HYDRAULIC MODELING AND GEOMORPHIC ANALYSIS OF SACRAMENTO RIVER, RM 184 TO RM 194 GLENN AND BUTTE COUNTIES, CALIFORNIA

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1.0 Introduction

1.1 Project Setting

This report addresses the hydraulic impacts of riparian restorations in selected areas and a potential bank revetment failure along County Road 29 on the Sacramento River near river mile (RM) 188. The hydraulic model used for this analysis extends from RM 184 to RM 194. As a result of a potential bank failure at County Road 29 a subsequent meander bend cutoff at Kimmelshue Bend on the Sacramento River is simulated in the hydraulic model. The locations of County Road 29 and Kimmelshue Bend are shown in **Figure 1.**

County Road 29 is situated along the outside of a meander bend on the right bank of the Sacramento River in Glenn County. The roadway is raised and acts as a levee, preventing most high flows from flowing across the neck of Kimmelshue Bend. The bend and other geographic features surrounding the site are depicted in **Figure 2**.

In January of 1995, high, sustained flows overtopped the road at several locations. The overtopping flows eventually caused a breach in the Road 29 embankment near RM 188. The washed out portion of Road 29 allowed the river to overflow through the downstream orchard and begin to form a cutoff through the bend. The site was repaired, yet it failed again in March of the same year from overtopping in a similar manner. Following this second failure a two-dimensional hydraulic model was developed for the U.S. Army Corps of Engineers (USACE) to evaluate the effectiveness of Road 29 as a flood control structure. The results of that analysis are contained in a report titled "Hydraulic Modeling of the Sacramento River and Butte Basin from RM 174 to RM 194" (Ayres Associates, 1997). The two dimensional hydraulic model used for that study was modified and refined for use in this analysis.

1.2 Authorization and Project Team

This analysis was authorized by The Nature Conservancy (TNC), Sacramento River Projects Office in Chico, California. The point of contact for TNC is Mr. Michael Roberts. The hydraulic modeling was conducted by the Sacramento office of Ayres Associates under the direction of Mr. Thomas W. Smith. P.E.

1.3 Purpose of Study

This study is part of the information collection phase of The Nature Conservancy's planning process within the Chico Landing sub-reach, where County Road 29 is located. The sub-reach planning process seeks to balance multiple uses and benefits within the floodplain of the Sacramento River. Therefore, this study investigates implementation of large-scale conservation strategies while maintaining public safety and flood control infrastructure.

As part of the analysis, the potential long-term impact of reducing maintenance to the existing revetment on the Sacramento River at County Road 29 combined with planned riparian restorations was considered. This report focuses on two primary concerns regarding a meander bend cutoff through Kimmelshue Bend. The first concern is the effect on the operation of the flood relief structures for controlling overbank flows into the Butte Basin, and the second is the effect of potential changes in river alignment that could occur in downstream reaches of the river.

2.0 Two-Dimensional Hydraulic Modeling

2.1 Methodology

Three modeling scenarios were analyzed; existing conditions and two potential future conditions. These scenarios were all run for two flow conditions, 195,000 cfs and 370,000 cfs, resulting in a total of six hydraulic runs. The existing condition model was used as a baseline to evaluate the effects of the two potential scenarios under review. The existing condition model was revised to represent the two different scenarios, which are described in detail later in this report. An existing two-dimensional hydraulic model of the Butte Basin area, previously developed for the USACE (Ayres Associates, 1997), was available for use in this study.

The model scenarios were assembled using SMS (Surface-Water Modeling Software). SMS is a pre- and post-processor for surface water modeling and analysis. It serves as the graphical interface used to edit the two-dimensional model as well as visualize and analyze the results. A finite element mesh is used to define the geometry of the model. The mesh consists of rectangular and triangular elements, as seen in **Figure 3**.

RMA-2V (US Army, 1997) is the computational computer program used to analyze the finite element mesh of the Butte Basin hydraulic model. The RMA-2V program computes water surface elevations and velocity components for subcritical, free surface flow in two-dimensional flow fields. Velocity and water depths are computed for each node in the model mesh.

Primary input parameters to the computer model include geometric description of the flow network (finite element mesh), boundary conditions that designate flow and water surface elevation, kinematic eddy viscosity coefficients that describe turbulence characteristics, and Manning's roughness coefficients that characterize hydraulic roughness and subsequent friction losses.

2.2 Original Model Description

In 1997, Ayres Associates developed a two-dimensional hydraulic model for the USACE to analyze flow splits over various flood relief structures in the Butte Basin area (Ayres Associates, 1997). This model used topographic and bathymetric data collected in 1995. The entire model extended from RM 174 to RM 194. Figure 3 shows the finite element mesh used to define the geometry of the model. The mesh consists of over 9000 rectangular and triangular elements and over 25,000 corner and mid-side nodes. The boundary conditions include the river flow rates and downstream water surface elevations from the January 1995 flood event. The model was also calibrated to the high water marks collected from the same event. Manning's roughness coefficients were used to represent the different material types throughout the project area. These same material types were used in all runs utilized in this analysis. **Table 1** lists the roughness coefficients used in the original and subsequent models. Further details of the development of this model are contained within the Butte Basin report prepared for the Corps (Ayres Associates, 1997).

Table 1. Manning's Roughness Coefficients (n Values)

Element Type	Description	Manning's n Value
1	Main channel	0.035
2	Heavy riparian vegetation (Forest)	0.160
3	Orchards	0.150
4	Cultivated field (fallow)	0.035
5	Bare sand bars	0.040
6	Stony Creek bed	0.040
7	Pasture/Grassland	0.035
8	County Road 29	0.020
9	Abandoned Channel	0.160
10	Savannah	0.050

2.3 Hydraulic Model Scenarios

This study incorporates three model scenarios, with two flow conditions, resulting in a total of six hydraulic model runs. The three model scenarios analyzed were, existing conditions, limited restoration conditions, and meander bend cutoff conditions (with limited restoration). Each condition was run at two flow rates: 195,000 cfs (January 1995) which is considered to be between a 10 to 20-year return period and 370,000 cfs (100-year runoff based on Cottonwood Creek Hydrology Report, Corps of Engineers, 1997 and the approximate 200-year runoff based on USACE Comprehensive Study, 2000). All of the hydraulic models use 1995 river and floodplain topography. A summary of the six runs is shown below in **Table 2**.

Table 2. Model Scenarios and Associated Flows

Scenario	195,000 cfs	370,000 cfs
Existing Conditions	X	X
Restoration Conditions	XX	XXX
Cutoff Conditions	XXX	XXX

X – Model Runs developed under the previous Butte Basin modeling effort (Ayres Associates, 1997)
XX – Model previously developed for the U.S. Fish and Wildlife Service (Ayres Associates, 2001)
XXX – Model runs performed for this study.

The river flows used in this study were intended to test the effects that these runoffs would have on the river configurations analyzed. The 1995 flood peak of 195,000 cfs was used since it was an event that has recently occurred, and was seen by those who lived in the area at the time. The 370,000 cfs flow was used to show the characteristics of larger flows through the area of interest, as well as provides a basis to predict the impacts of larger floods. The six runs and the associated flow conditions are summarized in the following paragraphs.

- **Existing River Conditions**

  The two existing conditions model runs portray the river and floodplain for discharges of 195,000 and 370,000 cfs and incorporate the land use and topographic conditions from the 1995 mapping. These runs provide baseline conditions from which to compare changes in velocity and water surface elevation due to potential topographic changes (i.e. Road 29 cutoff) or land use changes (i.e. riparian restoration). The existing condition land use conditions are shown in **Figure 4**.

- **Restoration Conditions**

  As a part of the Environmental Assessment (EA) project conducted by the U.S. Fish and Wildlife Service, several parcels of land bordering the Sacramento River were identified for potential riparian restoration. Three of these parcels are contained within the limits of this model. They are identified as the Kaiser Unit, Phelan Unit, and the Koehnen Unit and are shown in Figure 2. TNC staff provided the potential restoration scenarios and the resulting land use changes are reflected in **Figure 5**. As a result of the proposed changes in land use, new Manning's roughness coefficients were selected for the elements that represented areas identified for restoration. This scenario only looks at the effects of the proposed riparian restorations and does not take into account future orchard development on private lands or other potential land use changes.

- **Road 29 Cutoff Scenario**

  The Road 29 cutoff scenario was modeled to evaluate the potential effects of a breach in the Road 29 levee and expected riparian restoration within the old abandoned river channel. This cutoff scenario is patterned after a breach that occurred in 1995 and is the most drastic (from a hydraulic and geomorphic standpoint) that would be expected. Other potential cutoff scenarios are discussed in Section 4.0.

It is believed that the ceasing of maintenance of some flood control infrastructure (for example the bank protection at Road 29), rendered less necessary through conservation acquisition, may represent significant savings in flood damage to the local communities. In addition, strategies such as a channel cutoff may offer perhaps the most effective ecosystem restoration benefit. Restoration of river process could provide a proactive approach to future regulation for listed species. Multiple use and benefit strategies such as this would only be pursued if public safety and the function of the flood control system are maintained and thus the primary purpose of this model run.

The Road 29 cutoff runs were performed with the geometry in the model modified to simulate a cutoff of Road 29. Two flow simulations were run for this scenario, one for an inflow of 195,000 cfs and another for an inflow of 370,000 cfs. These runs model a potential meander bend cutoff with the location based upon the historic breaches of Road 29 (January and March of 1995). These runs are considered to be a worst case scenario for the hydraulics effects on the flow relief structures in the area. The topography of the land outside of the cutoff within the model is unchanged from the existing condition. The land use is the same as the restoration condition with the exception of the abandoned channel as shown in **Figure 6**. The Road 29 cutoff is the same size and location as the original model previously developed for USACE (Ayres Associates, 1997).

3.0 Discussion of Modeling Results

3.1 Existing River Conditions

The water depths for the existing conditions runs of 195,000 cfs and 370,000 cfs are shown in **Figures 7** and **8** and velocity contours for the same respective runs are shown in **Figures 9** and **10**. The velocity contours utilize a color plot to graphically show distribution of velocities within the main river channel and overbank floodplain. These results are used as the baseline conditions for comparison with the other modeled scenarios.

3.2 Restoration Conditions

The velocity distribution plots for the restoration scenario are shown in **Figures 11** and **12** for the 195,000 cfs and the 370,000 cfs flows, respectively. Graphical velocity contour plots of the resulting velocities for the restoration runs showed little visible difference when compared to the existing condition runs as shown in **Figures 13** and **14**. However there was some change in water surface elevation. A color contour plot of the water surface elevation difference between the existing condition runs and the restoration runs is presented in **Figures 15** and **16** for the 195,000 cfs flow and 370,000 cfs flow respectively**.** Both figures show some increase in water surface within the Kaiser and Phelan Units. Increases within the Kaiser Unit are approximately 0.7 feet within that unit and only 0.3 to 0.4 feet at the eastern and western edges of both models. The effect of restoring the Phelan Unit increases the maximum water surface elevation slightly with the maximum increase within the unit of approximately 0.8 feet and approximately 0.4 feet at the edges of both models. At the M&T Flood Relief Structure (FRS) a small decrease (approximately 0.1 to 0.2 feet) is noted for the 370,000 cfs runs and a small increase (approximately 0.1 feet) is noted for the 195,000 cfs run.

3.3 County Road 29 Cutoff

The resulting velocity distribution plots for the Road 29 cutoff scenarios within the river and floodplain are shown in **Figures 17** and **18** for 195,000 and 370,000 cfs respectively. In addition, velocity differential and depth differential plots are included to clearly indicate changes in velocity and water depth due to cutoff scenario. The differential plots comparing the existing conditions to cutoff conditions are shown in **Figures 19, 20, 23, and 24** (for 195,000 and 375,000 cfs). The plots showing the difference between restoration conditions and the cutoff scenario are in **Figures 21, 22, 25, and 26** (for195,000 and 375,000 cfs). Some increase in velocity and depth are noted in the main river channel immediately downstream of where the cutoff re-enters the channel. Water depths increase at the cutoff location and downstream where flows re-enter the main channel. Depths decrease over a significant area upstream of the cutoff and to the east of the main channel.

Table 3 shows the overall flow distribution between the flood relief structures and the main stem of the river by modeled scenario. The table shows the total flow that enters the Butte Basin and that which is passed downstream into the leveed reach of the Sacramento River Flood Control Project.

Table 3. Butte Basin Flow Splits By Modeled Scenario

Scenario	195,000 cfs		370,000 cfs	
	Confined Flow Between Levees	Flow into Butte Basin	Confined Flow Between Levees	Flow into Butte Basin
Existing	139,000	56,000	187,000	183,000
Restoration	139,000	56,000	187,000	183,000
CR 29 Cutoff	144,000	51,000	191,000	179,000

4.0 Geomorphic Analysis

4.1 General

A cutoff of a bend on the Sacramento River in the vicinity of the Road 29 site could have an impact on river meandering and potentially produce problems for the Ord Ferry Road and bridge located downstream at RM 184.3. The following geomorphic analysis examines three potential cutoff scenarios and discusses the potential impacts of these cutoff scenarios on river meandering and the threat to nearby structures. These potential scenarios are based on our professional judgement of likely possibilities. The affected reach of the Sacramento River generally extends from about RM 184 to RM 191.

Cutoffs can occur either as chute cutoffs or neck cutoffs as shown in **Figure 27**. Chute cutoffs are generally short and form across point bars, often as a result of shoaling in the upstream limb which forces flow across the point bar. Neck cutoffs form in the overbank areas across the neck of a bend. The potential impacts of a neck cutoff includes a temporary oversteepening of the river in the area of the cutoff, increased migration of bends upstream and downstream of the cutoff, and increased bank erosion. The river becomes temporarily oversteepened because the channel length in the cutoff reach has decreased but the change in elevation between the ends of the cutoff has not. This results in a steeper slope between the ends in the cutoff. The river adjusts to this steeper slope and the resultant increase in shear stress by adjusting its channel geometry through bed and bank erosion.

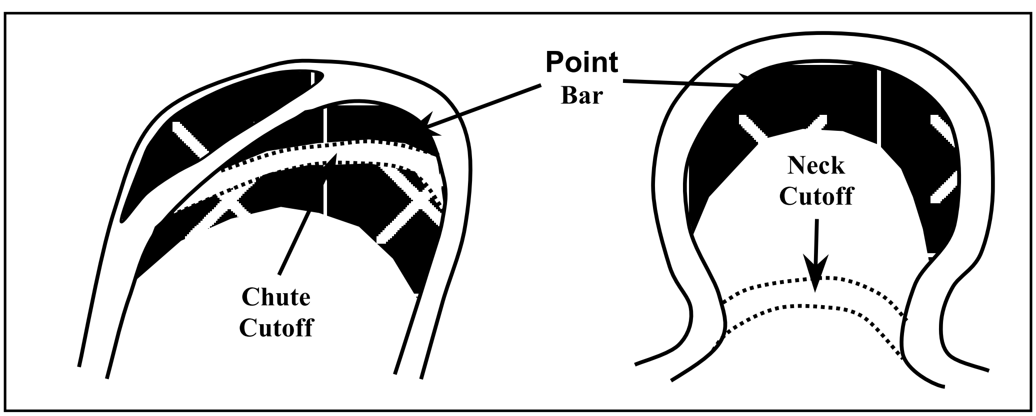

Figure 27. Sketch of chute and neck cutoffs.

The geomorphic analysis performed under this task is based on professional judgment, site reconnaissance, and a previous study in the area (Ayres Associates, 1997). The previous study evaluated the cutoff potential at several sites in this reach of the river. The following suggested cutoff scenarios are based on an extension of this work.

4.2 Setting

The Sacramento River is highly sinuous from RM 184 to 191 and contains several fairly tight, tortuous bends. **Figure 28** shows the historic pattern of the river displayed over USGS topographic maps of the area and the 1997 bankline obtained from aerial photographs. The river forms a large "S" pattern which is defined by the Monroeville Bend (RM 187.5 to RM 189.5) and the double-lobed Kimmelshue Bend (RM 186 to RM 187.5). The Road 29 site is located on the right bank at about RM 187.5 in the upstream limb of Kimmelshue Bend, which also forms the downstream portion of Monroeville Bend.

The reach from RM 184 to RM 191 is significantly influenced by three major factors. These factors are overbank flows in the area of Golden State Island/Murphy Slough (RM 190.5), heavy sediment contributions from Stony Creek (RM 190), and the constriction of the floodway by the Ord Ferry Road Bridge. The influx of sediment from upstream reaches and from Stony Creek, the loss of flood flows through the M&T FRS, and backwater induced by the floodway constriction of the river at the Ord Ferry Road Bridge contribute to potentially significant aggradation and bar development in the reach. These factors can increase the magnitude of meander migration.

The USACE and the California Reclamation Board have been concerned with the potential cutoff of the Monroeville Bend for many years. The potential effects of a cutoff on the Monroeville Bend was predicted to have a detrimental impact on the effectiveness of the M&T FRS at Murphy Slough and could potentially induce the cutoff or rapid downvalley migration of the Kimmelshue Bend as well. Rock riprap bank protection has been placed along the outer banks on most of the bends upstream of RM 186.5 in an effort to halt active bend migration and the possible cutoff of the Monroeville Bend (Figure 28). Concrete rubble has also been placed on the eroding outer banks of the bends between RM 185.5 and 186.5 by private landowners.

4.3 Effects of Cutoff at Road 29

If a cutoff through Road 29 (Kimmelshue Bend) were to occur, the main channel would most likely abandon the current meander bend. In addition to shortening the effective reach length downstream of the M&T FRS, the flow in the main channel would move away from the 3-B's overflow area. Despite these changes, the cutoff scenario would only have a small negative effect (approximately 2%) by increasing the flow in the main stem of the Sacramento River as compared to existing conditions. Based on the modeled cutoff scenario, the flow in the main stem of the river would be 4,000 cfs greater for the 370,000 cfs event (see Table 3).

A cutoff at Road 29 will also increase the delivery of sediment to the downstream reaches as a result of both increased transport capacity and increased sediment supply due to channel adjustments within the cutoff. Further sediment deposition could be expected at the existing split-flow reach at about RM 185 just upstream of the Ord Ferry Bridge. Continued and accelerated sedimentation in this location has the potential to increase erosion of the left bank and may lead to re-occupation of a former channel in the left overbank thus threatening the present east approach to the Ord Ferry Bridge.

4.4 Potential Cutoff Scenarios

The cutoff scenarios presented in this report and are based on our experience and expertise in river geomorphology. Although these are likely scenarios, other variations could be encountered based on unforeseen changes in river and floodplain topography or hydrology.

Since many scenarios are possible, the alignment used in the hydraulic model was a straight-line, neck cutoff, similar to the initial overflow path of the 1995 breach of Road 29. This alignment was chosen for the hydraulic model in order to determine the most extreme hydraulic conditions for the flow splits between the overflow structures into the Butte Basin and the main stem of the Sacramento River.

The first potential cutoff scenario is a neck cutoff across Kimmelshue Bend as shown in **Figure 29**. Of the two alignments shown, 1A is the modeled 1995 overflow alignment and 1B is the most likely eventual alignment. The probability of this scenario occurring is moderate and initially may not have an impact on the Ord Ferry Road Bridge other than changing the flow alignment relative to the bridge opening. The high right bank at and just upstream of the bridge is composed of very cohesive, well-cemented material that is resistant to erosion. The right bank has occupied its present location for well over 100 years. However, much of the sediment generated from the cutoff may deposit in the channel just upstream of the bridge. This in turn, may cause bank erosion on the east bank which will eventually threaten the approach to the Ord Ferry Bridge.

The second cutoff scenario is show in **Figure 30** and consists of a chute cutoff across the upstream limb of Kimmelshue Bend, the downstream migration of the downstream limb, and the development of downstream meanders. Under this scenario, the channel length of Kimmelshue Bend would shorten and the bend radius would decrease resulting in a shift in erosion of the left bank further downstream. This would also produce a downstream shift of the crossing point of the thalweg in the downstream limb of Kimmelshue Bend and the growth and southwestward development of the small bend centered at about RM 185.5. As the bend at RM 185.5 continues to develop southwestward, it would also cause a relatively equal and opposite bend to form downstream. The downstream bend would likely reoccupy an old slough east of the Ord Ferry Road bridge. This old slough represents the channel position of the river in 1896.

Although less likely to happen than the first scenario, the second cutoff scenario is possible and could have a significant impact on the stability and safety of the Ord Ferry Road Bridge. If the channel alignment downstream of RM 186 as shown in Figure 30 occurs, the bridge potentially could be flanked and the road east of the bridge destroyed. Even though this meander development and channel alignment in the area of the bridge is less likely to occur, the potential for damage to or flanking of the east bridge abutment under this scenario is relatively high. However, it is more plausible that this problem would be recognized well beforehand and appropriate measures would be taken by the Reclamation Board and Butte County to prevent this part of the cutoff scenario from occurring.

Finally, a third cutoff scenario was examined that consists of a major chute cutoff developing across the upstream half of Kimmelshue Bend as shown on **Figure 31**. The result of this scenario is the expansion and southeastward extension of Kimmelshue Bend producing a major shift in the location of the downstream channel. The river would likely occupy a position well eastward of its present location between the bridge and RM 186.5. This alignment would also result in the flanking of the bridge and destruction of the road as described in the previous scenario; however, it is also possible that the channel could maintain its present alignment through the bridge.

The second and third scenarios are less likely to occur because they would require substantial meander development and the migration of the river southeastward between the bridge and RM 186.5. However, the river in this reach has generally not shifted much from its present position in the last 100 years. Yet, the presence of meander scars on the floodplain well east of the present channel position between the bridge and Kimmelshue Bend does not preclude the possibility of the river migrating south-eastward and flanking the bridge.

5.0 Conclusions

Based upon our knowledge of this reach of the river, our geomorphic expertise, and the modeling results presented in this report, we offer the following conclusions:

1. A meander bend cutoff at Road 29 through Kimmelshue Bend will have a small effect on the distribution of flood flows between the Butte Basin and the flood control levees on the Sacramento River. Our hydraulic analysis shows that the amount of flow reaching the leveed reach of the river will increase by approximately 4% for the 195,000 cfs event and approximately 2% for a flow of 370,000 cfs for the modeled cutoff scenario .

2. The modeled riparian restoration scenarios show moderate increases in water surface elevations within the Phelan and Kaiser units for the given restoration conditions. The amount of flow reaching the leveed reach of river is unchanged for the modeled restorations.

3. There is a moderate probability that a major flood can produce a neck cutoff of Kimmelshue Bend at Road 29. This cutoff will probably result in little change in the position of the river downstream of RM 186. Although the probability is low, a cutoff can induce the development of downstream meanders, through in-channel bar development from the increased sediment loads, and can increase southeastward channel migration that could eventually threaten the approach to the Ord Ferry Road Bridge.

6.0 References

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