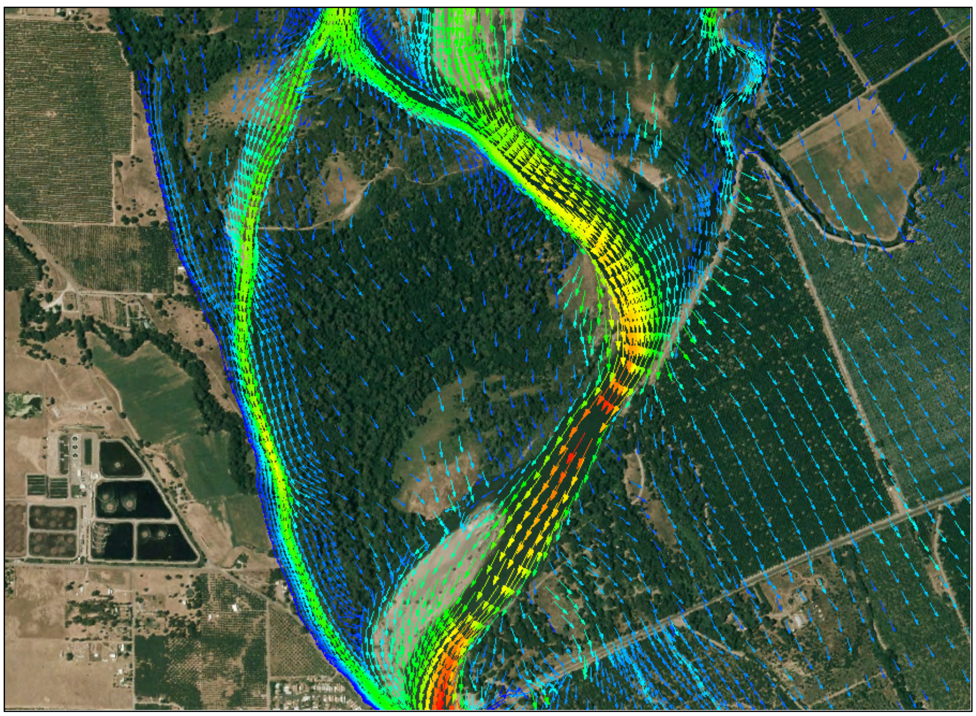
HYDRAULIC ANALYSIS, CONCEPTUAL DESIGN, AND PRELIMINARY COST ESTIMATE FOR THE KOPTA SLOUGH FLOOD DAMAGE REDUCTION AND HABITAT RESTORATION STUDY ON THE SACRAMENTO RIVER, RM 216 TO RM 224

TEHAMA COUNTY, CALIFORNIA

December 28, 2009



Prepared For:

Department of Water Resources
Northern Region Office
2440 Main Street
Red Bluff, CA 96080

AYRES ASSOCIATES

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DWR Contract Number 4600008120

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1.0 INTRODUCTION

1.1 General

This report summarizes the findings of two-dimensional hydraulic modeling for potential restoration habitat, bank rock removal, bank protection, and reconnection of Kopta Slough to the main channel. The hydraulic modeling study provides engineering analysis of existing and alternative conditions in support of the feasibility study for the Kopta Slough Flood Damage Reduction and Habitat Restoration Project. The goals of the Project are to reduce flood damage to public resources and to restore habitat and ecosystem function. The study area is the Sacramento River in the vicinity of Kopta Slough, between river mile (RM) 216 to RM 224, as shown in **Figure 1**. A more detailed map of the study area, including river miles, the State Recreation Area, existing US Fish & Wildlife Service restoration property and the Kopta Slough property, is shown in **Figure 2**. The project elements being considered consist of the following options:

- Habitat restoration on roughly 177 acres.
- Removal of rock from the right bank of the Sacramento River, between RM 220 and 221.
- Placement of rock bank protection to protect the existing Woodson Bridge and the City of Corning Sewer Outfall.
- Construction of a channel to reconnect Kopta Slough to the main channel of the Sacramento River.

A hydraulic model of the Sacramento River, from RM 216 to RM 224, was developed to assist in analyzing this effort.

1.2 Background

This unleveed reach of the Sacramento River has an active meandering channel bed with wide floodplains. Upstream of Woodson Bridge, extensive existing rock protection on both channel banks maintains the river's alignment through the bridge and prevents erosion. The land in the floodplains is a mix of agriculture and both restored and natural riparian habitats. Historic bank alignments show that the main channel used to be located in the present day Kopta Slough alignment, as shown in **Figure 3**.

The original model used for this analysis was developed for the US Army Corps of Engineers in 2005. However, the project was canceled before completion. Many of the initial conceptual ideas came from that previous study and were refined to help evaluate alternatives for this study. The model was rebuilt to reflect the recent changes in the river system, including land use, channel alignment, and topography. The model was also refined in the areas of interest for this study.

Figure 1. Study Location Map

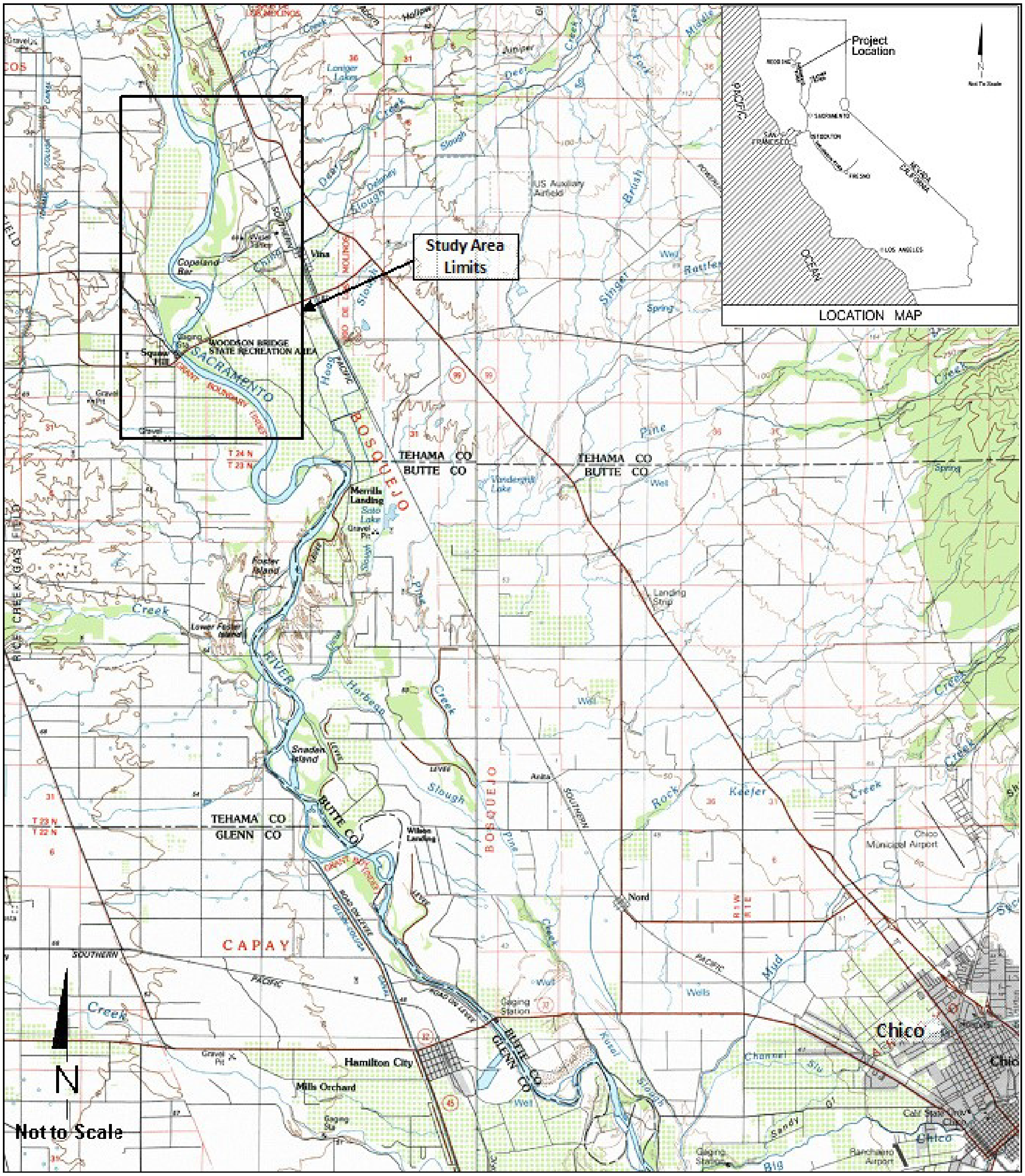


Figure 2. Study Area

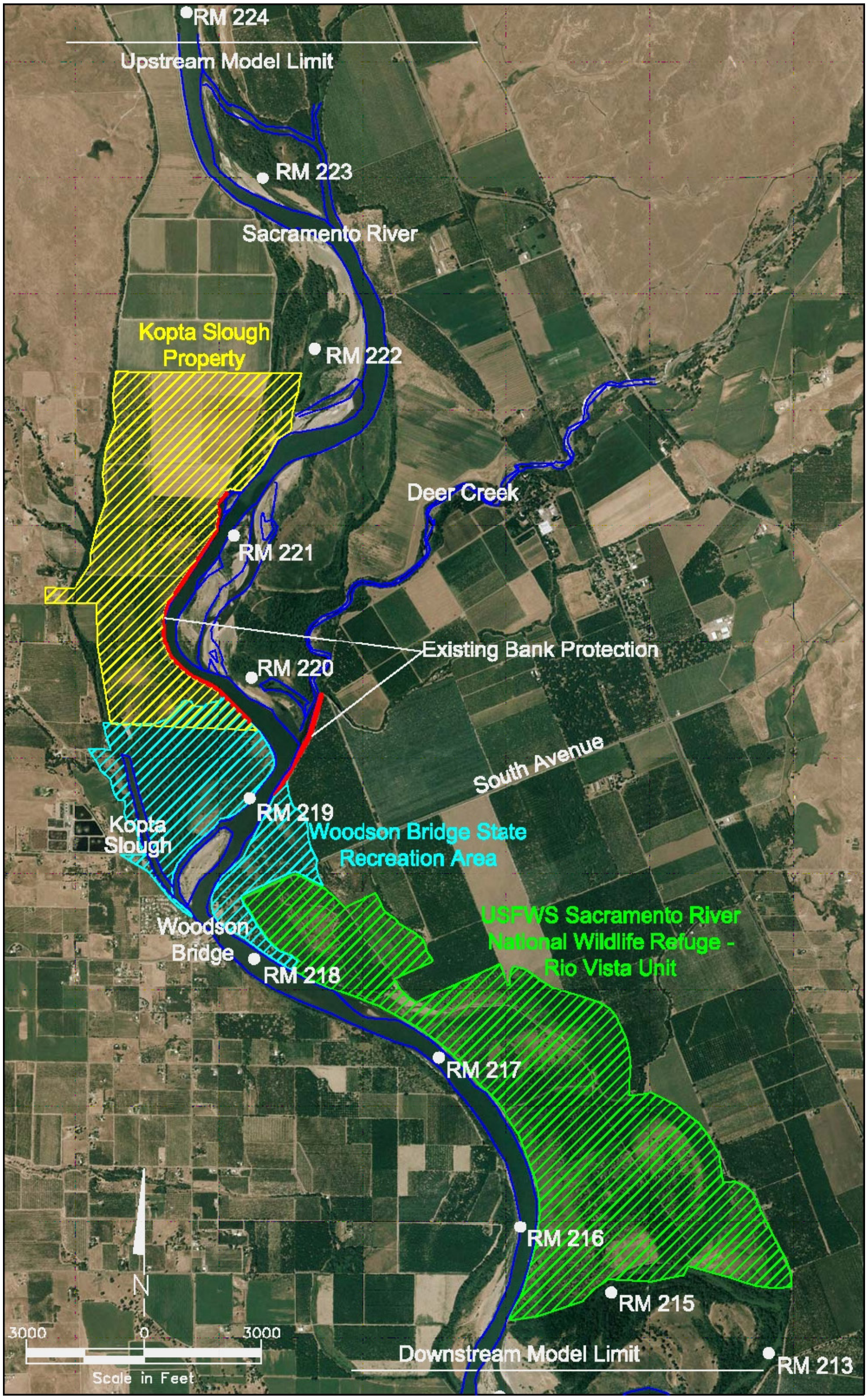
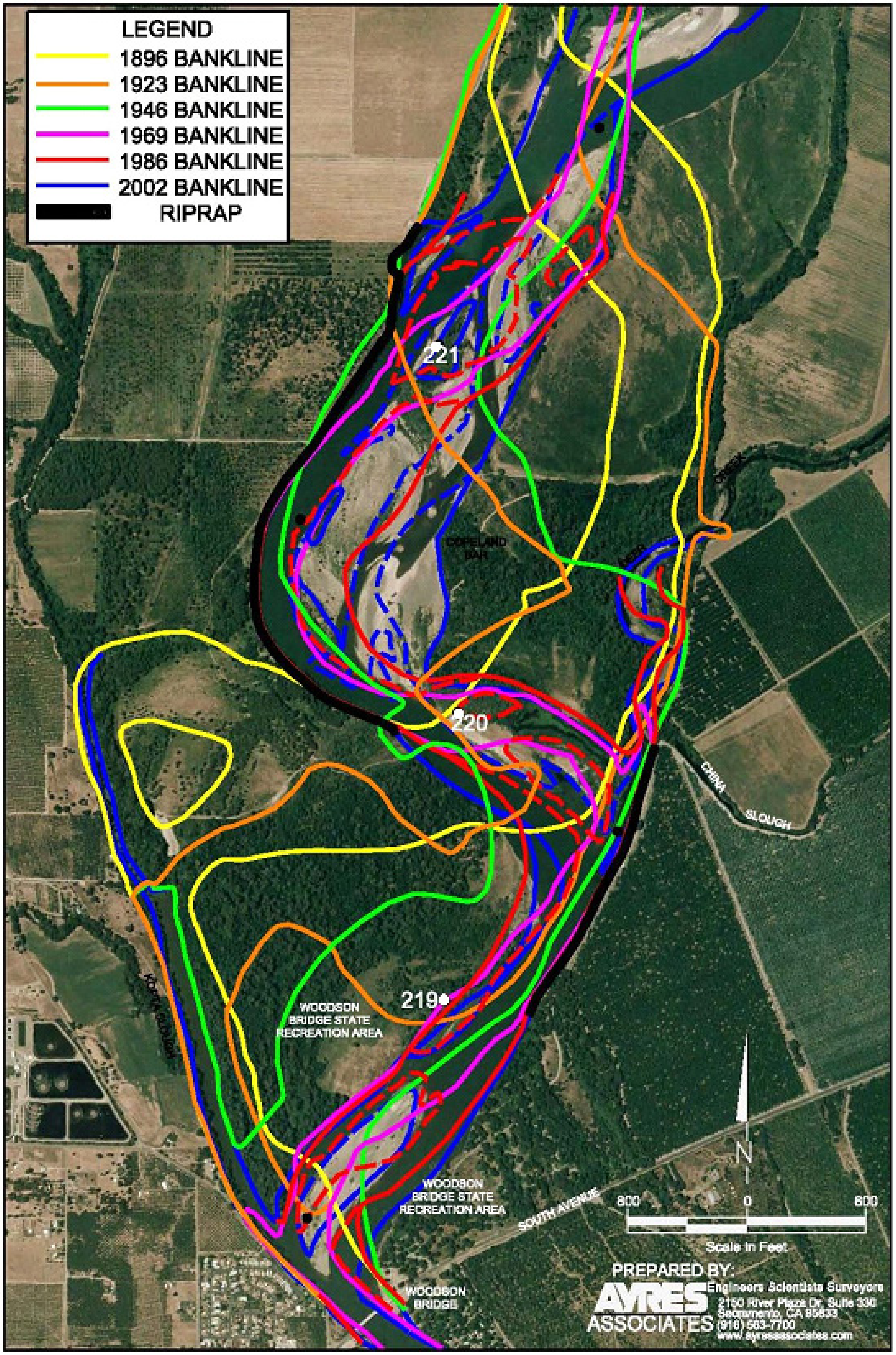


Figure 3. Sacramento River Historic Banklines



1.3 Purpose and Scope

The purpose of this study is to model potential alternatives for reducing flood damage through reduced bank erosion to public resources and restoring habitat and ecosystem function to the areas near the Woodson Bridge State Recreation Area.

The scope of the study is outlined in the following tasks:

a. Develop and calibrate a 2-dimensional hydraulic model using the USACE 1997 topography and the DWR 1998 topography to represent the channel. The calibration is based on the 1997 flood event, with high water data surveyed by DWR.
b. Determine the bankfull discharge and use the USACE's Sacramento River Comprehensive Study data for the 100-year and 10-year events to run existing conditions. The existing conditions model will be updated using the 2008 survey provided by DWR, and all land uses will be updated to represent the current (fall 2008) conditions.
c. Run six hydraulic models as determined by DWR, consisting of a single flow event (bankfull, 10-year, or 100-year) and a combination of the following options: a) rock removal; b) overflow floodplain connection to Kopta Slough; c) bank protection for the erosion at Woodson Bridge; d) bank protection for the City of Corning sewer outfall; and e) habitat restoration on the Kopta Slough property.
d. Plot GIS coverage of the modeling results of the velocity, water surface elevation, and shear stress. Conceptual designs and costs for the different modeled scenarios will also be developed.

1.4 Acknowledgments

This study was scoped through the Department of Water Resources, Northern Region Office, through their contract with EDAW. This study is through contract number 4600008120, Task 3 of DWR. The project manager for DWR is Mr. Todd Hillaire, PE, and the project manager for Ayres Associates is Mr. Thomas W. Smith, PE, GE.

The 1997 (RM 216 and south) topographic data was provided by the USACE. The 1998 topographic data (RM 218 and north) and the 2008 topographic data were provided by DWR. The use of previous models was allowed by USACE. Restoration data for the Rio Vista Restoration project was provided by US Fish & Wildlife Service. Guidance on habitat restoration planting was provided by Ryan Luster at The Nature Conservancy.

2.0 STUDY ELEMENTS

2.1 Overview of Study Elements

For this study, DWR provided five elements for consideration. These elements and options are summarized below:

1. Rock Revetment Removal at RM 220.5
    a. No rock Removal
    b. Partial Length Rock Removal
        i. Partial Vertical
        ii. Full Vertical
        iii. Notched Full Vertical

    iv. Notched Partial Vertical
  c. Full Length Rock Removal
    i. Partial Vertical
    ii. Full Vertical
    iii. Notched Full Vertical
    iv. Notched Partial Vertical

2. Overflow Floodplain Connection to Kopta Slough
  a. No Improved Channel
  b. Pilot channel connection to Kopta Slough
  c. Channel Connection to Kopta Slough

3. Erosion Protection at Woodson Bridge
  a. No site improvements
  b. Bendway weirs with upper bank vegetation
  c. Low berm with upper bank vegetation
  d. Bank armor with upper bank vegetation
  e. Spur dikes with upper bank vegetation

4. Erosion Protection at the City of Corning Sewer Outfall
  a. No site improvements
  b. Bendway weirs with upper bank vegetation
  c. Bank armor with upper bank vegetation
  d. Low berm with upper bank vegetation
  e. Spur dikes with bank vegetation

5. Habitat Restoration on the Kopta Slough Property
  a. No site improvements
  b. Riparian habitat restoration
    i. Terrain contouring
    ii. No terrain contouring

2.2 Rock Revetment Removal at RM 220.5

The rock removal option consists of no action, partial rock removal, and full rock removal. The existing revetment extends from RM 221.1 to RM 220, as shown in **Figure 2**.

For the rock revetment removal, the element was split into two options, removal of the full length of rock (about 7,300 ft) or removal of the downstream half of the rock (4,000 ft), as shown in **Figures 4 and 5**, respectively. Within these 2 options there were additional options; for the lateral removal of the rock, the options were to either remove as one large section or remove it in a notching pattern. The notching pattern would remove sections of rock and leave other sections, as shown in **Figures 6 and 7** for the full length (2,800 ft) and half length (1,400 ft), respectively. For the vertical bank, either rock would be removed for the entire bank height (26 ft) or only removed from the top portion of the bank (12 ft), as shown in **Figures 8 and 9**, respectively. The existing berm behind the rock would also be excavated to match the existing floodplain elevation.

Figure 4. Full Length Rock Revetment Removal

Figure 5. Half Length Rock Revetment Removal

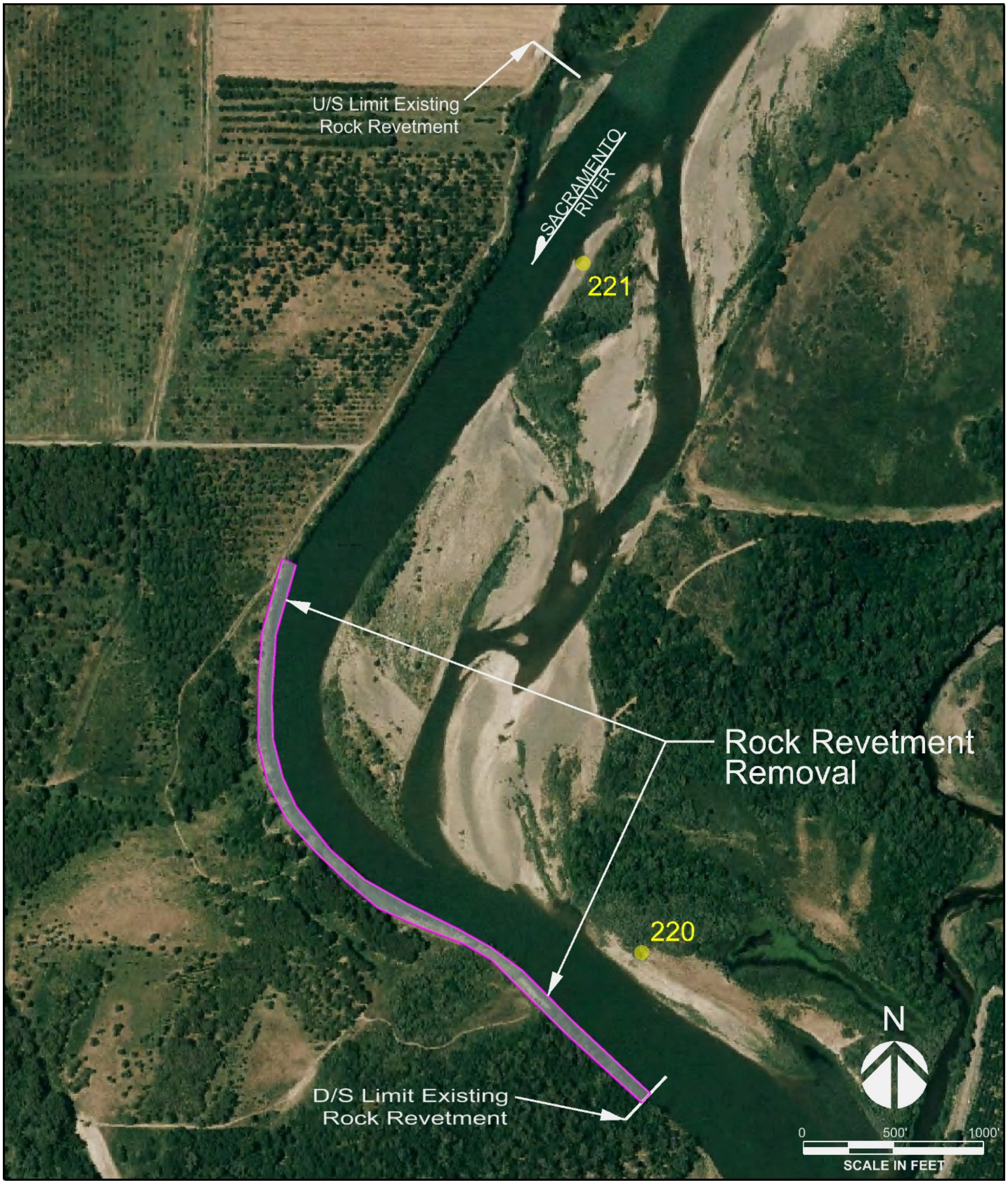


Figure 6. Full Length Notching Rock Revetment Removal

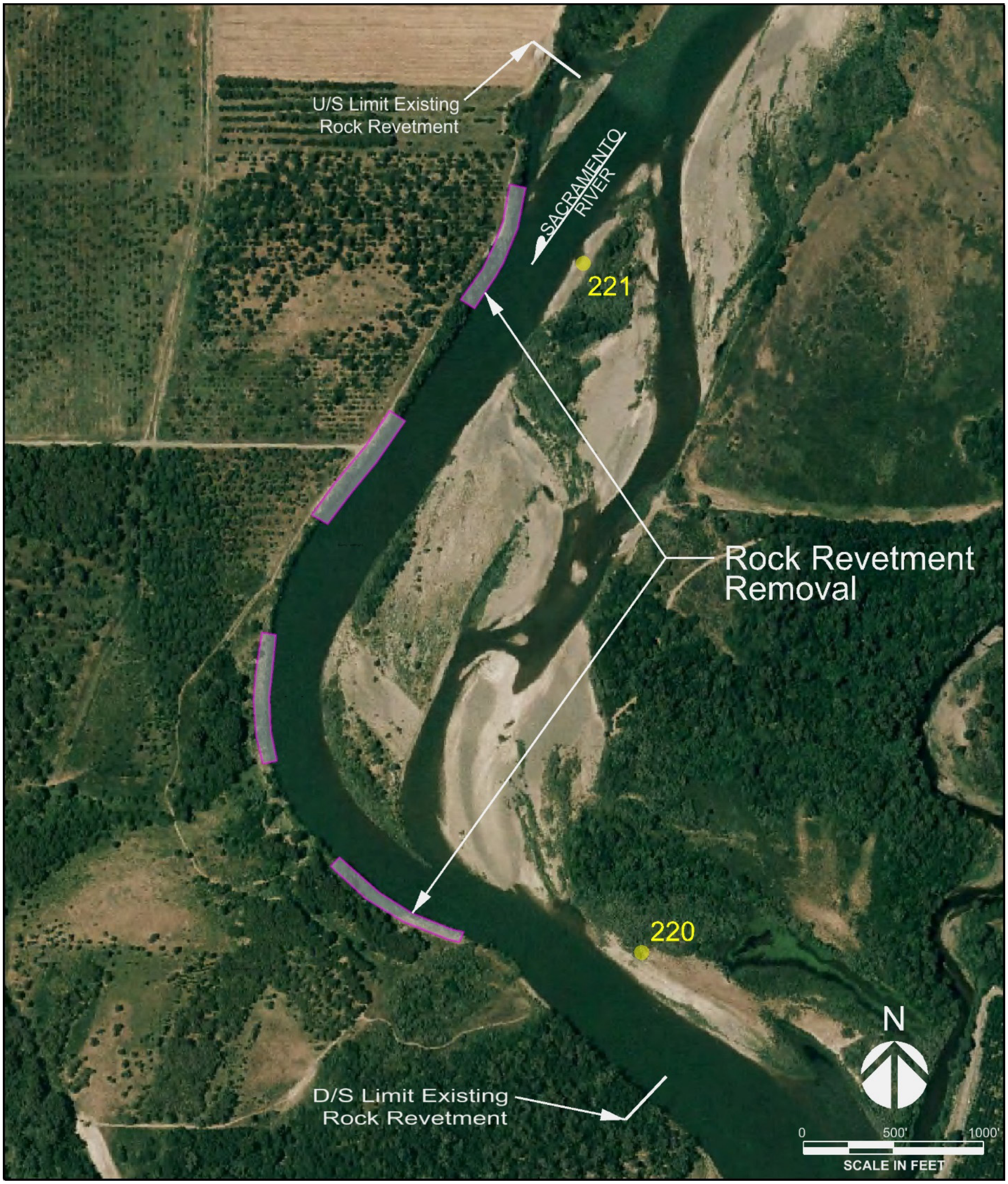


Figure 7. Half Length Notching Rock Revetment Removal

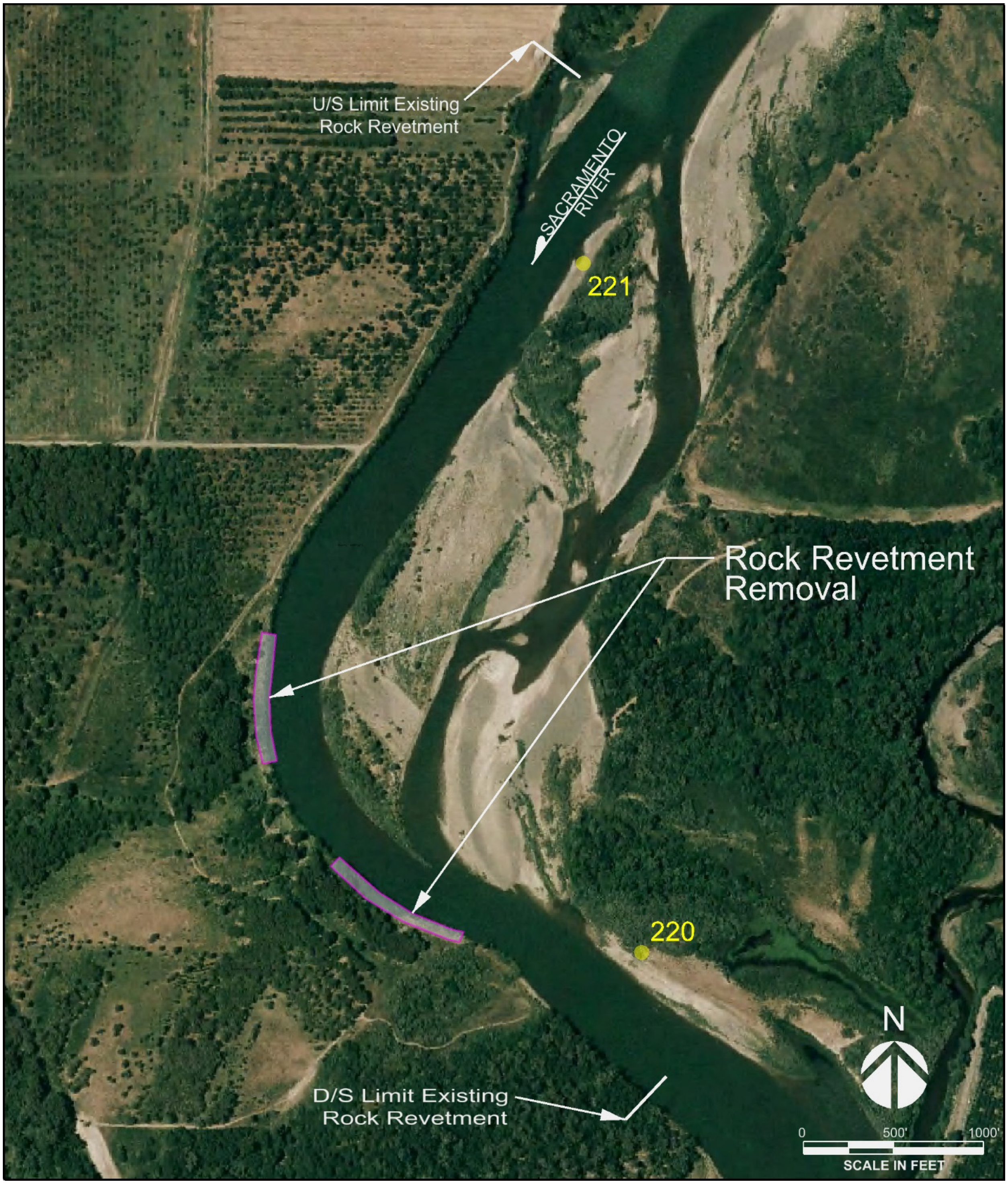


Figure 8. Full Bank Height Rock Revetment Removal Cross Section

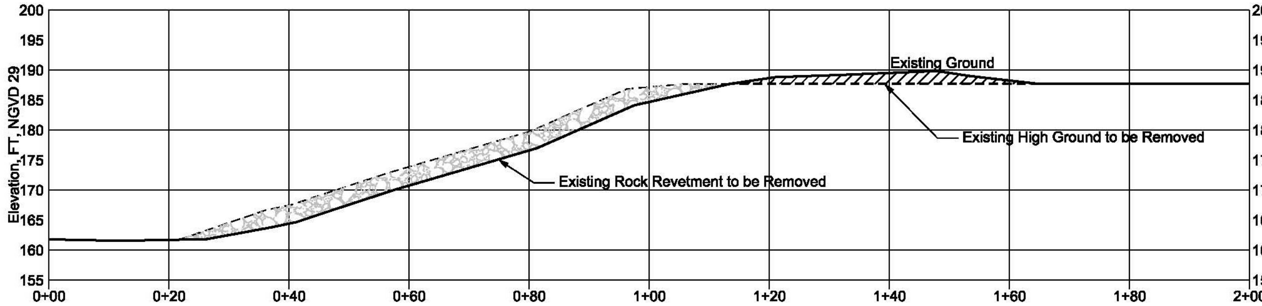
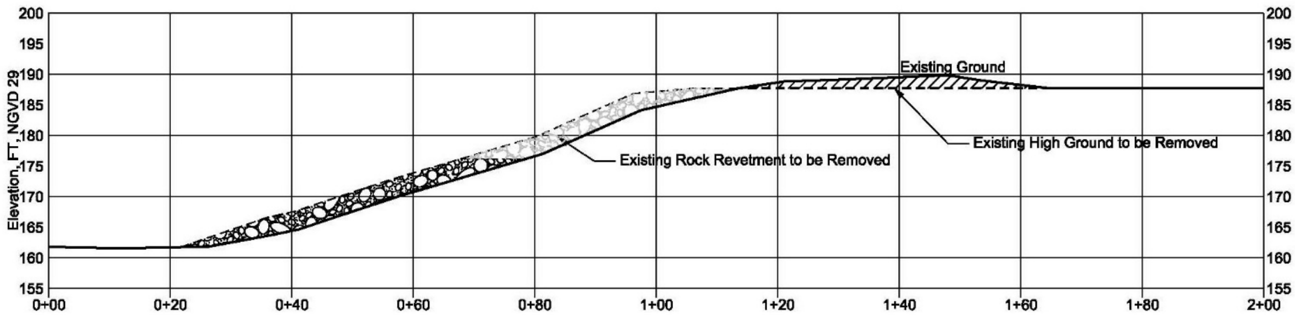


Figure 9. Half Bank Height Rock Revetment Removal Cross Section



The preliminary construction cost of these options is summarized in **Table 1**.

Table 1. Preliminary Construction Costs for Rock Revetment Removal Element

Vertical (Bank) Removal Option	Lateral Removal Option			
	Partial Length	Full Length	Notching Partial Length	Notching Full Length
Partial Vertical	$453,800	$840,370	$159,670	$319,340
Full Vertical	$907,600	$1,680,730	$319,340	$638,680

With regard to the selection of any one of these options, environmental implications and public safety should be kept in mind. The notching option could cause a hazard to boating if the channel moves west and leaves large sections of rock in the middle of the navigable waterway. The partial length of rock removal may not have as much of an environmental benefit and with the opening of the channel, there is potential for the channel to migrate and leave a large section of rock in the channel. The full vertical/full length rock removal was selected for hydraulic analysis because it brackets the hydraulic effects between no action and largest potential effect.

2.3 Overflow Floodplain Connection to Kopta Slough

The floodplain connection to Kopta Slough element consists of no action, a pilot channel, and a full channel connection. Historical alignments (see Figure 3) show that the Sacramento River flowed through the current floodplain and Kopta Slough; however, approximately 80 years ago the river cut off from Kopta Slough. After the cutoff, USACE rock revetment (project rock) was placed through the natural Kopta Slough floodplain connection, thus hindering the river from a potential natural reconnection to Kopta Slough. The no action option means that no excavation will occur to encourage the Sacramento River to reconnect to Kopta Slough and hope that the reconnection would happen naturally through other study elements.

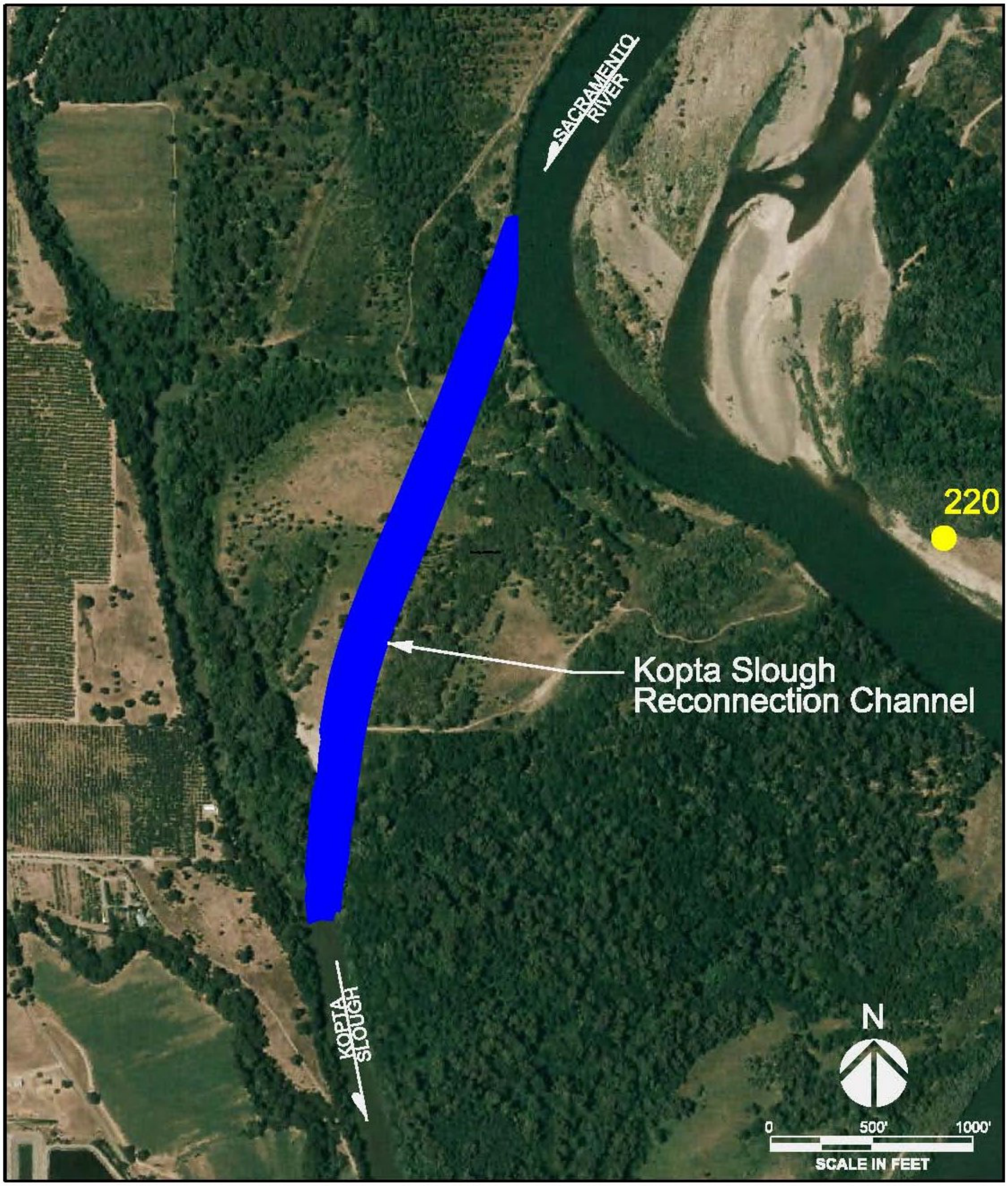
The location of the channel reconnection is shown in **Figure 10**. This location was based on a low spot in the bank and the river's natural tendency to flow through this location at high flows. The reconnection would be either through a pilot channel or a fully excavated channel. The pilot channel provides an initial start for the Sacramento River to re-connect with Kopta Slough. It would be approximately 8 ft wide and connect the Sacramento River to entrance of the existing Kopta Slough. The full Kopta Slough reconnection involves creating a new channel to force the water into Kopta Slough. The reconnection channel would be approximately 110 ft wide on the bottom (based on present bottom width of existing Kopta Slough), extend from the Sacramento River channel invert to the Kopta Slough channel invert, and have 2:1 side slopes.

The preliminary construction costs for these options are summarized in **Table 2**.

Table 2. Preliminary Construction Cost Estimate for Kopta Slough Connection

Connection Option	Cost
Pilot Channel	$205,910
Full Channel Connection	$6,355,380

Figure 10. Location of Kopta Slough Connection



2.4 Erosion Protection at Woodson Bridge

The erosion protection along the right bank of Woodson Bridge was analyzed separately from protection at the City of Corning sewer outfall because these areas may require different types of protection or protection may be required at only one of these locations.

Four protection options were developed to evaluate the most effective solution along with being environmentally friendly. The protection options included, no site improvements, bendway weirs with bank vegetation, low berm with upper bank vegetation, spur dikes with upper bank vegetation, and bank armor with upper bank vegetation.

Bendway weirs act to redirect the flow away from the bank and into the channel. The weirs would extend into the channel and be placed at an angle to ensure the redirection of flow. The design for this study includes 13 weirs, spaced 100 ft apart, protecting 1,200 ft of bank, as shown in **Figure 11**. The weirs would be approximately 6 ft high, with 1.5:1 side slopes, and a crest width of 2 ft. The top of the weir would be at about the summer low flow water level and may require the use of buoys to prevent them from becoming a navigational hazard. The configuration of these weirs is shown in **Figure 12**. Vegetation would be placed on the existing bank where the velocities are lower than 5 ft/s to protect the bank from erosion. In addition, the vegetation would have environmental benefits and be aesthetically pleasing.

Another erosion protection option for Woodson Bridge was the use of spur dikes with bank vegetation. Spur dikes are similar to bendway weirs; however, they are designed differently and their goal is to produce deposition on the banks rather than redirect flow. For this design 13 dikes would extend perpendicular to the banks into the channel, spaced approximately 100 ft apart for 1,200 ft, as shown in **Figure 13**. The configuration of the dikes is shown in **Figure 14**.

Another option for protecting Woodson Bridge is building a low berm. The low berm would extend approximately 1,900 ft, in the vicinity of high velocities, as shown in **Figure 15**. The berm would extend approximately 20 ft into the main channel at the summer low flow water surface elevation with a 2:1 slope to the bottom of the channel. Some rock will need to be placed up the slope where the velocities exceed 5 ft/s. The remaining upper slope will be protected with bank vegetation. The configuration of this design is shown in **Figure 16**.

For the bank armor option, the rock would be placed in the same location as the low berm (Figure 15). The rock would extend past the mean summer water level until the velocity is below 5 ft/s, as shown in **Figure 17**. The remaining upper slope will be protected with vegetation.

Figure 11. Plan View of Bendway Weirs at Woodson Bridge

Figure 12. Cross Section showing a typical Bendway Weir at Woodson Bridge

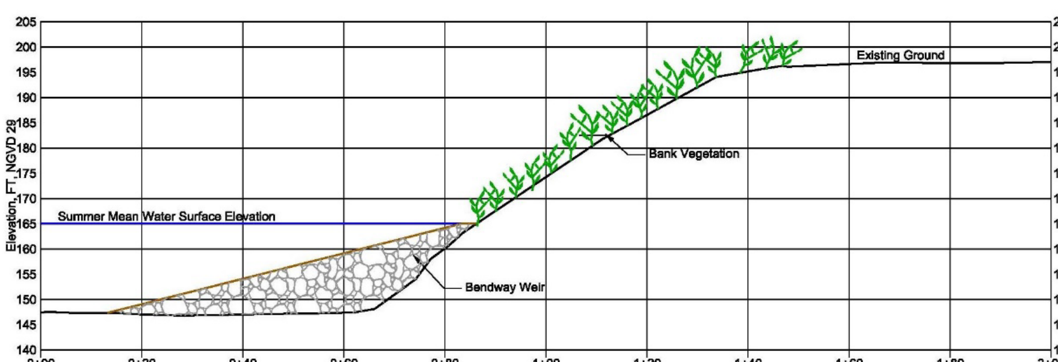


Figure 13. Plan View of Spur Dikes at Woodson Bridge

Figure 14. Cross Section of a typical Spur Dike at Woodson Bridge

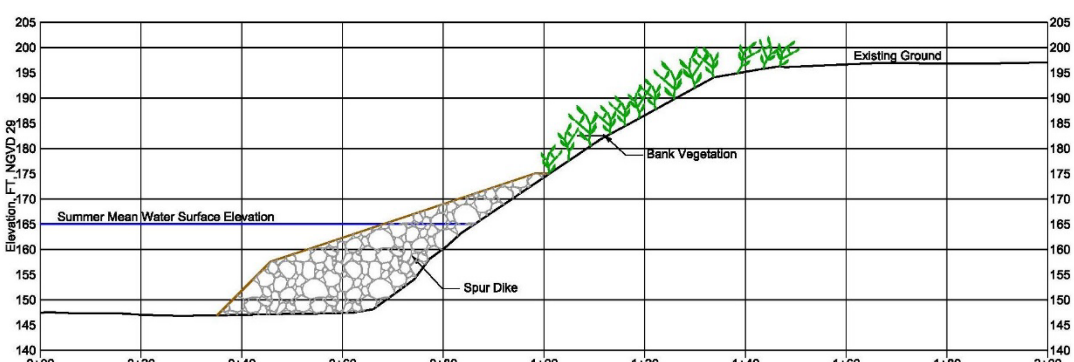


Figure 15. Plan View of Bank Armor/Low Berm Location at Woodson Bridge

Figure 16. Cross Section for Low Berm Protection at Woodson Bridge

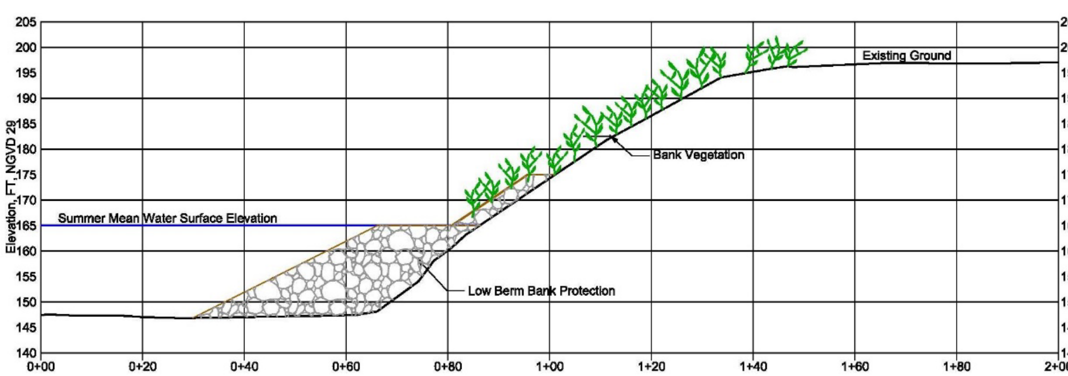
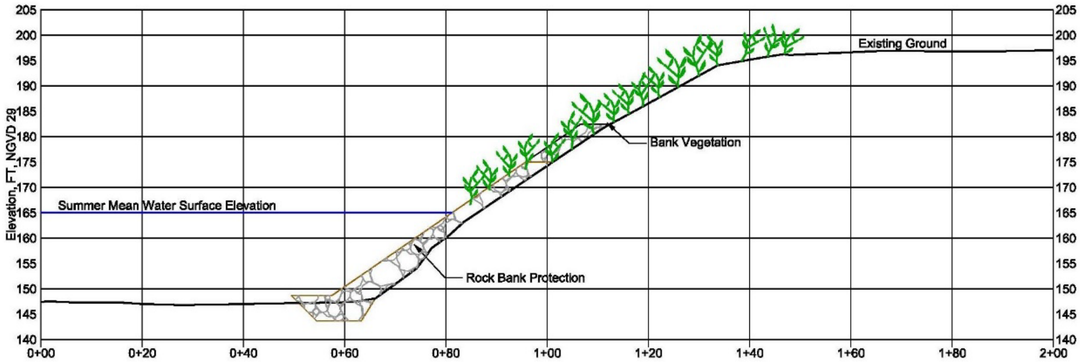


Figure 17. Cross Section for Bank Armor Protection at Woodson Bridge



The preliminary construction costs for this element are shown in **Table 3**.

Table 3. Preliminary Construction Cost Estimate for Erosion Protection at Woodson Bridge

Erosion Protection Option	Cost
Bendway Weirs	$1,144,630
Spur Dikes	$972,940
Low Berm	$2,661,270
Bank Armor	$1,430,790

The bendway weirs would redirect the flow more towards the opposite bank. However, the redirection of flow could affect the boat launch and the Woodson Bridge footings, located on the opposite bank. Since the location is considered boating recreation area there is a concern that the spur dikes could be a hazard to boaters and would therefore be unlikely to be selected. Because of the pinch point at the bridge crossing, the low bench could slightly reduce the cross sectional area and likely increase the water surface or velocity through the bridge. The bank armor with upper bank vegetation was the chosen option for hydraulic modeling.

2.5 Erosion Protection at the City of Corning Sewer Outfall

The bank near the City of Corning sewer outfall has some rock, but the soil is not the erosion resistant Tehama formation found upstream, and changes in the river may cause erosion. An erosion pocket is forming a few hundred feet upstream, which could continue downstream without protection. To prevent this from occurring, erosion protection options were considered to protect the existing infrastructure. Protecting the City of Corning sewer outfall consists of five different measures: no improvements, bendway weirs with bank vegetation, bank armor with vegetation, low berm with bank vegetation, and spur dikes with bank vegetation.

The bendway weirs act to redirect the flow away from the bank and back into the middle of the channel. This would redirect the high velocities away from the erodible soils in the vicinity of the

City of Corning sewer outfall. The weirs are placed at an angle to ensure the redirection of flow and extend to the middle of the channel. The design for this study includes 6 weirs, spaced 100 ft apart, protecting 500 ft of bank, as shown in **Figure 18**. The top of the weir would be at the summer low flow water level and may require the use of buoys to prevent them from becoming a navigational hazard. The configuration of these weirs is shown in **Figure 19**. Vegetation would be placed along the existing bank to provide additional erosion protection, environmental features, and for aesthetics.

The next measure for protecting the City of Corning sewer outfall was the use of spur dikes with bank vegetation. Spur dikes are similar to bendway weirs; however they are designed differently to produce deposition on the banks rather than redirect flow. For this design 6 dikes would extend perpendicular to the banks into the channel, spaced approximately 100 ft apart for 500 ft, as shown in **Figure 20**. The configuration of the dikes is shown in **Figure 21**.

Bank armor was considered for the City of Corning sewer outfall and would extend approximately 900 ft in the location shown in **Figure 22**. The bank armor would consist of toe rock and continue up the bank until the velocities dropped below 5 ft/s. Bank vegetation will be planted on the upper bank to provide additional protection and a more natural aesthetic look. The configuration of this measure is shown in **Figure 23**.

Another option for protecting the City of Corning sewer outfall is building a low berm. The low berm would cover the same area as the bank armor, as shown in **Figure 22**. The berm would extend out approximately 20 ft at the summer low flow water surface elevation with a 2:1 slope to the bottom of the channel. Rock will need to be placed half way up the bank slope where the velocities are greater than 5 ft/s. The upper slope will also be protected with bank vegetation. The configuration of this design is shown in **Figure 24**.

Figure 18. Plan View of Bendway Weirs at the City of Corning Sewer Outfall

Figure 19. Cross Section of a typical Bendway Weir at the City of Corning Sewer Outfall

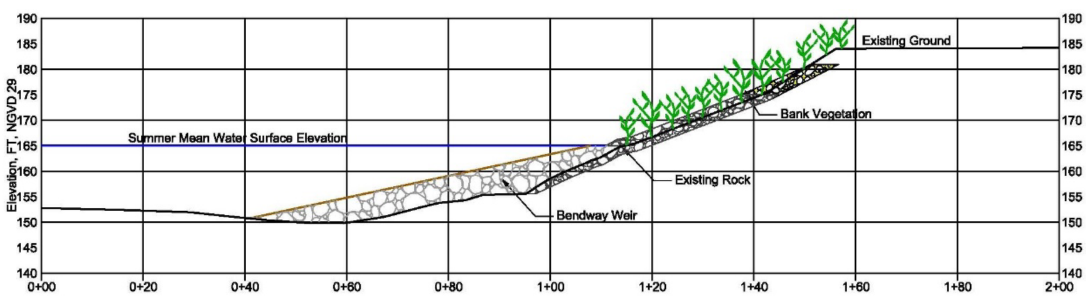


Figure 20. Plan View of the Spur Dikes at the City of Corning Sewer Outfall

Figure 21. Cross Section of a typical Spur Dike at the City of Corning Sewer Outfall

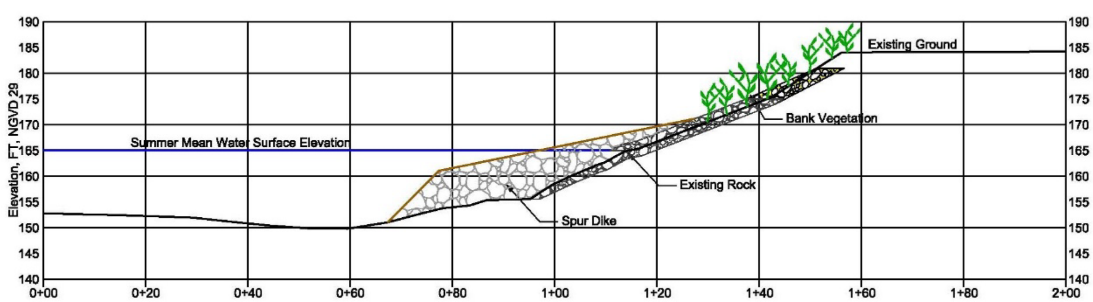


Figure 22. Plan View of Bank Armor/Low Berm at the City of Corning Sewer Outfall

Figure 23. Cross Section of the Bank Armor at the City of Corning Sewer Outfall

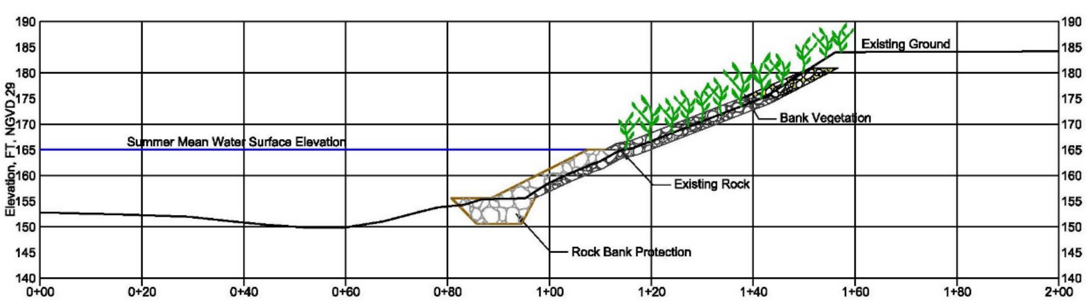
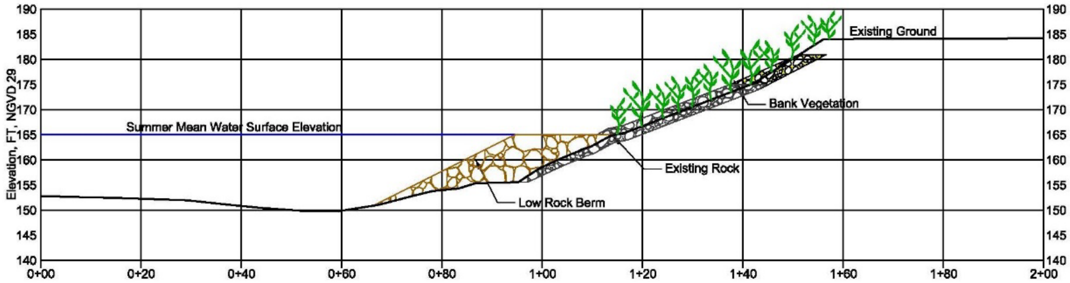


Figure 24. Cross Section of the Low Berm at the City of Corning Sewer Outfall



The preliminary construction cost estimates for the erosion protection at the City of Corning sewer outfall is shown in **Table 4**.

Table 4. Preliminary Construction Cost Estimates for Erosion Protection at the City of Corning Sewer Outfall

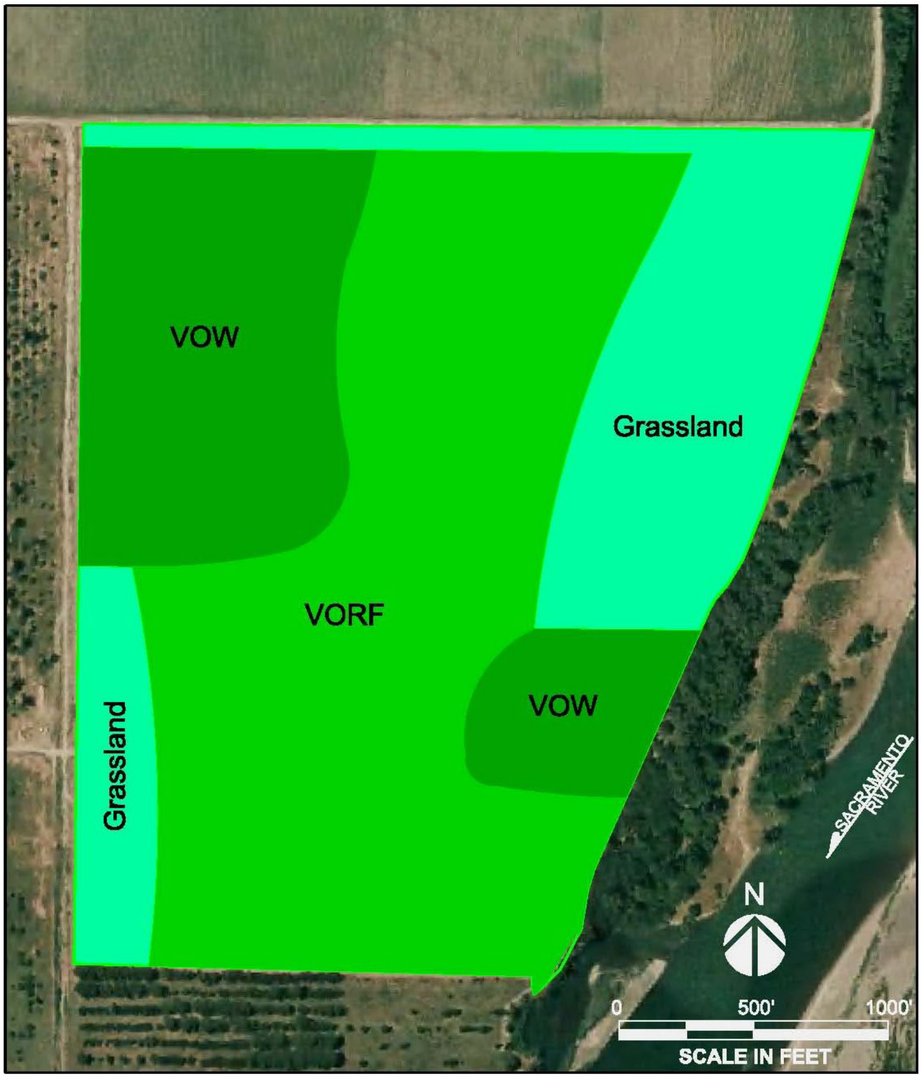
Erosion Protection Option	Cost
Bendway Weirs	$363,490
Spur Dikes	$309,456
Bank Armor	$908,720
Low Berm	$491,200

The bendway weirs and spur dikes options were eliminated from further consideration because of the potential hazard for boaters at water levels near their crest elevations. The low berm option was selected for hydraulic modeling since the bench would also help dissipate the energy of the sewer releases.

2.6 Habitat Restoration on Kopta Slough Property

The habitat restoration site is on the right overbank floodplain between RM 221 and 222. For this element the choice is to either have a full riparian planting or to base planting on what the soil can support and what will have the least effect to the system. Many habitat restorations have been performed on the upper Sacramento River, and the best results have come from planting a mix of forest, savannah, and grassland. After discussions with The Nature Conservancy, a plan was made for the best layout of the existing soil types and depth to ground water table. The habitat restoration includes 85 acres of Valley Oak Riparian Forest (VORF) through the center of the restoration site, 45 acres of Valley Oak Woodland (VOW), and 47 acres of grassland. The upstream end of the restoration site includes a grassland buffer. The layout of the proposed restoration is shown in **Figure 25**.

Figure 25. Habitat Restoration Plan for the Kopta Slough Property



3.0 HYDRAULIC MODELING ANALYSIS

3.1 General

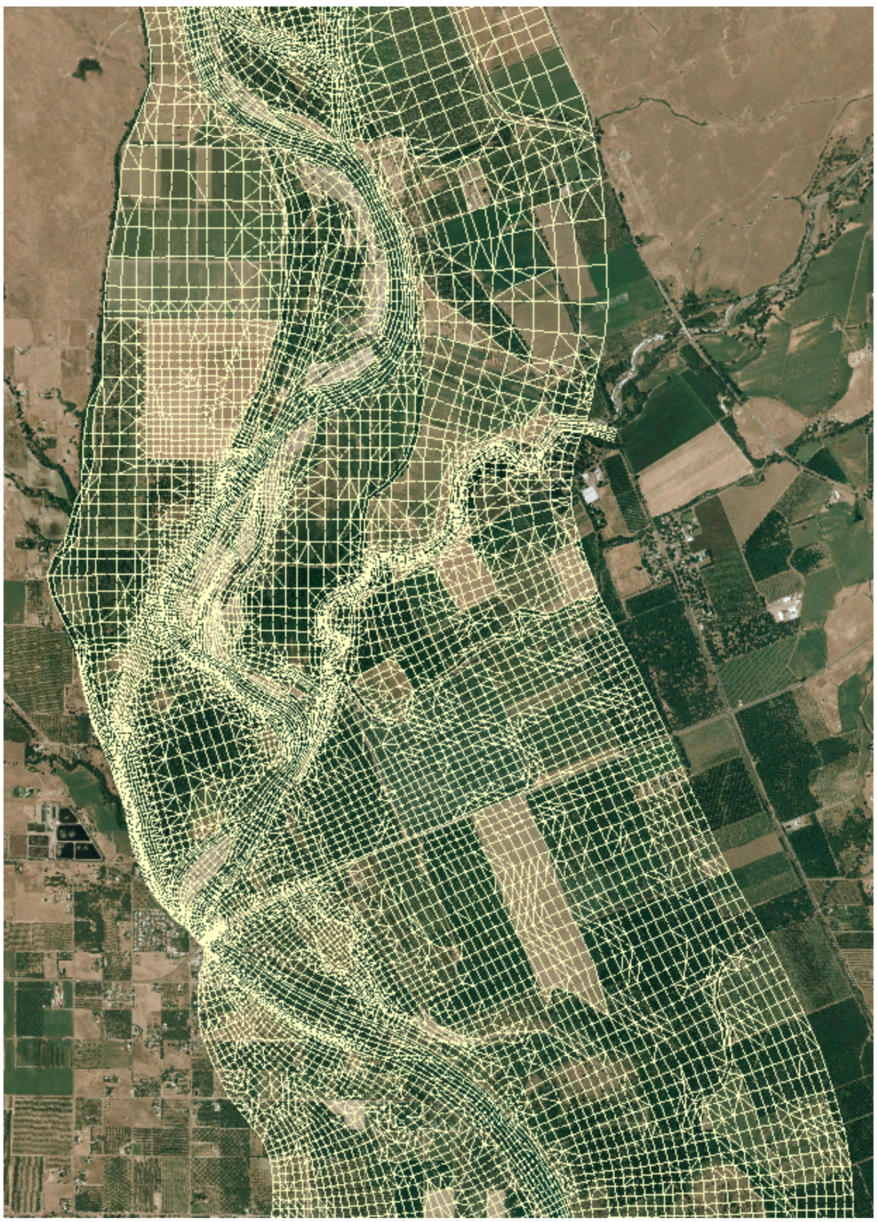
The two dimensional (2D) hydraulic modeling tool used for this study was the RMA-2V program, maintained and distributed by the USACE and modified by Ayres Associates. The program has been used extensively for similar projects on the Sacramento River and has proven to be an effective model for representing river and overbank flow conditions. The Surface-Water Modeling System (SMS), Version 10 software was used to develop the model and view model results.

3.2 Model Development

The geometric definition of the study reach is depicted in the form of a finite element network of triangular and quadrilateral elements known as a mesh. The mesh (overlaid on an aerial) developed for this study is shown in **Figure 26**. The elements were sized and oriented to represent hydraulic features, breaklines, structures, and topographic changes. Each element contains corner and mid-side nodes that represent a point in space (X, Y, Z) and define the topography of the study reach. Each element is assigned a material type that represents the land use using Manning's roughness values. For Woodson Bridge, the piers and embankment were modeled as holes in the mesh.

The topography used to develop the mesh came from three mapping efforts. The initial mesh was developed with the 1997 USACE Sacramento River mapping downstream of RM 218, and the 1998 DWR Sacramento River mapping was used for upstream of RM 218. These two topographies were used for the calibration run. The model was subsequently updated for the existing and with study conditions using the channel conditions from the 2008 topography and bathymetric data provided by DWR.

Figure 26. Finite Element Mesh



3.3 Material Roughness

The material types within each element were categorized based on land use and roughness characteristics. The material types were assigned to each element in the mesh based on aerial photography from 1998 for the calibration run and 2006 for the existing and developed conditions. The Rio Vista Unit (swale restoration) was updated based on drawings published by US Fish & Wildlife. Field reviews were performed on November 6, 2008 and December 18, 2008, to verify the land uses, check existing bank protection, investigate the swales on the Rio Vista Unit, and double check eroded bank locations. A summary of the roughness values used for this study is listed in **Table 5**. The initial roughness values were assigned based on previous modeling efforts in this area and refined based on the calibration.

Some land use names require definitions. The “bridge footprint” represents the areas around the bridge footing where there are eddy current effects. The “orchard/homes” represents an area that is mixed with homes and surrounding orchards. The “trailer park/forest” represents an area that is mixed with trailers and riparian forest. The land use “Valley Oak Riparian Forest” does not represent a different land use than the “riparian forest,” but the label was used to distinguish it as the habitat restoration on the Kopta Slough property.

The land use values were not adjusted for different flow events. In some cases the roughness values need to be adjusted for flow depths; however that was not the case for this analysis. For example, if the flow depth through an orchard is only at the tree trunk level, then the value would be lower than if the depth was into the branches. Since the 100-year and the 10-year event flows (which use the floodplains) are relatively large, a variation in the roughness values was not used. For the bankfull event, the flow was mostly confined to the channel. The main channel in this reach of the river is deep and so the roughness was not adjusted as if might be for a wider-shallow channel.

The land use plots for the existing conditions bankfull, 10-year, 100-year, Scenario 1, Scenario 2, Scenario 3, Scenario 4, Scenario 5, and Scenario 6 are in the Appendix on Plates 1, 6, 11, 16, 25, 34, 43, 52, and 61, respectively. Only the areas inundated by the flood event are shown on the maps.

Table 5. Material Roughness

Land Use	Manning’s Roughness Value
Bridge Footprint	0.05
Channel	0.025
Crops	0.035
Highway	0.014
Light Forest	0.07
Orchard	0.07
Orchard/Homes	0.075
Pasture/Grassland	0.025
Revetment	0.045
Riparian Forest	0.11
Sand/Gravel Bar	0.035
Savannah	0.04

Land Use	Manning’s Roughness Value
Shrubs	0.06
Side Channel	0.035
Structures	0.20
Trailer Park/Forest	0.12
Valley Oak Riparian Forest (VORF)	0.11
Valley Oak Woodland (VOW)	0.05
Young Riparian	0.08

3.4 Boundary Conditions

The limits of the hydraulic modeling are RM 224 to 216 on the Sacramento River and approximately 2 miles of Deer Creek, as shown in **Figure 2**. The boundary conditions for the calibration model were provided by DWR Northern Region Office. This storm event was chosen given the availability of data, the significant high flow, and the availability of surveyed high water marks.

The flows for the storm events were provided by the USACE based on the best available data. The Water Management Section of the USACE ran a new Hamilton City storm centering analysis to develop appropriate hydrographs to estimate the 100-year, 10-year, and 2-year flows.

For the bankfull event, the flow is typically a 2-year flood event. However, the previous modeling effort found that a 2-year flood (100,270 cfs) was slightly higher than bankfull. An iterative process was used to lower the flow until the model was at bankfull conditions at the bridge and downstream. Given that there are areas of low ground, some overbank areas were still wet.

For the bankfull model a normal depth calculation was used for the downstream boundary. However, for the other runs where there was a large amount of overbank flow, normal depth did not provide results that were reliable and the elevations from the USACE UNET model (Comprehensive Study) were used.

The boundary conditions for all flow events are summarized in **Table 6**.

Table 6. Boundary Conditions

Flood Event	Flow at Vina Gage	Sacramento River Inflow (at RM 224)	Deer Creek Inflow	Downstream Water Surface Elevation (RM 216)
	cfs	cfs	cfs	ft
Calibration	199,700*	175,700	24,000	181.5
Bankfull	95,100	90,000	5,100	172.5
10-year	168,548	154,518	14,030	180.00
100-year	293,700	267,033	26,667	184.7

* 154,000 cfs through the bridge section and 45,700 cfs in the overbank.

4.0 HYDRAULIC MODELING SCENARIOS

Multiple hydraulic runs were performed for this analysis. Since it was not feasible to run each element separately, the scenarios are an aggregate of the selected elements. In addition, running an aggregate of the elements will show us if there are any combined hydraulic effects from the multiple elements, and may result in the greatest increases. Since the habitat restoration element is the most likely to be implemented in any project configuration, it was included in all the scenarios, as well as a scenario where it is the only element. The chosen scenarios are described in detail in the following sections.

4.1 Calibration Run

The calibration run consists of performing a hydraulic model with known variables to ensure accuracy of the model. For this study, the model was calibrated to the 1997 high flow event because good data was available from this historic flow. The 1997 USACE and 1998 DWR bathymetric mapping and aerial imagery from 1998 were used to identify land uses during the storm event. Known calibration points consisted of data from the gage adjacent to Woodson Bridge (Sacramento River at Vina Bridge [Vina gage], DWR No. A02700) and two additional surveyed points on Deer Creek. The Manning's roughness values from the previous modeling effort were used and adjusted so the modeled water surface elevations matched actual measured water surface elevations.

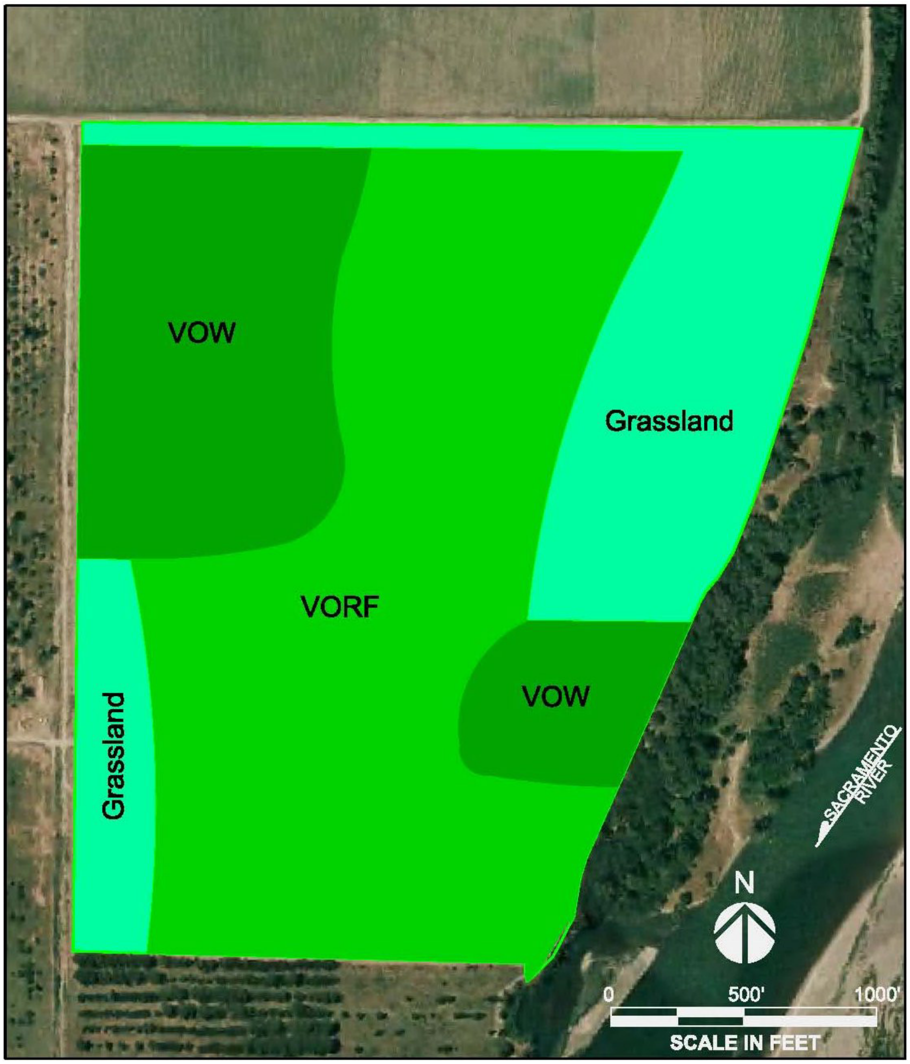
4.2 Existing Conditions Model Run

The existing conditions runs simulate the present (late 2008) condition of the river under 3 flow conditions, 100-year event, 10-year event, and a bankfull flow. The topography for this run, as well as the proposed scenarios, was from a bathymetric survey of the study reach conducted by DWR in 2008 and merged with the previous 1998 DWR topography for complete coverage of the study area. The overbanks of the DTM were also verified for accuracy. With the new mapping, the alignment of the channel moved slightly in spots, and in-channel sand/gravel bars had changed. Aerial imagery from 2007 was used to update the land uses; these were verified by a field reviews on November 6, 2008 and December 19, 2008.

4.3 Scenario 1 – Habitat Restoration, 100-year Event

Scenario 1 simulates the 100-year flow in combination with the restoration condition for the Kopta Slough Property. The model represents a restoration condition to the Kopta Slough property. The area of proposed restoration is used for crops, which is alfalfa in the existing condition. The restoration habitat consists of a mixture of Valley Oak Riparian Forest (VORF), Valley Oak Woodland (VOW) and Grassland, as shown in **Figure 27**.

Figure 27. Habitat Restoration Plan for the Kopta Slough Property



4.4 Scenario 2 – Habitat Restoration, Rock Removal, Bank Protection, 10-year Event

Scenario 2 simulates a 10-year flow in combination with habitat restoration on Kopta Slough property, removal of existing rock bank protection, and bank protection at Woodson Bridge and the City of Corning sewer outfall. The restoration habitat is the same as described in Scenario 1. The rock revetment removal will be from the right channel bank from RM 220 to 221, roughly one and a half miles of rock, as shown in **Figure 28**. The cross section view of the rock removal is shown in **Figure 29**. The rock will be removed as shown in the figure, the high berm along the bank will be lowered to floodplain elevation, and the land use will be changed to shrubs. The land use category of shrubs best represents the post-revetment removal condition in that they are likely to grow on the site (given their presence in the surrounding areas). The modeled roughness represents the eventual full growth condition for the greatest potential hydraulic effects. The bank protection will consist of rock armor for the protection of Woodson Bridge, and a low berm for the protection of the City of Corning sewer outfall, as shown in **Figure 30**. Cross sections showing the rock armor and low berm protection are shown in **Figures 31** and **32**, respectively. The ground elevation will be changed to match the rock design and the land use will be changed to revetment. The rock will extend up the bank to the elevation where the velocity is greater than 5 ft/s.

Figure 28. Location of Rock Revetment Removal

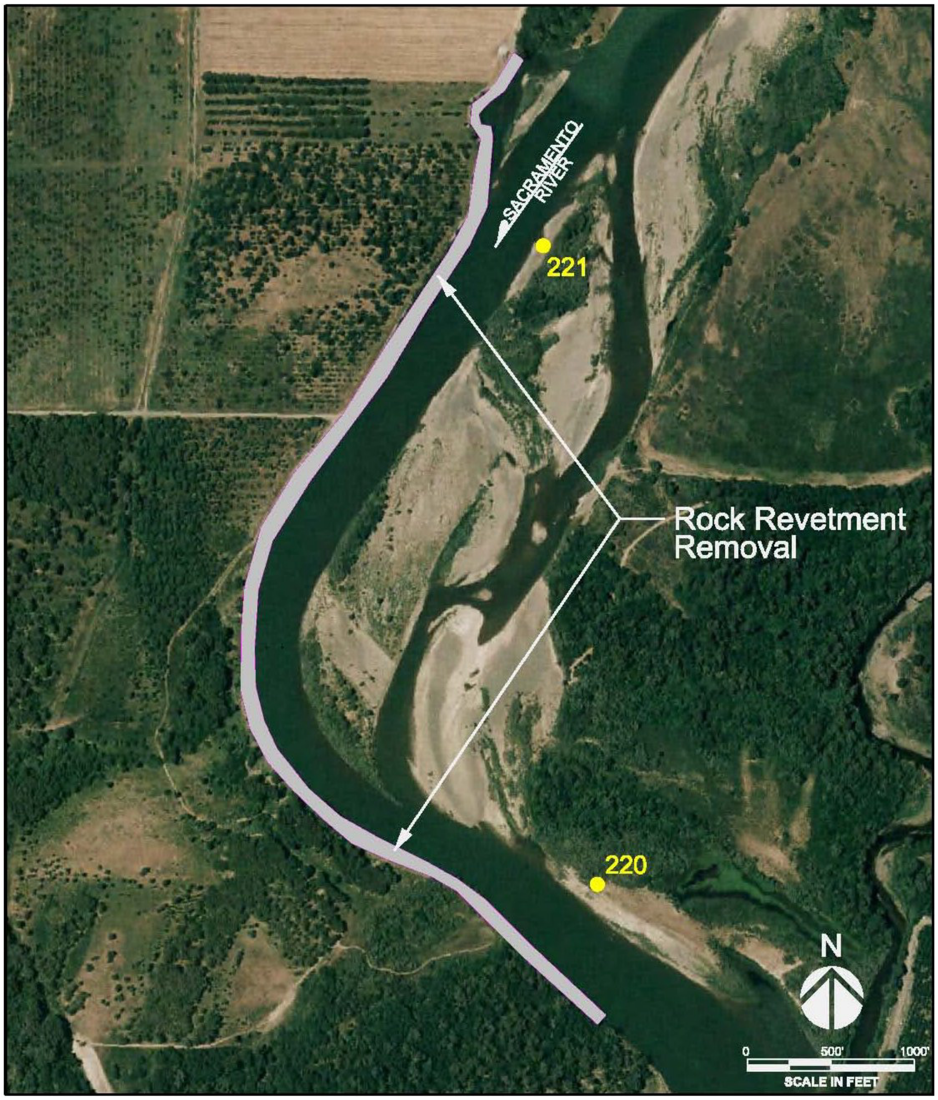


Figure 29. Cross Section showing Rock Revetment to be Removed

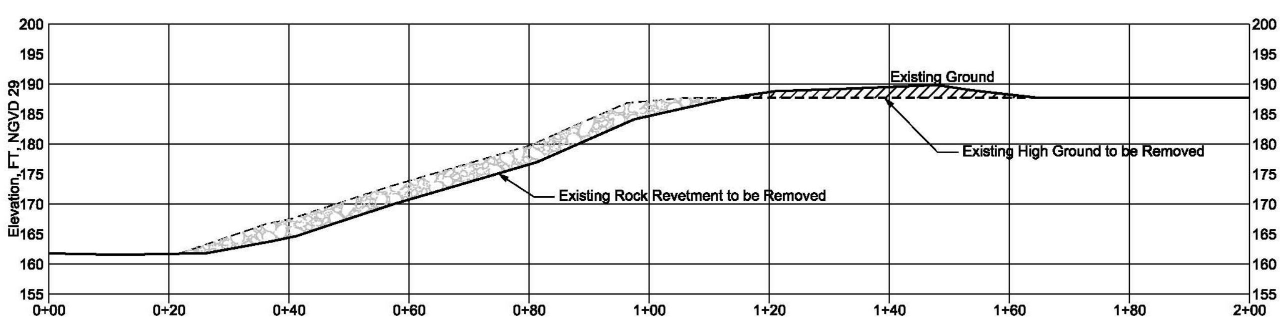


Figure 30. Location of Bank Protection at Woodson Bridge and the City of Corning Sewer Outfall

Figure 31. Cross Section showing Rock Armor Protection at Woodson Bridge

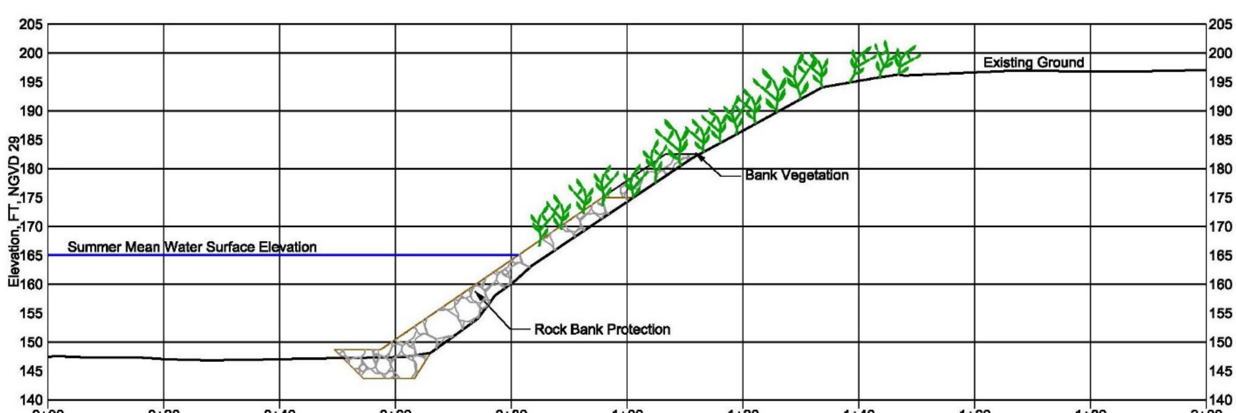
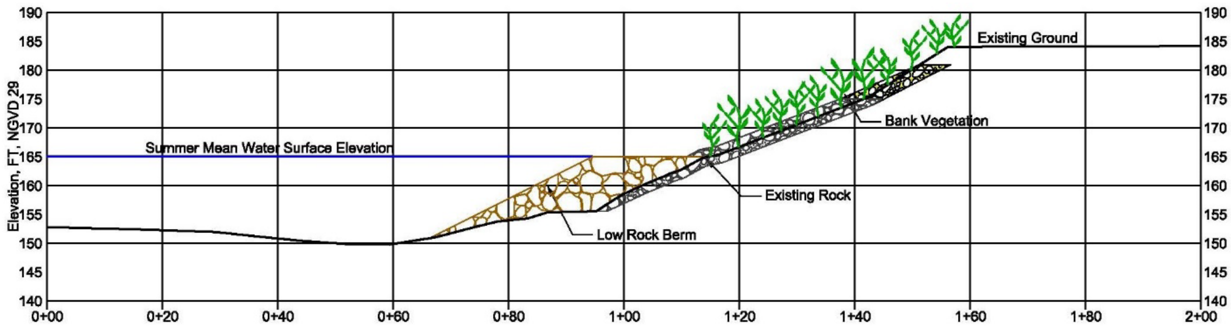


Figure 32. Cross Section showing Low Berm with Rock Armor at the City of Corning Sewer Outfall



4.5 Scenario 3 – Habitat Restoration, Rock Removal, Bank Protection, 100-year Event

Scenario 3 represents a 100-year flow in combination with habitat restoration on the Kopta Slough property, removal of existing rock bank protection, and bank protection at Woodson Bridge and the City of Corning sewer outfall, as described in Section 4.4.

4.6 Scenario 4 – Habitat Restoration, Bank Protection, Kopta Connection, 10-year Event

Scenario4 simulates a 10-year flow in combination with the restoration condition on the Kopta Slough property, bank protection at Woodson Bridge and the City of Corning Sewer Outfall, and a full channel connection to Kopta Slough. The restoration habitat is the same as described in Scenario 1. The bank protection is the same as discussed for Scenario 2. The alignment of the full channel connection to Kopta Slough is based on the recommended alignment by our geomorphologist from the previous study, as well as the low ground elevations and the river's natural tendency to flow through this location during high flows. The connection channel would be approximately 110 ft wide on the bottom (based on present bottom width of existing Kopta Slough), extend from the Sacramento River channel invert to the Kopta Slough channel invert, and have 2:1 side slopes. The Kopta Slough invert elevation at the entrance will be at elevation 160 ft (NGVD), about a foot higher than the Sacramento River elevation. The channel slope will be linear to the existing top of Kopta Slough (roughly 0.0028 slope). The configuration of this full connection channel is shown in **Figure 33,** and the cross section is shown in **Figure 34**.

Figure 33. Alignment of the Kopta Slough Reconnection Channel.

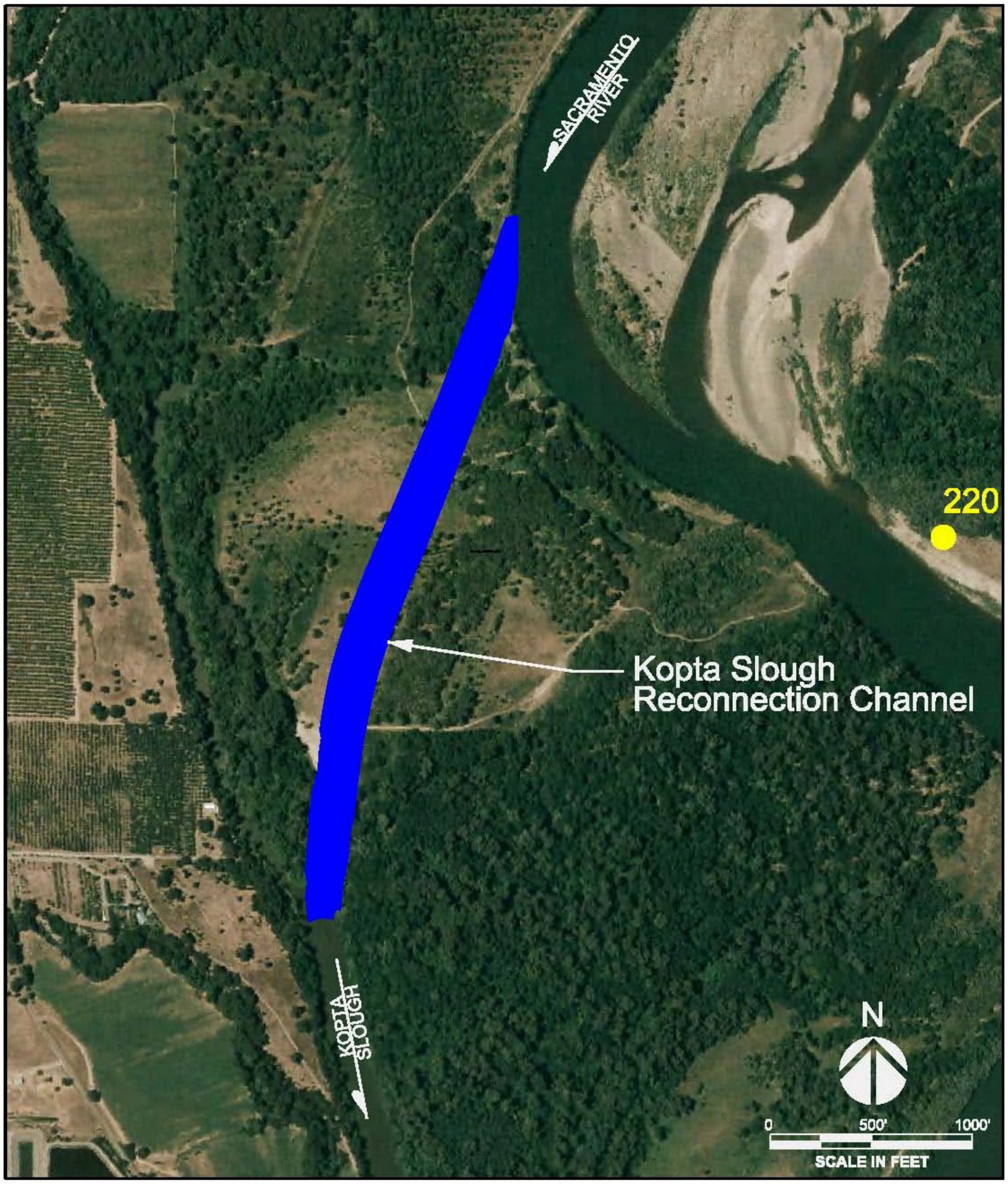
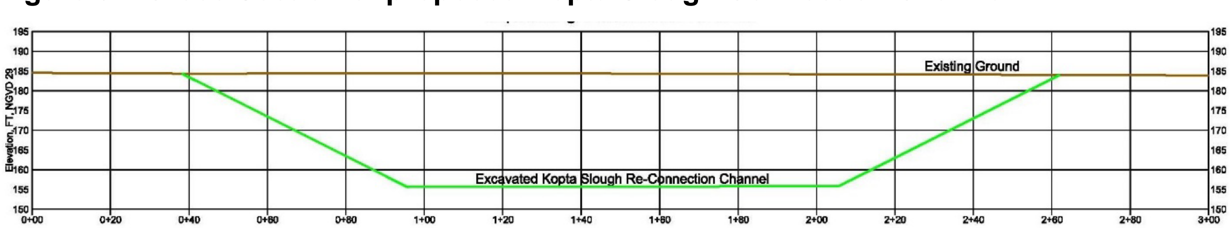


Figure 34. Cross Section of proposed Kopta Slough Connection Channel



4.7 Scenario 5 – Habitat Restoration, Bank Protection, Kopta Connection, 100-year Event

Scenario 5 represents a 100-year flood event, with habitat restoration on the Kopta Slough property, bank protection at Woodson Bridge and the City of Corning Sewer Outfall, and a full channel connection to Kopta Slough, as described in Section 4.6.

4.8 Scenario 6 – Habitat Restoration, Bank Protection, Kopta Connection, Bankfull Event

Scenario 6 represents a bankfull flood event, with habitat restoration on the Kopta Slough property, bank protection at Woodson Bridge and the City of Corning Sewer Outfall, and a full channel connection to Kopta Slough, as described in Section 4.6.

5. 0 CALIBRATION

Hydraulic model calibration is performed to establish the accuracy of a model, typically by simulating a historic flow with documented high water marks. The first attempt at calibration was to the January 2, 1997 peak flood event using the recorded stage at the Vina stream gage. The peak flow recorded by DWR at the Vina gage was 154,000 cfs and the recorded stage was 186.57 ft (converted to NGVD 29). The USGS gage on Deer Creek near Vina reported a flow of 24,000 cfs.

However, we subsequently learned that the Vina gage is calibrated to only record the flow through the Woodson Bridge section (main river section) and the flow in the overbank area (across South Avenue) is not included in the total.

The total flow to the system was not known; therefore, a second attempt to calibrate was tried using different estimated flow splits (overbank vs. main channel) to determine if we could solve the hydraulic model and achieve the correct flow through the Woodson Bridge section. However, we finally realized that this was a very slow process, and there were too many unknowns for this calibration to be successful.

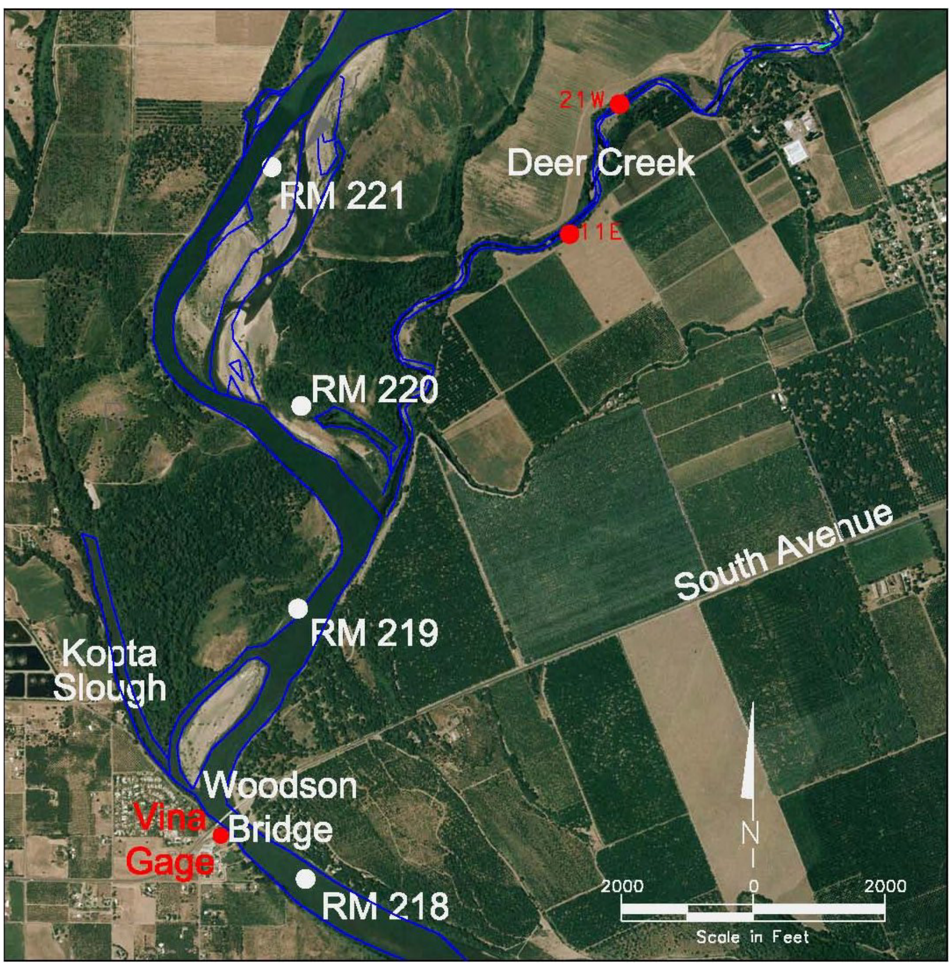
Finally, in order to get a better estimate of the flow split at the bridge we investigated available historic data. DWR was able to provide detailed records for the January 24, 1970 flood event where measurements were made for both the Woodson Bridge section (main river section) and the overbank flow across South Avenue. For this event, the flow through the main channel was 162,900 cfs and the overbank flow was 53,800 cfs. This was a 75/25 percent flow split. Since this appeared to be the only recorded data for both the main channel and the overbank floodplain, it was used to as the most reliable piece of data to estimate the percentage of flow in the overbank for the 1997 event. However, the 1970 event could not be run as a calibration event since we did not have the river topography for that particular event nor adequate aerial information to accurately assign model roughnesses for the land uses in the overbank. However, we did find aerial imagery from 1976 and it generally showed that there was slightly less dense vegetative growth than the current condition (approximately 10 % less), so we estimated a 10% reduction in the overbank flow to account for the increase in vegetation density. This resulted in an estimated overbank flow of 45,700 cfs, for a 77/23 percent flow split (main channel/overbank).

There were only three documented high water marks in the study area, as shown in **Figure 35**. One of them was located at the Vina gage on the Sacramento River. The Vina gage recorded elevation data in 15 minute increments. This high-water mark is the most important since it is within the study area. Surveyed high water marks (21W and 11E) were located on Deer Creek and are close to the model boundary, which does not make them ideal for comparisons. Therefore, we adjusted the roughness values in the system to approximate the flow within the main channel section and the water surface elevation at the gage. Through many trial runs, we narrowed in on roughness values that gave us the closest values for documented flow through the bridge section at the recorded water surface elevation.

The final run for the calibration model resulted in a in-channel flow of 151,029 cfs at the bridge section, which is about 3,000 cfs less than the recorded, (roughly a 2% difference) at a water surface elevation of 187.63 ft (NGVD), about one foot higher than the recorded stage (186.57 ft) which was considered to be more than adequate to demonstrate any hydraulic differences in the proposed elements.

In the exercise to calibrate this model, we learned that there were too many unknowns to call this a truly calibrated model throughout the entire study reach. However, it is considered adequate for a before and after comparison of the impacts of the alternatives reviewed in this study. The results of this modeling should be further refined if they are to be used for the determination of detailed water surface elevations or base flood levels.

Figure 35. High Water Marks



6.0 RESULTS

We have presented in the results section the velocity, water surface elevations, and shear stress values. Typically the range of values is shown in contour fashion along with some point maximum values. All graphics relating to the results are provided on plates in the **Appendix**.

6.1 Bankfull Event – Existing Conditions

The bankfull, existing conditions, results for velocity, water surface elevation, and shear stress are provided in **Plates 2 – 5**. The velocity results show that while most of the water is contained within the channel banks, some flow is on the sand/gravel bars adjacent to the river and in the overbank area adjacent to Kopta Slough where the ground elevations are low. The velocities in the main channel range from about 4 ft/s to slightly more than 10 ft/s. A maximum point velocity of about 11.1 ft/s is adjacent to the left bank of the Woodson Bridge SRA at about RM 219, as shown on Plate 2. This bank is protected with rock; however, just downstream, velocities are in the 7 to 8 ft/s range and the bank is actively eroding. The velocity is up to 13.5 ft/s through the bridge section, with slightly higher velocities adjacent to the piers. Velocities reach 9 ft/s at the location of the City of Corning sewer outfall. The velocity is slow, roughly below 2 ft/s, and non-erosive in the overbank areas.

For shear stress, typically values above 0.5 psf are considered erosive for vegetated banks. The bankfull model shows that the shear stress throughout the majority of the river is below the 0.5 psf threshold, and therefore, non-erosive from a shear stress perspective. Along the right bank at RM 223, the shear stress is high and potentially erosive. This area is subject to eddy currents and appears to have eroded slightly over the years; however the process is slowed from the adjacent road. The shear stress at the bend at RM 220.5 is greater than 1.0 psf; however the rock protection that is along the bank is resistant to the higher shear stresses. The shear stress is up in the 2 psf range along the left bank adjacent to the Woodson Bridge State Recreation Area (SRA). This bank is actively eroding and erodes even during lower flow events. The shear stress is greater at the upstream ends of the in-channel sand/gravel bars where the river is actively eroding.

6.2 10-year Event, Existing Conditions

The 10-year existing conditions results for velocity, water surface elevation, and shear stress are provided in **Plates 7 - 10**. The results show significant overbank flow, with the total floodplain width ranging from one and a half to two miles. The velocity within the channel is greater than 5.0 ft/s and the overbanks are generally less than 3 ft/s. Peak velocity of 10.7 ft/s occurs adjacent to the left bank of the Woodson Bridge SRA, as shown on Plate 7. Velocities approach 12.1 ft/s on the sand/gravel bar on the left bank, adjacent to the Woodson Bridge SRA, just upstream of the bridge. The velocity remains high through the bridge section with peaks on the piers of up to 15 ft/s. The velocity adjacent to the City of Corning sewer outfall is 10.5 ft/s and most likely is causing the current erosion. In the overbank, where the Kopta Slough connection is proposed, the velocity is up to 4.3 ft/s and is most likely eroding a small area in the floodplain.

For shear stress, almost all of the overbanks are non-erosive, and only localized areas are considered erodible along the channel banks. Just upstream of the existing Kopta Slough channel, the shear stresses are 2.2 psf and considered erosive. The shear stress along the right bank at RM 223 is about 2.5 psf, and further erosion is likely. The shear stresses are greater than 2 psf along the right bank at RM 220 to 221; however the rock armor is preventing erosion.

Along the sand/gravel bar of the left bank on the upstream side of Woodson Bridge, the shear stress reaches 3 psf and is eroding. The historic banklines (Figure 3) show that this bank has been receding for years. On the right bank of the Woodson Bridge, the shear stresses are just above 2 psf, and the bank is visibly eroding. Much of the left bank between RM 216 and 218 has shear stress values between 2 to 3 psf, and bank erosion is likely. The shear stress values at many of the sand/gravel bars are high, and erosion is likely.

The embankment along the left bank of the Woodson Bridge separates the in-channel flow from overbank flow. The flow reconnects immediately after the embankment. For the existing 10-year event, 83% (140,800 cfs) of the flow is going through the main channel and under Woodson Bridge, while 17% (27,744 cfs) is flowing through the overbank and across South Avenue.

6.3 100-year Event, Existing Conditions

The 100-year existing conditions results for velocity, water surface elevation, and shear stress are provided in **Plates 12 – 15**. The results show slightly more overbank flow than the 10-year event, with the total floodplain width just over two miles. The velocity in the channel is greater than 6 ft/s and the overbanks are all under 5 ft/s, with most of it under 3 ft/s. The velocity reaches 10.4 ft/s on the left bank adjacent to the Woodson Bridge SRA, as shown on Plate 12, where the bank is eroding. The velocities are quite high through the bridge and for about a half mile downstream, with values above 12 ft/s just downstream of the bridge near the City of Corning sewer outfall. The velocities on the bridge piers reach 15 ft/s, and are probably causing pier scour.

For the shear stress, the majority of the overbank is below the 0.5 psf threshold of erosion on vegetated banks. The shear stress is considered erosive at the upper end of the existing Kopta Slough channel. The shear stress along the right bank at RM 223 is about 2.5 to 4 psf and further erosion is likely. The shear stresses are greater than 2 psf along the right bank at RM 220 to 221; however the rock armor is preventing erosion. Along the sand bar of the left bank on the upstream side of Woodson Bridge, the shear stress reaches 4 psf and is eroding. On the right bank of the Woodson Bridge, the shear stresses are almost 3 psf, and the bank is visibly eroding. Much of the right bank between RM 216 and 218 has shear stress values between 2 to 4 psf, and bank erosion is likely. The shear stress values at many of the sand/gravel bars are high and erosion is likely.

The flow is divided into in-channel flow and overbank floodplain flow from the left bank embankment of Woodson Bridge. For the 100-year event, 57% (168,337 cfs) of the flow is going through the main channel and under Woodson Bridge, while 43% (125,363 cfs) is flowing through the overbank and across South Avenue.

6.4 Scenario 1

Scenario 1 represents habitat restoration on Kopta Slough property run for the 100-year event. The results for velocity, velocity differential, water surface elevation, water surface elevation differential, shear stress, and shear stress differential are provided in **Plates 17 - 24**.

The velocity increases in the proposed grassland section of the habitat restoration on the Kopta Slough property, with a maximum increase of 0.8 ft/s on the southwestern area and 1.1 ft/s in the northeast corner, as shown on Plate 17. The velocity through this section is low, 3 ft/s or less, so the proposed habitat restoration is unlikely to cause erosion on the property or adjacent lands. This scenario does cause an increase in the middle of the main channel of the river, from

4.0 ft/s to 4.7 ft/s, which should not cause any negative effects on the channel banks. The velocity decreases through the Valley Oak Riparian Forest section of the restoration site where the roughness is greater than the existing conditions.

The habitat restoration planting increases water surface elevation on the property and increases of up to 0.1 ft continue for about three-quarters of a mile upstream. The increase stretches nearly the entire width of the floodplain. The greatest increase is 0.35 ft at the upstream end of the restoration site in the grassland buffer. A small area of decrease, with a maximum decrease of 0.22 ft, is at the downstream end of the restoration site and on the adjacent land. This restoration scenario does not affect the amount of in-channel flow under Woodson Bridge.

There are some localized areas of increases in shear stress throughout the VORF section of the restoration. These areas are at the upstream side of the VORF plantings, with maximum increases of 0.4 to 0.5 psf. The existing shear stress is about 0.1 psf or less, so the increases should not cause erosion through the restoration site. Minor areas of increase in shear stress were found along the edges of the restoration site; however the shear stress is still in the non-erosive range.

6.5 Scenario 2

Scenario 2 represents habitat restoration on Kopta Slough property, rock revetment removal at RM 220.5, and bank protection at Woodson Bridge and the City of Corning Sewer Outfall run for the 10-year event. The results for velocity, velocity differential, water surface elevation, water surface elevation differential, shear stress, and shear stress differential are provided in **Plates 26 – 33**.

Most of the changes in velocity are on the restoration property, with small (roughly 0.2 ft/s) increases just west of the habitat restoration and on the sand/gravel bar to the east. Within the habitat restoration on the Kopta Slough property, the grassland areas have increases, with the maximum increase of 0.7 ft/s. Since the velocities are all less than 2 ft/s, the changes should not affect erosion patterns. The removal of the rock revetment on the right bank shows minor increases in velocity of 0.1 to 0.3 ft/s. The velocity increase may cause erosion along the bank and potentially send more water into the west overbank area.

Some velocity increases are along the proposed bank protection. An increase of up to 0.7 ft/s occurs about 800 ft upstream of the bridge, on the right bank, and an increase of up to 0.7 ft/s occurs about 1200 ft downstream of the bridge, on the right bank, as shown in Plate 26. Upstream of the bridge, the velocities are less than 2 ft/s and should not cause erosion. In the downstream area, velocities are between 4 to 5 ft/s; however the bank protection should withstand future erosion. Two small areas about 400 ft and 500 ft south of the bridge show an increase of over 1 ft/s, however this is deceptive, as there was an eddy in this location before and the bank protection has smoothed it out. The velocity increases up to 0.6 ft/s on the bank opposite the rock protection through the sand/gravel bar and boat ramp parking lot. The velocity is still relatively low throughout most of this area; however it could potentially cause erosion on the upstream end of the sand/gravel bar.

The habitat restoration causes an increase in water surface elevation of 0.1 ft for 1000 ft upstream of the Kopta Slough property. There are also two localized areas of 0.2 ft increase in the grassland section of the restoration. There is a tiny section of water surface decrease, no more than 0.1 ft, at the downstream end of the restoration site. The water surface elevation is unchanged from the rock revetment removal or the proposed bank protection at Woodson

Bridge and the City of Corning sewer outfall. The study conditions have minimal effects (less than 0.5%) on the in-channel flow under Woodson Bridge.

This scenario results in small localized changes to the shear stress. In the restoration site, the middle of the VORF has an increase of 0.1 psf. The shear stress increases by almost 0.5 psf along the rock revetment removal section. This increase could cause erosion along the bank. The shear stress increases by more than 2.0 psf along the added bank protection for Woodson Bridge, however the rock should be sufficient to prevent erosion. A small area of 0.5 psf increase occurs on the left bank, downstream of the bridge, and erosion is likely.

6.6 Scenario 3

Scenario 3 represents restoration habitat on Kopta Slough property, rock removal at RM 220.5, and bank protection at Woodson Bridge and the City of Corning Sewer Outfall for the 100-year event. The results for velocity, velocity differential, water surface elevation, water surface elevation differential, shear stress and shear stress differential are provided in **Plates 35 - 42**.

The greatest velocity changes are from the habitat restoration. Velocity increases in the grassland zones, reaching up to 0.8 ft/s in the southwestern corner of the restoration and 1.2 ft/s in the northeastern corner of the restoration. With these increases, the velocity is in the 3 to 4 ft/s range which means erosion is possible, but well-maintained vegetation should prevent it. The property immediately west of the grassland restoration has increases up to 0.7 ft/s; however the velocities are still under 2.5 ft/s, which should not result in erosion. The habitat restoration causes an increase in the main channel up to 0.6 ft/s, putting velocities in the 5 ft/s range. The velocity decreases through out the VORF section of the restoration. Along the rock revetment removal section, the velocity decreases for most of the bank where the rock will be removed. About 700 ft upstream of the bridge, an increase of 0.9 ft/s brings the velocity up to 3.0 ft/s, so no adverse effects should be seen. Another increase from the rock bank protection is about 1200 ft downstream of the bridge thus increasing up to a maximum of 0.8 ft/s and bringing the velocity up to 4.5 ft/s. This increase should not cause any erosion as the rock will protect the bank.

The habitat restoration causes an increase in water surface elevation upstream of the site for about one mile, and the increase stretches the entire floodplain width. The greatest increase in water surface is 0.4 ft in the grassland buffer. The rock revetment removal at RM 220.5 causes no changes to the water surface elevation. There is a 0.1 ft increase for 30 ft just downstream of the bridge from the bank protection at Woodson Bridge. The study conditions have minimal effects (less than 1%) on the in-channel flow (167,231 cfs) under Woodson Bridge and in the overbank floodplain (126,469 cfs).

Shear stress increases in some localized areas throughout the VORF section of the restoration. The increases are all at the upstream side of the VORF plantings, with maximum increases of 0.4 to 0.5 psf. The shear stress is about 0.3 psf or less, so the increases should not cause erosion through the restoration site. Minor increases were also found along the edges of the restoration site; however the shear stress is still in the non-erosive range. The shear stress increases along the bank removal section. The rock revetment was preventing erosion and its removal will likely cause erosion. Increases were found throughout the bank protection at Woodson Bridge; however the rock should prevent erosion.

6.7 Scenario 4

Scenario 4 represents a 10-year event for restoration habitat on Kopta Slough property, connecting Kopta Slough to the main channel, and bank protection at Woodson Bridge and the City of Corning Sewer Outfall. The results for velocity, velocity differential, water surface elevation, water surface elevation differential, shear stress and shear stress differential are provided in **Plates 44 - 51**.

In the habitat restoration site, velocities increase in the grassland zones, with a maximum of 0.7 ft/s, and decreases throughout the VORF zone. There is a small area of increase (up to 0.3 ft/s) on the adjacent land to the west. There is an increase in the channel adjacent to the restoration site; however this is attributed to the Kopta Slough connection.

The reconnection of Kopta Slough increases the velocity in the main channel for about a mile and a half upstream of the slough reconnection. Within the new slough channel, the maximum velocity increase is 3.8 ft/s in the area that had been considered overbank. There is also a large increase in velocity at the upstream end of the existing Kopta Slough, up 3.3 ft/s (flow increases by about 14,000 cfs within the Slough area), which should help move potential sediments through the system. The velocities within the Kopta Slough reconnection section range from 3 to 5 ft/s and should keep the sediment suspended and moving through the system. The reconnection causes an increase in the main channel of 0.25 to 1 ft/s upstream of the reconnection from RM 220.5 to 221.5. The reconnection also results in a decrease of about 0.5 to 1 ft/s in the main channel, downstream of the connection, from RM 218.5 to 220.5. This decrease may slightly slow the existing erosion along the left bank adjacent to the Woodson Bridge SRA. The main channel velocities are between 6 and 8 ft/s and should not cause sediment to drop out. Along the left bank at RM 218.5, there is an increase in velocity from the combined effects of the reconnection of Kopta Slough and the bank protection at Woodson Bridge and the City of Corning sewer outfall. The velocities increase up to 1.5 ft/s in an area of already high velocities (5 to 7 ft/s) so more erosion on the sand/gravel bar is possible.

The reconnection of Kopta Slough causes an increase in water surface elevation, with a maximum of 0.7 ft, isolated to the land surrounding the Kopta Slough reconnection and into a section of the main channel, at RM 219. A large decrease (maximum of 0.65 ft) in water surface elevation occurs upstream of the Kopta Slough connection. The decrease stretches across the entire floodplain and upstream to RM 222. It also negates the increases in water surface elevation from the habitat restoration. The restoration scenario does not affect the amount of in-channel flow under Woodson Bridge.

For shear stress, most changes are in the Kopta Slough and the bank protection areas. In the restoration site, a small increase of 0.1 psf is in the middle of the VORF. At the entrance to the Kopta Slough reconnection, the banks are subjected to stresses of nearly 1 psf. This will cause some erosion at the entrance and may slightly widen the channel at the top. However, the existing rock protection will prevent the entrance from becoming much larger. The shear stress increases by over 1 psf along the banks of the existing Kopta Slough. This should cause some beneficial erosion by widening the existing channel. The shear stress increases by over 1.0 psf at the bank protection site, but the rock protection should prevent erosion.

6.8 Scenario 5

Scenario 5 represents a 100-year event for restoration habitat on Kopta Slough property, connecting Kopta Slough to the main channel, and bank protection at Woodson Bridge and the

City of Corning Sewer Outfall. The results for velocity, velocity differential, water surface elevation, water surface elevation differential, shear stress and shear stress differential are provided in **Plates 53 – 60**.

In the habitat restoration site on the Kopta Slough property, velocities increase in the grassland zones, with a maximum of 1.1 ft/s, and decreases throughout the VORF zone. The area west of the habitat restoration increases by up to 0.6 ft/s, bringing the area up to 3 ft/s, still relatively calm. Small areas in the overbank upstream of the restoration planting also have increases, bringing the velocity up to 5 ft/s and potential for erosion. The velocity in the main channel, from RM 220.5 to 221.5, has increases between 0.5 to 1.5 ft/s from the combined effect of the habitat restoration on the Kopta Slough and the reconnection of Kopta Slough.

The maximum velocity increase within the Kopta Slough reconnection occurs within the first quarter mile of the reconnection channel and increases by as much as 3.4 ft/s. This area had relatively slow velocities (around 2 ft/s) when it was an overbank flow condition, and the velocity for the full flowing channel is near 5 ft/s. This velocity should keep sediment moving through the system and prevent sediment build-up. The upstream end of the existing Kopta Slough has a large increase in velocity, with a maximum of 2.9 ft/s (flow increases by about 11,000 cfs within the slough area), which should help move potential sediments through the system. The reconnection of Kopta Slough results in a decrease in velocity of about 0.3 to 0.7 ft/s through the main channel, from RM 218.5 to 220.5. This decrease may slightly slow the existing erosion along the left bank adjacent to the Woodson Bridge SRA. The main channel velocities from RM 218.5 to 220.5 remain between 7 and 8 ft/s and keep sediment moving through the system.

At the bridge bank protection site, there are slight increases upstream and downstream, but it should not have any significant effect because of rock protection. The opposite bank has an increase in velocity from the combination of the bank protection and the reconnection of Kopta Slough. The velocities increase up to 0.5 ft/s in an area of already high velocities (5 to 6 ft/s) so more erosion on the sand/gravel bar is possible.

The reconnection of Kopta Slough causes an increase in water surface elevation, with a maximum of 0.4 ft, on the land surrounding Kopta Slough. A large area of decrease in water surface elevation is upstream of the slough, from RM 219 to almost 222. A small area of increase (just over 0.1 ft) occurs on the left bank along the Woodson Bridge SRA property at RM 218.5. This increase may result in flooding occurring earlier. Another small area of increase is located at the top of the habitat restoration site, with a maximum increase of 0.12 ft in the grassland buffer. The scenario does not affect the amount of in-channel flow under Woodson Bridge.

Shear stress within the habitat restoration on the Kopta Slough property increases slightly with a maximum 0.5 psf in the VORF area. A small area at the top of a sand/gravel bar, roughly one mile upstream of the restoration, has a shear stress increase of 0.9 psf. At the entrance of the reconnection channel to Kopta Slough, the banks are subjected to stress of 1.8 psf. This will cause some erosion at the entrance and may widen the channel at the top. The existing rock revetment will prevent the entrance from becoming much larger. If the existing rock is eventually removed, erosion is likely. The shear stress increases by 2.8 psf along the banks of the existing Kopta Slough. This should cause some beneficial erosion by widening out the existing channel. The Kopta Slough connection causes some increases in shear stress (maximum of 0.6 psf) along the edges of the large sand/gravel bar in the center of the channel at RM 221. The shear stress increases by just over 2.0 psf along the length of the bank protection for Woodson Bridge and City of Corning sewer outfall, but the rock protection should prevent erosion.

6.9 Scenario 6

Scenario 6 represents a bankfull event for restoration habitat on Kopta Slough property, connecting Kopta Slough to the main channel, and bank protection at Woodson Bridge and the City of Corning Sewer Outfall. The results for velocity, velocity differential, water surface elevation, water surface elevation differential, shear stress, and shear stress differential are provided in **Plates 62 - 69**.

The velocity through the Kopta Slough connection increases by as much as 4 ft/s. During a bankfull event the existing slough is mainly a backwater channel with low velocities and the connection makes it an active channel where the flow increases by about 16,000 cfs. The velocities are between 4 to 5 ft/s, which should keep sediments moving through the system. Just upstream of the entrance to the Kopta Slough, the main channel of the Sacramento River has divided flow around a large sand/gravel bar. The opening up of the floodplain with the reconnection to Kopta Slough results in more flow coming down the right channel (of the divided channel between RM 220 and 221), increasing the velocity over 1 ft/s. The velocity increases from RM 220.5 to 222.5. On the right bank at RM 218.5, the bank protection for Woodson Bridge and the City of Corning sewer outfall causes velocity to decrease. However, the left bank, opposite Woodson Bridge, increases by 2 ft/s through the sand/gravel bar and could cause erosion during lower flow events. There is a decrease in main channel velocity between RM 218.5 and 220.5, which may slightly reduce the on-going erosion along the left bank adjacent to the Woodson Bridge SRA.

The water surface elevation increases by 1.8 ft in the new Kopta Slough channel, in the area that was previously considered backwater. The bank protection and new Kopta Slough channel cause a slight increase (0.1 to 0.2 ft) through the bridge section, and the increase continues for roughly 2,000 ft upstream of the bridge in the main channel. The Kopta Slough reconnection reduces the amount of flow in the main channel between RM 218.5 and 220.5 and reduces the water surface elevation upstream of the reconnection to RM 222.

The reconnection causes increases (maximum of 1.9 psf) along the banks of the existing Kopta Slough, which will likely cause erosion and channel widening. The shear stress increase at the entrance of the Kopta Slough should cause erosion and channel widening; however the existing bank protection will limit the amount. The shear stresses decrease slightly (0.1 to 0.2 psf) through the main channel between RM 218.5 and 220.5. This reduction on the left bank adjacent to the Woodson Bridge SRA will slightly reduce the stress on the currently eroding bank. At the Woodson Bridge bank protection site, the shear stress increases by as much as 1.5 psf, but the rock should prevent erosion.

7.0 CONCLUSIONS

Based on the results of the hydraulic modeling we offer the following conclusions:

- The study elements selected for hydraulic analysis were the full height and full vertical length of rock removal at RM 220.5, channel connection to the existing portion of Kopta Slough, bank armor with upper bank vegetation at Woodson Bridge, low berm with upper bank vegetation at the City of Corning sewer outfall, and habitat restoration on the Kopta Slough property as per TNC guidelines.

- For Scenario 1, the restoration site and the main channel have some velocity increases. The water surface elevation increases slightly for about 3/4 of a mile upstream from the site. Shear stress increases in localized areas. These changes should not have any negative effects on the river or increase erosion potential.

- For Scenario 2, the restoration site, rock revetment removal area, and the bank protection areas show some velocity increases; however none of the increases should cause further erosion. Only the restoration site has minor increases in water surface elevation. The shear stresses along the rock revetment removal at RM 220.5 increase and could cause erosion.

- For Scenario 3, the restoration site has some velocity increases, which should not cause erosion with well-maintained vegetation. The proposed bank protection area has some localized velocity increases, which the bank protection should protect from erosion. Minor increases in water surface elevation occur upstream of the restoration site and just downstream of Woodson Bridge. Some localized areas of shear stress increases occur at the restoration site, the rock revetment removal, and bank protection areas, but they should not cause erosion.

- For Scenario 4, the velocities increase within the habitat restoration site, Kopta Slough reconnection, and the bank protection areas. The increases through the Kopta Slough reconnection are due to the newly created channel, and velocity should be high enough to keep sediment moving through the slough. The decrease in velocity between RM 218.5 and 220.5 may slightly reduce the on-going erosion on the left bank adjacent to the Woodson Bridge SRA. The water surface elevation increases through the created Kopta Slough channel. Localized areas of shear stress increase occur on the restoration site and bank protection; however they should not cause erosion. Shear stress increases at the entrance to the Kopta reconnection.

- For Scenario 5 there are velocity increases within the restoration site and the bank protection areas but these increases should not have any negative effects. In the Kopta Slough reconnection, the increases are due to an overbank floodplain becoming a full flowing channel, and the increase should prevent sediment from accumulating. The decrease in velocity between RM 218.5 and 220.5 may slightly decrease the on-going erosion on the left bank adjacent to the Woodson Bridge SRA. Water surface elevations increase but they should not have any negative effects. Shear stress increases along the east bank of the existing Kopta Slough and the entrance to the connection channel will likely cause beneficial erosion. Shear stress increases at the restoration site and bank protection area should not cause further erosion.

- For Scenario 6 velocities increase through Kopta Slough by as much as 4 ft/s, so sediment should not accumulate during lower storm events. An increase in velocity on the sand/gravel bar opposite the bank protection may cause erosion. The decrease in velocity between RM 218.5 and 220.5 may slightly decrease the on-going erosion on the left bank adjacent to the Woodson Bridge SRA. The water surface elevation increases in the Kopta Slough reconnection, but decreases in the main channel between RM 218.5 and 222. Shear stress increases along the banks of the existing Kopta Slough and the entrance to the connection channel will likely cause beneficial erosion. There is also shear stress increases at the bank protection area but the rock should prevent further erosion.

- There were minimal changes (less than a percent) to the flow under Woodson Bridge for each of the scenarios.

APPENDIX A – HYDRAULIC MODEL OUTPUT PLOTS

(This appendix is available upon request.)

APPENDIX B – CONSTRUCTION COST ESTIMATE SUMMARIES

COST ESTIMATES

Cost estimates have been prepared for the construction of the proposed improvements for Kopta Slough. Estimates have been prepared for the six elements of the restoration study and include estimates for on-site mitigation/revegetation features. Quantities calculated for bank protection design materials were used to develop the most accurate cost estimates possible.

Construction cost estimates presented in this document have been prepared using the USACE cost estimating software, MII. Specific unit prices for each item of construction have been developed using local wage and equipment rates (supplied by the USACE). Labor rates, along with fringe benefits, have been updated using the Davis-Bacon Act guidelines from February 29, 2008. Equipment costs are based on the 2007 Region 7 Equipment Cost Book used for the MII cost estimating software. Material costs were based on estimates received from varying supply companies.

In addition to the elements, a contingency of 20% was added to account for uncertainties, 10% was added to account for permits, and another 10% was added for the design.

Construction costs have been estimated using land-based methods and equipment. The construction costs for all scenarios reflect the most likely construction methods based upon past experience at similar sites. The Kopta Slough connection cost assumes spoiling off-site at a local gravel pit off Hall Road approximately 5 miles southwest from Woodson Bridge.

Table B-1. Summary of the Construction Costs for each of the Elements

Element	Cost
Rock Revetment Removal at RM 220.5	$1,680,731
Kopta Slough Reconnection	$6,355,383
Bank Protection at Woodson Bridge	$1,430,790
Bank Protection at the City of Corning Sewer Outfall	$491,198
Habitat Restoration	$1,750,726

Table B-2. Summary of Costs for Scenario 1

Element	Cost
Habitat Restoration	$1,750,726
Element Installation Total	$1,750,726
Permits @10%	$175,073
Design	$175,073
Contingency @ 20%	$350,145
Total Estimated Element Cost	**$2,451,017**

Table B-3. Summary of Costs for Scenario 2 and 3

Element	Cost
Habitat Restoration	$1,750,726
Rock Revetment Removal at RM 220.5	$1,680,731
Bank Protection at Woodson Bridge	$1,430,790
Bank Protection at the City of Corning Sewer Outfall	$491,198
Element Construction Total	$5,353,446
Permits	$535,345
Design	$535,345
Contingency @ 20%	$1,070,689
Total Estimated Element Cost	**$7,494,825**

Table B-4. Summary of Costs for Scenarios 4, 5, and 6

Element	Cost
Habitat Restoration	$1,750,726
Kopta Slough Reconnection	$6,355,383
Bank Protection at Woodson Bridge	$1,430,790
Bank Protection at the City of Corning Sewer Outfall	$491,198
Element Construction Total	$10,028,097
Permits	$1,002,810
Design	$1,002,810
Contingency	$2,005,619
Total Estimated Element Cost	**$14,039,336**