Physical modeling experiments to guide river restoration projects
Project Information

1. **Proposal Title:**
Physical modeling experiments to guide river restoration projects

2. **Proposal applicants:**
Frank Ligon, Stillwater Sciences
William Dietrich, University of California, Berkeley

3. **Corresponding Contact Person:**
Frank Ligon
Stillwater Sciences
2532 Durant Avenue, Suite 201 Berkeley, CA 94704
510 848-8098
frank@stillwatersci.com

4. **Project Keywords:**
Fluvial Geomorphology
Habitat Restoration, Instream
Restoration 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:**
Private for profit

9. **Location - GIS coordinates:**
Latitude: 37.915
Longitude: -122.329
Datum: NAD27

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

Located west of Highway 580 approximately 4 miles North of the University of California, Berkeley's main campus.

10. **Location - Ecozone:**
Code 16: Inside ERP Geographic Scope, but outside ERP Ecozones

11. **Location - County:**
Contra Costa

12. **Location - City:**
Does your project fall within a city jurisdiction?
Yes

If yes, please list the city: Richmond

13. **Location - Tribal Lands:**
Does your project fall on or adjacent to tribal lands?
No

14. **Location - Congressional District:** 7

15. **Location:**
California State Senate District Number: 9
California Assembly District Number: 14

16. **How many years of funding are you requesting?** 3

17. **Requested Funds:**
a) Are your overhead rates different depending on whether funds are state or federal?
No

If no, list single overhead rate and total requested funds:
Single Overhead Rate: 142%
Total Requested Funds: 2,488,003

b) Do you have cost share partners already identified?
UC Berkeley is a co-applicant and they will be providing significant in-kind services as described in the text of the proposal, section D.2.

c) Do you have potential cost share partners?
See 17(b), above.

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?
Yes

If yes, identify project number(s), title(s) and CALFED program.

98E-09	**Merced River Corridor Restoration Plan-Phase II** **Ecosystem Restoration Program**
2000-E-05	**Merced River Corridor Restoration Project-Phase III** **Ecosystem Restoration Program**
99-B152	**A Mechanistic Approach to Riparian Restoration in the San Joaquin Basin** **Ecosystem Restoration Program**
Service Agreement 010801	**Tuolumne River Coarse Sediment Management Plan** **CALFED Service Agreement**
Contract 01A120210D	**M&T Ranch Pump Intake Assessment** **CALFED Contract**
Contract B-81491	**Saeltzer Dam Removal Analysis** **CALFED Contract**

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?
Yes

If yes, identify project number(s), title(s) and CVPIA program.

CVPIA 11332-9-MO79	**Merced River: Ratzlaff Project**	**AFRP**
CVPIA 11332-9-MO80	**Stanislaus River: 2 Mile Bar**	**AFRP**
CVPIA 11332-0-MO09	**Stanislaus River: Smolt Survival**	**AFRP**
CVPIA 11332-1-GO06	**Calaveras Salmonid Limiting Factors Study**	**AFRP**
99173	**Merced River Corridor Restoration Plan-Phase I**	**AFRP**

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)
Gary Parker, University of Minnesota
(612) 627-4575, parke002@tc.umn.edu

Thomas Lisle, USDA Forest Service
(707) 825-2930, tlisle/psw_rsl@fs.fed.us

David Montgomery,University of Washington
(206) 543-4270, dave@bigdirt.geology.washington.edu

21. **Comments:**

Environmental Compliance Checklist
Physical modeling experiments to guide river restoration projects

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.
Research will be conducted inside an existing building.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*
CEQA Lead Agency:
NEPA Lead Agency (or co-lead:)
NEPA Co-Lead Agency (if applicable):

3. **Please check which type of CEQA/NEPA documentation is anticipated.**
CEQA
-Categorical Exemption
-Negative Declaration or Mitigated Negative Declaration
-EIR
X none
NEPA
-Categorical Exclusion
-Environmental Assessment/FONSI
-EIS
X none

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?
None

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

PERMISSION TO ACCESS PROPERTY
Permission to access city, county or other local agency land.
Agency Name:
Permission to access state land.
Agency Name:
Permission to access federal land.
Agency Name:
Permission to access private land.
Landowner Name:

6. **Comments.**

Land Use Checklist
Physical modeling experiments to guide river restoration projects

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?**
No

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).
Indoor research only.

4. **Comments.**

Conflict of Interest Checklist
Physical modeling experiments to guide river restoration projects

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):
Frank Ligon, Stillwater Sciences
William Dietrich, University of California, Berkeley
Leonard Sklar, University of California, Berkeley
Michael Fainter, Stillwater Sciences

Subcontractor(s):
Are specific subcontractors identified in this proposal?
No

Helped with proposal development:
Are there persons who helped with proposal development?
No

Comments:

Budget Summary
Physical modeling experiments to guide river restoration projects

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.

See budget detail following this page.

Budget Summary

Year 1

Year 1	Direct Labor Hours	Salary	Benefits	Travel	Supplies & Expendables	Services / Consultants	Equipment	Other Direct Costs	Total Direct Costs	Indirect Costs	Total Costs
Task 1. Review existing and planned projects	240	$ 7,420	$ 2,300	$ 825	$ -	$ -		420	$ 10,965	$ 12,664	$ 23,629
Total cost Task 1 Year 1	**240**	**$ 7,420**	**$ 2,300**	**$ 825**	**$ -**	**$ -**	**0**	**420**	**$ 10,965**	**$ 12,664**	**$ 23,629**
Task 2. Flume construction for tasks 3 and 4	850	$ 35,052	$ 10,866	$ -	$ 350,000	$ 410,150		1,488	$ 807,556	$ 135,402	$ 942,958
Total cost Task 2 Year 1	**850**	**$ 35,052**	**$ 10,866**	**$ -**	**$ 350,000**	**$ 410,150**	**0**	**1487.5**	**$ 807,556**	**$ 135,402**	**$ 942,958**
Task 3a. Gravel augmentation experiments	850	$ 35,052	$ 10,866	$ -	$ 10,000	$ 85,600		1,488	$ 143,006	$ 68,947	$ 211,953
Task 3b. Numerical modeling of gravel augmetation experiments	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Total cost Task 3 Year 1	**850**	**$ 35,052**	**$ 10,866**	**$ -**	**$ 10,000**	**$ 85,600**	**0**	**1487.5**	**$ 143,006**	**$ 68,947**	**$ 211,953**
Task 4a. Dam removal experiments	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Task 4b. Numerical modeling of dam removal experiments	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Total cost Task 4 Year 1	**0**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
Task 5a. Channel/floodplain restoration flume experiments	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Task 5b. Numerical modeling of Task 5a	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Total cost Task 5 Year 1	**0**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
Task 6. Information dissemination	440	$ 12,343	$ 3,826	$ -	$ 1,000	$ 533		770	$ 18,472	$ 21,090	$ 39,562
Total cost Task 6 Year 1	**440**	**$ 12,343**	**$ 3,826**	**$ -**	**$ 1,000**	**$ 533**	**0**	**770**	**$ 18,472**	**$ 21,090**	**$ 39,562**

Year 2

Year 2	Direct Labor Hours	Salary	Benefits	Travel	Supplies & Expendables	Services / Consultants	Equipment	Other Direct Costs	Total Direct Costs	Indirect Costs	Total Costs
Task 1. Review existing and planned projects	130	$ 4,152	$ 1,287	$ 825	$ -	$ -		228	$ 6,492	$ 7,123	$ 13,615
Total cost Task 1 Year 2	**$ 130**	**$ 4,152**	**$ 1,287**	**$ 825**	**$ -**	**$ -**	**$ -**	**$ 228**	**$ 6,492**	**$ 7,123**	**$ 13,615**
Task 2. Flume construction for tasks 3 and 4	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Total cost Task 2 Year 2	**0**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**0**	**0**	**$ -**	**$ -**	**$ -**
Task 3a. Gravel augmentation experiments	500	$ 20,301	$ 6,293	$ -	$ 5,000	$ 70,978		875	$ 103,446	$ 41,993	$ 145,440
Task 3b. Numerical modeling of gravel augmetation experiments	200	$ 10,581	$ 3,280	$ -	$ -	$ -		350	$ 14,211	$ 17,917	$ 32,128
Total cost Task 3 Year 2	**700**	**$ 30,881**	**$ 9,573**	**$ -**	**$ 5,000**	**$ 70,978**	**0**	**1225**	**$ 117,657**	**$ 59,910**	**$ 177,567**
Task 4a. Dam removal experiments	500	$ 20,301	$ 6,293	$ -	$ 10,000	$ 70,978		875	$ 108,446	$ 42,493	$ 150,940
Task 4b. Numerical modeling of dam removal experiments	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Total cost Task 4 Year 2	**500**	**$ 20,301**	**$ 6,293**	**$ -**	**$ 10,000**	**$ 70,978**	**$ -**	**$ 875**	**$ 108,446**	**$ 42,493**	**$ 150,940**

Task 5a. Channel/floodplain restoration flume experiments	800	$ 33,809	$ 10,481	$ -	$ 15,000	$ 109,834		1,400	$ 170,523	$ 69,761	$ 240,284
Task 5b. Numerical modeling of Task 5a	200	$ 10,581	$ 3,280	$ -	$ -	$ -		350	$ 14,211	$ 17,917	$ 32,128
Total cost Task 5 Year 2	**1000**	**$ 44,390**	**$ 13,761**	**$ -**	**$ 15,000**	**$ 109,834**	**$ -**	**$ 1,750**	**$ 184,734**	**$ 87,677**	**$ 272,412**
Task 6. Information dissemination	440	$ 12,837	$ 3,979	$ -	$ 1,000	$ 533		770	$ 19,119	$ 21,924	$ 41,043
Total cost Task 6 Year 2	**440**	**$ 12,837**	**$ 3,979**	**$ -**	**$ 1,000**	**$ 533**	**0**	**770**	**$ 19,119**	**$ 21,924**	**$ 41,043**

Year 3

Year 3	Direct Labor Hours	Salary	Benefits	Travel	Supplies & Expendables	Services / Consultants	Equipment	Other Direct Costs	Total Direct Costs	Indirect Costs	Total Costs
Task 1. Review existing and planned projects	130	$ 4,319	$ 1,339	$ 825	$ -	$ -		228	$ 6,710	$ 7,404	$ 14,113
Total cost Task 1 Year 3	**$ 130**	**$ 4,319**	**$ 1,339**	**$ 825**	**$ -**	**$ -**	**$ -**	**$ 228**	**$ 6,710**	**$ 7,404**	**$ 14,113**
Task 2. Flume construction for tasks 3 and 4	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Total cost Task 2 Year 3	**0**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**0**	**0**	**$ -**	**$ -**	**$ -**
Task 3a. Gravel augmentation experiments	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Task 3b. Numerical modeling of gravel augmetation experiments	0	$ -	$ -	$ -	$ -	$ -		0	$ -	$ -	$ -
Total cost Task 3 Year 3	**0**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**0**	**0**	**$ -**	**$ -**	**$ -**
Task 4a. Dam removal experiments	800	$ 35,161	$ 10,900	$ -	$ 5,000	$ 125,611		1,400	$ 178,073	$ 72,624	$ 250,697
Task 4b. Numerical modeling of dam removal experiments	200	$ 11,004	$ 3,411	$ -	$ -	$ -		350	$ 14,765	$ 18,632	$ 33,398
Total cost Task 4 Year 3	**1000**	**$ 46,166**	**$ 14,311**	**$ -**	**$ 5,000**	**$ 125,611**	**$ -**	**$ 1,750**	**$ 192,838**	**$ 91,256**	**$ 284,094**
Task 5a. Channel/floodplain restoration flume experiments	800	$ 35,161	$ 10,900	$ -	$ 5,000	$ 116,011		1,400	$ 168,473	$ 71,664	$ 240,137
Task 5b. Numerical modeling of Task 5a	200	$ 11,004	$ 3,411	$ -	$ -	$ -		350	$ 14,765	$ 18,632	$ 33,398
Total cost Task 5 Year 3	**1000**	**$ 46,166**	**$ 14,311**	**$ -**	**$ 5,000**	**$ 116,011**	**$ -**	**$ 1,750**	**$ 183,238**	**$ 90,296**	**$ 273,534**
Task 6. Information dissemination	440	$ 13,350	$ 4,139	$ -	$ 1,000	$ 533		770	$ 19,792	$ 22,792	$ 42,583
Total cost Task 6 Year 3	**440**	**$ 13,350**	**$ 4,139**	**$ -**	**$ 1,000**	**$ 533**	**0**	**770**	**$ 19,792**	**$ 22,792**	**$ 42,583**

Total Year 1	2380	$ 89,867	$ 27,859	$ 825	$ 361,000	$ 496,283	$ -	$ 4,165	$ 979,999	$ 238,102	$ 1,218,101
Total Year 2	2770	$ 112,561	$ 34,894	$ 825	$ 31,000	$ 252,322	$ -	$ 4,848	$ 436,449	$ 219,128	$ 655,577
Total Year 3	2570	$ 110,000	$ 34,100	$ 825	$ 11,000	$ 242,156	$ -	$ 4,498	$ 402,578	$ 211,747	$ 614,325
Total all years	7720	$ 312,428	$ 96,853	$ 2,475	$ 403,000	$ 990,760	$ -	$ 13,510	$ 1,819,026	$ 668,977	$ 2,488,003
Total Task 1	500	$ 15,891	$ 4,926	$ 2,475	$ -	$ -	$ -	$ 875	$ 24,167	$ 27,191	$ 51,357
Total Task 2	850	$ 35,052	$ 10,866	$ -	$ 350,000	$ 410,150	$ -	$ 1,488	$ 807,556	$ 135,402	$ 942,958
Total Task 3	1550	$ 65,934	$ 20,439	$ -	$ 15,000	$ 156,578	$ -	$ 2,713	$ 260,663	$ 128,857	$ 389,520
Total Task 4	1500	$ 66,466	$ 20,604	$ -	$ 15,000	$ 196,589	$ -	$ 2,625	$ 301,284	$ 133,749	$ 435,034
Total Task 5	2000	$ 90,555	$ 28,072	$ -	$ 20,000	$ 225,845	$ -	$ 3,500	$ 367,973	$ 177,973	$ 545,946
Total Task 6	1320	$ 38,529	$ 11,944	$ -	$ 3,000	$ 1,599	$ -	$ 2,310	$ 57,383	$ 65,806	$ 123,188
Total all tasks	7720	$ 312,428	$ 96,853	$ 2,475	$ 403,000	$ 990,760	$ -	$ 13,510	$ 1,819,026	$ 668,977	$ 2,488,003
check	-	-	-	-	-	-	-	-	-	-	-

Budget Justification
Physical modeling experiments to guide river restoration projects

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

Employee Hours Christian Braudrick 1490 Yantao Cui 1310 Michael Fainter 540 Leonard Sklar 3180 Frank Ligon 360 Tom Cheang 600 Ethan Bell 240 Senior Tech (TBD) 4150 Junior Tech (TBD) 3100 Grad. Student (TBD) 12,000

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

Employee Rate Christian Braudrick $79.75 Yantao Cui $152.61 Michael Fainter $107.45 Leonard Sklar $130.04 Frank Ligon $150.80 Tom Cheang $62.40 Ethan Bell $72.38 Senior Tech (TBD) $83.20 Junior Tech (TBD) $31.20 Grad. Student (TBD) $36.40

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

Stillwater pays 31% in benefits to employees in all categories.

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

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

Estimated break-down of supply costs: Office supplies: $1,000.00. Computing supplies: $2,000.00. Lab supplies: $400,000.00. Lab supplies include the materials used to construct and modify the flume.

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.

UC-Berkeley (UCB) is the primary subcontractor. UCB researchers will be conducting project and analysis review and assisting with experiment development and application of models. In Task 2, UCB researchers will assist with flume construction ($6,500). In tasks 3, 4, and 5, UCB researchers will assist with conducting experiments and reviewing experiment results and analyses ($12,750).

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.

New equipment will not be purchased for the project. Materials procured to construct and modify the flume are included in lab supply costs.

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.

Coordination with subconsultants, data management, supply procurement, and project administration are the principal project management activities in the proposed project and are estimated to require $93,728. These costs are budgeted within all tasks.

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

Costs associated with computer systems and networks are included in Other Direct Costs.

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.

Stillwater's indirect costs include office expenses (rent, utilities, telephones, computer supplies, data connectivity, etc.), office staff, insurance, legal and accounting costs, proposal expenses and depreciation for capital items such as furniture and office equipment. As no specific place was provided, contractor fee was also included in the Indirect Costs column.

Executive Summary
Physical modeling experiments to guide river restoration projects

Successful application of the restoration strategies of gravel augmentation, dam removal, and floodplain and channel reconstruction, to rivers of the Bay-Delta watershed is limited by large gaps in the scientific understanding of the underlying fluvial geomorphic processes. In particular, little is currently known about how river bed texture and mobility are influenced by episodic sediment delivery, or how floodplain channel geometry and stability are influenced by changes in the discharge and sediment supply regimes. In collaboration with the University of California, Stillwater Sciences is proposing an experimental program to investigate these fundamental questions, with the goal of developing practical science-based methodologies for designing and implementing these restoration strategies. We will use the hydraulic laboratories at the University of California's Richmond Field Station to test mechanistic hypotheses regarding the processes underlying each restoration strategy. For gravel augmentation, we will vary the timing and amount of model gravel supplied to an armored alternating bar channel, and will measure the temporal and spatial variation in the fraction of the bed composed of a target spawnable gravel size. For dam removal, we will allow channel incision into model reservoir deposits of varying width and grain size and document the rate of gravel evacuation and downstream channel evolution for various discharges. For floodplain and channel redesign, we will conduct the first systematic experiments on the influence of variable discharge and sediment supply on channel width and meander migration rate, using an innovative experimental model substrate recently shown to be capable of supporting self-formed, freely migrating meandering channels. Experimental results will be used to calibrate and extend existing numerical models, in order to provide improved tools to restoration practitioners. We will build strong linkages to existing and future CALFED supported research and restoration projects through: project reviews, annual workshops, a technical advisory panel, and published restoration guidelines.

Physical modeling experiments to guide river restoration projects

Prepared for
CALFED Ecosystem Restoration Program

Submitted by
Stillwater Sciences
2532 Durant Avenue
Berkeley, CA 94704

and

Dr. William E. Dietrich
Department of Earth and Planetary Sciences
University of California, Berkeley

October 7, 2002

Stillwater Sciences

A. PROJECT DESCRIPTION: PROJECT GOALS AND SCOPE OF WORK

A.1 Problem Statement

CALFED has identified a number of strategies for restoring Bay-Delta tributaries. Three such strategies include: 1) injecting gravel to compensate for the loss of coarse sediment trapped behind dams; 2) removing diversion dams to open access to upstream habitats and restore fluvial geomorphic continuity; and, 3) reconstructing river channels and floodplains to be more in balance with a regulated flow regime as a means of restoring fluvial geomorphic processes.

CALFED has already provided funding for several projects that employ these restoration strategies on the Tuolumne, Merced, and Stanislaus Rivers, as well as Clear Creek. Experience with these projects highlights several significant gaps in the scientific understanding of fluvial geomorphic processes, particularly concerning how river bed texture and mobility are influenced by episodic sediment delivery, and how floodplain and channel geometry and stability are influenced by changes in the discharge and sediment supply regimes. The lack of a strong scientific basis for design decisions has often forced project implementers to rely on their professional judgment, which is typically based on qualitative conceptual models and site specific past experience.

The quantitative methods that are available to guide implementation of these restoration strategies were generally developed to solve more narrowly focused engineering problems. For example, in floodplain restoration projects on the Merced and Tuolumne Rivers (e.g. DWR, 2001), one-dimensional water surface profile modeling was used to select the channel width that will produce bed mobility and overbank flooding at specific discharges. This method cannot predict, however, if this is the channel width that would naturally occur under the regulated flow regime, whether the channel can be expected to widen or narrow, or whether the channel will migrate laterally and at what rate. These are cutting-edge questions in fluvial geomorphology, and they illustrate how river restoration practice is currently ahead of the science.

CALFED's adaptive management approach will help promote learning from river restoration projects. However, an adaptive management approach alone will be insufficient to address many of the key scientific questions underlying river restoration strategies. For example, if a reconstructed channel and floodplain do not perform as expected under high flow conditions, it may be difficult to explain why, because such large-scale restoration projects usually involve changing many variables simultaneously. As a result, it will be more difficult to identify causal relationships, and the ambiguous results will limit the scientific insight that can be gained.

Incorporating adaptive management into river restoration projects can yield valuable information, but these lessons can be comparatively expensive. For example, channel-floodplain reconstruction projects in the Central Valley typically costs tens of millions of dollars to implement, owing to the large scale of earth-moving required. If such a project does not perform as predicted, then the lessons derived from the project will come at a hefty price, and the cost of re-designing and re-implementing the project to provide the desired benefits may be prohibitive. The high cost of project implementation is also a disincentive to the type of experimental approach most likely to yield clear scientific insight. For example, a suite of channel reconstruction projects might be designed in coordination to test specific hypothesis, such that the set of projects encompass a wide range of values of the experimental variable of interest. This experimental approach would virtually guarantee that some projects would perform poorly, so that scientific insight gained in this way would come at great cost.

The adaptive management approach to river restoration also produces a very slow learning process, relative to CALFED's 30-year planning horizon. Many of CALFED's proposed restoration strategies for tributaries require high flows to provide the energy necessary to test the design of a project.

In California's semi-arid climate, several years may elapse before a significant high flow occurs. Furthermore, multiple high flow events may be required evaluate fully the performance of a reconstructed channel. As a result, adaptive management of large-scale river restoration projects could require decades for clear lessons to be learned. This delay in the learning feedback loop could prevent projects that are implemented early in the restoration program from informing the design of similar Bay-Delta projects .

To accelerate the pace of learning, for a fraction of the cost required to implement a single channel-floodplain reconstruction project, we are proposing to conduct a series of physical modeling experiments to address some of the fundamental and unresolved scientific questions underlying the river restoration strategies of gravel augmentation, dam removal, and floodplain and channel reconstruction. Physical models have been essential engineering tools in the design of dams, flood control projects, and many other structural interventions that have caused much of the habitat degradation that CALFED seeks to repair (e.g. Sharp, 1981). Physical experimentation has also been at the heart of the basic scientific research that has provided the analytical tools for numerical models of fluvial processes. For example, insight from flume studies underlies our understanding of bedload sediment transport (e.g. Gomez and Church, 1989; Buffington and Montgomery, 1997), controls on channel width (e.g. Ikeda et al., 1988), downstream fining (e.g. Seal, et al., 1997), and the mechanics of flow through meander bends (e.g. Hooke, 1975). Physical modeling has also been used to guide large-scale ecosystem restoration projects. For example, a scale model of the Kissimmee River system was developed at the University of California's Richmond Field Station, and the modeling was instrumental in defining a restoration program for the river (Shen et al. 1994). Similarly, Parker et al. conducted laboratory studies to examine the effects of modifying flow diversions on mountain channels, with the results informing restoration efforts in Idaho (2002). Also, Wilcock conducted physical experiments that helped to define channel maintenance flow releases for the Trinity River (1998).

We will use the extensive hydraulic laboratories at the University of California's Richmond Field Station to conduct the proposed modeling, using both well-established and innovative experimental techniques. The experiments will focus on achieving two broad goals, both of which represent areas of inquiryfor which limited progress has been made in previous field, experimental and theoretical studies. First, we seek to develop a mechanistic understanding of river channel response to episodic delivery of bedload size sediments, as occurs in both gravel augmentation and dam removal projects. We will test specific hypotheses for the spatial and temporal evolution of channel bed texture and geometry following pulses of sediment delivery, and for the potential mobilization of coarse bed armor due to the injection of finer gravel. Second, we seek to establish quantitative relationships between equilibrium channel geometry and the full distribution of discharges and sediment supply events, whether natural or regulated. Such quantitative relationships would better guide the process of designing and reconstructing "scaled-down" channels in restoration projects that aim to restore active fluvial geomorphic processes on regulated streams, such as bedload sediment transport, bar formation and migration, and bank erosion and lateral channel migration. Progress on both sets of questions would represent significant advances in geomorphic science as well as applied river restoration practice, as described in more detail in the project justification below.

The experimental results from the physical modeling will be used to calibrate, refine and extend existing numerical models for predicting sediment transport and bed texture response to changes in sediment supply, sediment mobilization and transport following dam removal. The modeling experiments will also contribute to numerical models that predict meander planform evolution. These refined numerical models represent an important bridge between the laboratory and the field, since the models will serve as tools that project implementers can use to design and implement restoration projects in the field.

To maximize the usefulness of these experiments to CALFED restoration projects, we plan several activities to build strong linkages with previous, ongoing and future river restoration projects, and with other researchers working on river restoration issues under CALFED auspices. These linkages are depicted schematically in Figure 1. We intend for this experimental program to serve as a bridge between fluvial geomorphology research and river restoration practice. As described in more detail below, we will review experience in previous and ongoing restoration projects to help refine the experimental design and scaling of experiments. We will also convene a technical review panel to oversee the experimental program and facilitate information dissemination. To help restoration practitioners gain a direct understanding of the proposed flume experiments, we will also hold annual workshops at the Richmond Field Station to stimulate scientific discussion among restoration practitioners and scientists.

A.2 Justification

This section describes conceptual models and initial hypotheses to be tested for each of three CALFED restoration strategies: 1) gravel augmentation, 2) dam removal and 3) floodplain and channel reconstruction. We also briefly discuss the scientific basis for scaling between laboratory physical models and the field prototype.

A.2.1 Gravel augmentation

CALFED has identified gravel augmentation as a restoration action to be applied on several Bay-Delta tributaries regulated by dams, including Clear and Putah Creeks, as well as the Feather, Yuba, Bear, American, Mokelumne, Calaveras, Stanislaus, Tuolumne, and Merced Rivers (CALFED, 2000). The general goal of gravel augmentation projects is to improve spawning and rearing habitat by modifying grain-size distributions within the channel bed and increasing the frequency of bed movement (CALFED, 2000). Channels requiring gravel augmentation are typically armored by coarse, relatively immobile sediments, usually as a result of upstream dams that block sediment transport to downstream reaches and reduce the frequency of high flow events that mobilize the channel bed.

When designing a gravel augmentation project, an implementer must consider several factors, including: the grain size distribution of the sediment to be added; the volume of gravel to inject; the frequency of gravel addition that will be required in light of sediment transport; and how the added gravel will interact with potential modifications to the flow regime and/or channel geometry.

Lutrick (2001) reviewed the implementation of three recent gravel augmentation projects, two of which were funded by CALFED, providing a summary of the design and specifications for each project. In each case, design decisions were based primarily on judgment and circumstance, rather than on scientifically-based predictive models of fluvial geomorphic processes. For example, the volumes of gravel added were determined primarily by budgetary constraints. The range of grain sizes were chosen to be small enough to be moved by spawning salmonids, but the possibility of mixing with the existing coarse bed materials (and thereby diminishing the intended bed fining) was not considered and no quantitative predictions of the extent or expected duration of habitat improvements were made. Monitoring indicates that some habitat improvement resulted from gravel augmentation at these sites, however, the lack of clear design methods limits the usefulness of these projects in guiding future gravel augmentation designs.

There are currently tools available to assist project implementers in designing gravel augmentation projects to address some of the underlying scientific questions described above. For example, Stillwater Sciences has developed a numerical model of mixed grain size bedload sediment transport, the EASI model, which can provide quantitative predictions of changes in bed texture and mobility that may result from gravel augmentation. However, this and other available models are one-dimensional (i.e. only downstream variation is considered) and assume *continuous* sediment supply. Gravel augmentation programs generally represent *episodic* sediment supply conditions, because the practical constraints of cost, available material, permitting restrictions, and site access require that sediment be injected into the channel as discrete events and at a few locations. Thus, gravel injection projects typically constitute pulses of sediment delivery followed by a period of bed adjustment, and, in the absence of further sediment supply, a gradual return to the pre-augmentation state

There is a growing awareness that the nature of sediment supplied to the channel affects bed texture and mobility. For example, Dietrich et al. (1989) showed that for the case of continuous sediment delivery, median grain size and the size of the mobile fraction of the bed area are both functions of the rate of sediment supply relative to the ability of the stream to transport the load. Currently, little is known about how channel bed texture and mobility vary in response to the *episodic* delivery of sediment. There is experimental evidence that when finer-grained sediments are added to a relatively immobile coarse-grained bed, there is an increase in overall bed mobility (Whiting et al., 1988). However, we lack the theory or empirical data to help predict how rapidly the bed texture will adjust, how that adjustment will be spatially distributed across a heterogeneous bar-pool topography, how far adjustments will reach downstream, and how long the improved bed texture can be expected to persist in the absence of sustained gravel augmentation.

We hypothesize that the beneficial effects of episodic gravel augmentation, expressed as the increase in fraction of the bed area composed of a desired grain size distribution, should scale with the mass of gravel added relative to the mass of bedload material that could be transported by the suite of discharges occurring during the interval between gravel additions. We further hypothesize that to stimulate bed mobility, the most effective grain size distribution for augmentation should be finer than the desired bed distribution because of the potential for introduced finer sediments to stimulate mobilization of the armor layer, and should scale with the difference between the mean grain sizes of the existing armor and the target distribution. The time scale of bed adjustment and subsequent relaxation to the pre-augmentation state should depend on the residence time of the added gravel, which should also be a function of the potential transport rate and the extent of armor mobilization.

Our conceptual model for the time response of bed texture to gravel augmentation is depicted in Figure 2. Small gravel additions should create a small improvement in bed texture for a relatively short time. Moderate gravel additions should produce a more significant change in bed texture, which should also persist for a considerably longer time. We do not expect a linear relationship between mass of gravel added and the extent of bed texture improvement because topographically favorable deposition sites will eventually become saturated. Rather, large gravel additions beyond some threshold amount should primarily extend the duration of bed fining. Figure 3 compares the expected effect of regular gravel additions at different augmentation frequencies. For a constant rate of gravel augmentation, more frequent additions should maintain a more constant bed texture. The expected downstream translation, diffusion, and attenuation of the sediment pulse are depicted in Figure 4.

We propose to test these hypotheses with a series of flume experiments, which are detailed in section A.3. In a long flume with a pre-existing armored bed with alternating bar-pool topography, we will systematically vary the size distribution and volume of added gravel, as well as the interval between gravel additions, and we will measure the spatial and temporal response of the bed. We will compare our experimental results with predictions from a numerical sediment transport model. From the physical and numerical results we will generalize a set of practical guidelines for determining the optimal size distribution, gravel mass and augmentation frequency for a range of field conditions.

A.2.2 Dam Removal

The CALFED Ecosystem Restoration Program includes the removal of dams to restore access to upstream salmonid habitats and to restore geomorphic continuity in the channel. CALFED has already funded scientific field studies and physical modeling in association with the decommissioning of Saeltzer Dam on Clear Creek. The focus of these studies was to examine the potential movement of sediment that had accumulated behind the dam. CALFED also has a unique opportunity to conduct adaptive management experiments for dam removal with the three dams that are planned for decommissioning on Battle Creek.

A key uncertainty in dam removal cases is the fate of reservoir sediment stored upstream of the dam. Ecologically sensitive areas downstream of proposed dam removal sites (such as spawning riffles) could be buried by reservoir sediment transported downstream. In order to limit downstream effects, managers often require the removal of reservoir sediment, which is often the most costly component of dam removal operations. In addition, many streams downstream of dams are starved of sediment, and in the case of Clear Creek, sediment was being removed from the reservoir while being added to the stream at another location. Currently, numerical modeling is used to assess the potential fate of downstream sediment, but the relative scarcity of dam removal projects limit the opportunities for validating these models. Also, land managers are generally reluctant to trust the results of models that have not been validated, so they often require extensive mining of reservoir sediments to minimize the risk of potential downstream impacts. The mining of this sediment prevents field validation of the sediment transport model. Physical modeling of sediment releases following dam removal, for a variety of general hydrologic and sedimentological settings, can provide the essential data to improve and test numerical models and guide dam removal designs and management decisions.

The uncertainties surrounding the sediment transport following dam removal can be viewed as two basic processes: the release of sediment from behind the dam and the downstream response to that sediment. Sediment release from the reservoir is the most uncertain component to predict.

We hypothesize that the rate of release of sediments from reservoir deposits following dam removal, for a given reservoir volume, should depend on three principle variables: the grain size distribution, the discharge regime, and the width of the reservoir relative to the width of the channel as it incises into the deposit. From studies of the evolution of sediment waves (e.g. Lisle et al. 1997), we hypothesize that the sediment release rate from the reservoir will decay exponentially following dam removal. Our hypotheses are illustrated schematically in Figure 5A-C, in which bedload sediment release rate is plotted against the logarithm of time so that the exponential decay plots as a straight line. Rapid sediment evacuation is favored by relatively fine grain size distributions, high discharges and narrow reservoir widths. Relatively high peak bedload sediment release rates should occur for coarse size distributions and high discharges, but should be independent of reservoir width. We will use the experiments outlined below to test the exponential sediment release hypothesis and explore the controls of grain size distribution, reservoir width and discharge regime on value of the decay exponent.

Very few physical modeling experiments have been conducted to examine the evolution of reservoir deposits. Eric Larsen and John Wooster of U.C. Davis recently completed some preliminary physical modeling studies on the evolution of a reservoir deposit as part of a CALFED study on the removal of Saeltzer Dam (Larsen and Wooster, personal communication). Janssen (1999) used the U.C. Berkeley Richmond Field Station flume facilities to perform experiments on the efficiency of self-formed channels in reservoir deposits in flushing sediments during reservoir draw-down. We will build on these experiments to provide the first comprehensive experimental exploration of the controls on sediment release following dam removal.

The downstream response to dam removal is fundamentally dependent on rate of reservoir sediment release. The conceptual framework for evaluating downstream response is identical in principle to the gravel augmentation case, except that the magnitude of the sediment pulse is potentially larger by several orders of magnitude. Rather than providing a small fraction of the total historic sediment load in multiple pulses, dam removal introduces in a single pulse a volume of sediment larger than the historic annual load by a factor that scales roughly as the age of the dam. We are concerned with both the downstream bed response to the addition of coarse load and the water quality response to the addition of fine load. The time scale of these responses may be vastly different, depending on the reservoir geometry, with a rapid burst of high concentration suspended load followed by slow passage of a diffusing wave of coarse bedload.

In our physical modeling of the downstream response we will monitor bed grain size adjustment, bed elevation changes and other morphologic changes such as pool filling, and suspended sediment concentration. These experimental results will be compared predictions of the DREAM model for the same input parameters, and compared to published modeling results from other dam removal studies (Cui and Wilcox, 2001; Stillwater Sciences, 2000).

A.2.3 Channel and floodplain redesign

The development of California's water supply system has radically altered the Sacramento and San Joaquin Rivers and their tributaries. Large water supply dams have generally reduced the magnitude, duration, and frequency of peak flows, while simultaneously depriving downstream reaches of a fundamental building block of habitat by trapping the supply of coarse sediment from upstream reaches. Since it is generally infeasible to remove large water supply dams, restoring geomorphic function and ecological habitat value to the downstream reaches of regulated rivers will require, in many cases, redesigning the channel geometry and floodplain elevations to adapt to the changed hydrologic regime. Also, understanding the relationship between stable channel geometry and the discharge distribution and sediment supply regime is required to define dam releases in a way to achieve fluvial geomorphic objectives. Channel and floodplain reconstruction projects often aim to restore channel migration as well, which has generally been reduced on Bay-Delta tributaries because of the reduction in peak flows and sediment supply, as well as levee construction and channelization.

Unfortunately, there remain large gaps in our understanding of the linkages between the discharge distribution and stable channel geometry and rates of lateral migration. Although there is a strong empirical correlation between the downstream variation in channel width and the 'bank full' discharge that typically has a recurrence interval of 1.5 to 2.0 years (Leopold and Maddock 1953), no theory exists to explain this observation. The only mechanistic theory for channel width (Parker 1978a, 1978 b) assumes that the banks and bed are composed of the same cohesionless material, and it applies only to a single 'dominant' discharge. Similarly, Johannesson and Parker's (1989) theory for meander migration, which has been widely applied in modeling floodplain evolution (e.g. Howard 1992; Larsen 1995), assumes a single steady discharge and makes no allowance for the role of variable sediment supply.

An important constraint on building and testing theoretical models for these processes has been the lack of a methodology for creating laboratory-scale channels that have self-formed stable widths and that form migrating meanders. Model channels composed of sand-sized and larger material do not build bars and banks on the inside of migrating bends and consequently widen until switching to a braided configuration (e.g. Friedkin 1945). Recently, Smith (1998) succeeded in creating migrating channels that, for the first time, maintain a constant width, using a weakly cohesive mixture of silt-sized silica and clay (photograph 1). Smith's (1998) meandering channels form many of the morphologic features of large floodplain rivers, including meander cutoffs and scroll bars. In collaboration with Dr. Dietrich, Smith has continued his experiments at the University of California's Richmond Field Station, investigating the role of variable sediment supply in influencing lateral migration rates.

Smith's innovative floodplain modeling technique offers the possibility of creating a general methodology for physically modeling the dynamics of self-formed channels. Currently, Smith's experimental apparatus is too small to accurately scale the forces driving sediment transport and bank erosion. However, a larger experimental basin, with the capacity to accommodate larger discharges and rates of sediment supply, may be sufficient to reliably reproduce the dynamics of meandering channels at a laboratory scale. Although this effort is somewhat speculative, the potential benefit of such a methodology is enormous for theory and for practical application.

We propose to use this new technique to investigate the fundamental question of how freely-formed meandering channels respond to changes in discharge and sediment regime. If we are successful, the proposed modeling would provide new tools for solving one of the most problematic and common restoration problems: how to manipulate the distribution of discharges released from upstream dams to drive fluvial geomorphic processes. We would also improve our understanding of, and ability to predict, rates of lateral channel migration.

In natural channels subjected to a wide range of discharges, stable channel widths result from the integrated effect of both rare, high magnitude and frequent, low magnitude events. Wolman and Miller, in their classic paper (1960), and more recently Andrews and Parker (1987), have shown that 'bankfull' discharges are typically those that accomplish the most net sediment transport, when sediment discharges are integrated over many years. Thus, simply restoring the pre-dam frequency of bankfull events is unlikely to restore channel dynamics fully, in the absence of geomorphic work accomplished by the larger magnitude, less frequent events.

We hypothesize that the stable channel width can be related deterministically to two measures of the distribution of discharges, one that reflects the total volume of runoff carried by the channel, and another that reflects the variability in the discharge distribution. As depicted in Figure 6, shifts in either of these quantities should result in changes in channel width. For the case of shifts in the total runoff volume without changes in the variance, we expect the width to vary with the square root of some representative, or dominant discharge, in accordance with the common field observation. We further expect that wider channels will correlate with larger discharge variance, all else being equal; however, we are unaware of any theory or systematic set of observations to constrain this relationship.

Three other variables relevant to channel and floodplain redesign should affect the relationship between channel width and discharge distribution: sediment supply rate, floodplain width, and bank strength. Sediment supply can be expected to strongly covary with discharge; that is, all else being equal, we expect wider channels for greater rates of sediment supply, as depicted in Figure 6. Levees reduce effective floodplain width, increasing the geomorphic effectiveness of large magnitude discharges. Thus, levee setback or removal may tend to offset the geomorphic benefits of restoring peak discharges. Bank strength exerts a first-order control on channel width, and is often primarily a function of the type and density of riparian vegetation.

The controls on meander migration rate are a separate question from the channel width problem; however, the issue of meander migration rate can be addressed conveniently in the same experimental program. The Johannesson and Parker (1989) model for meander evolution, and others based on it (Howard 1992; Larsen 1995), predict that the rate of bank erosion depends on the strength of bank materials and the increase above the mean in flow velocity and depth in the near bank region induced by the flow curvature. Some researchers argue that migration rates depend upon the rate of sediment deposition by bedload on the point bar (Howard, 1992; Ikeda, 1989), so that increases in sediment supply should force more rapid bank erosion and bend migration.

Utilizing Smith's (1998) model floodplain substrate, we will structure a series of experiments to test hypotheses that examine the role of variable discharge and sediment supply in controlling channel width and meander migration rate . In a 40 foot long, 12 foot wide model floodplain basin, we will generate a set of discharge distributions, systematically varying the discharge mean and variance along with sediment supply, and measure the resulting stable channel width and document the pattern and rate of meander formation and migration. We will compare experimental results with predictions of the Johannesson and Parker (1989) meander migration model, examining in particular the relative influence of sediment supply variations on lateral migration rates.

A.2.4 Scaling experimental results to field application

Laboratory experiments must be properly scaled if they are to provide scientific insight useful for guiding restoration projects in the field. There are several ways of scaling between model (the flume) and prototype (the river), each of which we will employ to some extent. The first and most essential method involves maintaining a similar balance of forces using non-dimensional scaling parameters (e.g. Yalin 1971; Sharp, 1981; Baker et al. 1991). For example, the Froude number, which can be thought of as the ratio of kinetic energy to potential energy in the flow, should be the same in the flume and the river. These fundamental scaling relationships are very well established in the river hydraulics and fluvial geomorphological literature (e.g., Southard and Boguchwal, 1978; Karcz and Kersey, 1980; Kochel and Ritter, 1987; Lisle et al. 1997). In the experiments proposed here we will use up to six non-dimensional parameters (Table 1) to assure a proper match between the balance of forces in the flume and a representative river reach.

A second scaling method is to reproduce in miniature the exact dimensions and characteristics of a particular reach of river, in order to test a specific project design. Such 'scale modeling' must also satisfy the requirements of the non-dimensional scaling ratios described above. This approach is generally not appropriate for addressing fundamental scientific questions because the relevant variables cannot be varied through a sufficiently wide range. Scale models of particular restoration project sites are, however, useful for testing methodologies developed from the results of prior experiments that use what could be considered a generic channel configuration. In the final phase of this project, we propose to use a scale model of a CALFED funded floodplain and channel restoration project, assuming the prior experiments are successful in providing the basis for a design methodology.

An additional method for scaling the flume experiments is to use data from a variety of field projects to guide the range over which we vary the relevant variables in each experiment. For example, in the case of gravel augmentation, the total mass of gravel added can be scaled by the transport capacity of the reach (Table 1). We will use data from CALFED funded projects to make sure that our experimental range of gravel mass additions encompasses the range of values used in field applications. These field data will also provide conceptual 'stepping stones' for describing the experimental results and their implications to managers and restoration practitioners because we can plot the field values on the same graph as the experimental data from the flume.

A.3 Approach

Task 1 Review existing, ongoing and planned gravel augmentation, dam removal and floodplain and channel reconstruction projects, and convene a technical advisory panel.

CALFED has already provided funding for several restoration projects that involve gravel augmentation, dam removal, and channel-floodplain reconstruction. Thus, restoration practitioners have been gaining rich experience in dealing with the underlying scientific questions that the proposed physical modeling will address. As a first step in designing flume experiments, and to help ensure that the proposed physical modeling will be relevant to restoration managers, we will review past experience in designing and implementing gravel augmentation, dam removal and floodplain and channel reconstruction projects, both in California and beyond. Building on the work of Lutrick (2001), we will compile a database of project design methods, specifications and monitored outcomes. A corollary benefit of this review exercise will be to establish or strengthen collegial relationships with project designers and managers. The data collected will be used to refine our experimental hypotheses and designs and will be used to guide scaling of the flume results to the field. We will continue to track the progress of ongoing projects semi-annually throughout the duration of the experimental program.

To help collect information on the design and implementation of gravel augmentation, dam removal, and channel-floodplain reconstruction projects, and to help guide the development of the proposed physical modeling experiments, we will establish a technical advisory panel. The panel will be composed of scientists experienced in addressing the key scientific issues underlying these projects, as well as restoration practitioners who are actively involved in designing or implementing these types of projects. We anticipate that the panel will meet semi-annually throughout the three year duration of the experimental program. The technical advisory panel will review experimental design, procedures and results, and will review the incorporation of the experimental results into the revised numerical models and test the model interfaces. Panel members will also participate in the annual workshops and assist in arranging visits to appropriate field sites for students and staff conducting the experiments (as described in Task 6: Information Dissemination).

Task 2 Construct and modify flumes for experiments

The experiments described in detail below will utilize the hydraulic modeling facilities at the University of California's Richmond Field Station. For the gravel augmentation and dam removal experiments, an existing flume and associated support infrastructure will be modified to accommodate: a wider range of discharges; controlled sediment feed and sediment removal; and precision measurements of bed topography and bed texture. We will also add a variable width upstream reservoir to the existing flume to contain model sediment deposits. For the channel and floodplain redesign experiments, a new experimentation basin will be constructed, and existing support infrastructure will be modified to accommodate the controlled supply of fine cohesive sediment and a wide range of water discharges. Specifications for the experimental equipment and experimental designs are described below for the each restoration strategy.

Task 3a Physical modeling of gravel augmentation

The gravel augmentation experiments will be conducted in a 120 foot long, three foot wide, tilting flume. Water is recirculated while sediment is not; sediment must be added at a controlled rate and is removed by a trap at the downstream end. Each run will be initialized by establishing an alternate bar bed configuration with a constant discharge and constant supply rate of a poorly sorted gravel mixture. Once an equilibrium bed configuration is established, the sediment supply will be cut off and the bed allowed to coarsen through winnowing of the finer grains, until a relatively immobile armor is established. We will then introduce pulses of a moderately sorted, relatively fine gravel mixture and monitor the evolution of the bed topography and texture.

In the first set of runs we will use a dynamic hydrograph and systematically vary the mass of gravel added, the time interval between gravel additions, and the grain size distribution of gravel added. Varying each of these three variables independently through three values (low, medium, high) will require 27 runs. The hydrograph regime will be the same for each run. We will use a dynamic hydrograph to create the initial "quasi-equilibrium" channel that has a coarser channel bed. The hydrograph will be scaled from a series of representative hydrographs from Central Valley rivers. Upon the establishment of the "quasi-equilibrium" state, fine gravel will be introduced and the same hydrograph will be used to examine the variation in bed texture. In a second set of runs we will vary the hydrograph to simulate the net affect of a wide distribution of discharges, such as would be experienced in the field. For these varying discharge runs we will use only a limited set of combinations of gravel mass, size and addition frequency, chosen to represent the range of bed response obtained in the constant discharge experiments.

To measure the bed response to gravel augmentation we will expose the bed at regular intervals (by turning off the discharge) and map the patches of similar grain size distribution. We will use pebble counts to characterize the grain size distributions of each patch. We will also monitor the topographic evolution of the bed with a laser microtopographic scanner. The scanner has a vertical resolution of less than 0.1 mm allowing precise measurements of changes in bar height, pool depth, bed form spacing, and bed aggradation and degradation. From these measurements we will construct graphs of the fraction of the bed area covered with patches of various grain size distributions, and the topographic properties of the bed, as functions of time and space for each combination of control variables. An explanation of hydraulic parameters used to scale the experimental results from flume experiments to the field is shown in Table 1.

Task 3b Numerical modeling of gravel augmentation

The experimental results will be used to test and validate Stillwater Sciences' EASI model. The EASI model was developed for quick evaluation of bed mobilization and the gravel transport rate at a river reach for a certain discharge or duration curve. This model is intended to complement existing sediment transport models based on Parker (1990a, 1990 b) (e.g., Cui et al. 1996, Cui and Parker 1997, Cui et al. 2001, Cui and Wilcox 2001) and should become a useful tool for restoration managers and practitioners to assess gravel augmentation projects. The primary advantage of this model is that it is very easy to use, and thus, has outstanding potential for application by managers and geomorphologists without a strong background in numerical modeling.

We will compare our experimental results with the predictions of the EASI model, for the same set of input parameters. Because the model is one dimensional (downstream variation only), we can test whether the lateral variations that occur in the physical model (and in the field) have an important influence on the extent of habitat improvement compared to the model predictions. We can also test how the model performs in predicting the rate of change of bed properties given the unsteady forcing in sediment supply.

The proposed experiments apply a dynamic hydrograph and sediment feed, allowing the channel aggradation and degradation. We can also use the results to validate existing sediment transport models in conditions similar to those found in natural rivers. We propose to validate the model of Cui et al. (2001), which is the most recent of the model based on Parker (1990 a, 1990 b). The validation of this model will allow for increased confidence and much wider application of the model in the future restoration projects.

Task 4a Physical modeling of the impacts of dam removal

For the dam removal experiments we will use the same 120 ft long, 3 ft wide flume discussed in the gravel augmentation experiments, modified by the addition of a model reservoir sediment tank at the upstream end of the flume (Figure 8). The model reservoir will be wedge shaped, with movable walls to allow for variations in reservoir width. Water will be introduced upstream of the reservoir and will flow across the deposit before entering the flume. A sediment mixture of controlled grain size distribution will be placed in the reservoir to form a delta-shaped deposit, held in place by at the downstream end by a gate (model dam).

Because the most cost effective (and controversial) method of dam removal is complete dam removal, our initial condition will be instantaneous dam removal. Partial, or gradual dam removal can also be investigated in the constructed flume. Prior to dam removal an armored, alternate bar-pool channel configuration will be established in the downstream flume following the same protocol described above for initializing the flume prior to gravel augmentation.

Removal of the dam will initiate a headward migrating incising channel that will gradually evacuate the sediment deposit in the model reservoir. We will monitor the release of sediment and migration of the sediment plume through the downstream channel by repeat topographic surveys of the reservoir deposit, and by collecting bedload measurements with miniature Helly-Smith samplers and turbidity measurements with calibrated OBS sensors. As in the gravel augmentation experiments, we will shut off the discharge to expose the bed in order to map the bed texture and survey the bed with the laser microtopography scanner.

In the first set of runs we will hold the reservoir width constant and vary the grain size distribution of the reservoir sediment deposit, ranging between a coarse deposit with less than 20% finer than model gravel, to a fine deposit with greater than 80% finer than model gravel. For each grain size distribution we will vary the discharge. A total of nine runs will be required to independently vary grain size distribution and discharge through three values each.

In the second set of runs we will vary the reservoir deposit width and thus the reservoir volume, holding the grain size distribution constant. Reservoir width will be changed by adjusting the angle of the wing walls enclosing the model reservoir deposit. The angle will be adjusted between zero and 60 degrees. For each reservoir width we will vary the discharge. A total of nine runs will be required to independently vary reservoir width and discharge through three values each.

Task 4b Numerical model of dam removal studies

Stillwater Sciences has already developed and applied numerical models for dam removal projects for Soda Springs Dam, North Umpqua River, Oregon, Marmot Dam, Sandy River, Oregon, and Saeltzer Dam, Clear Creek, California. Stillwater Sciences is currently merging and improving those models to develop a user-friendly dam removal express assessment model (DREAM) package for NFMS/NOAA. The validation of the model will allow for increased confidence of the model and wider application to facilitate future dam removal projects.

We will compare our experimental results with the predictions of the DREAM model for the same input parameters in order to better calibrate the model and interpret the experimental results in terms of the process physics embodied in the model. We will also use the results to interpret the numerical modeling studies developed by Stillwater Sciences for NMFS/NOAA, and the dam removal model applied to Clear Creek, CA and the Sandy River in Oregon (Cui and Wilcox 2001).

Task 5a Physical modeling of channel and floodplain redesign

The channel and floodplain redesign experiments will be conducted in a 40 ft long, 12 foot wide tilting basin, filled with a weakly cohesive silica silt and clay mixture. Water and sediment will be introduced at controlled rates at the upstream end and will flow through an evolving channel to a tailwater basin at the downstream end. Sediment will be supplied by a speed calibrated, motor-driven auger that removes damp sediment from a supply hopper. Access to the interior of the basin will be provided by a rolling platform bridge that will span the width of the basin.

Each run will be initialized by grading the model floodplain into a smooth planar surface, and cutting a linear triangular notch down the center. As can be expected from Smith's (1998) experiments, the channel will rapidly widen until reaching a stable equilibrium width, while bars will form and begin to drive lateral migration. Each run will be allowed to proceed until the migrating channel has occupied a large fraction of the basin area, or until the channel encounters the sidewall. Run times are expected to range between 20 and 200 hours. As Smith (1998) found, interrupting the run overnight has no apparent effect on the outcome.

In the first set of runs we will maintain a constant discharge throughout the run. Discharge will be varied over an order of magnitude. For each discharge we will vary sediment supply through three levels, low, medium and high. For five values of discharge, this will require 15 runs.

In the second set of runs we will vary discharge widely throughout each run, so that the channel experiences a full distribution of discharge magnitudes and durations, such as depicted in Figure 6. Discharge variation will be controlled by a computer-driven electronic gate valve in the water supply line. The same computer program will also set the rate of sediment supply by controlling the rotation rate of the sediment delivery auger. We will independently vary the mean and variance of the discharge distribution, and the relative sediment supply rate. For three means, three variances and two relative sediment supply rates, a total of 18 runs will be required.

In the third set of runs we will consider the confining effect of a set of levees that narrow the floodplain by factors ranging from two to five. We will use the results of the second set of runs to select the parameter values most likely to reveal the sensitivity of channel width and migration rate to floodplain width. In a final set of runs, we will simulate the evolution of a floodplain and channel design taken from an ongoing field restoration project. The floodplain slope and width, discharge and sediment regime, and initial channel geometry will all be scaled from the field condition. The choice of which variables to vary and the range of variation will be determined in coordination with the team implementing the field project.

For each run we will make frequent measurements of the active channel width along the length of the basin and the rate of lateral migration. Periodically, the water and sediment supply will be shut off to measure the channel and floodplain topography with a laser microtopography scanner. For low relief surfaces the scanner has a vertical precision of less than 0.1 mm. We will also periodically measure the rate of sediment transport, using miniature Helly-Smith bedload samplers, and by removing water samples with a syringe. The strength of banks, bar and floodplain deposits will be measured with a custom-built miniature shear vane. We will also use dye injection techniques to estimate water velocities and flow structure. From these measurements we will construct graphs of channel width and meander migration rate as functions of discharge mean and variance, sediment supply and bank strength. We will use the model of Ikeda et al. (1988) model for channel width under constant discharge as a theoretical framework for analyzing our experimental channel width results. The key scaling parameters for relating these experimental results to the field are the Froude, Shields and Reynolds, and Weber numbers defined in Table 1.

Task 5b Numerical modeling of channel and floodplain redesign

Several numerical models will be explored. One of the simpler ones is the meander migration model developed by Parker and colleagues (1989), and extended by Larsen (1995). Larsen is currently exploring the use of the model on the main stem of the Sacramento River. Here we will have a unique opportunity to test the meander theory and to explore how to include the effects of varying sediment supply and discharge.

Experimental data will be used to guide the development of a model for channel width that builds upon previous work and explicitly includes sediment supply and variable discharge effects. We anticipate new numerical models will need to be developed to address this problem and use the experimental data.

Task 6 Information dissemination

Since the proposed physical modeling will address many of the key scientific questions underlying gravel augmentation, dam removal, and channel-floodplain reconstruction projects, it will be important to disseminate the results of this research to the many restoration practitioners that will be involved in implementing these projects on behalf of CALFED. The technical advisory panel described in Task 1 will help to broadcast the results. In addition to the panel, we intend to disseminate the results via five methods:

1) We will organize three annual one-day workshops at the Richmond Field Station hydraulics laboratory for restoration practitioners and managers and other scientists working on fluvial geomorphic research. These meetings will combine technical presentations covering experimental design, methods and results to-date with facilitated discussion by participants of their field experiences and implementation concerns. Through these annual workshops, we intend for the experimental project to provide a forum and catalyst for restoration practitioners, managers and researchers to debate and build consensus on restoration methods.
2) The implications of the experimental results for restoration design and river management will be synthesized in a set of practical guidelines, one for each of the three restoration strategies (gravel augmentation, dam removal, and channel and floodplain redesign). The guidelines will be written for restoration practitioners and managers, and they will describe methods for evaluating the restoration potential of a site, data collection needs and priorities, appropriate use of numerical models, optimization (in terms of both implementation cost and restoration benefit) of restoration opportunities regarding modifying channel morphology, sediment supply and flow regime, and adaptive management techniques for monitoring and refinement of project implementation. Each report will reflect not only the insight gained in the flume experiments, but also the results of the discussions during the annual workshops and input from the technical advisory panel. Each report will also make extensive use of the database and review of existing and ongoing projects to illustrate scientifically sound restoration practice.
3) We will draft and submit several papers to peer-reviewed technical journals. Because the proposed modeling will address cutting-edge scientific questions in the field of fluvial geomorphology and river hydraulics, it will be important to disseminate the scientific progress made through this project to a broad professional and academic audience.
4) We will develop and maintain a web site that will serve as a clearinghouse of information on each of the three restoration strategies, including detailed and frequently updated documentation of the ongoing experiments. The website will also include links to other relevant sites and downloadable documents. Our goal is to create the definitive web-based resource for these three restoration strategies.
5) We will produce a video that documents and summarizes the experimental results and synthesizes the guidelines for restoration design. The video will also include documentation of experimental trials in progress. The video will be aimed at an audience of restoration practitioners and managers.

A.4 Feasibility

The experiments will be conducted in the hydraulic laboratories at the University of California's Richmond Field Station in Richmond, CA. Dr. Dietrich has a memorandum of understanding with the College of Engineering of the University of California, Berkeley, granting use of these facilities for applied and theoretical experiments on river dynamics and morphology. Dr. Dietrich's current research group includes several doctoral students working at the Field Station on experimental projects in fluvial geomorphology. The remaining space at the Richmond Field Station is more than adequate to implement the experiments proposed in this project. The gravel augmentation and dam removal experiments will utilize an existing flume that requires rehabilitation and modification. A new titling basin will be required for the channel and floodplain reconstruction experiments; however, this apparatus can utilize some of the existing plumbing, drainage and water containment structures. The Field Station supplies electricity, water and sewage services. Extensive carpentry and machine shops are available to support flume construction and maintenance.

A.5 Performance Measures

The methods and results of these physical and numerical modeling studies will be peer-reviewed and submitted to national scientific journals for publication. Comments received from peer-reviewers will be submitted to CALFED as a performance measure.

A.6 Data Handling and Storage

This project will result in the collection and development of data and information over a 3-year period, and will build on previously obtained data. All data collected for baseline monitoring, as-built surveys, and post-project monitoring will undergo standard Stillwater Sciences QA/QC procedures before the originals are archived. This process includes review of laboratory notes and data, a check for accuracy of data entry, and creation of working and back-up copies of original data sheets to eliminate possible loss of or tampering with original data. All data will be archived at Stillwater Sciences. Back-up copies of electronic data will also be maintained off-site.

A.7 Expected Products/Outcomes

Several of the expected products and outcomes for this project are described in Task 6: Information Dissemination, in Section A.3 of this proposal. This project will include: three annual workshops; six semi-annual meetings of a technical advisory panel; three reports for each restoration strategy, containing guidelines for project designers; professional papers to be submitted to peer-reviewed journals; a descriptive video; and an actively maintained website.

Other key products of this project will be refined numerical sediment transport models. The experimental results of the proposed modeling will be used to calibrate, refine and extend existing numerical models for predicting sediment transport and bed texture response to changes in sediment supply, as well as sediment mobilization and transport following dam removal. Improved numerical models form a bridge between the new insight gained from the empirical experimental results and the application of that knowledge in predicting fluvial geomorphic processes and designing restoration projects in the field. One numerical model that will be refined for use in designing restoration projects will be the EASI model. The EASI model was developed by Stillwater Sciences to provide a simple, user-friendly sediment transport assessment. The EASI model is a coarse sediment transport model that can be used to assess the average bedload transport rate and mobility thresholds based upon channel geometry, flow, and the grain size distribution of the bed. Using the EASI model, the effect of changes in the flow regime, channel geometry, and grain size distribution on the bedload transport rate can be easily assessed by varying the input parameters. The EASI model has been applied to several Central Valley tributaries, including Clear Creek, the Merced River, and the Tuolumne River. Model application on both Clear Creek and the Merced River was funded by CALFED as part of the Saeltzer Dam decommissioning and a previous CALFED PSP grant, respectively.

The EASI model adapts the surface-based bedload equation of Parker (1990a,b), which was developed for a wide rectangular channel, to a natural river cross section. The input parameters to the EASI model include channel cross section, channel surface grain size distribution, water discharge, floodplain Manning's n, and reach-average water surface slope. Output of the model includes bedload transport rate, bedload grain size distribution and normalized Shields stress (which can be used to assess mobility thresholds).

We also anticipate that the new insights derived from the laboratory experiments will produce additional, more narrowly focused hypotheses that will be appropriate for testing in the field at the scale of individual restoration projects.

A.8 Work Schedule

The work will be completed within three years of receiving the contract. A schedule of the sequence of tasks is shown in Figure 9.

B. APPLICABILITY TO CALFED ERP AND SCIENCE PROGRAMS GOALS AND IMPLEMENTATION PLAN AND CVPIA PRIORITIES

B.1 ERP, Science Program and CVPIA Priorities

This project directly addresses several restoration priorities identified in Section 3 of the PSP, including Priorities SR-2, SR-3, SR-7, SJ-1, SJ-2, and SJ-6 (see Table 2 for a fuller description of how this project will contribute to each of these priorities).

Many of these PSP restoration priorities describe the need for developing mechanistic models of riverine function to help guide restoration efforts. A key goal of this project is to develop a mechanistic understanding of river channel response to episodic delivery of bedload size sediments.

Other restoration priorities emphasize the development of sediment transport models to assist the restoration of Bay-Delta tributaries. In addition to the physical modeling of sediment transport proposed in this project, a key outcome of the proposed modeling will be the enhancement, validation, and calibration of a numerical sediment transport model, the EASI model, to help predict bed texture and mobility.

Several of the PSP restoration priorities also emphasize replenishing gravel in regulated river channels and removing fish passage barriers on Bay-Delta tributaries. This proposal will directly address key scientific questions, and underlying design issues, associated with gravel augmentation and dam removal projects.

Finally, some of these restoration priorities defined in the PSP call for the continuation of channel-floodplain reconstruction efforts and floodplain enhancement project for San Joaquin river tributaries. This project examines the scientific questions and design issues associated with channel and floodplain reconstruction projects, so that the results of the proposed modeling will produce more scientifically based methods and tools to assist in designing these complex projects.

In addition to responding directly to several PSP restoration priorities, this project also addresses several ERP, Science Program, and CVPIA goals and restoration priorities. The proposed modeling will directly contribute to ERP Goal 2: Rehabilitating Natural Processes. By developing scientifically based methods and tools to guide the design of restoration projects, this project will also contribute to ERP Goal 1: Recovering At-Risk Species, and ERP Goal 4: Protecting and Restoring Functional Habitats (see Table 3 for a description of how the project will contribute to each of these goals).

This project responds directly to the CALFED Science Program goal of advancing our understanding of physical processes, because it focuses on some of the cutting-edge scientific questions in the field of fluvial geomorphology. This project will also contribute to the Science Program goal of comparing the effectiveness of different restoration strategies, because the proposed modeling is focused upon three key restoration strategies adopted by CALFED: gravel augmentation, dam removal, and channel-floodplain reconstruction projects. This project also contributes to the CALFED Science Program goal of advancing the scientific basis for regulatory activities. Currently, gravel augmentation programs can be limited by regulatory restrictions that limit the amount of sediment that can be injected into a channel. As a result, the scale of gravel augmentation projects can be constrained. Similarly, valuable sediment accumulated behind dams is often mined in association with dam decommissioning because of regulatory requirements, potentially depriving downstream reaches of a key source of bed material. The proposed modeling will provide more scientifically based methods and tools for assessing the scale of needed gravel augmentation, as well as sediment mining associated with dam removal, to help guide regulatory decisions.

B.2 Relationship to Other Ecosystem Restoration Projects

This project has a bearing upon numerous CALFED restoration projects, including projects that have already received funding, projects proposed to CALFED in recent years, and future projects that will be required to implement the restoration actions defined in the Ecosystem Restoration Program Plan, Volume II (2000). For example, the proposed modeling will investigate key scientific questions and design issues associated with channel and floodplain reconstruction projects. CALFED has already provided funding for several large-scale channel-floodplain projects in the past few years, including:

- Lower Clear Creek Floodway Restoration Project, Phase 2 (ERP-98-F15)
- Tuolumne River Setback Levees and Channel Restoration (ERP-98-F06)
- Tuolumne River Mining Reach Restoration (ERP-97-M09)
- Tuolumne River Channel Restoration, Special Run Pool 9(ERP-97-M08)
- Merced River Salmon Habitat Enhancement, Ratzlaff Reach (ERP-99-B05)
- Merced River Salmon Habitat Enhancement, Robinson Ranch Site (ERP-01-N06)

CALFED has also received proposals in the last couple of years for additional large-scale channel and floodplain modification projects, including:

- Lower Clear Creek Floodway Restoration Project Phase 3 & 4 (2001-C201)
- Tuolumne River Mining Reach Restoration Project No. 3: Warner-Deardorff Segment (2001-C209)
- Tuolumne River Restoration: Special Run Pool 10 (2001-B201)
- Merced River Phase IV: Dredger Tailings Reach (2002-158) (directed action)

In addition to these proposed projects, CALFED will need to solicit or develop other channel-floodplain reconstruction projects to complete the implementation of the ERP.

Similarly, CALFED has already provided funding for gravel augmentation projects on the Stanislaus and Tuolumne Rivers, and numerous other gravel injection projects will be required to achieve CALFED restoration goals. CALFED funding helped support the decommissioning of Saeltzer Dam on Clear Creek, and three more dams are scheduled for removal on Battle Creek. By focusing on gravel augmentation, dam removal, and channel-floodplain reconstruction projects, the proposed modeling will develop more scientifically based methods and tools to help guide the design, implementation, and monitoring of these future projects.

B.3 Requests for Next-phase Funding

N/A

B.4 Previous Recipients of CALFED Program or CVPIA Funding

Previous funding awarded to the applicants from the CALFED or CVPIA programs are described in detail in Table 4.

B.5 System-wide Ecosystem Benefits

This project is designed specifically to guide the design and implementation of current and future restoration projects that employ gravel augmentation, dam removal, and channel-floodplain reconstruction as restoration strategies. Because these strategies will be used in many different restoration projects on a number of Bay-Delta tributaries, this project will have far-reaching effects. The annual workshops to be hosted at Richmond Field Station, and the technical advisory panel to be convened, will also help to gather together scientists and restoration practitioners working on similar problems. The information exchange through the workshops and advisory panel should help to stimulate synergies among current and future projects. The physical modeling conducted in this project will also complement and build upon other scientific investigations on Bay-Delta tributaries, including: Michael Singer's geomorphic investigation on the Sacramento River; Eric Larsen's modeling of channel migration on the Sacramento River; geomorphic investigations conducted on the Cosumnes and Mokelumne Rivers by Jeff Mount and other UC Davis scientists, including bed fining; and sediment transport modeling associated with Saeltzer dam decommissioning on Clear Creek, conducted by Stillwater Sciences and Eric Larsen and John Wooster of UC Davis.

B.6 Additional Information for Proposals Containing Land Acquisition

N/A

C. QUALIFICATIONS

The project team consists of Stillwater Sciences and research faculty and staff in the departments of Earth and Planetary Science and Civil and Environmental Engineering at the University of California, Berkeley. Stillwater Sciences will be the contractee and point of contact for CALFED. Dr. William Dietrich will be the point of contact and project manager for UC Berkeley. Both Dr. Dietrich and Mr. Leonard Sklar have extensive experience conducting physical modeling experiments at the Richmond Field Station.

Stillwater Sciences is a firm of biological, ecological, and geological scientists. The company specializes in developing new scientific approaches and technologies for problem-solving in aquatic and terrestrial systems and has extensive experience and in-house ability in GIS applications to environmental analyses. Its founding members have over fifty years of experience in freshwater and fluvial geomorphology. Recent projects include impact assessment and restoration of rivers affected by hydroelectric dams, timber harvest, and irrigation in California and the Pacific Northwest.

Mr. Frank Ligon is an aquatic ecologist and geomorphologist with over 20 years of experience in examining the role of fluvial processes and morphology in the ecology of stream fish, invertebrates, and plant communities. He has successfully managed several complex, long-term projects involving watershed analysis, salmon ecology and restoration, geomorphology and riverine ecosystem restoration.

Dr. Yantao Cui is a civil engineer with over fifteen years of experience in hydraulic engineering, with the last seven years of his research focused on modeling sediment dynamics in regulated rivers in areas of California, the Pacific Northwest, Florida, China, and Papua New Guinea. He is currently developing the EASI gravel transport model to provide guidance in river restoration projects, to be applied to several CALFED-funded projects in the Merced and Tuolumne rivers, Clear Creek and other streams in California. Dr. Cui is a recognized expert in the development of models assessing the response of rivers to landslides and debris flows, reservoir removal, gravel extraction and addition, and has participated in studies on the effects of woody debris jams on sediment transport. Dr. Cui has experience applying sediment transport models to investigate dam removal options on several rivers including: Saeltzer Dam on Clear Creek, Marmot Dam on the Sandy River, and Soda Springs Dam on the North

Umpqua River, Oregon. Stillwater Sciences recently received funding from NOAA/NMFS to develop user-friendly numerical models to assess the fate of reservoir sediment following dam removal for various reservoir and channel bed substrates.

Mr. Christian Braudrick is a fluvial geomorphologist who has assessed channel morphology, sediment transport, and hydrology of fluvial systems in California, Oregon, Washington, and Utah. Mr. Braudrick has also managed projects on dam removal on Clear Creek, CA and stream restoration for the Chelan River, WA. On Clear Creek he helped develop and implement a monitoring plan to assess numerical modeling of sediment transport following the removal of Saeltzer Dam. On the Chelan River he helped develop channel restoration measures and define a minimum flow regime to improve salmonid habitat and ecosystem function for the Chelan River. Mr. Braudrick has also conducted research on the dynamics and geomorphic role of large woody debris in streams, using physical modeling experiments to investigate large woody debris dynamics for a range of log and stream sizes.

Mr. Leonard Sklar is a fluvial geomorphologist and a civil engineer. Mr. Sklar is an expert in sediment transport issues, particularly in the California Coast Range, Central Valley, Oregon Coast Range, and Oregon Cascades regions. His academic and professional work has focused on his mechanistic and quantitative understanding of landscape processes and evolution, especially pertaining to river incision (river incision and valley development are a crucial link between tectonics and landscape evolution). He is an expert on bedrock channel incision by fluvial processes, including the role of sediment loading on rates of incision. Mr. Sklar has a decade of experience designing and conducting physical modeling experiments investigating fundamental fluvial geomorphic processes.

University of California, Berkeley **Dr. William Dietrich** chairs the Earth and Planetary Science Department, University of California, Berkeley. Dr. Dietrich's research has been instrumental in the development of the watershed analysis methodologies that are now being used to guide much of the planning effort for the restoration of Pacific salmon. Much of his recent work has focused on the downstream effects of dams and land use on fluvial systems, including the linkages between physical processes and aquatic biota, and the development of methods for restoring degraded rivers.

D. COST

D.1 Budget

Please see the attached budget summary form. The costs are approximately evenly divided between the prime contractor, Stillwater Sciences, and U.C. Berkeley, which will be a sub-contractor. On the attached budget form, U.C. Berkeley's costs are listed as "Services/Consultants" and include: two graduate students (12,000 hours or full-time for three years), 4150 hours for university technicians to build and maintain the flumes and other equipment, and 3100 hours for undergraduate student assistants. No faculty salary is included because Professor Dietrich has agreed to donate his time.

D.2 Cost-sharing

The University of California will make 'in-kind' contributions to this project by providing facilities for the experiments and for meetings. The use of the experimental facilities including rent, utilities, security, and janitorial services has an 'in-kind' value of $216,000 for the three years of the study. U.C. Berkeley will also provide facilities for 15 meetings with a total value of $10,000. Finally, Professor Dietrich will donate his time to the project as he will collect no salary, and this amounts to at least $10,000 per year in salary contribution. The total value of UC Berkeley's 'in-kind' contribution to this project is $346,000.

E. LOCAL INVOLVEMENT

N/A

F. COMPLIANCE WITH STANDARD TERMS AND CONDITIONS

Stillwater Sciences will sign contracts as prime contractor with the University of California as subcontractor.

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Table 1. Hydraulic parameters used to scale flume experiments to the field.

Process	Hydraulic scaling parameter	Dimensionless Equation	Explanation of Variables
Flow hydraulics	Froude Number	$Fr = \frac{u}{\sqrt{gh}}$	u = water velocity h = water depth g = the acceleration of gravity
Water and sediment interraction	Particle Reynolds Number	$R_p = \frac{D\sqrt{ghS}}{\nu}$	D = grain diameter S = water surface slope ν = the dynamic viscosity
Sediment transport	Shields Number	$\tau^* = \frac{hS}{R_b D}$	R_b = the non-dimensional buoyant sediment density
Hypothesized gravel addition scaler*	N/A	$R_g = \frac{M_g}{\int Q_s dt}$	the M_g = mass of gravel added Q_s = potential volumetric sediment transport rate
time scale of bed texture evolution*	residence time	$T_r = \frac{Kw^2 D}{Q_s}$	w = channel width K = dimensionless empirical coefficient that scales with the depth of the active surface layer.
Surface tension	Weber number	$W = \frac{\rho U^2 h}{\sigma}$	σ = surface tension stress for the model substrate

* indicates new dimensionless parameters resulting from the discussion in the gravel augmentation justification section.

Table 2. Applicability to PSP Priorities.

<table>
<tr><th>Priority</th><th>Description</th><th>Sub-descriptions</th></tr>
<tr><td>SR-2</td><td>Restore fish habitat and fish passage particularly for spring-run Chinook salmon and steelhead trout and conduct passage studies.</td><td>• Replenish spawning gravel
• Facilities improvements and fish passage programs</td></tr>
<tr><td colspan="3">The proposed modeling will directly address scientific questions underlying gravel augmentation and dam removal as restoration strategies. The results of the modeling will provide restoration practitioners with more scientifically based methods and tools to use in designing their gravel augmentation projects by addressing such issues as: the grain size distribution of the sediment to be added; the volume of gravel to inject; the frequency of gravel addition that will be required in light of sediment transport; the interaction of added gravel with potential modifications to the flow regime and/or channel geometry. The proposed experiments will also provide scientific methods and tools for examining how sediment accumulated behind dams will move downstream in association with the removal of dams as fish passage barriers, as is planned for Battle Creek.</td></tr>
<tr><td>SR-3</td><td>Conduct adaptive management experiments in regard to natural and modified flow regimes to promote ecosystem functions or otherwise support restoration actions.</td><td>• Mechanistic models as restoration tools
• Effects of managed flow fluctuations</td></tr>
<tr><td colspan="3">One primary goal of the proposed experiments is to develop a mechanistic understanding of river channel response to episodic delivery of bedload size sediments, as occurs in both gravel augmentation and dam removal projects. By modeling channel-floodplain reconstruction projects, the proposed experimentation is also targeted at enhancing our understanding of the linkages between discharge and stable channel geometry and rates of lateral migration. This project will also contribute to assessing the effects of managed flow releases from dams, because one product of the proposed modeling will be an enhanced numerical sediment transport model (EASI), which will allow practitioners to “game” the effects of different discharges upon bed texture and mobility.</td></tr>
<tr><td>SR-7</td><td>Develop conceptual models to support restoration of river, stream, and riparian habitat.</td><td>• Compare conceptual models and develop restoration performance measures for tributary streams and rivers</td></tr>
<tr><td colspan="3">The proposed experimentation is targeted at fundamental scientific questions in the field of fluvial geomorphology. By addressing some of these key scientific uncertainties, the proposed modeling will provide basic theoretical concepts that will contribute to defining and revising conceptual models of river function.</td></tr>
<tr><td>SJ-1</td><td>Continue habitat restoration actions including channel-floodplain reconstruction projects and habitat restoration studies in collaboration with local groups</td><td>• Channel-floodplain reconstruction projects
• Gravel augmentation projects</td></tr>
<tr><td colspan="3">As described above, the proposed modeling will directly address scientific questions underlying gravel augmentation as a restoration strategy. The results of the modeling will provide restoration practitioners with more scientifically based methods and tools to use in designing their gravel augmentation projects by addressing such issues as: the grain size distribution of the sediment to be added; the volume of gravel to inject; the frequency of gravel addition that will be required in light of sediment transport; and the interaction of added gravel with potential modifications to the flow regime and/or channel geometry. The proposed experimentation is also targeted specifically at channel-floodplain reconstruction projects to enhance our understanding of the linkages between discharge and stable channel geometry and rates of lateral migration. We intend to continue engaging local groups by inviting experts engaged in channel-floodplain and gravel augmentation projects on San Joaquin River tributaries to be part of the technical advisory panel for this project.</td></tr>
</table>

Table 2. Applicability to PSP Priorities.

<table>
<tr><th>Priority</th><th>Description</th><th>Sub-descriptions</th></tr>
<tr><td>SJ-2</td><td>Restore geomorphic processes in stream and riparian corridors</td><td>• Hydrologic and sediment transport models as restoration tools for the main stem San Joaquin river and its tributaries below Friant Dam.
• San Joaquin floodplain evaluation</td></tr>
<tr><td colspan="3">The proposed modeling will directly respond to the call for developing sediment transport models to be used as restoration tools. In addition to the physical models developed to examine sediment transport, the results of the flume experiments will allow the extension, validation, and calibration of numerical sediment transport models, such as Stillwater Sciences' EASI model, to examine how the episodic delivery of sediment to a river channel affects bed texture and mobility. By examining many of the key scientific questions underlying channel-floodplain reconstruction projects, this project will also contribute to projects designed to increase floodplain inundation through floodplain modifications.</td></tr>
<tr><td>SJ-6</td><td>Conduct adaptive management experiments in regard to natural and modified flow regimes to promote ecosystem functions or otherwise support restoration actions.</td><td>• Mechanistic models as restoration tools.
• Instream flow programs
• Effects of managed flow fluctuations</td></tr>
<tr><td colspan="3">As described above, a primary goal of the proposed experiments is to develop a mechanistic understanding of river channel response to episodic delivery of bedload size sediments, as occurs in both gravel augmentation and dam removal projects. By modeling channel-floodplain reconstruction projects, the proposed experimentation is also targeted at enhancing our understanding of the linkages between discharge and stable channel geometry and rates of lateral migration. This project will also contribute to assessing the effects of managed flow releases from dams, because one product of the proposed modeling will be an enhanced numerical sediment transport model (EASI), which will allow practitioners to "game" the effects of different discharges upon bed texture and mobility.</td></tr>
</table>

Table 3. Contributions to ERP Goals and Objectives.

Goal 1: Endangered and Other At-risk Species and Native Biotic Communities Achieve recovery of at-risk native species dependent on the Delta and Suisun Bay as the first step toward establishing large, self-sustaining populations of these species; support similar recover of at-risk native species in San Francisco Bay and the watershed above the estuary; and minimize the need for future endangered species listings by reversing downward population trends of native species that are not listed.	
Objective 1: Achieve, first, recovery and then large self-sustaining populations of the following at-risk native species dependent on the Delta, Suisun Bay, and Suisun Marsh: Central Valley winter-, spring- and fall/late fall-run chinook salmon ESUs, Central Valley steelhead ESU, delta smelt, longfin smelt, Sacramento splittail, green sturgeon, valley elderberry longhorn beetle, Suisun ornate shrew, Suisun song sparrow, soft bird's-beak, Suisun thistle, Mason's lilaeopsis, San Pablo song sparrow, Lange's metalmark butterfly, Antioch Dunes evening primrose, Contra Costa wallflower, and Suisun marsh aster.	*The proposed modeling will indirectly contribute to this goal. By enhancing our understanding of channel response to the episodic delivery of sediment to a river channel, and by providing tools for predicting the effects of flow regimes and channel geometry upon bed texture and mobility, this project will contribute to the design of restoration projects so as to improve aquatic and riparian habitat conditions to benefit sensitive salmonid species.*
Goal 2: Ecological Processes Rehabilitate natural processes in the Bay-Delta estuary and its watershed to fully support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities and habitats, in ways that favor native members of those communities.	
Objective 5: Establish hydrologic regimes in streams, including sufficient flow timing, magnitude, duration, and high flow frequency, to maintain channel and sediment conditions supporting the recovery and restoration of native aquatic and riparian species and biotic communities.	*The proposed modeling will support the enhancement, validation, and calibration of numerical sediment transport models. These numerical models can be used to "game" the effects of different discharges upon bed texture and mobility for a wide range of conditions. As such, this project will directly contribute to this objective.*
Objective 6: Reestablish floodplain inundation and channel-floodplain connectivity of sufficient frequency, timing, duration, and magnitude to support the restoration and maintenance of functional natural floodplain, riparian, and riverine habitats.	*By examining the scientific questions and design issues associated with channel and floodplain reconstruction projects, the proposed modeling will help guide the design of restoration projects to help restore fluvial geomorphic function. Consequently, this project will contribute directly to this objective.*
Objective 7: Restore coarse sediment supplies to sediment-starved rivers downstream of reservoirs to support the restoration and maintenance of functional natural riverine habitats.	*The proposed modeling will help guide the design of gravel augmentation projects that are implemented in Bay-Delta tributaries. This project will provide guidelines to help determine the size distribution, volume, and periodicity of gravel injection for specific tributaries. The proposed modeling will also help guide balancing introduced gravel with potential changes to channel geometry and discharge. As a result, this project will contribute directly to this objective.*
Goal 4: Habitats Protect and/or restore functional habitat types in the Bay-Delta estuary and its watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, and aesthetics.	
Objective 2: Restore large expanses of all major aquatic, wetland, and riparian habitats, and sufficient connectivity among habitats, in the Central Valley and its rivers to support recovery and restoration of native species and biotic communities and rehabilitation of ecological processes. These habitat types include riparian and shaded riverine aquatic, instream, fresh emergent wetlands, seasonal wetlands, other floodplain habitats, lacustrine, and other freshwater fish habitats.	*The proposed modeling will indirectly contribute to this goal. By enhancing our understanding of channel response to the episodic delivery of sediment to a river channel, and by providing tools for predicting the effects of flow regimes and channel geometry upon bed texture and mobility, this project will contribute to the design of restoration projects so as to improve aquatic and riparian habitat conditions.*

Table 4. Previous receipt of CALFED or CVPIA funding.

Project title	Program/Project Number	Current status	Project milestones
Stillwater Sciences previous CALFED Program funding			
Merced River Corridor Restoration Plan-Phase II	ERP/ Project #98E-09	complete	(1) social, institutional, and infra-structural opportunities and constraints to restoration analysis; (2) baseline evaluations of geo-morphic and riparian vegetation conditions
Merced River Corridor Restoration Project-Phase III	ERP/Project #2000 E-05	Complete (October 2002)	development of (1) geomorphic-ally functional channel and flood-plain design guidelines; (2) the Merced River Corridor Restoration Plan; (3) conceptual designs for 5 top-priority restoration projects
A Mechanistic Approach to Riparian Restoration in the San Joaquin Basin	ERP/#99-B152	starting-up/in progress	(1) literature and existing data review; (2) development of conceptual model and study plan
CALFED Sacramento/San Joaquin Tributary Assessments	ERP/	complete	assessment protocol applied to the Tuolumne River and Deer and Clear creeks
Diversion Effects on Fish/ Environmental Water Account	ERP/ Contract 1425-96-CA-20-03420	in progress	draft report in progress
Tuolumne River Coarse Sediment Management Plan	Service Agreement #010801	in progress	(1) fine sediment report; EACH and stock recruitment modeling underway
M&T Ranch Pump Intake Assessment	Contract 01A120210D	complete	developed mitigating techniques for sediment burial of pump intake
Saeltzer Dam Removal Analysis	Contract B-81491	complete	(1) application of sediment transport model to a dam removal project; (2) pre- and post-dam removal channel monitoring
Stillwater Sciences previous CVPIA funding			
Merced River Corridor Restoration Plan-Phase I	AFRP/	complete	formation of the Merced River Stakeholder Group and Technical Advisory Committee
Merced River: Ratzlaff Project	AFRP/CVPIA 11332-9-MO79	complete	provide comments on existing and proposed restoration efforts; coordinate with Merced River Restoration Project
Stanislaus River: 2 Mile Bar	AFRP/CVPIA 11332-9-MO80	complete	prepare summary of restoration potential and strategies, focusing on geomorphic opportunities and constraints
Stanislaus River: Smolt Survival	AFRP/CVPIA 11332-0-MO09	complete	prepare assessment of coded wire tag and multiple mark-recovery smolt survival assessment programs
Calaveras River Spawning Habitat Evaluation	AFRP/	complete	conduct reconnaissance-level evaluation of steelhead and salmon habitat conditions and population dynamics
Calaveras Salmonid Limiting Factors Study	AFRP/CVPIA 11332-1-GO06	in progress	(1) reconnaissance surveys are underway

Stillwater Sciences was not the prime contractor on the highlighted contracts.

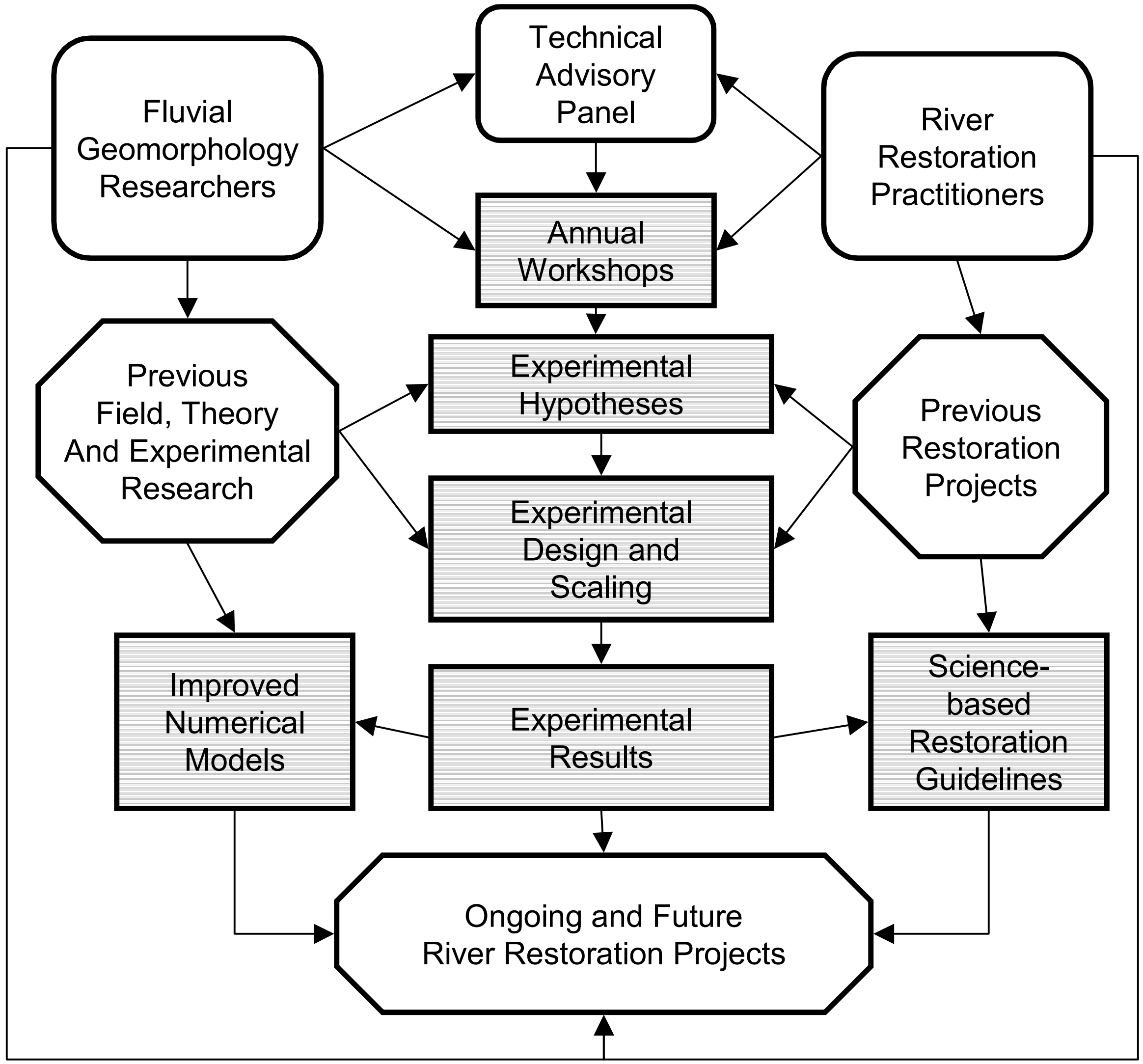

Figure 1. Schematic representation of linkages between the proposed experiments and ongoing and future restoration projects.

These experiments will help bridge the gap between fluvial geomorphology research and restoration practice. Researchers and practitioners will contribute to the technical advisory panel and annual workshops. Previous research and project experience will inform experimental hypotheses, design and scaling. Experimental results will be used to improve numerical models and produce practical guidelines for restoration. Each of these products will contribute to a stronger scientific basis for ongoing and future river restoration projects employing the strategies of gravel augmentation, dam removal and floodplain and channel reconstruction.

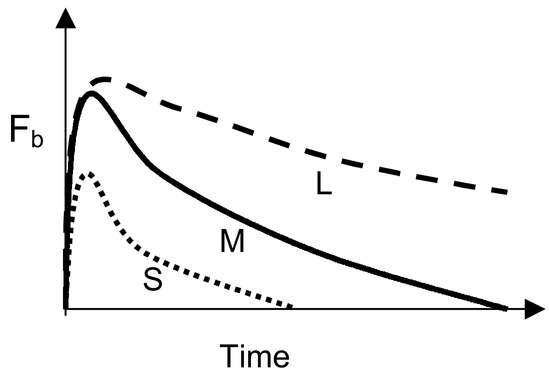

Figure 2: Hypothesized improvement in fraction of bed (F_b) composed of target grain size distribution for single pulse of gravel augmentation of various amounts, small (S), medium (M), and large (L). Rapid improvement is followed by relaxation back to the pre-augmentation state. Larger augmentation amounts result in greater and longer-lasting improvements, however, moderate augmentation masses may be most efficient due to bed saturation.

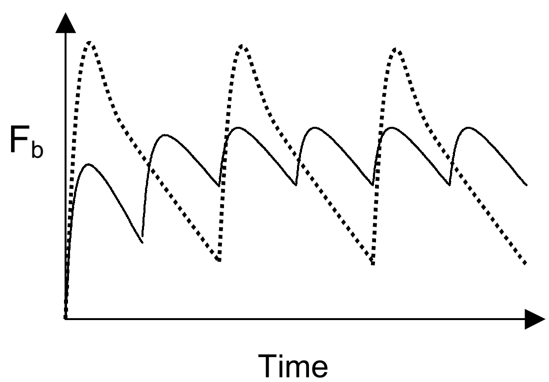

Figure 3: Hypothesized improvement in fraction of bed (F_b) composed of target grain size distribution for multiple pulses of gravel augmentation. Dashed line represents a larger amount repeated at longer intervals, solid line represents a smaller amount repeated more frequently. Total gravel mass added assumed equal for both scenarios. Both scenarios results in similar average bed composition over time, however, more frequent augmentation results in less variability but perhaps at greater management cost.

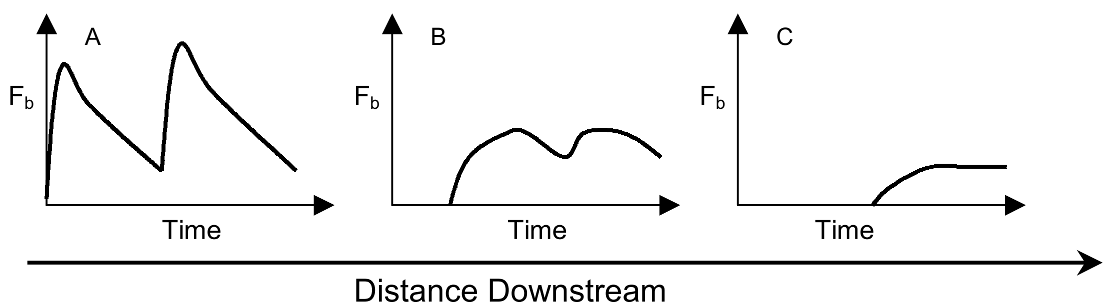

Figure 4: Hypothesized improvement in fraction of bed (F_b) composed of the target grain size distribution at three locations along the river. Near the location of gravel addition (A), both the size of the effect on bed composition and the rate of change are greatest. Some distance downstream (B), the response is lagged, damped and somewhat diffused. Further downstream (C), the extent of improvement in bed composition is lower still, but the oscillations caused by episodic sediment augmentation upstream may not be noticable.

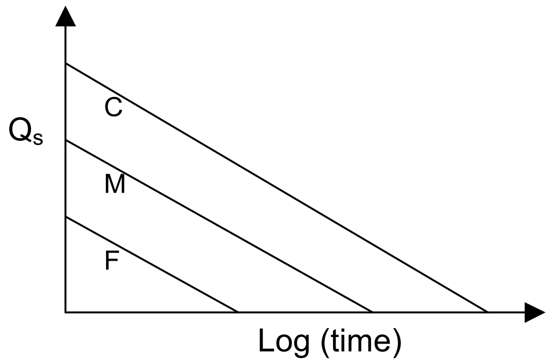

Figure 5A: Hypothesized variation in reservoir bedload sediment release rate (Q_s) over time for coarse (C), medium (M) and fine (F) grain size distributions. Total reservoir sediment volume assumed to be equal but the fraction in bedload size class will be greater for coarse than for fine distributions. Note that the exponential decline in sediment release rate plots as a straight line in semi-log space.

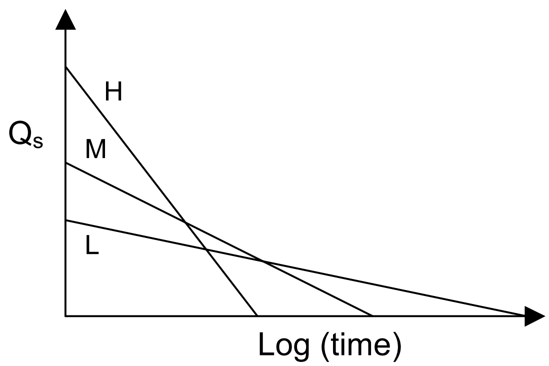

Figure 5B: Hypothesized variation in reservoir bedload sediment release rate (Qs) over time for high (H), medium (M) and low (L) discharge, assuming fixed reservoir width and grain size distribution. Total area under each curve is equal and represents the initial reservoir sediment volume.

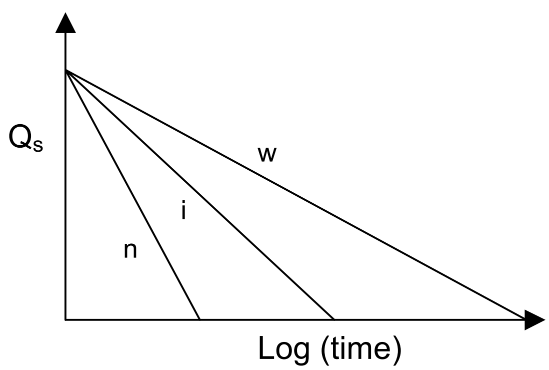

Figure 5C: Hypothesized variation in reservoir bedload sediment release rate (Qs) over time for wide (w), intermediate (i) and narrow (n) reservoir width, assuming fixed discharge and grain size distribution.

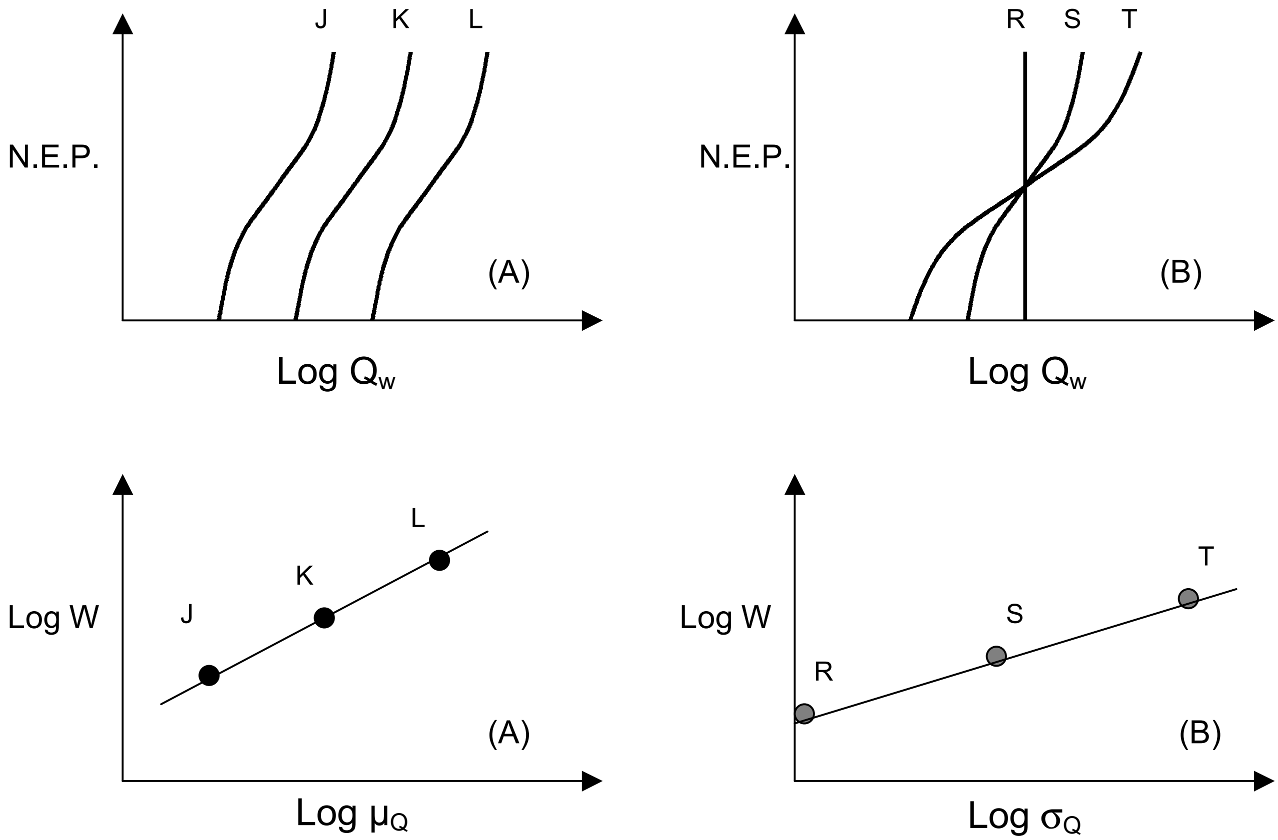

Figure 6: Conceptual representation of the hypothesized relationship between channel width and discharge distribution. Discharge distribution is characterized by the non-exceedence probability (N.E.P.) for the full range of possible discharges (Q_w). For fixed variance of the discharge distribution (case A) we expect channel width to vary as a log-linear function of some representative 'dominant' discharge (μ_Q). The slope of this line is typically 0.5 for alluvial channels. For fixed 'dominant' discharge (case B) we expect channel width to increase with greater distribution variance (σ_Q). Flood storage and diversion by upstream dams typically reduce both μ_Q and s_Q leading to smaller channels.

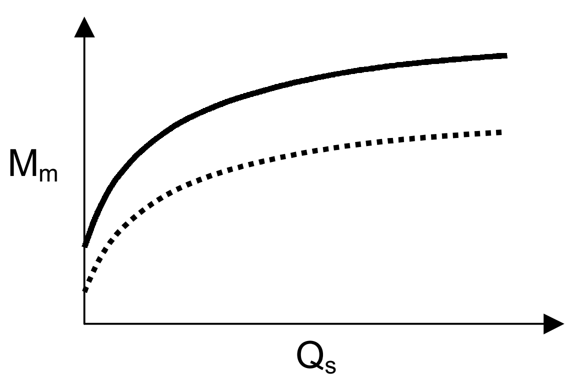

Figure 7: Hypothesized dependence of meander migration rate (M_m) on bedload sediment supply rate (Q_s), for channel banks composed of weak (solid line) and strong (dashed line) materials, and assuming fixed discharge distribution.

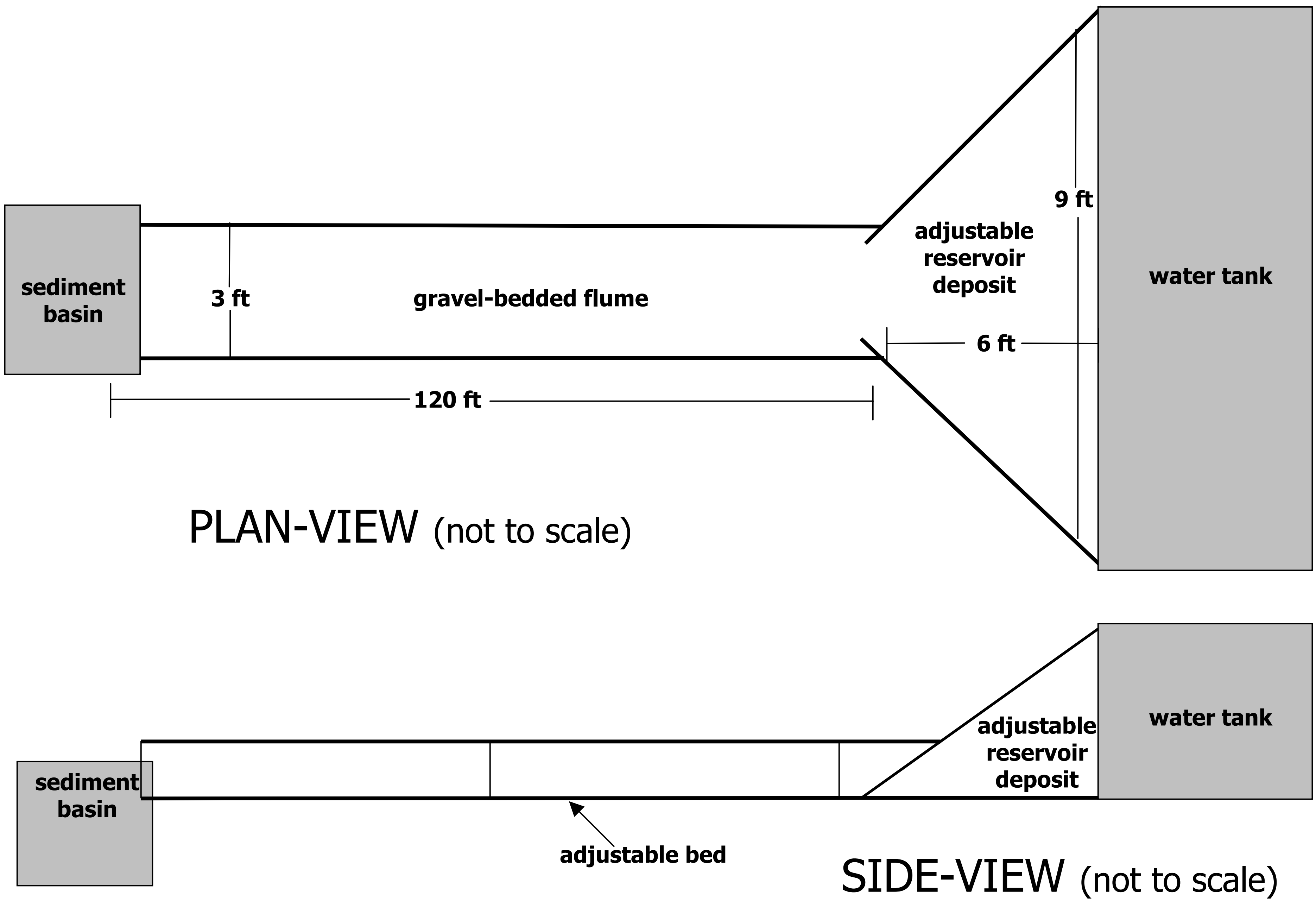

Figure 8. Plan and side view of the flume to be used in the gravel augmentation and dam removal experiments.

Figure 9. Schedule

YEAR 1

Task	Description	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
1	Review implemented, ongoing and planned restoration projects	■	■				■						■
2	Flume construction/modification for tasks 3, 4 and 5	■	■	■	■	■	■	■	■	■	■	■	■
3a	Gravel augmentation experiments							■	■	■	■	■	■
3b	Numerical modeling of gravel augmenation experiments												
4a	Dam removal experiments												
4b	Numerical modeling of dam removal experiments												
5a	Floodplain reconstruction experiments												
5b	Numerical modeling of channel and floodplain experiments												
6	Information Dissemination			■			■			■			■

YEAR 2

Task	Description	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
1	Review implemented, ongoing and planned restoration projects						■						■
2	Flume construction/modification for tasks 3, 4 and 5												
3a	Gravel augmentation experiments	■	■	■	■	■	■						
3b	Numerical modeling of gravel augmenation experiments	■	■	■	■	■	■	■	■	■	■	■	■
4a	Dam removal experiments							■	■	■	■	■	■
4b	Numerical modeling of dam removal experiments												
5a	Floodplain reconstruction experiments	■	■	■	■	■	■	■	■	■	■	■	■
5b	Numerical modeling of channel and floodplain experiments							■	■	■	■	■	■
6	Information Dissemination			■			■			■			■

YEAR 3

Task	Description	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May
1	Review implemented, ongoing and planned restoration projects						■						
2	Flume construction/modification for tasks 3, 4 and 5												
3a	Gravel augmentation experiments												
3b	Numerical modeling of gravel augmenation experiments												
4a	Dam removal experiments	■	■	■	■	■	■						
4b	Numerical modeling of dam removal experiments	■	■	■	■	■	■	■	■	■	■	■	■
5a	Floodplain reconstruction experiments	■	■	■	■	■	■						
5b	Numerical modeling of channel and floodplain experiments	■	■	■	■	■	■	■	■	■	■	■	■
6	Information Dissemination			■			■			■			■

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