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: 131.14

       Total Requested Funds: 2,472,750

b) Do you have cost share partners already identified?

No

c) Do you have potential cost share partners?

No

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

No

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

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

No

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

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

<u>Physical modeling experiments to guide river restoration projects</u>

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".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

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

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

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

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

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

      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

<u>Physical modeling experiments to guide river restoration projects</u>

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

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

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

Applicant(s):

Frank Ligon, Stillwater Sciences
William Dietrich, University of California, Berkeley

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.

Independent of Fund Source

Year 1													
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Flume construction for tasks 2 and 3	3200	$67,066	$22,649		$180,000	$5,000		5600	5600.0	$124,760	5600.00
2A	Gravel augmentation experiments	3200	$67,066	$22,649			$5,000			0.0	$106,200	0.00
4A	Channel/floodplain restoration flume experiments	4000	$68,675	$23,192		$150,000	$6,000		7700	7700.0	$124,605	7700.00
5	Information dissemination	209	$6,032	$2,037			$533		366	366.0	$9,597	366.00
		10609	0.00	0.00	0.00	0.00	0.00	0.00	13666.00	13666.00	0.00	13666.00

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
2A	Gravel augmentation experiments	3200	$69,749	$23,555			$5,000		5600	5600.0	$110,988	5600.00
3A	Dam removal experiments	3200	$69,749	$23,555			$5,000		5600	5600.0	$110,988	5600.00
4A	Channel/floodplain restoration flume experiments	4400	$71,422	$24,119			$6,000		7700	7700.0	$113,934	7700.00
5	Information dissemination	209	$6,032	$2,037			$533		366	366.0	$9,597	366.00
		11009	0.00	0.00	0.00	0.00	0.00	0.00	19266.00	19266.00	0.00	19266.00

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
2B	Numerical modeling of gravel augmetation experiments	240	$13,603	$4,594					420	420.0	$21,481	420.00
3A	Dam removal experiments	6620	$154,969	$52,334			$12,000		11585	11585.0	$246,598	11585.00
3B	Numerical modeling of dam removal experiments	240	$13,603	$4,594					420	420.0	$21,481	420.00
4A	Channel/floodplain restoration flume experiments	4033	$58,259	$19,674			$2,400		7058	7058.0	$92,764	7058.00
4B	Numerical modeling of Task 4a	240	$13,603	$4,594					420	420.0	$21,481	420.00
5	Information dissemination	209	$6,032	$2,037			$533		366	366.0	$9,597	366.00
		11582	0.00	0.00	0.00	0.00	0.00	0.00	20269.00	20269.00	0.00	20269.00

Grand Total=53201.00

Comments.

On-line forms do not appear to be adding task or year totals correctly. Complete budget forms are attached to the proposal package.

Budget Justification

Physical modeling experiments to guide river restoration projects

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

Employee Hours Christian Braudrick 1500 Yantao Cui 2200 Michael Fainter 450 Leonard Sklar 3000 Frank Ligon 450 Tom Cheang 240 Ethan Bell 240 Senior Tech (TBD) 4500 Junior Tech (TBD) 9000 Grad. Student (TBD) 12000

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

Employee Rate Christian Braudrick $26.50 Yantao Cui $46.71 Michael Fainter $38.02 Leonard Sklar $43.82 Frank Ligon $50.30 Tom Cheang $27.04 Ethan Bell $24.07 Senior Tech (TBD) $30.00 Junior Tech (TBD) $9.01 Grad. Student (TBD) $9.01

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

Stillwater pays 33.78% in benefits to employees in all categories.

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

There are no travel costs associated with this project.

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: $327,000.00 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 1, UCB researchers will assist with flume construction ($5,000). In tasks 2, 3, and 4, UCB researchers will assist with conducting experiments and reviewing experiment results and analyses ($40,400). In Task 5, UCB will contribute to information dissemination by assisting the development of project videos and the project website ($1,600).

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 be 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 $107,238. 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.

Stillwaters 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

Restoration strategies, such as gravel augmentation, dam removal, and channel and floodplain redesign, have been developed for many rivers in the CALFED area. There is, however, little scientific information available to guide the implementation of these restoration strategies and determine the role of variable discharge and sediment supply in controlling channel geometry and bed dynamics. Given this lack of information and the complex, dynamic nature of rivers and riparian ecosystems, there is a significant risk of restoration project failure. In collaboration with the University of California, Berkeley, Stillwater Sciences is proposing a focused program of experimental studies to guide implementation of three key restoration strategies: gravel augmentation, dam removal, and channel and floodplain redesign. The proposed experimentation and physical modeling has the potential to significantly reduce the risk of project failures by (1) testing and extending existing numerical models, and (2) providing new quantitative understanding of how rivers respond to restoration activities. The proposed project has two phases. In Phase I, we will use the hydraulic laboratories at the University of California¡¦s Richmond Field Station to conduct a series of flume and basin experiments to test mechanistic hypotheses regarding the processes underlying each restoration strategy. h For gravel augmentation, we will supply model gravel 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. h For dam removal, we will allow channel incision into model reservoir deposits of varying width and grain size and document the rate of sediment evacuation for various discharges. h For channel and floodplain 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. In Phase II, the experimental results of Phase I will be used to test and improve existing numerical models. The overall product of the proposed project will be a suite of numerical and physical modeling approaches that can be used to guide implementation of CALFED¡¦s restoration strategies.

Proposal

Stillwater Sciences

Physical modeling experiments to guide river restoration projects

Frank Ligon, Stillwater Sciences
William Dietrich, University of California, Berkeley

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

September 21, 2001

Stillwater Sciences

A. PROJECT DESCRIPTION: PROJECT GOALS AND SCOPE OF WORK

A.1 Problem

With planning and financial support from CALFED, one of the most ambitious restoration programs ever attempted will take place on the Sacramento and San Joaquin rivers and their tributaries in the coming years. Although a set of restoration strategies has been identified (e.g. gravel augmentation, dam removal, channel and floodplain redesign), there is little basic scientific research available to guide decisions on how, where, and in what combination to apply them. Numerical modeling of geomorphic processes can provide valuable insight, but only to the extent that the model's simplifying assumptions are valid. And while adaptive management allows modifications to be made to poorly designed projects, this approach is equivalent to performing experiments without controls, making it difficult to interpret and generalize the results. As a result, restoration practitioners are often forced to rely on their best judgement, which is typically based on past experience and qualitative conceptual models for the fluvial process mechanics. Given the complex dynamic nature of rivers and the ecosystems that derive from them, there is a significant risk that some expensive and high profile restoration projects will fail to achieve their basic objectives.

Physical modeling of the process mechanics underlying specific restoration strategies has the potential to reduce significantly the risk of project failures in two ways: 1) by testing and extending existing numerical models, and 2) by providing new quantitative understanding of how rivers respond to restoration activities. 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 science 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 (Ikeda et al. 1988), downstream fining (Seal, et al. 1997), and the mechanics of flow through meander bends (Hooke 1975).

The proposed physical modeling experiments could be applied to a variety of restoration projects in the Sacramento/San Joaquin River system. In this proposal we present three general studies that examine restoration strategies used in CALFED projects that seek to model projects currently funded or under consideration by CALFED. These studies will be used to derive general relationships between restoration strategies and physical processes that could be used to design future restoration projects.

Various land uses have altered aquatic habitat and geomorphic function in the Sacramento River and its tributaries. Dams and reservoirs on the mainstem and its tributaries have reduced peak flows, intercepted coarse sediment, and limited the range of anadromous salmonids. Sediment has also been directly removed from channels for gold and aggregate mining. Additionally, bank protection, levees, and vegetation encroachment have altered the geometry of channel cross sections. In order to mitigate these changes to geomorphic and ecologic function, managers, scientists, and engineers have been spending a great deal of time and money trying to restore geomorphic processes and habitat structure to the Sacramento River and its tributaries. These changes are often addressed by three key restoration strategies: gravel augmentation, dam removal and channel and floodplain redesign. We are proposing a focused program of experimental and numerical studies to guide implementation of these restoration strategies.

This will be a collaborative project between Stillwater Sciences and Dr. William E. Dietrich, chair of the Department of Earth and Planetary Science at the University of California, Berkeley. We will use the extensive hydraulic laboratories at the University of California's Richmond Field Station, which were recently used to guide the successful restoration of the Kissimmee River in Florida (Shen et al. 1994). We will modify existing flumes and support infrastructure, and where needed will construct new experimental equipment specifically designed for testing these restoration strategies. The Richmond Field Station provides an excellent location to develop physical models for stream restoration because it has the infrastructure necessary to support intensive and large-scale physical modeling studies and because it is conveniently located for demonstrating the methods and results to the community of restoration practitioners working in the Sacramento/San Joaquin watershed.

These flume facilities will also be used to validate existing and new numerical tools for gravel augmentation, dam removal and channel and floodplain redesign. Stillwater Sciences has developed the EASI model as a tool for quick evaluation of gravel augmentation and channel and floodplain redesign projects. The experiments will allow for the validation and improvement of this model for a much wider application to future restoration projects. Stillwater Sciences has also developed numerical models for sediment transport following the removal of dams and is currently integrating and improving those models to a user-friendly package named DREAM (Dam Removal Express Assessment Model). Stillwater Sciences recently received funding from NOAA/NMFS to develop the DREAM models. The proposed experiments will allow for validation and improvement of DREAM and allow for wider application in the future. The acceptance and successful application of DREAM may allow for improvements and more cost effective dam removal process in the future. In addition to EASI and DREAM, Stillwater Sciences is proposing to develop a 1-D sediment transport model for the Merced River in the Dredger Tailings Reach to guide ongoing and proposed restoration efforts. The proposed experiments will aide in the development and refinement of the Merced River sediment transport model and the ongoing restoration projects. Another potential modeling tool under consideration by Stillwater Sciences is a user-friendly sediment transport model that can be applied by land managers and gravel mining corporations to develop gravel mining operations with minimized impact to stream ecosystems. Instream gravel mining still occurs in some California and Pacific Northwest rivers, and a model is urgently needed to provide insight into methods of gravel extraction that limit damage to aquatic ecosystems. This gravel mining model could also benefit from our proposed flume facilities.

A.2 Justification

The following section will describe three distinct components of this proposal pertaining to three restoration strategies: gravel augmentation, dam removal, and channel/floodplain redesign.

Gravel augmentation

The goal of gravel augmentation is to improve spawning and rearing habitat by modifying grain-size distributions within the channel bed and increasing the frequency of bed movement. Channels requiring gravel augmentation are typically armored by coarse, relatively immobile sediments, as a result of dams that block sediment transport to downstream reaches and reduce the frequency of high flow events that typically mobilize the channel bed. Gravel augmentation may be used to restore some fraction of the historical sediment supply, and should ideally be combined with increases in the frequency and magnitude of high flows and possibly changes in channel cross-sectional geometry.

Design of gravel augmentation projects requires determining what grain size distribution to use, how much gravel to apply and how often, how far downstream and how quickly the effects will be felt, and how gravel augmentation will interact with modifications to the flow regime and channel geometry. The design must also seek to maximize habitat benefits while minimizing the costs of sediment handling, water purchase and channel modifications.

Currently, little is known about the basic scientific questions of how channel bed texture and mobility vary in response to episodic delivery of sediment. 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. Finer-grained sediments, when added to a relatively immobile coarse-grained bed can increase bed mobility and lead to formation of bedload sheets (Whiting et al., 1988). Thus, we expect that augmentation of the supply of finer gravel will cause both fining of the bed texture and increased mobilization of the armor layer to occur.

Numerical sediment transport models for heterogeneous sediment have produced promising results for channel response both in elevation and bed texture for rather simple cases of disequilibrium between sediment supply and transport capacity (e.g., Cui et al. 1996, Cui and Parker 1997, Cui et al. 2001). In the first case, Cui et al. (1996) and Cui and Parker (1997) developed two numerical models based on the surface-based bedload transport equation of Parker (1990) and simulated three sets of large scale flume experiments reported by Paola et al. (1992), Toro-Escobar et al. (1996) and Seal et al. (1995). The experiment was set at an aggradational environment and constant discharge and sediment were fed into the flume. In this case, the results of the numerical models were corroborated by physical experiments. In the second case, Cui et al. (2001) developed a numerical model based on the same equation to simulate the evolution of introduced sediment pulses and compared the results with those obtained in a laboratory flume. The discharge and sediment fed in the experiments are again set as constants in time. Comparison of the model and experiment matched very well for Run 3, which was especially designed for the validation of the numerical model. In the third case, Hansler applied a early version of a model developed by Cui and Parker (2001) to simulate the evolution of a landslide in the Navarro River, California. The simulation applied the discharge record in the river for the modeling period and obtained satisfactory results. This case is also simple in that the channel experienced only degradation during the modeling period. The validation of the models to channel response for natural conditions, e.g., the channel receives dynamic hydrograph and sediment supply, and experiences aggradation and degradation regularly, however, are lacking.

Because of practical constraints of cost and sediment availability, it is generally impossible to recreate either the magnitude or frequency of the historic discharge-driven, semi-continuous supply of sediment, in gravel augmentation restoration projects. Gravel augmentation must therefore involve 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. We currently 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.

Numerical models of mixed grain size bedload sediment transport, such as Stillwater's EASI model, which uses Parker's (1990 a,b) surface-based bedload transport theory, can provide quantitative predictions of changes in bed texture and mobility that may result from gravel augmentation. However, this and other available models (e.g. Wilcock?) are one dimensional (only downstream variation is considered) and assume continuous sediment supply.

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 over the interval between gravel additions. We further hypothesize that the most effective grain size distribution for augmentation should be finer than the desired bed distribution because of the potential for armor mobilization, 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 1. 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 2 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 3.

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, augmentation amount and interval between gravel additions and measure the spatial and temporal response of the bed. We will compare our experimental results with predictions from the EASI 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.

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. 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 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).

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.

Dam Removal

Dam removal is increasingly being viewed as a viable restoration option on many rivers throughout California and elsewhere in the US. Dam removal is being seriously considered on many rivers where their removal would improve anadromous salmonid access to upstream reaches, restore continuity to sediment transport, and act as a source of sediment to depleted reaches downstream.

A key uncertainty in all 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 salmonid redds) could potentially be buried by reservoir sediment transported downstream. In order to insure that downstream effects are limited, managers often recommend the removal of reservoir sediment. Removing reservoir sediment, however, is often the most costly component of proposed 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 asses the potential fate of downstream sediment, but these models have not been tested and without tests many land managers are reluctant to risk any downstream impacts. Physical modeling of sediment releases following dam removal, for a variety of general hydrologic and sedimentological settings, could provide essential data for improvement numerical models and guiding dam removal designs and management decisions.

Stillwater Sciences 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. These numerical models can be calibrated using the physical models conducted as part of this proposed study.

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. In past dam removal projects, most of the sediment deposited behind the dams were excavated before the dam removal, prohibiting field validation of the sediment transport model. Without such validation, land managers are unlikely to base their decisions on model results alone. The proposed experiments will allow for such validation.

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 hypothesizes are illustrated schematically in Figure 4A-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 limited physical modeling experiments have been done to date on the evolution of reservoir deposits. Eric Larsen and John Wooster of U.C. Davis have just 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).

Channel and floodplain redesign

The tributary and main stem channels of the Sacramento/San Joaquin river system have been significantly affected by the reduction in the magnitude and frequency of large discharges and loss of coarse sediment supply caused by upstream dam construction. Restoring geomorphic function and ecological habitat value to these channels requires, in many cases, redesigning the channel geometry to adapt to the changed hydrologic regime. An understanding of the relationship between the stable channel geometry and the discharge distribution and sediment supply regime is also required for estimating the potential benefits of changing the management protocol for upstream dam releases. Loss of peak flows and sediment supply, in combination with levee construction and channelization, have also led to greatly reduced rates of lateral channel migration. An important goal of floodplain redesign, including levee setbacks or removal, is to restore active channel migration where possible.

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 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 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, it 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. 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 fully restore channel dynamics, in the absence of geomorphic work accomplished by the larger magnitude, less frequent events.

We hypothesize that the stable channel width can be deterministically related 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 5, 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; all else 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 it 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. Migration rates have been argued to also depend 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.

We will test these hypotheses for the role of variable discharge and sediment supply in controlling channel width and meander migration rate with a series of experiments utilizing Smith's (1998) model floodplain substrate, detailed below in section A.3. 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.3 Approach

Task 1 Construct a flume to analyze gravel augmentation and dam removal

The experiments described in detail below will utilize 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, precision measurements of bed topography and bed texture. A variable width upstream reservoir to contain model sediment deposits will be added to the flume. For the channel and floodplain redesign experiments a new basin will be constructed, and existing support infrastructure modified to accommodate the controlled supply of fine cohesive sediment and a wide range of water discharges. Specifications of the experimental set-ups and experimental designs are given in the relevant sections below.

Task 2a 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.

The experimental results and model output will be synthesized to produce a set of practical guidelines for the design of gravel augmentation projects. In particular, will identify the trade-offs between the magnitude and frequency of gravel additions to assist in maximizing habitat benefits while minimizing project costs.

Task 2b Numerical modeling of gravel augmentation

In this task 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 therefore validate the 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.

The experimental results can also 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. Data from the experiments will be used to validate this model.

The deliverable for Tasks 2a and 2b will be a set of recommended guidelines for assessing the potential benefits of gravel augmentation using both empirical and numerical model results. The recommendations will be provided in the form of technical published papers, reports and through annual workshops and ongoing web dissemination.

Task 3a 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 7). 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. In addition, we also hypothesize that the effect of a partial removal will be similar to a complete removal if the remaining sediment volume in a partial removal is not an order of magnitude smaller than the original volume. We will perform the experiment for the partial removals to test the hypothesis.

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 3b 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 Oregon (Cui and Wilcox 2001). The experimental and numerical results will be synthesized to generate a set of guidelines and recommended methodologies for assessing the potential downstream channel response to sediment release following dam removal.

The deliverable for Tasks 3a and 3b will be a set of recommended guidelines for assessing the risks and potential benefits of managed sediment release following dam removal, using both empirical and numerical model results. The recommendations will be provided in the form of technical published papers, reports and through annual workshops and ongoing web dissemination.

Task 4a 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. Typical run times are expected to range between 20 and 100 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 5. 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.

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 mini-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 Parker and Ikeda's (date) model for channel width under constant discharge as a theoretical framework for analyzing our experimental channel width results. We will compare the lateral channel migration rate results with predictions from Larsen's (date) version of Parker's (date) meander migration model. The experimental results and model output will be synthesized to produce a set of guidelines for considering the influence of variable discharge and sediment supply in channel and floodplain restoration project designs. 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 4b 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 and now being explored for use on the Sacramento River by Eric Larsen. 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.

The deliverable for Tasks 4a and 4b will be a set of recommended guidelines for redesigning channels and floodplains in response to alterations in discharge and sediment supply regime, using both empirical and numerical model results. The recommendations will be provided in the form of technical published papers, reports and through annual workshops and ongoing web dissemination.

Task 5 Information dissemination

In order to effectively disseminate data and insight gathered during these experiments to scientists, engineers, and managers involved in stream restoration, we will produce a video, hold workshops, and provide the results on a web page.

We will produce a short video highlighting the major findings of the physical modeling experiments. We have found that videos are an effective way to relay information gained from flume experiments. Stillwater Sciences has experience producing short videos in both digital and analog formats.

The workshops will be open to scientists, engineers, and managers involved in CALFED projects. We will provide demonstrations of each of the physical modeling experiments, focusing on the most important linkages and variables. Each participant will be provided with reports detailing the physical modeling results.

To make our results widely available, we will summarize the modeling results on a web page dedicated to physical modeling of stream restoration. The website will be maintained by Stillwater Sciences and UC Berkeley and will provide updates on findings in the flume and workshops.

The deliverable for this task will be a summary memorandum of the workshop, the video, and a memorandum detailing the information on the web site.

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 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 fluvial geomorphology projects. The remaining space is more than adequate to implement the experiments outline above. The gravel augmentation and dam removal experiments will utilize an existing flume that require substantial rehabilitation and modification. A new titling basin will be required for the channel and floodplain redesign 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 through its overhead charge. 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

The overall product will be a suite of numerical and physical modeling approaches that can be used in concert to guide implementation of CALFED's restoration strategies in the coming years and decades. To disseminate our results directly to the restoration community, in addition to reports to CALFED and research papers published in the scientific literature, we will conduct a workshop including laboratory demonstrations, and will produce a video and maintain an extensive web site to document and explain our methods and results. Additional discussion of the various ways the information will be transferred is described above in Task 5.

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 8.

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 addresses several ERP, Science Program, and CVPIA goals and restoration priorities. The main objective of this project is to advance understanding of physical processes and their implications for restoration. The physical experiments described in this proposal provide an important, yet unused tool for examining physical processes in streams (a primary goal of the Science Program). We have focussed our investigations on three key restoration strategies: gravel augmentation, dam removal, and channel and floodplain redesign.

These studies will also address the Science Program goal of advancing the scientific basis of regulatory activities. Aside from providing insight into physical processes in their own right, physical models can be used to validate numerical models used as the basis for management decisions by various regulatory agencies. At present, many models are being used for applications that they were not originally intended for, or are being developed for new management practices and have not been tested. For example, a key question in dam removal projects is how to evaluate whether sediment should be excavated from the reservoir deposit. At present, regulatory agencies are using various sediment transport models as the basis of these decisions. But since few dams have been removed, and almost all of their reservoirs were excavated, there is little basis to evaluate these models. The experiments proposed as part of Task 3 could be used as a basis to evaluate the success of these models.

We will also support Strategic Goal #2 of the Ecosystem Restoration Program, which seeks to restore channel dynamics and sediment transport. Two major strategies of channel dynamics and sediment transport restoration programs addressing are gravel augmentation and channel/floodplain redesign. We will explicitly examine the underlying physical processes of these studies in tasks 2 and 4 of this study. The results from these tasks can be incorporated by managers to produce more efficient and successful restoration strategies.

Finally, this study will address ERP Multi-Region Goal # 6 to "ensure recovery of at-risk species by developing conceptual understanding and models that cross multiple regions." Our results can be used as the basis for three major restoration strategies (gravel augmentation, dam removal, and channel and floodplain redesign) that are commonly used to promote the recovery of at risk species. Additionally, insight gained into physical processes of these restoration strategies will inform critical linkages in conceptual models used as the basis for restoration strategies.

B.2 Relationship to Other Ecosystem Restoration Projects

This project is designed to provide additional information for restoration projects throughout the CALFED area and elsewhere. Many restoration projects use numerical models to evaluate the volume of sediment required for gravel addition projects, whether or not to remove reservoir sediment following dam removal, and for channel design. There is little basic scientific research available to guide decisions on how, where, and in what combination to apply these restoration strategies. Numerical modeling of geomorphic processes can provide valuable insight, but only to the extent that the model's simplifying assumptions are valid. And while adaptive management allows modifications to be made to poorly designed projects, this approach is equivalent to performing experiments without controls, making it difficult to interpret and generalize the results. Following the conclusion of the experiments, we will conduct a workshop to inform people involved in stream restoration of our results and what they mean for stream restoration projects. We will also produce a video and maintain a website to provide information to the widest possible audience. This project will therefore augment many restoration projects throughout the CALFED area.

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 2.

B.5 System-wide Ecosystem Benefits

The results of these physical modeling experiments will benefit restoration projects throughout the San Joaquin/Sacramento River system. These experiments will provide linkages between processes on gravel augmentation, dam removal, and channel/floodplain redesign. Because little is known about the basic scientific questions of how channel bed texture and mobility vary in response to episodic delivery of sediment, the potential success of gravel augmentation programs is unknown. In addition, design of gravel augmentation projects requires determining what grain size distribution to use, how much gravel to apply and how often, how far downstream and how quickly the effects will be felt. Data gained from these experiments will help to make future gravel augmentation programs more successful and should reduce their costs.

One of the most expensive components of dam removal is excavating the sediment from behind the reservoir. Understanding the linkages between the volume and grain size characteristics and their potential downstream impacts on channels with of various geometries and different grain size distributions could inform decisions about sediment excavation. Additionally, validating and informing numerical sediment transport models such as those applied to Saeltzer Dam removal on Clear Creek, will give managers more confidence in basing decision upon numerical modeling results.

Similarly, the experiments on channel and floodplain redesign can be applied to projects throughout the Sacramento/San Joaquin River system. Because we do not understand linkages between discharge regime, channel stability, and lateral migration, current channel and floodplain redesign projects focus on floodplain inundation during 1.5-2 year flow events and assume the channel will be stable and migration will continue. Defining these linkages will provide stream restoration projects with the tools necessary to optimize their channel design.

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.

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. As a modeler, Mr. Sklar has expertise in landscape evolution modeling, as well as event-based erosion models.

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 web forms for budget information.

D.2 Cost-sharing

No other funding commitments have been secured for the proposed project, and no cost-sharing requirements have been established.

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. If contracting differences between CALFED and the University of California with respect to rights in data are resolved prior to contracting, Stillwater and UC will be recommending that the prime/subcontractor relationships be reversed.

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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	$R_p = \frac{D\sqrt{ghS}}{v}$	D = grain diameter S = water surface slope ν = the dynamic viscosity
Sediment transport	Shields Number	$t^* = \frac{hS}{R_b D}$	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	$W = \frac{rU^2 h}{s}$	σ = surface tension stress for the model substrate

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

Table 2. 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	in progress	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	starting-up/in progress	(1) reconnaissance surveys are underway

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

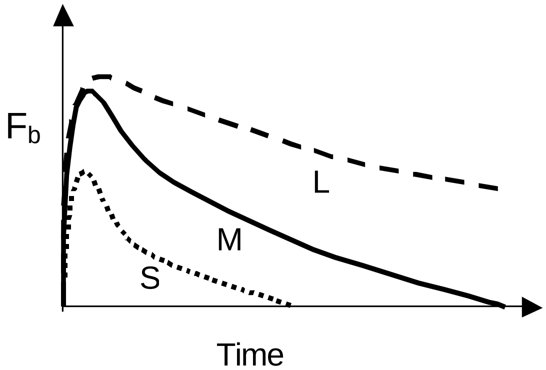


Figure 1: Hypothesized improvement in fraction of bed (F_b) composed of target grain size distribution for single pulse of gravel augmentation of various amounts, small (S), medium (M), and large (L). Rapid improvement is followed by relaxation back to the pre-augmentation state. Larger augmentation amounts result in greater and longer-lasting improvements, however, moderate augmentation masses may be most efficient due to bed saturation.

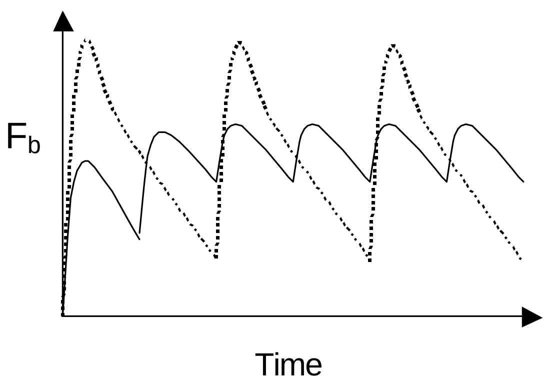


Figure 2: Hypothesized improvement in fraction of bed (F_b) composed of target grain size distribution for multiple pulses of gravel augmentation. Dashed line represents a larger amount repeated at longer intervals, solid line represents a smaller amount repeated more frequently. Total gravel mass added 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.

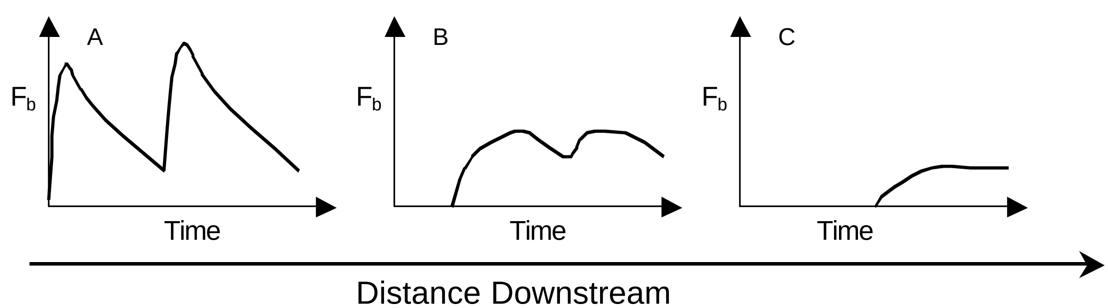


Figure 3: Hypothesized improvement in fraction of bed (F_b) composed of the target grain size distribution at three locations along the river. Near the location of gravel addition (A), both the size of the effect on bed composition and the rate of change are greatest. Some distance downstream (B), the 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.

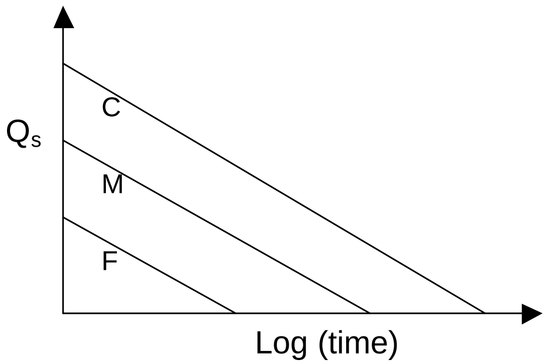


Figure 4A: Hypothesized variation in reservoir bedload sediment release rate (Q_s) over time for coarse (C), medium (M) and fine (F) grain size distributions. Total reservoir sediment volume assumed to be equal but the fraction in bedload size class will be greater for coarse than for fine distributions. Note that the exponential decline in sediment release rate plots as a straight line in semi-log space.

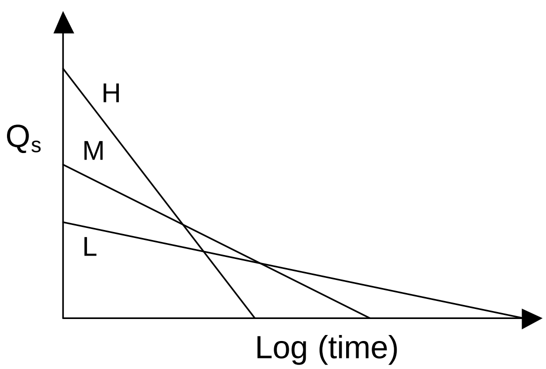


Figure 4B: Hypothesized variation in reservoir bedload sediment release rate (Qs) over time for high (H), medium (M) and low (L) discharge, assuming fixed reservoir width and grain size distribution. Total area under each curve is equal and represents the initial reservoir sediment volume.

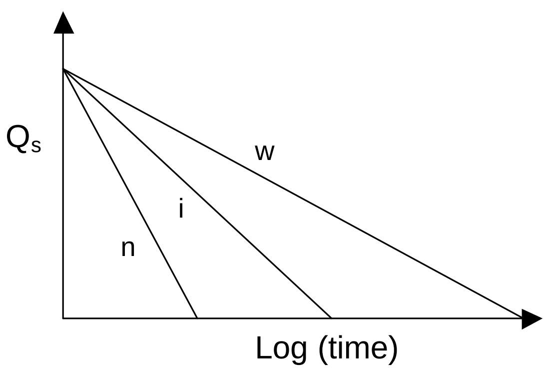


Figure 4C: Hypothesized variation in reservoir bedload sediment release rate (Qs) over time for wide (w), intermediate (i) and narrow (n) reservoir width, assuming fixed discharge and grain size distribution.

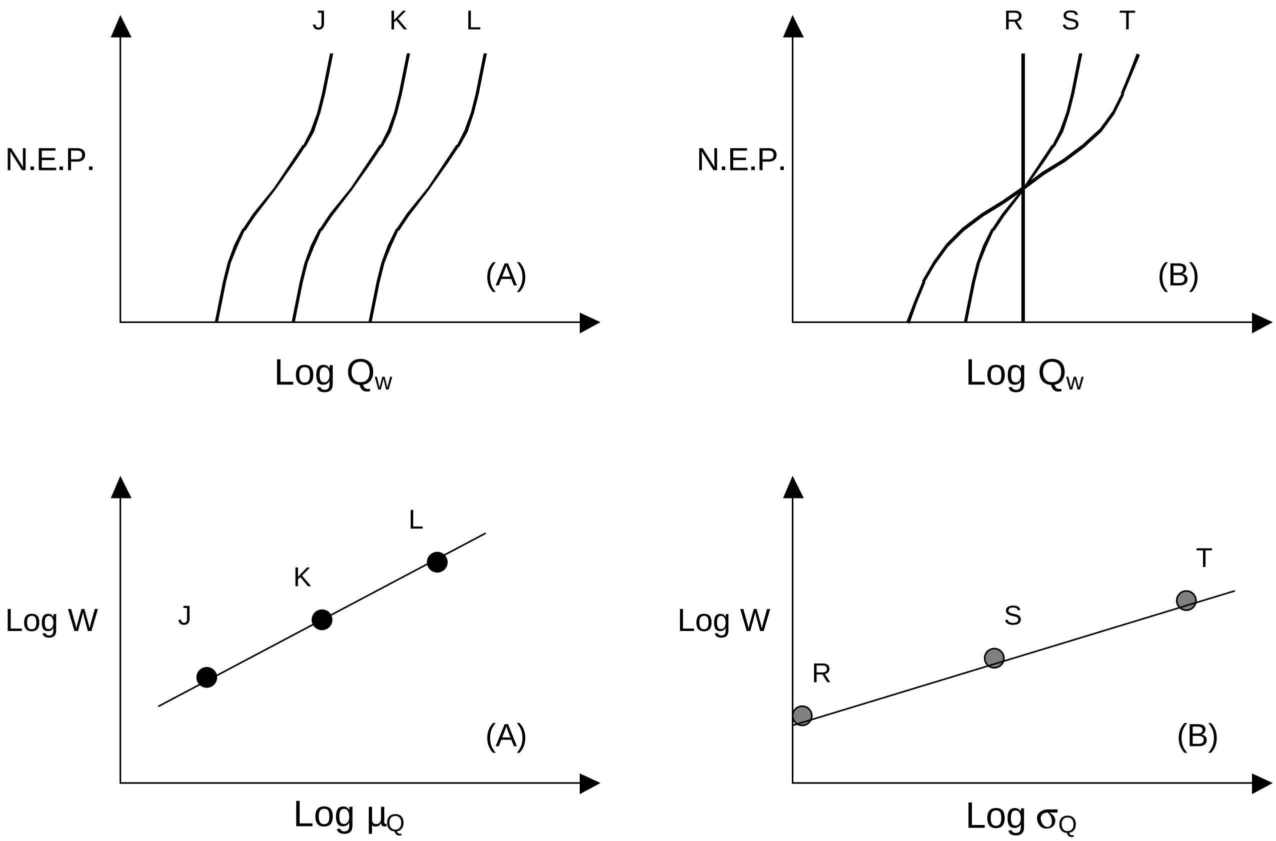


Figure 5: Conceptual representation of the hypothesized relationship between channel width and discharge distribution. Discharge distribution is characterized by the non-exceedence probability (N.E.P.) for the full range of possible discharges (Q_w). For fixed variance of the discharge distribution (case 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.

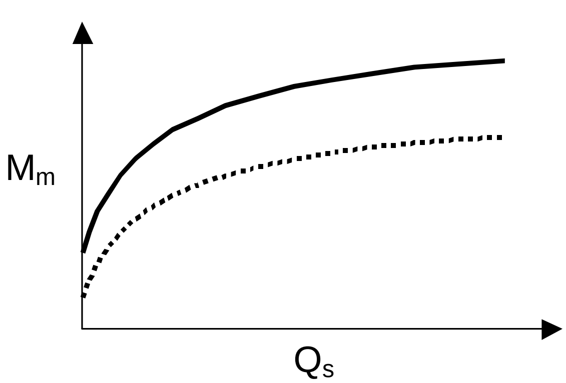


Figure 6: Hypothesized dependence of meander migration rate (M_m) on bedload sediment supply rate (Q_s), for channel banks composed of weak (solid line) and strong (dashed line) materials, and assuming fixed discharge distribution.

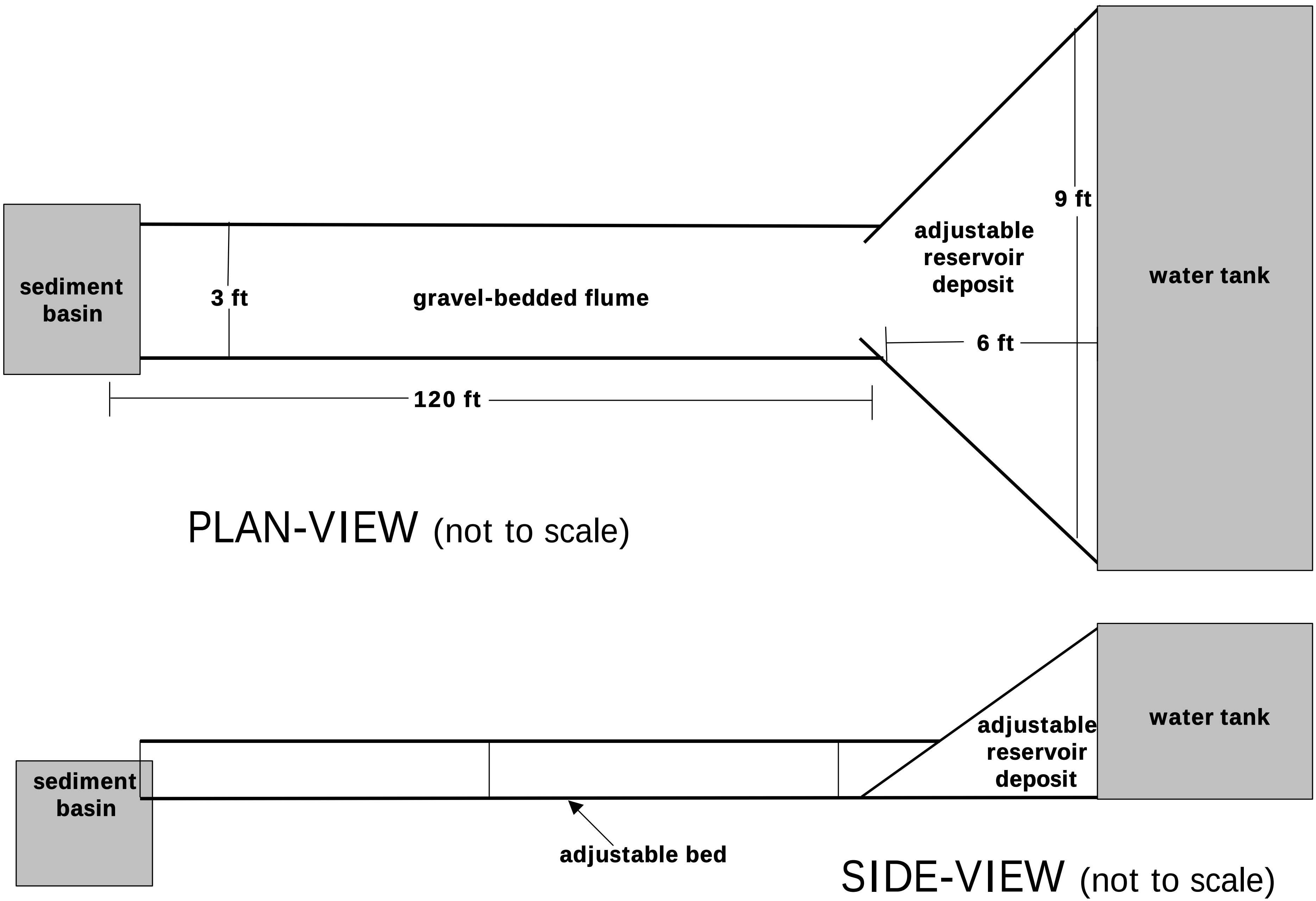
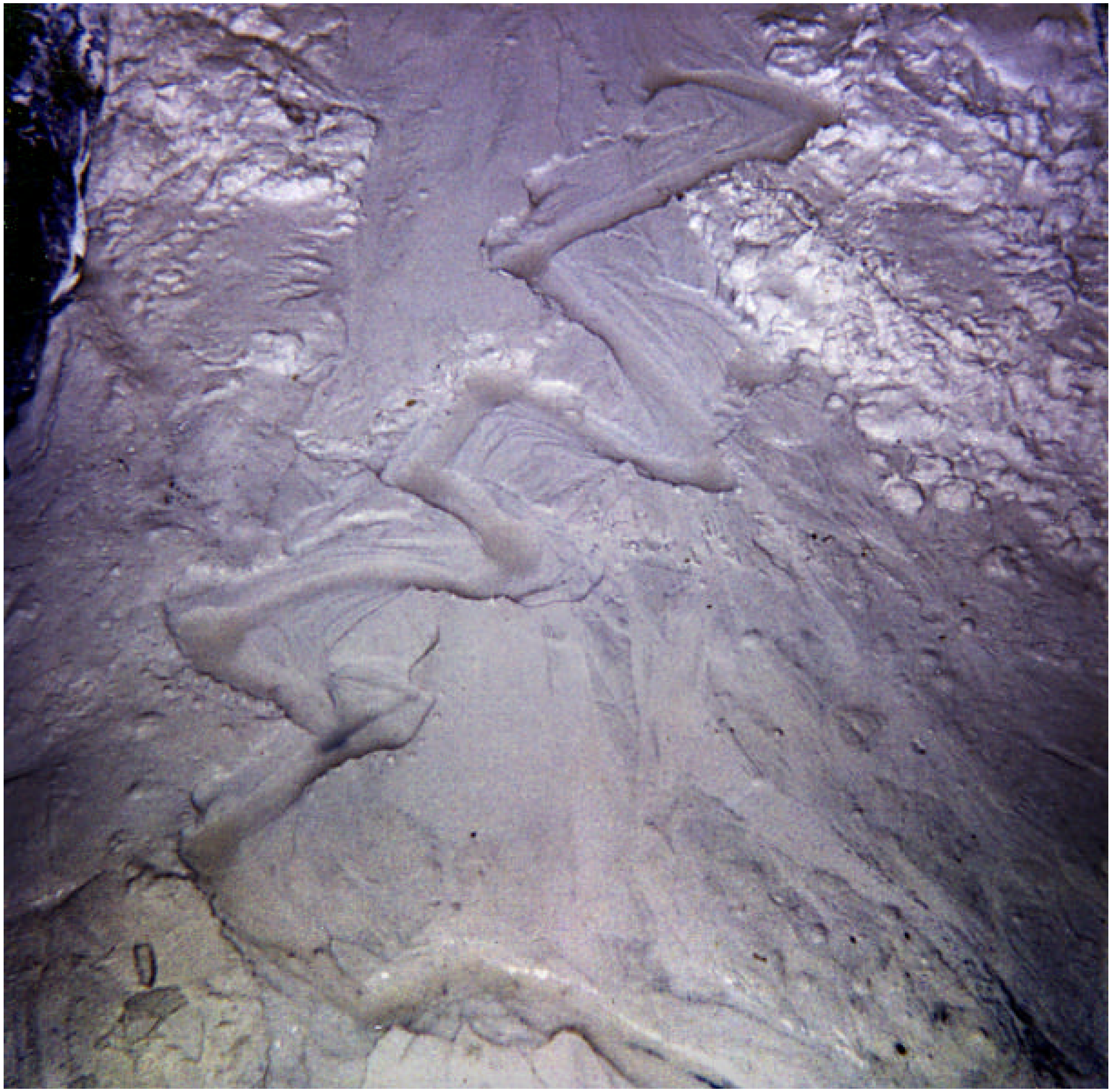


Figure 7. Plan and side view of the flume to be used in the gravel augmentation and dam removal experiments.



Photograph 1. Photograph of Smith's (1998) migrating channel.

Figure 8. Schedule

		YEAR 1												YEAR 2												YEAR 3											
Task	Description	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
1	Construct flume for tasks 2a and 3a	■	■	■	■	■	■																														
2a	Gravel augmentation experiments							■	■	■	■	■	■	■	■	■	■	■	■																		
2b	Numerical modeling of gravel augmenation experiments																			■	■	■	■	■	■												
3a	Dam removal experiments																			■	■	■	■	■	■	■	■	■	■	■	■						
3b	Numerical modeling of dam removal studies																												■	■	■	■	■	■	■	■	
4a	Floodplain reconstruction experiments	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
4b	Numerical modeling of channel and floodplain design																															■	■	■	■	■	■
5	Information Dissemination	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■