Introduction

To further the quantitative understanding behind restoring rivers, Stillwater Sciences, in conjunction with the University of California Berkeley and San Francisco State University, is conducting a series of physical modeling experiments at the Richmond Field Station (Richmond, CA) that address some fundamental scientific questions underlying the river restoration strategies of gravel augmentation, dam removal, and channel-floodplain redesign. The gravel augmentation and dam removal experiments are being conducted in a refurbished gravel bed flume that is equipped with state-of-the-art instrumentation for high precision measurements. The channel-floodplain redesign experiments are being conducted in a large basin in which a scaled-down channel is allowed to migrate within a substrate of fine sand and alfalfa (added for cohesion).

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.

More information, including a copy of the poster, can be downloaded at http://flume.stillwatersci.com.

Project goals

1) 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.

2) Establish quantitative relationships between equilibrium channel geometry and a range of discharges and sediment supply events, whether natural or regulated.
The Flume

The initial stage of the project required converting an existing wave-generating tank into a flume capable of transporting gravel in order to support the gravel augmentation and dam removal experimental trials. Prior to the development of this flume, California investigators often had to travel to Minnesota (Wooster 2003) or Mississippi (Venditti 2003) to conduct flume experiments. CBDA's investment in this project has provided California with a state-of-the-art physical modeling facility, which will continue to facilitate experiments to guide river restoration for many years to come.

Specifications
Dimensions: 92 ft long x 2.8 ft wide x 3.0 ft deep

Application: Testing scientific questions underlying how gravel augmentation and dam removal affect downstream sediment transport/deposition dynamics and bed texture.

Equipped with:
- Sediment delivery system
- Sediment weighing/removal system
- Water supply and removal system
- Automated instrument carriage that includes a photographic bed surface microtopographic measurement system, ultrasonic-based water surface measurement system, and underwater sonar-based bed microtopographic measurement system.

The Channel-Floodplain Basin

A prototype floodplain basin was first constructed to test theories about the lateral space required, and the proper bank cohesion necessary, to form a self-maintaining, stable-width, meandering channel in a confined laboratory setting. Once these requirements were understood, we applied lessons learned to the design and construction of the main basin to be used for the remainder of the experiments. These channel-floodplain basins are the only scale models in existence that are capable of reproducing the effects of vegetation on alluvial channel morphologic processes within a non-cohesive substrate.

Specifications
Dimensions: 58.5 ft long x 25 ft wide x 2.8 ft deep

Applications: Testing scientific questions underlying on how to reconstruct channels and adjacent floodplains to be in balance with regulated flow regime on river reaches downstream of dams.

Equipped with:
- Sediment delivery system
- Water supply and removal system
- Irrigation system for adding vegetation
- Manual instrument carriage mounted on a rail system that includes a photographic bed surface microtopographic measurement system, consisting of 3 cameras and 3 laser distance meters mounted at fixed locations on the instrument carriage.

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Quantifying channel response to variable flow in a meandering channel model

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Abstract

Large water storage dams have altered the morphology of many rivers by trapping sediment and decreasing the magnitude and duration of the seasonal peak flows which had been responsible for channel forming processes that involve sediment transport. We hypothesized that a full range of flows, characteristic of pre-dam conditions, are critical for developing a dynamic, yet sustainable meandering floodplain river. We explored the role of variable flow as represented by a typical flood hydrograph in our physical model experiments of a scaled-down, gravel-bedded, meandering floodplain river. Further, we explored how the channel responded during the rising limb, peak, and falling limb. Our model channel had erodible bed and banks and was allowed to evolve within a wide floodplain. We used a stepped hydrograph with a peak that resulted in overbank flooding, increased lateral migration rates, bar-connection with the floodplain, and stable channel depth. The main point bar grew to the elevation of the floodplain and connected to the inner bank once we provided overbank flow. The highest rates of bar growth, bank erosion, and lateral migration occurred during the peak flows. Total deposition and erosion rates remained equal as a function of discharge at and greater than bankfull. Deposition and erosion rates were generally greater during the rising limb, particularly during the lowest discharge. Our study represents the first attempts at quantifying a channel’s response to a systematic variation of flow in a three-dimensional physical model of a meandering floodplain channel. This work applies directly to influencing restoration design methods that, in the past, have rarely considered the role of higher magnitude flows in shaping the channel and influencing rates of morphologic change. We concluded that future floodplain-redesign projects should include the following conditions: 1) variable discharge with overbank flow; 2) sufficient bank strength provided by vegetation and finer sediments; 3) a wide sediment distribution to aid bar construction through selective transport; and 4) adequate sediment supply to maintain a mass balance of sediment within the system.
Conclusions

Overbank flow was needed to drive bank erosion, to deliver sediment into the chute separating the bar and inner bank, and to grow bars vertically up to the floodplain elevation. This allowed much of the bar to connect to the floodplain and advance in the direction of channel migration. The sediment flux remained closely balanced during the course of the two hydrograph runs. Rates of lateral migration, deposition, and erosion followed the hydrograph pattern. There were no periods during the hydrograph runs when deposition rates were consistently greater than erosion rates, or vice-versa. This is supported by the non-dependence that the ratio of deposition rates to erosion rates had on discharge. There were generally higher rates of deposition and erosion during the rising limb than the falling limb of the hydrographs. Exceptions to this behavior occurred at the downstream portion of the channel as the channel bend apex migrated toward this location after the peak step.

These findings support our hypotheses and suggest that the magnitude and the shape of the hydrograph contribute to a channel's morphology and therefore variable flow, not just the effective discharge or bankfull, should be considered as a key control on meandering river morphology.

Approaches to Restoration

Our study represents the first attempts at quantifying a channel's response to a systematic variation of flow in a three-dimensional physical model of a meandering floodplain channel. This work applies directly to influencing restoration design methods that, in the past, have rarely considered the role of higher magnitude flows in shaping the channel and influencing rates of morphologic change.

Based on our findings, the following conditions should be considered when planning for the restoration of meandering floodplain rivers:

1. Variable discharge including overbank stages to drive channel processes

2. Bank strength provided by vegetation and finer sediments to balance bank erosion and bar growth during high flow stages

3. Wide sediment distribution needed for selective transport upon bars to assist bar growth laterally and vertically

4. Adequate sediment supply to maintain relative mass balance (i.e.: transport-limited rather than supply-limited scenario)
INTRODUCTION

Large-scale sediment releases have the potential to have long-term impacts in downstream reaches. In particular, the fate of the fine sediment associated with large-scale sediment releases, such as those associated with the removal of dams, can have significant long-term negative impacts on a variety of downstream biological processes. Excessive infiltration of fine sediment may result in decreased egg survival rate due to the reduced intra-gravel flow that brings oxygen to the embryos. Fine sediment infiltration into spawning gravel may also result in difficulties for the alevins to emerge from the gravel deposit even if they can hatch successfully. In addition to its negative influences on fish embryo survival, excessive fine sediment infiltration may also reduce the numbers, diversity, and productivity of invertebrate communities that serve as the primary food source for salmonids and other fish species. With the increasing interest in understanding how sediment releases will affect overall stream ecology, a better understanding of the mechanisms of fine sediment infiltration into gravel-bedded channels is becoming increasingly important.

Study Design

This study was designed to examine:
1. the effects of the grain size distributions of the coarse bed material and infiltrating fine sediment on the extent of fines infiltration, and
2. the effects of the rate and duration of fine sediment feed on the extent of fines infiltration.
CONCLUSIONS

1. There is a strong correlation between the saturated fine sediment fraction and the grain size distributions of the infiltrating fine sediment and the gravel deposit that can be quantified with semi-empirical equations;
2. There is a relation that reasonably describes the vertical profile of fine sediment fraction in a stable gravel deposit;
3. An increase in fine sediment feed rate by a factor of 100 did not increase the degree of fine sediment infiltration;
4. Fine sediment infiltration is limited within a very shallow layer of the sediment deposit.

IMPLICATIONS

- Relations developed in this paper can be used to develop a numerical model which simulates the quantity and depth of fine sediment infiltration into a clean, coarse sediment deposit. This model could be applied to estimating infiltration into a clean gravel augmentation deposit or into salmonid redds that have been cleaned of fine sediment. The model can also be used to predict the quantity and depth of infiltration following the release of fine sediment following dam removal.
- Results from these experiments indicate that a higher magnitude delivery rate of fine sediment produces similar or less fine sediment infiltration into a static gravel bed than a slower more prolonged delivery rate of equivalent volumes of fine sediment. This observation can have important ramifications for dam removal projects where an objective is to minimize fine sediment infiltration, and suggests that staged dam removals that control and prolong the duration of fine sediment delivery to reaches downstream of the dam will likely produce as much if not more fine sediment infiltration than a rapid one-stage dam removal.

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