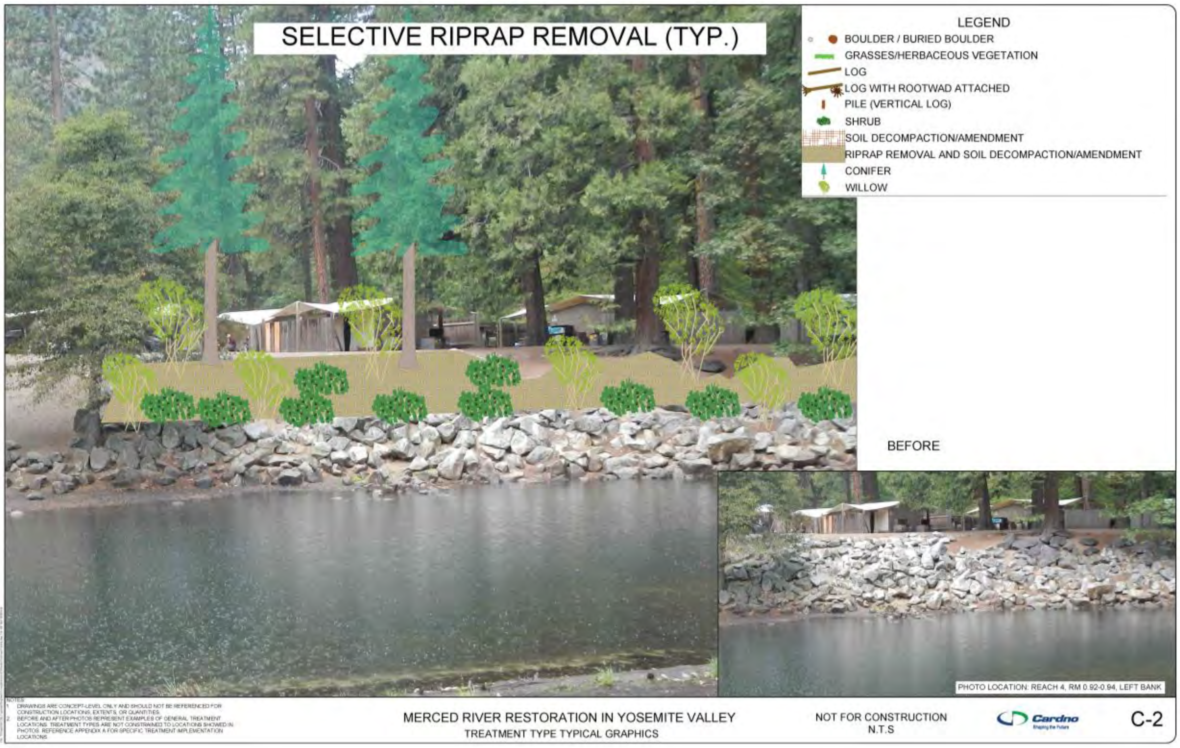


Figure B.7 Example detail of floodplain reactivation and revegation.

Selective Riprap Removal Examples



NOTES:
1. DRAWINGS ARE CONCEPT-LEVEL ONLY AND SHOULD NOT BE REFERENCED FOR CONSTRUCTION LOCATIONS, EXTENTS, OR QUANTITIES.
2. BEFORE AND AFTER PHOTOS REPRESENT EXAMPLES OF GENERAL TREATMENT LOCATIONS. TREATMENT TYPES ARE NOT CONSTRAINED TO LOCATIONS SHOWED IN PHOTOS. REFERENCE APPENDIX A FOR SPECIFIC TREATMENT IMPLEMENTATION LOCATIONS.

Figure B.8 Example graphic of selective riprap removal and revegetation.

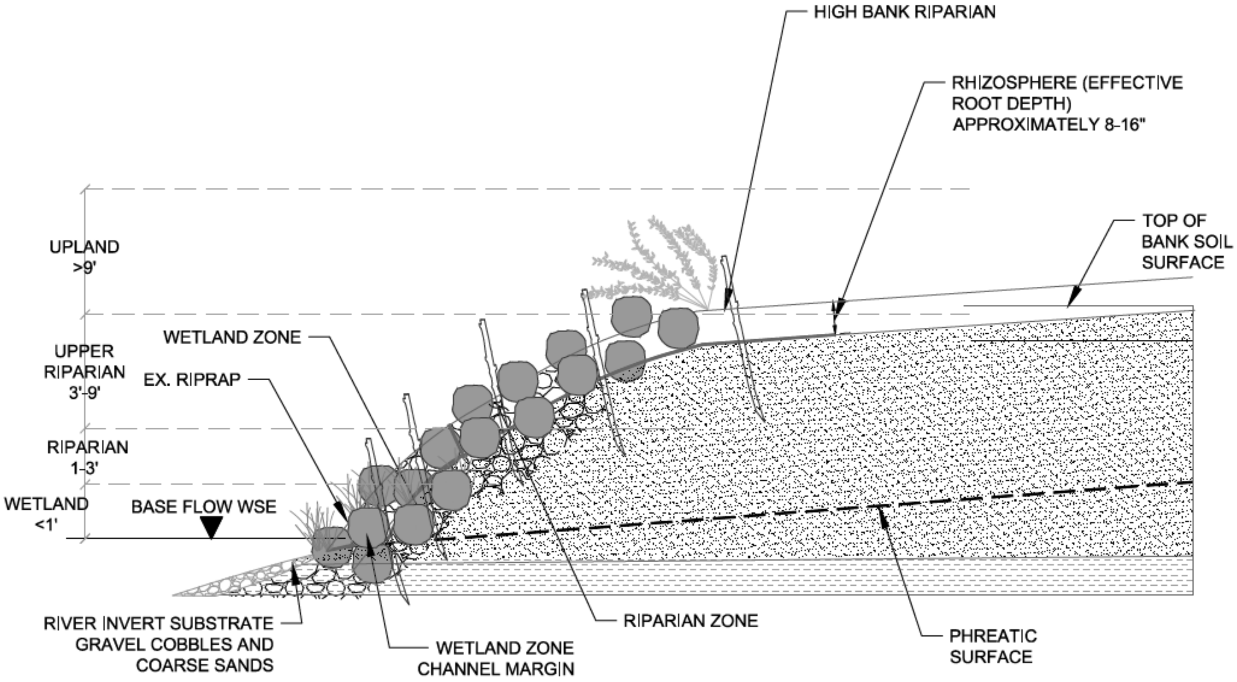


Figure B.9 Example detail of selective riprap removal and revegetation.

Figure B.10 Example photograph of revegetation after selective riprap removal.

Berm Removal

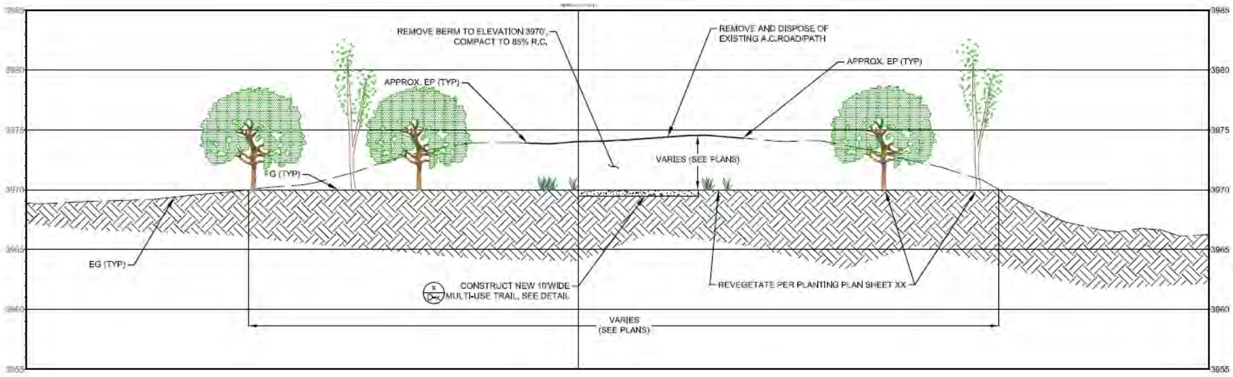
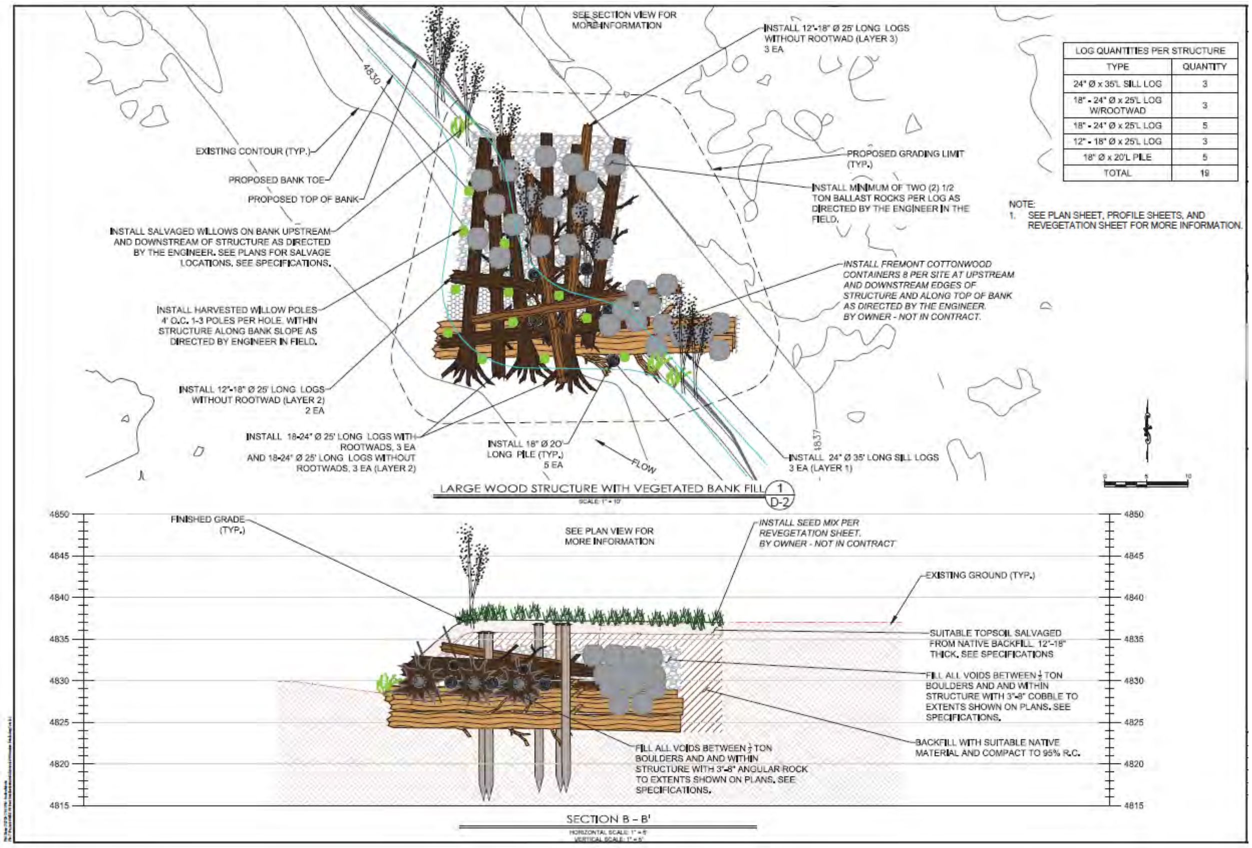


Figure B.11 Example detail of berm removal and revegetation.

Flow-deflecting ELJ Examples



LOG QUANTITIES PER STRUCTURE	
TYPE	QUANTITY
24" Ø x 35'L SILL LOG	3
18" - 24" Ø x 25'L LOG W/ROOTWAD	3
18" - 24" Ø x 25'L LOG	5
12" - 18" Ø x 25'L LOG	3
18" Ø x 20'L PILE	5
TOTAL	19

NOTE:
1. SEE PLAN SHEET, PROFILE SHEETS, AND REVEGETATION SHEET FOR MORE INFORMATION.

Figure B.12 Example detail of flow-deflecting ELJ.

Floodplain-building Logs Examples

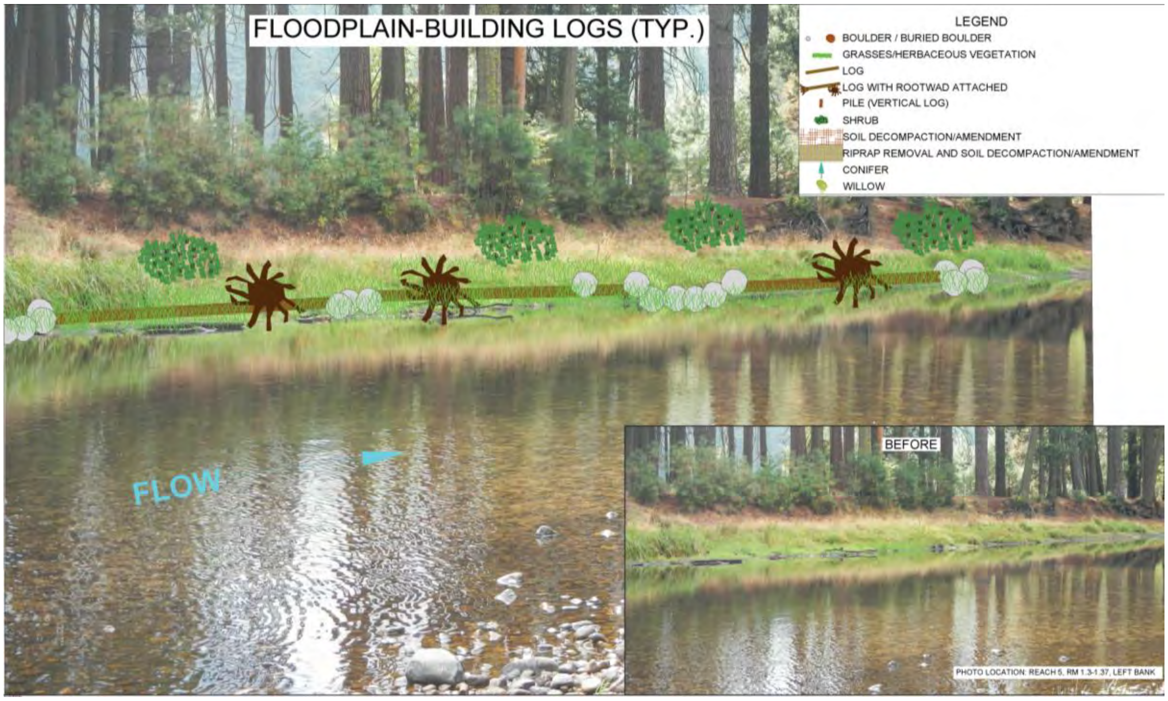


Figure B.13 Example graphic of floodplain-building logs and revegetation.

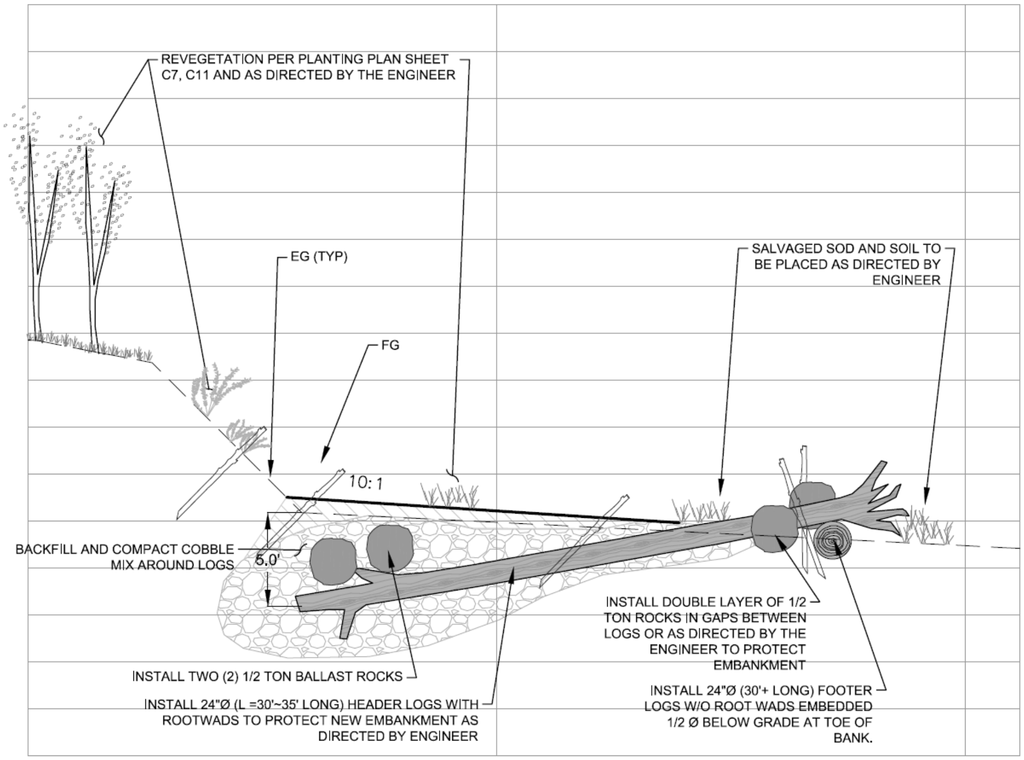


Figure B.14 Example detail of floodplain-building logs and revegetation.

Figure B.15 Example photograph of floodplain-building logs with revegetation.

Mid-bar-forming ELJs

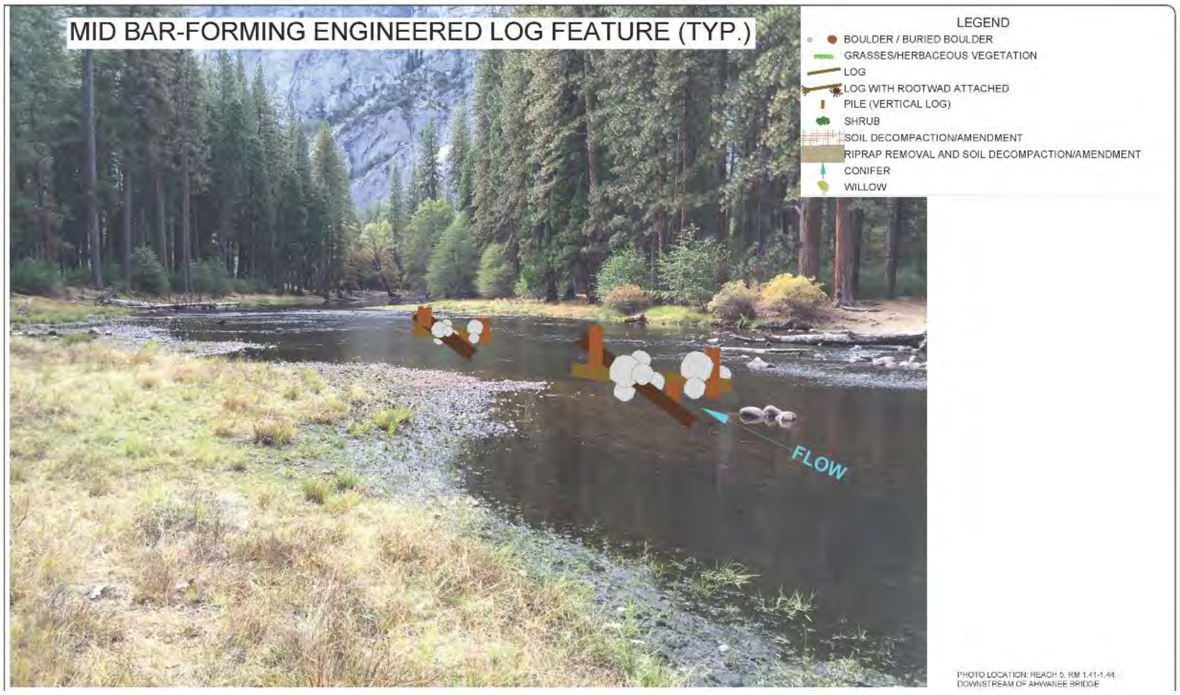


Figure B.16 Example graphic of mid bar-forming ELJs.

Figure B.17 Example photo of mid bar-forming ELJs.