MEANDER BEND MIGRATION NEAR RIVER MILE 178 OF THE SACRAMENTO RIVER

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REPORT FOR RIVER PARTNERS
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Executive summary

Historic maps from 1904 to 1997 show that the Sacramento River near the PCGID-PID pumping plant (RM 178) has experienced typical downstream patterns of meander bend migration during that time period. As the river meander bends continue to move downstream, the near-bank flow of water, and eventually the river itself, is tending to move away from the pump location.

A numerical model of meander bend migration and bend cut-off, based on the physics of fluid flow and sediment transport, was used to simulate five future migration scenarios. The first scenario, simulating 50 years of future migration with the current conditions of bank restraint, showed that the river bend near the pump site will tend to move downstream and pull away from the pump location. In another 50-year future migration scenario that modeled extending the riprap immediately upstream of the pump site (on the opposite bank), the river maintained contact with the pump site. In all other future migration scenarios modeled, the river migrated downstream from the pump site. Simulations that included removing upstream bank constraints suggest that removing bank constraints allows the upstream bend to experience cutoff in a short period of time. Simulations show the pattern of channel migration after cutoff occurs.

The area of floodplain reworked, which plays an important ecological role in the colonization of riparian vegetation, was calculated for each channel migration scenario. There are two major areas where the floodplain can be reworked in the five scenarios, one upstream from the pump location and one downstream. With no existing bank restraints removed, no cutoff occurs, and both areas experience a total of less than 10 acres of land reworked in 50 years, and rates of land reworked are less than 0.5 acres per year. For upstream removal scenarios (the last three of the five), total floodplain area reworked upstream of the pump is about 80 acres in 50 years. Rates of floodplain area reworked range from 4 to 5 acres per year immediately following cutoff. After about 40 years, the rates decline and approach what may be a steady state of land reworked of about 2 acres per year in the upper area. With upstream cutoff and no extension of the riprap near RM 178, total floodplain area reworked downstream of the pump is also about 80 acres, declining to a steady state of about one acre per year. Given removing the upstream riprap and allowing cutoff, there is no difference over 50 years in the area or rates of land reworked between the final two scenarios (a scenario that maintains the current riprap immediately upstream of the pump site (on the opposite bank) and a scenario which removes that riprap).

One scenario (second of five) suggests that, even if the channel migration near the pump site were stabilized, the bend upstream could be allowed to cutoff in order to provide natural regeneration of the upstream floodplain area without migration occurring at the pump site.

Contents

1.0 Introduction

The Sacramento River near RM 178, which is the current location of the PCGID-PID pumping plant (Figure 1), has experienced lateral and downstream meander migration in the last century. The reach in the vicinity of the pump has evolved in shape through natural processes of river meander migration. The pump is located on the west side of the river and the tendency for eastward migration of the channel is a concern because it affects pump operations. Understanding the dynamics of the river given different management scenarios will provide important information to inform decisions about effective long-term pump operation.

River meander migration is related to the channel planform shape, flow characteristics, bank erosion potential, and other factors (Johannesson and Parker 1989). The history of river meander migration at this site suggests why the river is currently moving away from the current pump site, and helps anticipate future migration. After a brief introduction to the historic planform shape of this reach from 1904 to 1997, which shows the history of channel migration, this report describes modeling scenarios, where the future migration of the river is simulated given different bank restraint conditions. The report also quantifies the area of land "reworked" given different management scenarios.

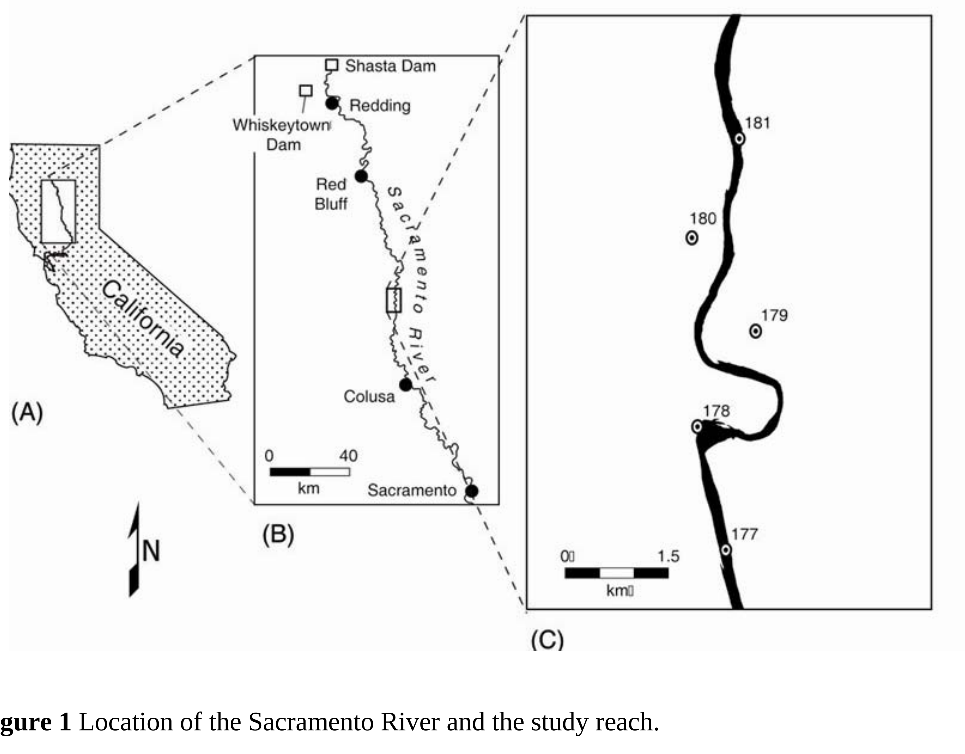

Figure 1 Location of the Sacramento River and the study reach.

2.0 Existing Conditions

2.1 Site Description

The PCGID-PID pumping plant is located at about RM 178 on the upper Sacramento River, about 75 river miles south of Red Bluff, and about 125 river miles north of Sacramento. In most naturally migrating rivers, local meander migration is related to the shape of the local meander bend and to the shape of the river upstream (e.g. Johannesson and Parker 1987, Furbish 1988, 1991). To consider the local migration near the pumping plant site (RM 178), this report looks at a longer reach that includes a section of river from roughly RM 177 to about RM 182 (Figure 2). This reach, like much of the river between Colusa (RM 143) and Red Bluff (RM 243), contains some areas having a moderate amount of bank constraint where the river does not move, some areas that are migrating and evolving in relation to the bank constraint, and some areas that are evolving freely.

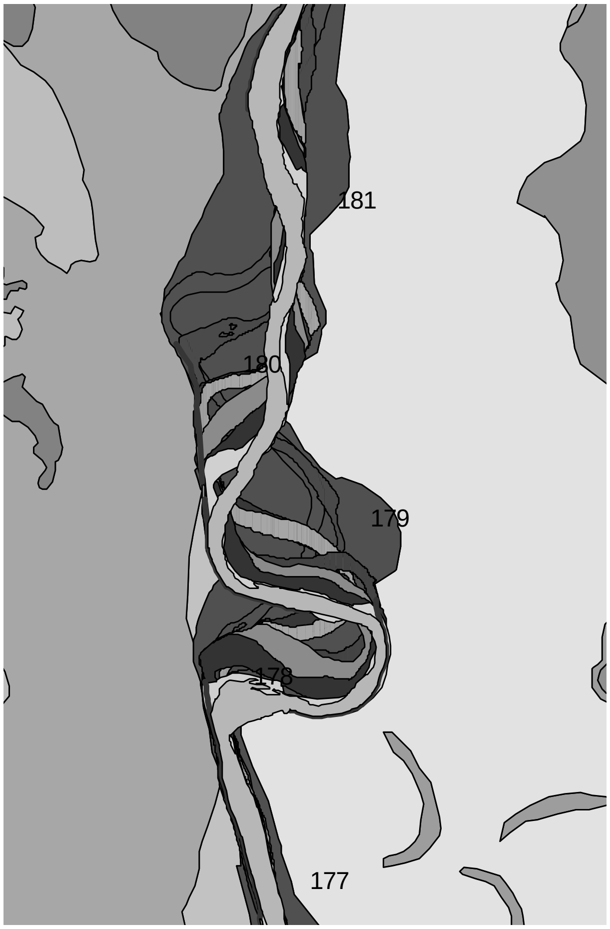

Figure 2 History of the channel location from 1904 to 1997. Red lines show man-made bank-constraints.

Figure 2 shows the history of the channel location from 1904 to 1997. Between river miles 181 and 178, a series of bends has migrated continuously, except when constrained by an erosion resistant bank or by man-made constraints. The apex (point of maximum curvature) of the upstream-most bend (on the western edge of the historic meander belt near RM 180.5 in 1904) moved from roughly RM 180.5 to RM 179 from 1904 to 1997. This bend moved downstream, but did not move laterally as it was constrained on the western bank by natural and man-made constraints. The bend that has continued to be located close to RM 178 has been similarly constrained from lateral (westward) migration and has moved downstream less than a half a mile. The other major bend, facing in the other direction and the outside of the curve to the east, lies between these two, and has had its apex move from about RM 179 to almost RM 178. Note that RM designations in this qualitative description of movement are used to denote the general down-valley direction, and are not meant to be exact. The large loop now occurring between RM 178 and 179 is currently of unusually large amplitude and curvature, and would have cut off had it not been constrained on its upstream limb.

Unconstrained meander bends tend to migrate naturally across the landscape (Brice 1984, Hooke 1984). Bend migration tends to follow patterns that can be described by mechanical laws of fluid flow and by other methods (Brice 1974, Hooke 1984, Ikeda and Parker 1989). When such meander bend migration occurs, an individual bend tends to move, unless constrained, both downstream and cross-stream. In other words, a bend will tend to migrate continuously downstream. At the same time, because of the cross-stream component of migration, a bend will tend to migrate cross-stream. As the bend migrates, it also changes shape.

Natural river meander bends tend to be curved. When a bend impinges laterally on a bank that is erosion-resistant, the curved shape tends to flatten against the resistant bank. As the bend moves downstream, the outward side of the bank tends to maintain contact with the location of the resistant bank. Once it has migrated sufficiently, the "end of the bend" will move downstream from the location, and the river channel will no longer maintain contact with the point in question. This is the tendency that is affecting the pump site. Even with the existing riprap, which constrains the downstream migration of most of the bend, the downstream-most section of the bend is unconstrained, and continues to migrate downstream, thus tending to "abandon" the pump. As this process progresses, the velocity of flow near the pump may be reduced, to an extent that flow magnitudes necessary for the fish screen may not be achieved.

As the river continues to evolve, the unconstrained section of the channel will tend to move downstream and the river channel will appear to move away from the western bank at the current location of the pumping plant. The river is "sliding along" the extreme western edge of the historic meander belt. This location, being the western edge of the meander belt zone, has functioned as a geologic control. At this site, the bend has been migrating almost entirely in the downstream direction. The outside of the bend reached the location of the pump site. Because this area was naturally resistant to erosion, the outside of the bend effectively "flattened out" and then "slid down the site," maintaining contact with the bank at the current pump location. Until recently the site was "stable" with respect to contact with the river.

Currently, the unconstrained portion of the bend is continuing to migrate naturally downstream. From the point of view of standing at the site, the channel appears to be moving away from the western bank.

3.0 Future Predictions

3.1 Introduction

One approach to understanding the future channel movement near the pump site is to model its future migration. As Larsen et al. 2002 recently did for a longer reach of the river upstream from this site, this report describes simulated channel migration using a channel migration model that is based on mathematical algorithms physics-based relationships for flow and sediment transport – the main physical processes responsible for channel migration (Larsen and Greco 2002). "Because the model is based on physical processes, it can accommodate changes in input variables and can predict the consequences of conditions, such as bank stabilization measures that have not existed in the past. Unlike empirically-based models, which tend to focus on local conditions, the physically-based numerical model integrates the effects of local morphology and upstream conditions.”[1]

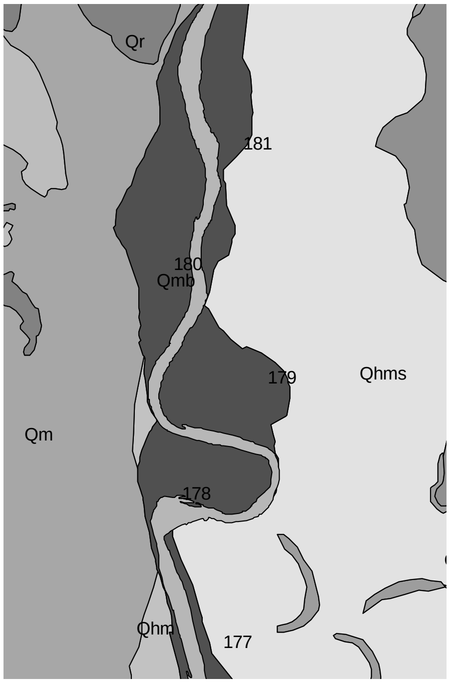

Figure 3 GIS geology layer. (California Department of Water Resources, 1995)

3.2 Methods

Heterogeneous Erodibility Surface

A heterogeneous erosion surface was created using a geographic information system (GIS) and imported into the river meander migration model. The spatial erodibility surface was developed from the GIS data by using a geology layer (Figure 3). The geology surface dataset was obtained from the California Department of Water Resources (CDWR 1995). All geology surface types were assumed to be erodible, except for Q_r (Riverbank formation), Q_m (Modesto formation), and Q_{oc} (Old channel deposits) which represent non-erodible areas based on their soil properties, sometimes called areas of geologic constraint. The dataset was converted to a 30 m grid based on erodibility potential. A map representing how certain geology types erode at different rates was derived from this GIS dataset. This erodibility surface was used as the basis for the riprap and cutoff scenarios.

Migration Modeling

Following the procedures of Larsen et al. (2002), “A steady flow of 80,000 cfs is used in the analysis, which approximates the calculated two-year return interval.” Slope, channel top width, and area of flow within the designated channel come from HEC-RAS output. Average depth is calculated using channel area and channel top width ($^{\text{(area)}}/_{\text{(top width)}}$). The overall slope for the study reach is calculated based on HEC-RAS model information. The slope used for the study reach was 0.00042 m/m. The following input parameters for the meander migration model for predictive modeling were calculated using the output of HEC-RAS:

- Slope: 0.00042 m/m
- Top width: 235 m (ft)
- Average depth: 5.4 m

Cutoff Simulation

A cutoff simulation was used to account for bend cutoffs across bend necks (Larsen et al. 2004). The sinuosity of each bend is calculated numerically by dividing the distance along the channel for a bend by the straight-line distance between the start and end points of the bend. A threshold sinuosity of 1.8 was set, by which bends were allowed to cut off given that other factors were

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[1] Larsen et al. 2002.

present. This was based on historical cutoff trends on the Sacramento River (Avery et al. 2003). The starting point of the simulated cutoff is located one-quarter of the bend upstream from the cutoff bend, and the ending point of the simulated cutoff is placed one-quarter of the length through the downstream bend. Finally, the cutoff is simulated only if erodibility is not constrained (by rip-rap, levees, and geologic constraints) along the straight line between the start and end points. If the cutoff conditions are met, the simulated river channel cutoff centerline is located in a straight line between the start and end points.

Cutoff events require that overbank flows occur (Avery et al. 2003). For a complete treatment of the timing of a cutoff, a variable hydrograph could be input into the flow conditions, with cutoff only being allowed to occur when the magnitude of flow was equal to the discharge of an overbank event. For the current modeling, we used an approximation of a constant flow rate (e.g. Johannesson and Parker 1985, 1989, Howard 1992, Larsen 1995, Howard 1996, Larsen and Greco 2002) and cutoffs were allowed to occur when the sinuosity threshold was reached. Although some details of the cutoff simulations (like the timing) would differ if we used a variable hydrograph, the general spatial patterns of our results would be similar to the patterns reported here.

3.3 Model Calibration

“Calibration of the meander migration model is required because the exact erodibility of the sediments within the study reach in not known. Calibration allows calculation of an erodibility field by running the model on historic channel data. Calibration also allows fine-tuning of the model to local conditions by adjusting the coefficient of friction.”[2]

Figure 4 shows the calibration of modeling. To calibrate, we used the observed locations of the channel in 1964 and in 1997. We adjusted bank erodibility near the channel until the 1997 modeled channel matched the observed 1997 channel location, as shown in Figure 4. In our calibration, we simulated the effect of the installation of the bank constraints in 1982. These conditions were then used for model predictions.

The calibration results show good agreement (Figure 4). Based on this calibration, we expect the overall direction and pattern of the predictions to be valid, although the timing and distances of movement could be better estimated with more extensive model calibration and validation.

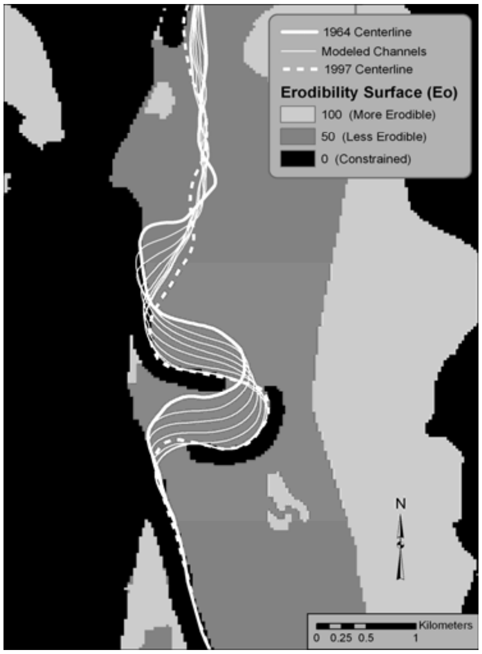

Figure 4 Sacramento River near pumping plant site, model calibration results. The initial observed channel location was in 1964, and the final observed channel location was in 1997. The calibrated simulated migration shows good agreement with the observed migration.

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[2] Larsen et al. 2002.

3.4 Prediction Results

Based on the input values for the hydraulic variables given above and the calibrated bank erosion values, five predictions 50 years into the future were made. The first predicted future channel movement with existing conditions, while the others predicted movement if different combinations of channel restraints upstream from the pump site were used.

Two main areas of interest emerge when discussing the results of modeling. The first is the area near the pumping plant site. As described in the section on historic migration, the small bend near RM 178, hereafter referred to as Bend 178, has been migrating southward, causing concern to the pumping plant. The second area of interest is the large bend that swings to the east, hereafter referred to as Bend A, which has been constrained from cutting off. Upstream from the two bends of major concern, from about RM 179 to RM 182, migration was simulated in all scenario cases. The pattern of simulation is similar in all cases, and is not discussed.

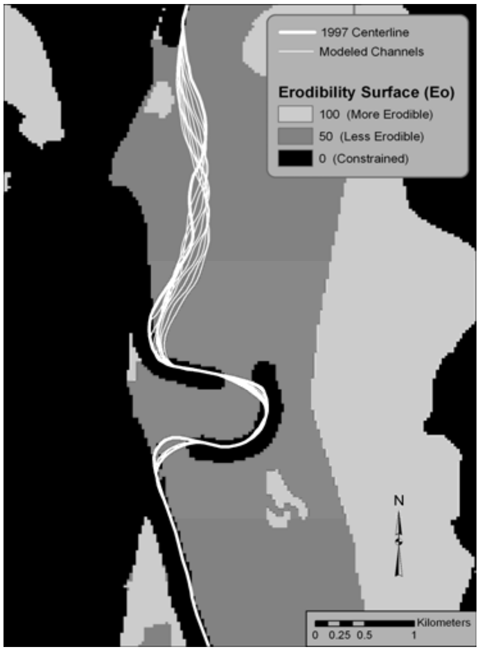


Figure 5 50-year simulated migration with no additional bank restraint

3.4.1 With no additional bank restraint

Figure 5 shows the channel location with 50 years of predicted migration using the input parameters that were used for the calibration, and the existing bank restraints as shown in Figure 5.

The migration of Bend 178 is similar to the migration that has been recently occurring and that has caused concern for the operation of the pumping plant.

The migration of Bend A (the large bend upstream from the pump) continues to be limited by the existing bank constraints.

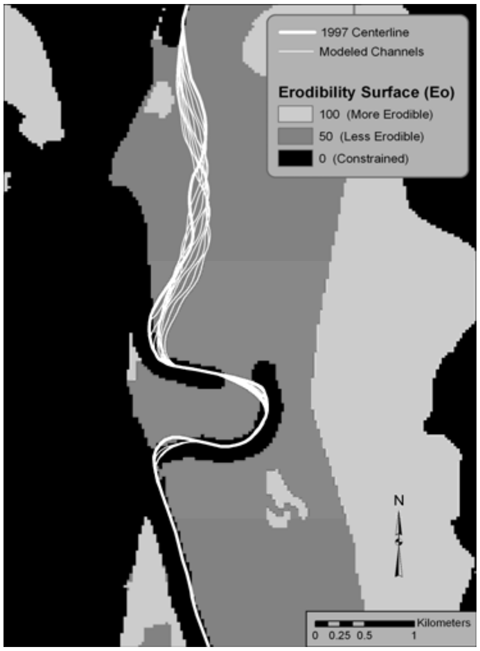


Figure 6 50-year simulated migration with additional bank restraint

3.4.2 With additional bank restraint

Figure 6 shows the channel location after 50 years of predicted migration with additional bank restraint installed upstream on the left bank (looking downstream). With the addition of bank restraint, the 50-year prediction suggests that the channel will cease to move away from the pump site. In essence, with bank restraint installed upstream to limit eastward migration, the channel ceases to “slide along the riprap” and ceases to migrate downstream.

The migration of Bend 178 is limited by the additional bank constraint. The model simulates a small amount of migration similar to the migration that has been recently occurring near the pumping plant. This indicates a tendency for migration at this location. In practice, extended bank restraint could most likely eliminate all this migration.

The migration of Bend A (the large bend upstream from the pump) continues to be limited by the existing bank constraints as in the previous simulation.

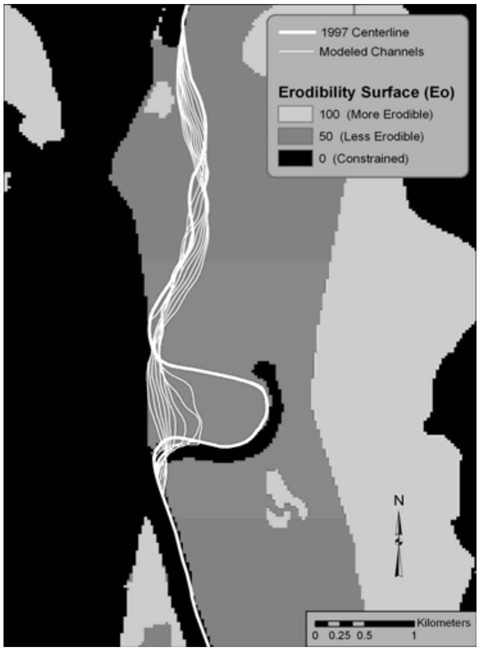


Figure 7 50-year simulated migration with the bank restraint removed from right bank of the bend upstream and the bank restraint extended near the pumping plant

3.4.3 With bank restraint removed from right bank of the bend upstream and the bank restraint extended near the pumping plant

Figure 7 shows the channel location after 50 years of predicted migration with the bank restraint removed from right bank (looking downstream) of Bend A (the large bend upstream from the pump) and the bank restraint extended near Bend 178. With the removal of bank restraint, the 50-year simulation shows that Bend A will cutoff.

As in the previous two simulations, the migration of Bend 178 is limited by the additional bank constraint. As in the previous simulation, the model simulates a small amount of migration similar to the migration that has been recently occurring near the pumping plant, indicating a tendency for migration at this location. The pattern in this scenario differs from that in the previous case because of the effects of the simulated cutoff at Bend A. In practice, extended bank restraint could most likely eliminate all this migration.

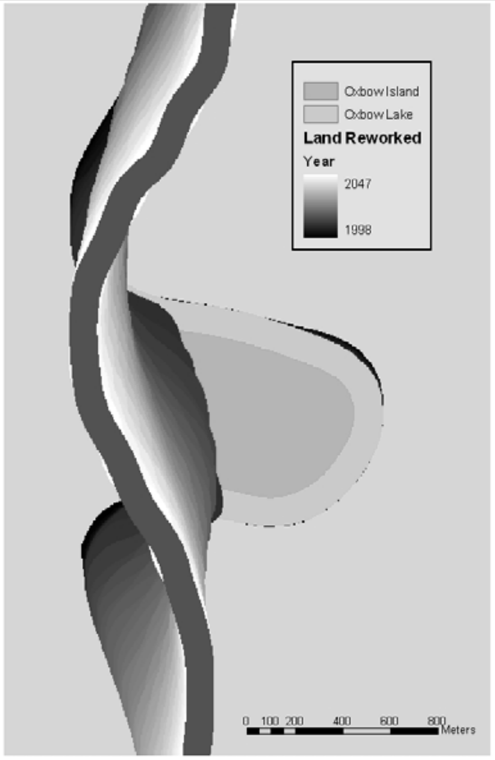


Figure 8 “Floodplain age map” of simulated migration with the bank restraint removed from the right bank of the bend upstream and the bank restraint extended near the pumping plant

In this scenario, the migration of Bend A is no longer limited by the bank constraints as in previous simulations, and a cutoff and subsequent migration are simulated. Figure 8 shows the pattern of floodplain creation due to the channel migration and cutoff. This “floodplain age” map indicates the older location of the simulated channel with darker tones, and younger ones with lighter tones of grey, shading to white. The river channel at the end of the simulated time is shown in dark grey, the “cutoff” island is represented, and the oxbow lake created by cutoff is also shown.

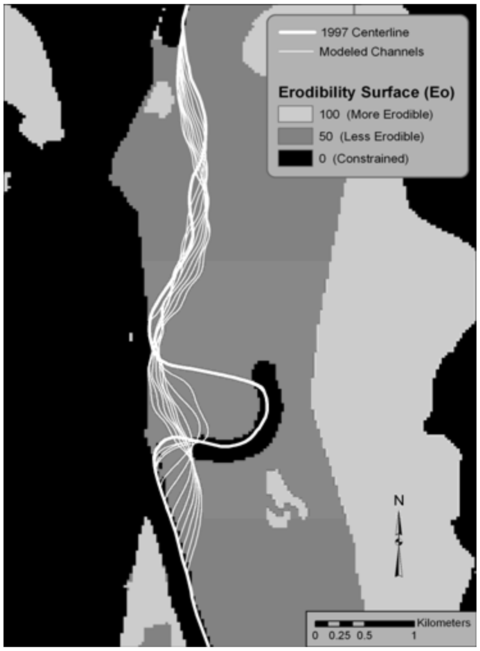


Figure 9 50-year simulated migration with bank restraint removed from the right bank of the bend upstream and the existing conditions near the pumping plant

3.4.4 With bank restraint removed from right bank of the bend upstream and the existing conditions near the pumping plant

Figure 9 shows the channel location after 50 years of predicted migration with bank restraint removed from the right bank of the bend upstream and the existing conditions near the pump. As above, with the removal of bank restraint, the channel cut off and there is significant migration in the upstream bend area.

In addition, the migration of Bend 178 is extensive and results in a significant amount of land reworked in the Llano Seco Riparian Conservation Area. The model simulates a large amount of migration where the bend apex “slides” along the western edge of the meander belt where westward migration is constrained. The simulation shows the apex moving more than a kilometer downstream.

As in the previous simulation, the migration of Bend A is no longer limited by the bank constraints as in the previous simulations, and a cutoff and subsequent migration is simulated.

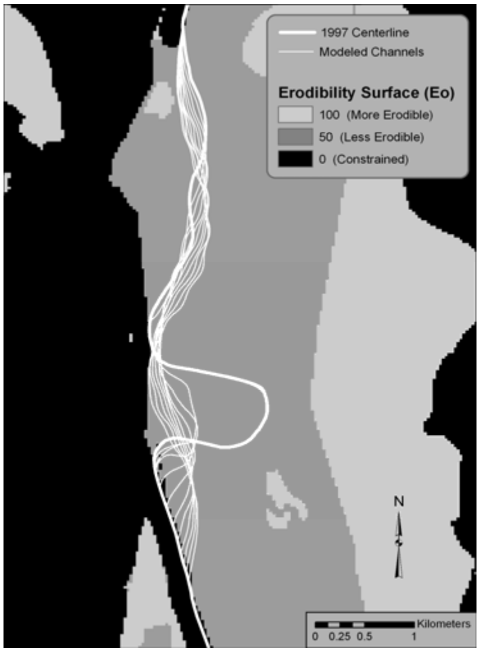


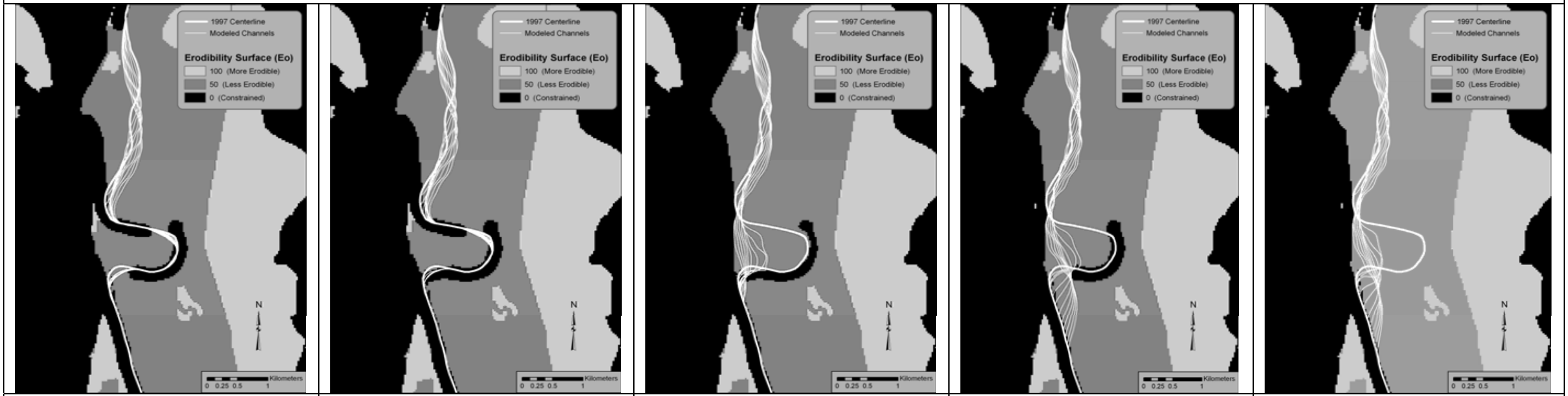
Figure 10 50-year simulated migration with bank restraint removed from the entire reach

3.4.5 With bank restraint removed from the entire reach

Figure 10 shows the channel location after 50 years of predicted migration with bank restraint removed from the entire reach. With the removal of bank restraint, the 50-year prediction suggests the channel will migrate in a manner similar to that of the previous simulation. Bend A cuts off, and Bend 178 migrates downstream more than a kilometer.

The simulated location of this scenario and the location of the previous scenario are similar, although some details of their migration patterns differ. As in the previous scenario, the migration of Bend 178 is extensive and results in a significant amount of land reworked in the Llano Seco Riparian Conservation Area.

Figure 11 Summary of meander migration 50-year prediction scenarios



No additional bank restraint

Bank restraint extended near the pumping plant

Bank restraint removed from right bank of the bend upstream and the bank restraint extended near the pumping plant

Bank restraint removed from the right bank of the bend upstream and the existing conditions near the pumping plant

Bank restraint removed from the entire reach

4.0 Area of Land Reworked

For each channel migration scenario, we calculated the area of floodplain reworked by simulated migration. Newly reworked floodplain (land eroded on one bank and subsequently deposited along the other) plays an important ecological role in allowing the colonization of early-seral riparian vegetation communities. This calculation of area reworked suggests how different channel migration scenarios might affect future riparian forest development both upstream and downstream from the pumping plant.

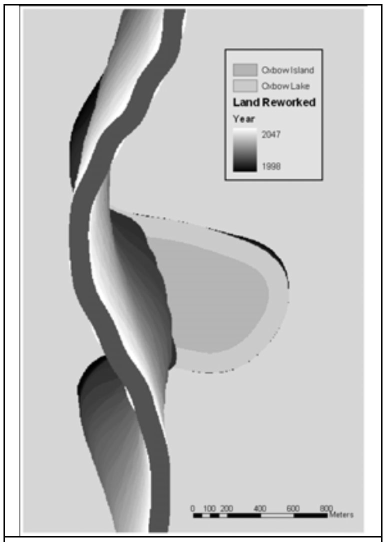


Figure 12 “Floodplain age map”

Figure 12 shows a typical floodplain age map from which calculations were made of the area of land reworked over time during the simulation time period. Based on these calculations, graphs were produced showing the rates of land reworked.

Calculations were performed for two areas: 1) the area of land reworked upstream from the pumping plant, and 2) the area of land reworked downstream from the pumping plant.

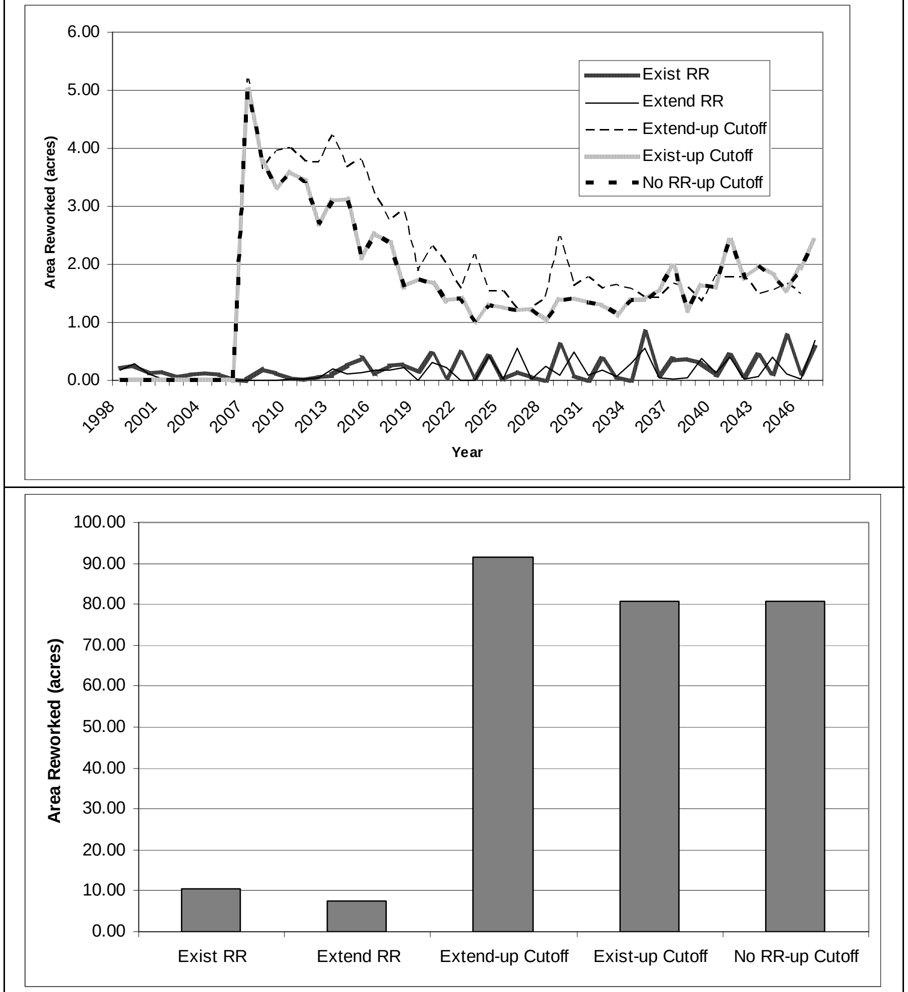


Figure 13 Area of land reworked upstream of the pumping plant.

4.1 Area of land reworked upstream of the pumping plant

Figure 13 shows two graphs that show the area of land reworked upstream from the pumping plant in each of the 50-year simulations. In each graph, results for all five scenarios are shown. The top graph shows the area of land reworked per year for each scenario. The lower graph shows the total area of land reworked.

“Exist RR” and “Extend RR” are the first two scenarios, where the upstream channel is not allowed to cut off. “Exist

RR” is the scenario with existing riprap, while “Extend RR” is the scenario with the riprap extended. The rate of land reworked (Figure 12 upper) is similar for both of these scenarios, and is generally less than 0.5 acres per year. The total area of land reworked in 50 years is about 10 acres for the case with existing riprap, and about 8 acres for the case with riprap extended.

The other three cases all show area of land reworked allowing a cutoff in Bend A (the large bend upstream from the pump). The rate of land reworked jumps to about 5 acres per year (upper graph) immediately after cutoff occurs, and then declines over 20 years to a somewhat steady rate of between 1 and 2 acres per year.

The final two cases are essentially identical, and the lines in the upper graph fall on top of each other, with the total area reworked in 50 years being about 80 acres. Slight differences emerge in the cases where riprap is extended and cutoff is allowed. The simulation shows that the “pinch” caused by the extended riprap results in more land reworked by the cutoff channel than if no “pinch” had been caused by the extended riprap.

4.2 Area of land reworked downstream of the pumping plant

Figure 14 shows the area of land reworked downstream from the pumping plant in each of the 50-year simulations.

The rate of land reworked (Figure 14 upper) is similar for the first three scenarios, and is generally less than 0.5 acres per year. The case with extended riprap and upstream cutoff shows more land reworked than the other two cases without cutoff, but it is significantly less than the two cases with cutoff. The total area of land reworked is 8,

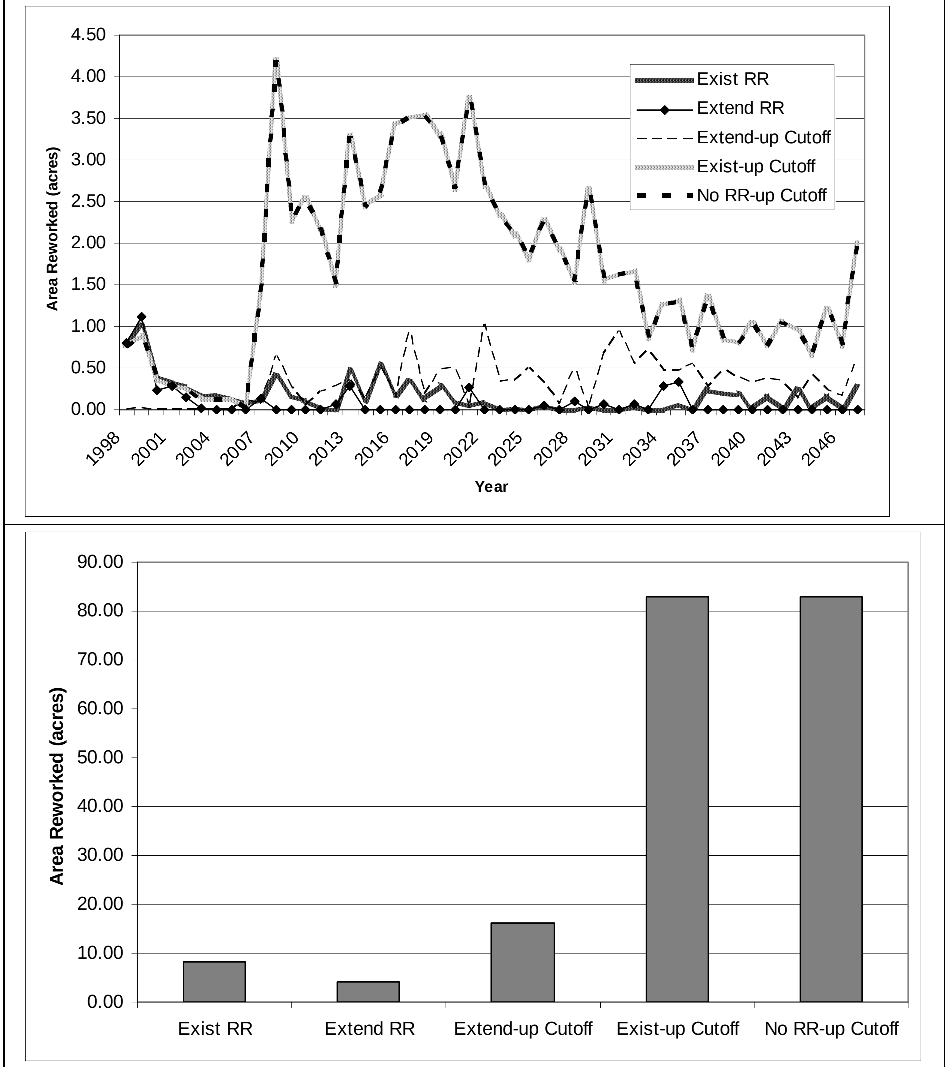


Figure 14 Area of land reworked downstream of the pumping plant

4, and 16 acres respectively for the first three scenarios, and is over 80 acres for the last two scenarios.

The final two cases both show the identical area of land reworked when a cutoff is allowed in Bend A (the large bend upstream from the pump). The rate of land reworked jumps to about 4 acres per year (upper graph) immediately after cutoff occurs, and then decreases over time, with a rate of roughly 1 acre per year at the end of the time period.

5.0 Discussion and Conclusions

The simulated migration patterns reveal extensive reworked land by the unconstrained migration of the channel if riprap is removed. The simulations were used to quantify the land reworked with different scenarios. These quantifications can be used to consider the ecosystem costs and benefits with different management scenarios.

One observation is that scenario three (bank restraint removed from right bank of the bend upstream and the bank restraint extended near the pumping plant) suggests that, even if the pump site were stabilized, the bend upstream could be allowed to cutoff and provide natural regeneration of floodplain area and other habitat benefits.

6.0 Acknowledgements

Part of the research for this study was based on previous work by Eric Larsen and by student research and modeling by Evan Girvetz, Alexander Fremier, and Alex Young at UC Davis.
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7.0 List of figures

8.0 References

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