Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River

Project Information

1. **Proposal Title:**

   Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River

2. **Proposal applicants:**

   David L. Brown, California State University, Chico
   G. Mathias Kondolf , University of California Berkeley
   Steven E. Greco, University of California Davis
   Karin A. Hoover, California State University Chico

3. **Corresponding Contact Person:**

   David Brown
   California State University Chico
   Dept. of Geosciences CSU Chico Chico, CA 95929-0205
   530 898-4035
   dlbrown@csuchico.edu

4. **Project Keywords:**

   Channel Dynamics
   Hydrology
   Riparian Ecology

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Channel Dynamics and Sediment Transport

8. **Type of applicant:**

   University

9. **Location - GIS coordinates:**

Latitude: 39.881

Longitude: -122.047

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Multiple floodplain waterbodies along the Sacramento River between Red Bluff and Colusa (River Miles 245-144).

10. **Location - Ecozone:**

    3.2 Red Bluff Diversion Dam to Chico Landing, 3.3 Chico Landing to Colusa

11. **Location - County:**

    Butte, Colusa, Glenn, Tehama

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    2nd and 3rd

15. **Location:**

    California State Senate District Number: 1,4

    California Assembly District Number: 2,3

16. **How many years of funding are you requesting?**

    2

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

       Yes

       If yes, list the different overhead rates and total requested funds:

State Overhead Rate: 20

Total State Funds: 782681

Federal Overhead Rate: 45

Total Federal Funds: 885733

b) Do you have cost share partners already identified?

No

c) Do you have potential cost share partners?

No

d) Are you specifically seeking non-federal cost share funds through this solicitation?

No

If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

No

Have you previously received funding from CALFED for other projects not listed above?

No

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

No

Have you previously received funding from CVPIA for other projects not listed above?

No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

No

Please list suggested reviewers for your proposal. (optional)

Stacy Cepello Dept. of Water Resources (530) 529-7352 cepello@water.ca.gov

Jeff Mount UC Davis (530) 752-7092 mount@geology.ucdavis.edu

Eric Larsen UC Davis (530) 752-8336 ewlarsen@ucdavis.edu

Thomas Dunne **UC Santa Barbara**

21. **Comments:**

Environmental Compliance Checklist

Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No

   b) Will this project require compliance with NEPA?

      No

   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      There will be no significant impacts on land, water, or other environmental resources.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   CEQA Lead Agency: None
   NEPA Lead Agency (or co-lead:) None
   NEPA Co-Lead Agency (if applicable): None

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   -Categorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

   b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit

Rivers and Harbors Act

CWA 404

Other Required

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land. Agency Name: To be identified through Task 1 Inventory of floodplain water bodies	Required
Permission to access state land. Agency Name: To be identified through Task 1 Inventory of floodplain water bodies	Required
Permission to access federal land. Agency Name: US Fish and Wildlife Service; Others to be identified through Task 1 Inventory of floodplain water bodies	Required, Obtained
Permission to access private land. Landowner Name: To be identified through Task 1 Inventory of floodplain water bodies	Required

6. **Comments.**

Once appropriate sampling locations have been identified through Task 1, all appropriate permissions and/or permits will be obtained.

Land Use Checklist

<u>Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River</u>

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   Yes

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   research only

4. **Comments.**

Conflict of Interest Checklist

<u>Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River</u>

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

David L. Brown, California State University, Chico
G. Mathias Kondolf , University of California Berkeley
Steven E. Greco, University of California Davis
Karin A. Hoover, California State University Chico

Subcontractor(s):

Are specific subcontractors identified in this proposal? Yes

If yes, please list the name(s) and organization(s):

G. Mathias Kondolf	University of California Berkeley
Steven E. Greco	University of California Davis

Helped with proposal development:

Are there persons who helped with proposal development?

Yes

If yes, please list the name(s) and organization(s):

Karin A. Hoover **California State University Chico**

Comments:

Budget Summary

Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

Federal Funds

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary** ***(per year)***	**Benefits** ***(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Inventory and Historical Evolution of Former Channel Water Bodies	2452	36933	10174	0	1514	0	0	0	48621.0	23143	71764.00
2	Hydrology and Water Quality	2353	36285	5812	2045	4064	0	0	0	48206.0	18966	67172.00
3	Sediment Cores to Determine History of Oxbow Sedimentation	4747	69236	14693	3445	5014	28000	15000	0	135388.0	37641	173029.00
4	Vegetation Assemblages	2252	33742	9631	2945	2014	0	0	0	48332.0	22983	71315.00
5	Development of a Sacramento River Science Consortium	315	7300	1571	0	5000	0	0	0	13871.0	3285	17156.00
6	Project Management	1651	28303	4966	2000	1514	0	0	0	36783.0	16438	53221.00
		13770	211799.00	46847.00	10435.00	19120.00	28000.00	15000.00	0.00	331201.00	122456.00	453657.00

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Inventory and Historical Evolution of Former Channel Water Bodies	1252	19447	4515	0	1516	0	0	0	25478.0	11870	37348.00
2	Hydrology and Water Quality	2380	37929	6844	2045	3566	0	0	0	50384.0	19718	70102.00
3	Sediment Cores to Determine History of Oxbow Sedimentation	4741	79513	16381	3445	3016	16000	0	0	118355.0	42988	161343.00
4	Vegetation Assemblages	2252	34100	8751	2945	2016	0	0	0	47812.0	22694	70506.00
5	Development of a Sacramento River Science Consortium	335	8399	2262	0	5000	0	0	0	15661.0	3780	19441.00
6	Project Management	2161	37783	9338	2000	1516	0	0	0	50637.0	22699	73336.00
		13121	217171.00	48091.00	10435.00	16630.00	16000.00	0.00	0.00	308327.00	123749.00	432076.00

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
		0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grand Total=885733.00

Comments.

Budget column totals reflect costs for all three collaborating campuses (CSU, Chico, UC Berkeley, and UC Davis)

Budget Justification

Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River

Direct Labor Hours. Provide estimated hours proposed for each individual.

CSU Chico D. Brown 02-03 (355 hrs) D. Brown 03-04 (272 hrs) K. Hoover 02-03 (151 hrs) K Hoover 03-04 (272 hrs) Grad Asst. Task 2 (1,250 hrs) Grad Asst. Task 3 (1,250 hrs) Undergraduate student 03 (400 hrs) Research Assistant (4160 hrs) UC Berkeley G.M. Kondolf 02-03 (176 hrs) G.M. Kondolf 03-04 (176 hrs) Visiting Postdoctoral Researcher (2080 hrs) Graduate Student Researcher I (2640 hrs) Administrative Assistant III (422 hrs) UC Davis S. Greco (1056 hrs) Research assistant (PGR III) (4224 hrs) Research Assistant (Assistant IV) (2640 hrs) Graduate Student research assistant (PGR I) (2112 hrs) Computer administrator (422 hrs)

Salary. Provide estimated rate of compensation proposed for each individual.

CSU Chico D. Brown 02-03 ($39/hr) D. Brown 03-04 ($42/hr) K. Hoover 02-03 ($38/hr) K Hoover 03-04 ($40/hr) Grad Asst. Task 2 ($12/hr) Grad Asst. Task 3 ($12/hr) Undergraduate student ($10/hr) Research Assistant ($15/hr) UC Berkeley G.M. Kondolf 02-03 ($44/hr) G.M. Kondolf 03-04 ($45/hr) Visiting Postdoctoral Researcher ($17/hr) Graduate Student Researcher I ($14/hr) Administrative Assistant III ($20/hr) UC Davis S. Greco (0.25 FTE of $7,000/quarter) Research assistant (PGR III) ($16/hr) Research Assistant (Assistant IV) ($8/hr) Graduate Student research assistant (PGR I) ($18/hr) Computer administrator ($19/hr)

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

CSU Chico Faculty overload/summer @ 13% Faculty Academic Year @ 25% Grad Students @ 8% Undergrad Students @ 12% Research Assistant (Full-time Foundation) 16%+$5,280 UC Berkeley Faculty: summer 9.2% Visiting Postdoctoral Researcher 17.0% Students:1.3%-3.0% Staff 23.0% UC Davis Faculty: Not charged Research assistant (PGR III) 17% Research Assistant (Assistant IV) None Graduate Student research assistant (PGR I) None Computer administrator 17%

Travel. Provide purpose and estimate costs for all non-local travel.

CSU Chico Local to field sites $1,000 International $4,000 UC Berkeley local to field sites $10,670 UC Davis local to field sites $ 6,000 NOTE: Funds requested for international travel are to subsidize the visit of French researchers.

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

Office $2000 Laboratory $1000 Computing $4800 Field supplies 12500 Workshop expenses $10,000 (facility charges, copying, refreshments, office supplies, mailing, shipping)

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

Isotope analyses Lab fees: Cs137 analysis 40 samples @ $50 = $2,000 C14 analysis 40 samples @ $50 = $2,000 Equipment rental: GPR Rental ($5000/week x 1 week) $5,000 GPR calibration and training (service contract: $3,800/day x 5 days) 19,000.

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

"Big Beaver" Earth drill with 40 feet of hollow stem augers $15,000

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

Task 6 direct costs total approximately $87,400 or about 10% of the budget. These costs cover regular project meetings of the P.I. team as well as consultation with visiting scientists from France. Other project management costs include preparation of material for presentation at the CALFED science conference and other meetings, preparation of data reports and maps for public distribution, meetings with CALFED Science Board staff regarding formation of the Sacramento River Science Consortium, and quarterly and final project reports.

Other Direct Costs. Provide any other direct costs not already covered.

None anticipated

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

CSU, Chico's federally-negotiated indirect rate for on-campus projects is 45% of salaries and wages. The rate is negotiated through the Department of Health and Human Services. The current rate is determined until 06/30/04. The rate covers general office and campus requirements; it does not include fringe benefits which are charged as direct costs.

Executive Summary

Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River

Former channels of alluvial rivers, such as oxbow lakes (cut-off meander bends), support rich plant and wildlife habitats, contribute significantly to floodplain productivity, and store water during high flows. Along the Sacramento River in the Central Valley of California, former channels contribute to the river systems biodiversity and heterogeneous habitat composition. Former channels constitute important floodplain aquatic habitats, which evolve over time from fully aquatic to fully terrestrial areas as they silt in, and the riparian forests that grow near and around oxbow lakes in the system comprise a diverse array of plant and tree species supporting greater diversity and richness of wildlife species than any other habitat type in the western United States. While former channels are known to support critical wildlife habitat and contribute significantly to the biodiversity of the river system, key information is missing on how they evolve over time (Marston et al 1995, Piégay et al 2001). To wisely manage these floodplain features in the Sacramento River system, we need to better understand their spatial extent, distribution, lifespan, developmental processes, and ecological characteristics. Due to human impacts such as land use conversion to agriculture and urban settlement, construction of levees, and reduced flooding regimes downstream of dams, much of the Sacramento Rivers floodplain habitats, including former channels and riparian forests, have been lost or damaged. Most of the remaining riparian forests occur in flood-prone areas, notably on the margins of channels and along oxbow lakes (Strahan 1984). The Nature Conservancy has identified the conservation of oxbows and other former channels as a priority to protect and restore the full range of habitat types within the Sacramento River system. We propose to conduct targeted research to better understand the ecological evolution of six former channels known to have cut off from the Sacramento River within the last century, and an additional six older former channels. By measuring such factors as the siltation rate, stratigraphic sequence of deposits, relevant water quality variables, hydrologic history, and surrounding vegetation distribution, we will be able to establish a time frame for the rate of physical evolution, sources of baseflow, and relationships among water chemistry, floodplain processes, and vegetation. Our results should increase understanding of how these dynamic floodplain features function and help decision-makers prioritize former channels for conservation and restoration. Finally, we hope to use this project as a model for future coordinated research on the Sacramento River system. Formation of a proposed Sacramento River Science Consortium will be explored through a series of four workshops held throughout the region. Outreach activities will seek to engage researchers from universities, governmental agencies, private-sector consultants, and non-governmental organizations.

Proposal

California State University, Chico

Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels along the Sacramento River

David L. Brown, California State University, Chico
G. Mathias Kondolf , University of California Berkeley
Steven E. Greco, University of California Davis
Karin A. Hoover, California State University Chico

Geomorphic and Ecological Investigation for Conservation and Restoration of Former Channels (Oxbow Lakes) along the Sacramento River

Proposal for targeted research submitted by

David L. Brown
California State University, Chico
Department of Geosciences
California State University, Chico
95929-0205

G. Mathias Kondolf
University of California, Berkeley
390 Wurster Hall
Berkeley, CA 94720-1839

Steven E. Greco
Department of Environmental Design
University of California
One Shields Avenue
Davis, CA 95616

Karin A. Hoover
Department of Geosciences
California State University, Chico
95929-0205

5 October 2001

PROJECT DESRIPTION

1. Problem

Oxbow lakes are abandoned river channels cut off during channel migration, which gradually fill in with fine sediment brought in by overbank flows and with organic matter produced by aquatic and terrestrial plants. Over time oxbow lakes evolve from aquatic to terrestrial habitats and the rate of change depends on several factors. Oxbow lakes and adjacent riparian forests host a high level of biodiversity yet the hydrologic and geomorphic processes that create, sustain, and drive their evolution are only now being studied, with research on rivers elsewhere but relatively little to date on the Sacramento system (Piégay et al. 2001, Henry et al. 1995, Greco 1999, Ward and Stanford 1995).

The Sacramento River is the state's largest and most important river system and comprises a rich ecosystem with a mosaic of diverse habitats, including many oxbow lakes. Since the mid-nineteenth century, however, human impacts have transformed the system dramatically. Conversion of floodplains to agriculture and the use of wood from forests along the river to fuel steamboats led to extensive cutting of the riparian forests and oak woodlands (Dutzi 1979, Kelley 1989, Greco 1999). Large dams on the river and its tributaries and an extensive levee system decreased river flows and constricted the floodplain. As a result, most of the riparian forests in the system have been destroyed, leading to a loss in habitat for many plant and animal species. Much of the remaining riparian forests along the Sacramento River occur between Red Bluff and Colusa, in a reach flanked by low floodplains in which the channel can still migrate to a limited extent. Within this riparian corridor, oxbow lakes and other former channels are "hotspots" of biodiversity. The sinuosity of the river measurably decreased over the 20^{th} century, attributable at least in part to the clearing of floodplain forest and consequent increase in velocities of overbank flows, in turn increasing the potential for chute cutoff (Brice 1977). These meander cutoffs are not currently offset by growth of meander bends because so many bends are stabilized by riprap, so a net straightening of the river has resulted.

The high ecological value of former channels makes them excellent candidates for conservation and restoration, but because they are evolving, dynamic features, it is not immediately clear how to conserve and restore them. We need basic information about the evolution of oxbow lakes, particularly silting-in dynamics, to develop an effective conservation strategy. For example, how well do existing ecological models of former channel evolution apply to the Sacramento River, and how well can they guide conservation decisions? As the magnitude and frequency of floods and suspended sediment loads has been reduced by upstream reservoirs, former channels are less frequently flooded, affecting their evolution. More importantly, reduced high flows mean less channel migration and thus less point bar growth and meander cutoff, creating fewer new surfaces for colonization by pioneer species, and thus less diversity in vegetation species and life stage (Johnson 1992). Restoration of floodplain aquatic and riparian habitats along the Sacramento will likely requires some renaturalization of the river's flow regime, but at this point we do not have enough understanding to inform the choice of flows needed. Similarly, actions to reconnect artificially isolated oxbow lakes (as undertaken along the upper Rhône by Henry et al. 1995) may be beneficial along the Sacramento, but we literally do not have sufficient understanding of the system dynamics now to make an evaluation. A better understanding of former channel processes along the Sacramento River should help us to select better priority sites for conservation, and to choose better among potential restoration actions.

In this study, we propose *to inventory former channel water bodies, document hydrologic relations a between the former and current channels, measure water quality in oxbow lakes, obtain and analyze sediment cores to determine the history of oxbow sedimentation and depth to groundwater, and sample and analyze vegetation assemblages.*

2. Justification

Conceptual Model

Oxbow lakes are dynamic features that exist as a transitional stage of an evolutionary progression from main river channel to upland and ultimately a return to river channel when the channel migrates into the old oxbow deposit. Our conceptual model for the development, evolution, and ultimate disappearance of oxbow lakes along the Sacramento River is illustrated in Figure 1. Channel cutoffs can occur either by meander neck cutoff (in which the meander bend grows progressively more tortuous until the neck remaining between successive bends thins and is finally breached) or by chute cutoff, in which flood flows across the meander bend begin eroding a more direct, 'shortcut' route across the bend, and this shortcut is adopted by the river either during the same flood or a later flood (Bravard and Gilvear 1996). The cutoff mechanism will influence the form of the resulting oxbow lake, but in either case the cutoff effects a transition from main channel environment to a flowing side channel, with a fully aquatic environment. Along the Sacramento River, such flowing side channels generally persist for a year or more following the cutoff. (In some river systems, the cutoff channel may transition to an oxbow slough during the flood producing the cutoff.)

As the main channel cuts off, it shortens the reach length thereby increasing the slope and erosive power of the flow, and commonly leading to channel incision. For example, when a meander bend immediately downstream of the intake to the Glen-Colusa Irrigation District (GCID) diversion cut off (by chute cutoff) in 1970, the mainstem incised and the water surface elevation decreased 1 meter at the entrance to the side channel on which the GCID diversion is located. In this case, the lowered water surface had negative consequences for the efficiency of a recently installed fish screen at the diversion. In the case of the cut-off meander bend, the downcutting of the bed means that the bed of the cutoff (old) channel will be higher than the newly incised main channel bed, which would tend to accelerate the isolation of the cut-off channel. Unfortunately, we have little historical documentation from which to estimate the amount of incision associated with most cutoffs along the Sacramento River, but this factor would affect the subsequent evolution of the oxbow.

As flow enters the side channel, its velocity decreases, and it deposits (usually sand-sized) sediment at the upstream end of the side channel. As this deposit builds, it further slows the current, inducing more rapid sedimentation and building in elevation, such that progressively higher and higher flows are required to connect the side channel to the river. The result is that the side channel is cut off from the flowing river at its upstream end by the plug, and connected to the river only at its downstream end, forming an oxbow slough.

The oxbow slough is inundated from its downstream end during moderate flows, as water backs up from the main channel, depositing mostly finer grained silts from suspension in the backwater environment of the slough. During floods large enough to top the plug, there will be stronger currents down the slough, limiting deposition in these events. Eventually the deposits grow to the point that the downstream end of the slough is plugged as well, leading to an isolated oxbow lake. As implied by the description above, the boundaries among flowing side channel, oxbow slough, and oxbow lake are flow dependent, with greater connectivity at higher flows. However, in practice we classify these features by their appearance on aerial photographs, which are typically shot during low flows in summer or fall.

Over time, the oxbow lake silts in as muddy overbank flood flows deposit sediment in the abandoned channel, and the oxbow transitions from aquatic to terrestrial. Eventually, it may fill completely, build up to higher elevations, and become indistinguishable from the rest of the higher terrace surfaces, which we can term upland habitats because their frequency of flooding is so rare. At any time in this cycle, the main channel may erode back into the feature, such that it is possible for a point to transition from upland, oxbow lake, oxbow slough, or even flowing side channel back to main channel.

Recent research on oxbow lakes in the Ain River system in France demonstrates that the silting-in dynamics of abandoned channels are largely influenced by the hydrologic connectivity between the former and active channels (Citterio and Piégay 2000, Piégay et al. 2001). Connectivity in turn, is influenced by the length and elevation of the alluvial plug between the main channel and the aquatic part of the abandoned channel. The plug fills in primarily as a function of the time and frequency of flooding events, channel geometry of the abandoned channels, and evolution of the main channel (e.g. the extent that it migrates away from the abandoned channel) (Piégay et al. 2001). Another study on the Ain River suggests that the composition and dynamics of vegetation communities in and adjacent to oxbow lakes are strongly controlled by erosion and deposition processes during flood events as well as the location of the cut-off channel within the river corridor (Piégay et al. 1999).

Depending on the nature of the cut-off mechanism and rates of infilling, oxbow lakes experience sporadic or intermittent connectivity with a river. However, because they are previous channels they retain a permanent connection with groundwater. After cutoff has occurred and before overbank sedimentation fills the channel, the water level within the oxbow reflects and depends on the elevation of the water table and rates of groundwater flow towards and, during high flow events, possibly away from the river. The actual depth of water within the oxbow, as well as the nature and rapidity of depth fluctuations, influences the life functioning of a variety of aquatic and riparian species. For example, water nutrient levels determined by groundwater fluxes are found to influence aquatic plant communities (Bornette et al. 1998). Determining controls on water depth, depth fluctuations, and nutrient supply is therefore critical to understanding the functioning of oxbow ecosystems.

Ecological Importance

Along an actively migrating alluvial river, the dynamic evolution of former channels creates a mosaic of habitats, i.e., areas of bare sand and gravel, patches of riparian vegetation at different stages of succession, and aquatic habitats at different stages of terrestrialization, i.e. in transition from fully aquatic channel to filled-in floodplain (Figure 2). These habitats support several threatened and endangered species within the riparian zone on the Sacramento River. The aquatic habitats support many life stages of anadromous fish species such as spring, winter and fall-run chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*). The terrestrial habitats associated with oxbow lakes also support many endangered species, for example, the western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) and Swainson's hawk (*Buteo swainsoni*). Understanding the regenerative processes of these habitats is critical to the long-term management of these species.

Project Type

This project falls under the category of *targeted research*, as our understanding of oxbow lake evolution along the Sacramento River is too limited at present to pursue even pilot projects. The results of this study can inform decisions about future flow regimes in the river, and help to design on-site projects to increase diversity, such as restoration of oxbows if warranted by the conceptual model.

3. Approach

We propose to study the geomorphic and hydrologic processes that have influenced and shaped former channels along the Sacramento River, as well as identify the composition and patterns of vegetation that exist adjacent to them. We will undertake this research in 6 tasks.

Task 1. Inventory and Historical Evolution of Former Channel Water Bodies

The first task is to conduct an inventory of existing and "former" floodplain water bodies (oxbow lakes). The existing water bodies will be mapped into a geographic information system (GIS) from current aerial photographs and each will classified into one of the following categories: (1) flowing side channel, (2) oxbow slough, (3) oxbow lake, or (4) upland, fully terrestrialized. The former or historical water bodies will be delineated using aerial photographs that depict organic soil traces combined with soil and topographical maps. Historical main-stem channels of the river will also be delineated from maps and aerial photographs to reveal the location of former channels. This inventory is important for estimating the rates of meander cut off and will show the full spatial distribution of these floodplain water features within the study reach (Red Bluff to Colusa).

From this inventory we will select a set of oxbow water features for intensive monitoring. To document the evolution of former channels from the time of formation, we will identify six oxbow lakes that cut off sometime since the beginning of the historical record (i.e. maps and aerial photographs) in 1887, and we will identify six older former channels for study. We will document the evolution of these oxbows since their cut off by mapping the extent and characteristics of oxbows on historical maps and aerial photography. We will rectify the images by digitizing landmarks (such as buildings or road intersections) that appear in sequential photographs and rectified topographical maps, and where necessary surveying the actual elevations of these points in the field to provide control. From this analysis we can measure changes over time of: (1) the area of open water in oxbow lakes, (2) the alluvial plug elevations, and (3) the area and height of riparian vegetation. We will measure these site attributes using GIS and photogrammetric software tools.

Task 2. Hydrology and Water Quality

We will observe the stage at each former channel and the adjacent mainstem over a range of discharges to develop stage-discharge relationships for the current and former channels. We will use these data with flow records from nearby recording stream gauges (e.g., Red Bluff, Hamilton City, Butte City) to develop stage hydrographs for the sites of conservation interest. At one site, we are installing a Hydrolab® (Quanta) instrument to record short-term stage fluctuations, providing continuous data for analyzing how the former channel responds to rainfall, changes in flow in the adjacent river, groundwater, and general patterns in water level fluctuations. We will measure the stage manually at the other oxbow lake sites on a less frequent basis but will establish similar relationships for these sites to document hydrologic connectivity with the main channel and to develop the history of water elevations in the current and former channels.

The Quanta instrument also will measure temperature, pH, dissolved oxygen, salinity, conductivity, and turbidity continuously, providing baseline data on water quality and nutrient content. These water chemistry factors will be measured manually at the other oxbow lake sites periodically as well for comparison. Nutrient levels have been shown to influence plant and animal species distribution within oxbow lake environments, and with this data, we can provide the physical and chemical basis for ecological models that will evaluate plant and animal response to oxbow lake evolution.

To determine the influence of groundwater and groundwater flow on water levels, level fluctuations and nutrient supply for oxbow lakes on the Sacramento River, we will install piezometers along a transect from behind (beyond) each oxbow lake to the main channel. At approximately 1-month intervals, and more frequently when water levels are fluctuating rapidly in the main channel (2-week intervals during spring and fall), we will measure water levels within the piezometers and gauge water quality factors including conductivity, pH, and temperature of the groundwater. These data will allow us to establish relations between water surface elevations in the main and former channels and the water table, to determine seasonal horizontal and vertical groundwater flow directions and direction reversals, and to identify the source of baseflow in former channels.

Task 3. Sediment Cores to Determine History of Oxbow Sedimentation

When the river and former channel water levels are relatively low, we will take sediment cores across the center and ends of the channel cutoff to analyze the stratigraphy and sedimentology of the deposits, measure sedimentation rates, and distinguish individual strata associated with depositional events. We will use hand augers in inaccessible sites or for thin deposits, and use a portable hollow-stem power drill coring device when access permits and where alluvial plug deposits are deeper. We will date strata within the cores using C^{14}, Cs^{137}, and Pb^{210} radionuclides to determine sedimentation rates over time. Establishing dates within the cores will also be important for correlating individual distinctive strata with known hydrologic events (e.g., floods capable of depositing sediment in the abandoned channel) and, in conjunction with the sedimentologic evidence, in determining the nature of changes in connectivity with the main channel as the oxbow evolves through time. These cores will provide a record of changing sedimentation caliber and rate over time in the oxbow lakes, which can be related to historical location of the oxbow with respect to the migrating channel and the history of flows to yield insight into evolution mechanisms. As part of this task we will also explore the use of a ground penetrating radar (GPR) system to accurately map the ground surface under dense tree cover, and to provide information on the substrate stratigraphy and depth of groundwater at each of our selected study sites. The hand and truck coring will be used to calibrate the GPR work.

Task 4. Vegetation Assemblages

We will map current vegetation in and adjacent to each former channel, recording plant species, density, and composition and see how these assemblages relate to water chemistry, notably nutrient levels. In addition to fieldwork, we will conduct a historical study of the former channels to document geomorphic and vegetative changes since their cutoff time through literature and aerial photographs. Assessing physical factors such as the alluvial plug length on aerial photographs over time will provide information on the evolving hydrologic connectivity to the main channel. We will analyze changes in structure and density of vegetation in relation to hydrologic and geomorphic changes.

Sediment cores taken from the center of oxbow lakes and radiometrically dated may also prove useful for palynologic and vegetation succession analysis. Lakes are principal environments where pollen grains accumulate today. Pollen extracted from organic-rich, dated (or bracketed) strata should indicate the vegetation succession in the vicinity of the oxbow as infilling occurred. Although species not representative of those living in proximity to the lake may be blown in or brought in by overbank flows, their relative numbers should be low compared to those species living adjacent.

Task 5. Development of a Sacramento River Science Consortium

This project provides a working model of a proposed science consortium between various university campuses focused on coordinated science efforts in the Sacramento River system. The team of P.I.s involved in this project has been collaborating with a variety of other researchers on Sacramento River projects as described below under "Related Studies and Support". We seek to expand Sacramento River research efforts by developing a consortium of institutions that coordinate activities. Our goal is to improve consortium member success in seeking diversified funding from sources such as the National Science Foundation, the Environmental Protection Agency, the U.S. Department of Agriculture, and other national competitive programs. Development of shared research facilities and equipment on or near the river is a short-term goal. Outreach efforts will be directed to recruit local and regional universities and colleges, state and federal agencies, non-governmental agencies, and private-sector interests. Four workshops will be held throughout the Sacramento-Bay-Delta region to solicit consortium participation and to develop a charter. We view this consortium as working closely with complementary efforts of Department of Water Resources staff and with the CalFed Science Board.

Task 6. Project Management

The project will be managed by the Principal Investigators, who will hold bi-monthly meetings in the field and/or at their respective universities. The field work will be coordinated out of Chico State University, with the UC Berkeley and UC Davis scientists coming up to Chico and the field sites for stays of several days during field work. The Nature Conservancy (TNC) supports this grant and will provide space at one or more of their facilities and other field logistical assistance (Greg Golet, TNC, personal communication). This arrangement has already proven effective in the initial pilot work, in which Ingrid Morken, a UC Berkeley graduate student has worked closely with TNC staff in trips of several days each to establish and survey the initial study sites, with TNC staff making measurements in between the more intensive work during Ingrid's visits. P.I. Brown will have responsibility for compiling and preparing quarterly progress reports. The final report will be written by the PIs with contributions from their staff and graduate students.

Participation by French Scientists

To provide expertise in oxbow lake research methods and analysis, Hervé Piégay, a fluvial geomorphologist at the National Center for Scientific Research in Lyon, France, and his doctoral student Anne Citterio will participate in the study. They have studied the geomorphic and ecological evolution of former channels on the Ain, Rhône, and Doubs Rivers in France for over five years, and have developed substantial insights into the ecological functioning of these floodplain features. The opportunity to draw on the experience and insights of our French colleagues will enhance the effectiveness of our research on the Sacramento River. The international collaboration also will bring knowledge from other systems across national borders and under different conservation management systems. Professor Kondolf has received a grant from the Council for International Exchange of Scholars to partially offset travel expenses for technical exchange between the two research programs, but funding is requested from Calfed to support travel expenses within California and for a post-doctoral stay in Berkeley for Anne Citterio, who is now completing her PhD thesis on evolution of oxbow lakes on the Ain River, France, so she can apply the same analytical techniques to the Sacramento River.

4. Feasibility

The proposed sampling and field measurements are feasible, as they have already been tried out on a pilot basis at sites along the Sacramento River. We have already received permission from the U.S. Fish and Wildlife Service to sample on the initial six former channel sites and have commenced initial data collection there. The additional six study sites will be selected, in part, based on willingness of landowners to participate in the study.

5. Performance Measures

Performance measures for this project will include publication of research findings in peer-reviewed journals. At this time, we anticipate at least one publication for Tasks 1 and 4, and two publications for Tasks 2 and 3. Effectiveness of workshops proposed in Task 5 will be measured through meeting evaluation forms completed by workshop participants. Timely submittal of quarterly and final project reports will be the performance measure for Task 6. Water quality data gathered in Task 2 will provide a benchmark for evaluating potential changes in water quality if river or local land-use changes. Presentations will be made to the CalFed Science Conference and other technical and public meetings such as the annual Fall American Geophysical Union meeting in San Francisco. The results of the Task 1 Inventory will be made available as a series of data report maps published in electronic and paper form. We will work with appropriate agencies to seek distribution outlets for the inventory results. Technical findings on the water bodies will be distilled into fact sheets and news feature articles that can be published in local, state, or national media.

6. Data Handling and Storage

Data will be initially stored by the P.I. leading on the respective tasks. The geographic information system (GIS) and computer photogrammetric work will be conducted at the Landscape Analysis and Systems Research (LASR) Laboratory directed by Dr. Steven Greco at U.C. Davis. Ultimately, it is envisioned that a central web site will be established to support the proposed Sacramento River Science Consortium. This site will provide access to project publications, data, maps, and interpretive information products described in Section 5. Mirror sites will be established at the three principal universities participating in this project.

7. Expected Products/Outcomes

Task	Journal Publications	Meeting Presentations	Data Reports	Media
1	Floodplain water body spatial distribution analysis	Scientific conference on wetlands or riparian systems	Inventory maps and summary; GIS Data Layers on CD or website	Feature article on distribution of oxbow lakes
2	Groundwater-river exchange; Chrono-sequence of oxbow lake chemistry	Groundwater-river exchange; Chrono-sequence of oxbow lake chemistry	Water quality of benchmark oxbow lakes	
3	Stratigraphy, sedimentology, and sedimentation rates of oxbow infilling on the Sacramento River; GPR soil stratigraphy near floodplain water bodies	Stratigraphy, sedimentology, and sedimentation rates of oxbow infilling on the Sacramento River; stratigraphic evolution of oxbow lakes	Sediment core benchmark analysis	Feature article
4	Time series and transition analysis of vegetation change along oxbow lake water bodies; Restoration strategies for oxbow lakes and other floodplain water bodies; Vegetation succession determined by palynological analysis	Scientific conference on river restoration or conservation ecology; Vegetation succession determined by palynological analysis	-Inventory maps and Summary of findings; Sacramento River pollen reference collection; GIS Data Layers on CD or website	Feature articles Animated time sequences of riparian ecosystem change

8. Work Schedule

Tasks 1, 2, and 3 are inseparable and form the core work of the proposal. Task 4 is essential, however, to making progress on Sacramento River ERP priority SR-7 described below. This is a relative timeline that extends over 24 months from the start date. Start date adjustments can be accommodated up to November 2002.

Task Oct-02 Jan-03 Apr-03 Jul-03 Oct-03 Jan-04 Apr-04 Jul-04 Sep-04

1 --------------------------→May-03

2 Dec-02 --→Aug-04

3 Sep-03 -----------→Mar-04

4 Mar-03 -→Jun-04 Mar-03---→Jun-04

[Could be deferred until a subsequent phase of investigation.]

5 Outreach Workshop 1 Workshop 2 Workshop 3 Workshop 4
[A minimum of two workshops are needed, but partial funding would be effective.]

6 Quarterly reports ---Final report

B. Applicability to CALFED ERP and Science Program Goals and Implementation Plan and CVPIA Priorities

1. ERP, Science Program and CVPIA Priorities.

SR-4.) Restore geomorphic processes in stream and riparian corridors.

This project would contribute significantly to the understanding of how geomorphic processes influence biological productivity in the floodplains of the Sacramento River. The analysis of historical development (regeneration) of riparian vegetation along oxbow lakes will inform restoration strategies designed to enhance habitat for a variety of aquatic and terrestrial species.

SR-7.) Develop conceptual models to support restoration of river, stream and riparian habitat.

Our proposal seeks to refine a conceptual model of the dynamic evolution of floodplain water bodies within the Sacramento River ecosystem between Red Bluff and Colusa. We will monitor and document basic structural components of the system such as stratigraphy, groundwater, and riparian vegetation composition and the change of these structural components over time.

2. Relationship to Other Ecosystem Restoration Projects.

The data collected on former channels contributes to and benefits from a National Science Foundation-funded project developing a biocomplexity model for the Sacramento River. Scientists from University of California (UC Berkeley, UC Davis, UC Santa Cruz), University of Montana, California State University Chico, and Point Reyes Bird Observatory are collaborating on the development of a biocomplexity model to link hydrology, geomorphology, vegetation, and bird communities of the system. Our data on the hydrology and geomorphology of oxbow lakes will be linked to models of riparian forest succession and habitat for bird communities, provide information on the ecological importance of former channels in the larger context of the Sacramento River ecosystem. The NSF grant funded initial data gathering on former channel hydrology in Spring 2001. As noted above, Professor Kondolf has received an award from the Council for International Exchange of Scholars to support collaborative interchange between our research team and that of Hervé Piégay working on former channels of the Ain, Rhône, and Doubs Rivers in France.

In a related CalFed proposal under this funding cycle entitled *Implementing a collaborative approach to quantifying ecosystem flow regime needs for the Sacramento River*, The Nature Conservancy and Stillwater Sciences have included a task to quantify fluvial geomorphic processes that create meander cutoffs. This analysis will complement our work on evolution of oxbow lakes once they are formed. Professor Kondolf will participate in the TNC project as an advisor and will insure the studies are coordinated such that the results generated can be combined into a coherent conceptual whole. This coordination will include selecting the same cutoffs to analyze where feasible.

3. Requests for Next-Phase Funding. Not applicable

4. Previous Recipients of CALFED Program or CVPIA funding.

None of the P.I.s has received previous CALFED as the primary applicant. Professor Kondolf has been funded by CVPIA to conduct geomorphic studies on Deer, Mill, and Clear Creeks from 1997-2000. However, P.I.s Brown, Kondolf, and Hoover have had or have current subcontracts to CALFED funding recipients.

5. System-Wide Ecosystem Benefits.

A greater understanding of the developmental dynamics of floodplain water bodies will help inform and guide restoration efforts of these important ecological resources. Since much of the riparian zone in the Sacramento River system has been extensively fragmented and diminished in extent many species currently lack a variety of suitable habitats. In the riverine/riparian environment the interface between land and water creates a highly productive environment which is known as the aquatic-terrestrial transition zone (ATTZ). The productivity of the ATTZ is influenced by the flood-pulse (Junk et al. 1989). When flood waters rise in a riverine system the floodplains and former channel areas (oxbow lakes) are reconnected to the main-stem channel allowing for the exchange of organisms and nutrients. Increases in the flood-pulse frequency has been shown to correlate with increases in fish biomass (Roux and Copp

1996).

6. Additional Information for Proposals Containing Land Acquisition. Not applicable

C. Qualifications

David L. Brown, Ph.D., Associate Professor, joined the Geosciences Department at CSU, Chico in August 1997. He teaches courses in hydrology and environmental science with an emphasis on interdisciplinary studies such as watershed hydrology. He supervises graduate students with a broad range of research topics, including riparian restoration hydrology, groundwater-surface water interactions, hyporheic zone processes, watershed analysis, and pesticide runoff. Since July 2000, Dr. Brown has served as the Science Director of the CSU, Chico Bidwell Environmental Institute. Over the past four years, he has been awarded 13 funded projects totaling more than $500,00 in total grants and contracts. In addition to the topics listed above, these projects include soil and groundwater characterization, surface water sampling, nonpoint source pollution, and analysis of conjunctive use of surface water and groundwater.

G. Mathias Kondolf is a fluvial geomorphologist whose research concerns environmental river management, influences of land-use on rivers, notably effects of mining and dams on river systems, interactions of riparian vegetation and channel form, geomorphic influences on habitat for salmon and trout, alternative flood management strategies, and assessment of ecological restoration. He has published over one hundred technical journal articles, book chapters, and reports on these and related topics. Dr. Kondolf is an Associate Professor of Environmental Planning and Geography at the University of California at Berkeley, where he teaches Hydrology for Planners, Restoration of Rivers and Streams, Ecological Analysis in Urban Design, and Introduction to Environmental Sciences. He received his Ph.D. in Geography and Environmental Engineering from the Johns Hopkins University, his MS in Earth Sciences from the University of California at Santa Cruz, and his AB in Geology (*cum laude*) from Princeton University. Dr. Kondolf has served as consultant to clients including the Federal Government of Germany, the US Fish and Wildlife Service, the US Army Corps of Engineers, the US Bureau of Land Management, the California Attorney General, the California Department of Fish and Game and Department of Water Resources, various water districts and utilities, aggregate producers, and environmental organizations. He has provided expert testimony to committees of the US Congress and California State Senate, the California State Water Resources Control Board, and other official bodies and legal proceedings. Dr. Kondolf was an author of Strategic Plan for, and is currently a member of the Science Board for the Calfed Ecosystem Restoration Program.

Steven E. Greco has degrees from the University of California, Davis (B.S. Landscape Architecture 1987, M.S. Ecology 1993, and Ph.D. Ecology 1999). Currently he is an Assistant Professor in the Landscape Architecture Program in the Department of Environmental Design at the University of California, Davis. His research interests include ecological restoration, species conservation, patch dynamics, historical landscapes, and spatial modeling of terrestrial and hydrological processes using geographic information system computer technology. Dr. Greco has worked on a variety of projects that integrate landscape architecture, planning and design with ecological principles. He has extensive experience with the Sacramento River ecosystem and its landscape dynamics.

Karin A. Hoover, Ph.D., Assistant Professor, joined the Geosciences Department at CSU, Chico in January, 2000 after 13 years as a Research Hydrologist at the Pacific Northwest National Laboratory. She teaches courses in hydrogeology, hydrology, and surficial processes. Her graduate and undergraduate students are working on projects relating to groundwater flow and water resources, subsidence, fate and transport of pesticides in the vadose zone, and fluvial sedimentology. She currently has a project with The Nature Conservancy to determine the effects of river channel changes on cottonwood recruitment along the Sacramento River.

D. Cost

2. Cost-Sharing.

No direct cost-sharing is available for this project.

E. Local Involvement

Being a targeted research project, the proposed work does not immediately emphasize the importance of involving local stakeholders. However, as noted previously, the inventory of former channel water bodies (Task1) may lead to selection of study sites on private lands or lands under local governmental jurisdiction. As appropriate, we will hold workshops in which we hope to learn from local stakeholders about the history and management of the oxbow lakes.

F. Compliance with Standard Terms and Conditions

The applicant will comply with the standard State and Federal contract terms described in Attachments D and E.

G. REFERENCES CITED

Bornette, G., C. Amoros, H. Piégay, J. Tachet, and T. Hein. 1998. Ecological complexity of wetlands within a river landscape. *Biological Conservation*. 85: 35-45.

Bravard, J. -P., and D. Gilvear. 1996. Hydrological and geomorphological structure of hydrosystems. Pp. 98-116 in G. E. Petts and C. Amoros (editors). Fluvial hydrosystems. Chapman and Hall, New York, NY.

Citterio, A. and H. Piégay. 2000. Infilling of former channels of the lower Ain river (South-eastern France): contemporary dynamics and controlling factors. *Geomorphologie: relief, processus, environnement.* 2: 87-104.

Dutzi, E. J. 1979. Valley oaks in the Sacramento Valley: past and present distribution. M.S. Thesis, Department of Geography, University of California, Davis, CA.

Greco, S. E. 1999. Monitoring Riparian Landscape Change and Modeling Habitat Dynamics of the Yellow-Billed Cuckoo on the Sacramento River, California. Ph.D. Dissertation. University of California, Davis.

Henry, C.P., C. Amoros, and Y. Giuliani. 1995. Restoration ecology of riverine wetlands: II. An example in a former channel of the Rhone River. *Environmental Management*. 19 (6): 903-913.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Pp. 110-127 in D. P. Dodge (ed.). Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106, Ottawa, Ontario.

Kelley, R. 1989. Battling the Inland Sea. University of California Press, Berkeley, CA. 395 p.

Marston, R. A., J. Girel, G. Pautou, H. Piégay, J. Bravard, and C. Arneson. 1995. Channel metamorphosis, floodplain disturbance, and vegetation development: Ain River, France. *Geomorphology.* 13: 121-131.

Piégay, H., G. Bornette, A. Citterio, E. Hérouin, B. Moulin, and C. Statiotis. 1999. Channel instability as a control of silting dynamics and vegetation patterns within perifluvial aquatic zones. *Hydrological Processes.*

Piégay, H., G. Bornette, and P. Grante. 2001. Assessment of silting-up dynamics of eleven cut-off channel plugs on a free-meandering river (the Ain River, France). *Applied Geomorphology, Theories, and Practice.* New York: John Wiley and Sons, Inc.

Roux, A.L., and G.H. Copp. 1996. Fish populations in rivers. Pp. 167-183 in G.E. Petts and C. Amoros (eds.). Fluvial Hydrosystems. Chapman and Hall, London

Strahan, J. 1984. Regeneration of riparian forests of the Central Valley. *California Riparian Ecosystems: Ecology, Conservation and Productive Management*, pp. 58-67. Berkeley, CA: University of California Press.

Ward, J. V. and J. A. Stanford. 1995. Ecological connectivity in alluvial rivers and its disruption by flow regulation. *Reg. Rivers Res. Management* 11: 105-119.

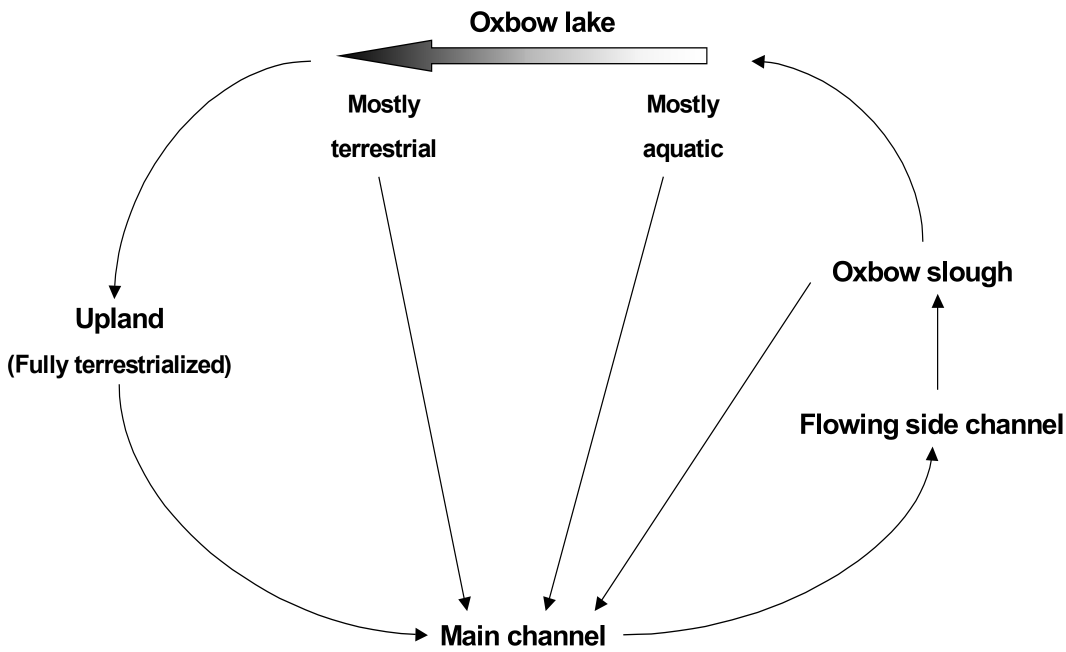

Figure 1: Conceptual process model of oxbow lake evolution.

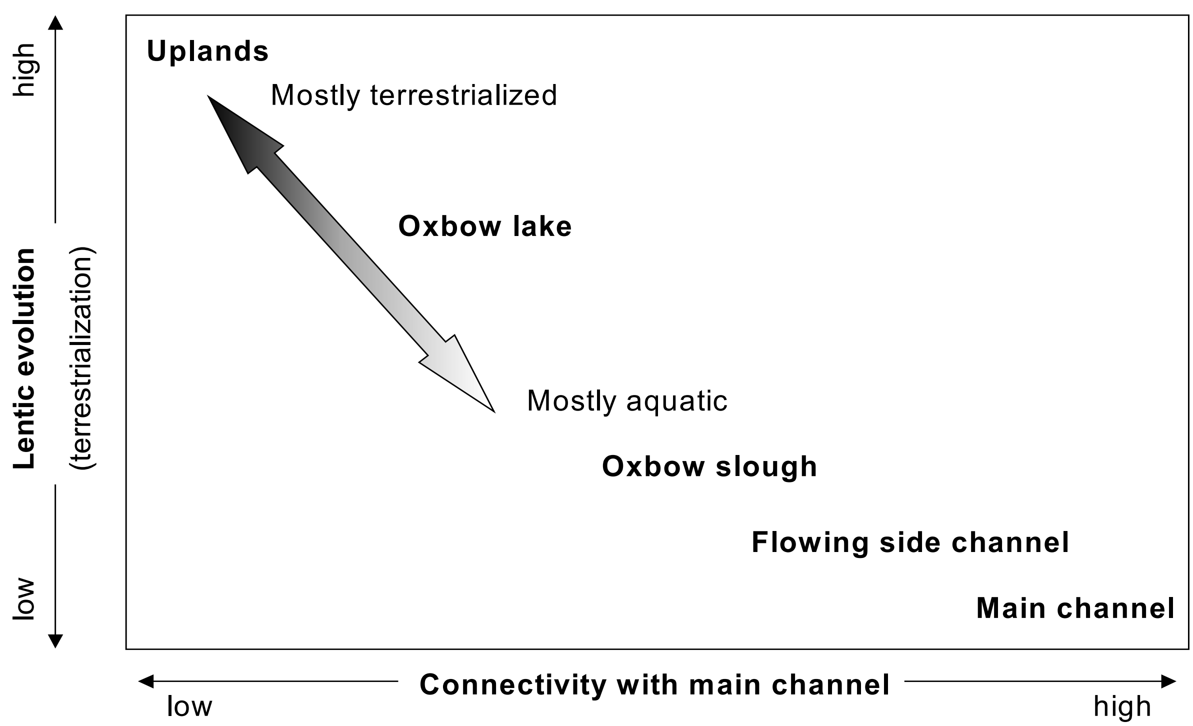

Figure 2: Conceptual model of oxbow lake evolution and its relationship to the main channel and upland environments.