Study 18

Continuous Surrogate Measurement of Bedload Sediment Transport using Hydrophone Installations on the San Joaquin River, California

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Proposal submitted to the San Joaquin River Restoration Program

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Introduction

Traditional methods for measuring coarse bedload sediment transport by discrete physical sampling tend to be slow, labor intensive and expensive (Gray *et al.* 2010). As such, bedload samples often are collected too infrequently to capture the temporal variability inherent in transport rates, which can vary significantly, sometimes by a factor of ten or more, over time periods of several minutes to hours for a given discharge (Gomez *et al.* 1989). Physical bedload sampling, as well as bedload transport formulae, have much larger uncertainty at low bedload transport rates (Gomez *et al.* 1989, Batalla 1997). For river restoration programs, such as the San Joaquin River Restoration Program, accurate estimates of bedload transport, often at low transport rates, are necessary but the limitations of physical sampling and bedload formulae make it difficult to obtain accurate estimates.

Surrogate measurement techniques, which use indirect methods for estimating bedload sediment transport, have demonstrated an ability to greatly augment discrete physical sampling programs and have great value as independent measures of bedload mobilization (Gray *et al.* 2010). The use of hydrophones to detect the sound generated by cobble- and gravel-sized particles moving along the riverbed (for example, Barton *et al.* 2010, Marineau *et al.* 2012) is one such type of surrogate technology. Hydrophones are relatively inexpensive, can operate nearly continuously, and may be deployed remotely (Gray *et al.* 2010). Hydrophones can be used to quantify bedload transport rates at high temporal resolution (e.g. seconds to hours) with calibration using physical bedload samples (e.g. Barton *et al.* 2008) or they can be used as stand-alone measurements to detect the threshold of mobilization and cessation of coarse bed material movement (e.g. Gendaszek *et al.* 2012).

Stereo hydrophones have significant advantages over individual hydrophone deployments (Marineau *et al.* 2012). One problem with singly-deployed hydrophones is that the distance between the sound source (e.g. a bedload particle in motion) and the hydrophone is not known. This creates uncertainty with the measured sound levels and inferred sediment transport rates (e.g. similar sound records are produced by close small rocks and distant large rocks). In contrast to single deployments, stereo hydrophones have the ability to pick up individual large sound peaks (e.g. rock impacts) at low bedload transport rates and can be more precisely calibrated to bedload transport rates (Marineau *et al.* 2012). With the addition of a second hydrophone station and one or two more hydrophones (i.e. 3 to 4 total hydrophones), individual sound peaks can be geo-located and spatially mapped over time (Marineau, unpublished data). This type of mapping potentially would be useful for determining specific habitat features (e.g. riffle tops, pools, or glides) that are affected by particular flows.

Significance to San Joaquin River Restoration Program

For the ~61 km long gravel-bedded portion of the San Joaquin River downstream of Friant Dam (Reaches 1A and 1B), hydrophone stations would significantly improve the temporal resolution of bedload transport estimates and would advance the objectives of the San Joaquin River Restoration Program (SJRRP). Of the four sampling stations located in this reach, three have regular sampling schedules that collect 8-10 bedload samples per year (Highway 41, Skaggs Bridge, and Gravelly Ford), and one has an irregular schedule that is sampled during high flows (Ledger Island) (SJRRP 2011). However, there are many more features of the release hydrograph that are not sampled (e.g. flow changes, ramping rates, and benches) which managers would like specifically related to bedload response. These four sampling sites would be good sites for co-located and calibrated hydrophone stations, which would greatly improve the temporal resolution of the bedload data and would then enable restoration managers to link flow releases to bedload response more directly.

There are several additional reasons for using hydrophones to increase the temporal resolution of bedload data in Reaches 1A and 1B. Much of the bedload sediment transport in these reaches occurs at relatively low transport rates (USGS 2012), which are difficult to sample with traditional physical sampling methods or to calculate with bedload transport formulae. Relatively small flows on the San Joaquin River have demonstrated the ability to move coarse bedload sediment but this effect is not consistent across all flows, nor is the transport rate similar across all flows. As an illustration, at the Highway 41 USGS bedload gaging site, bedload transport samples contained grain sizes up to 32 mm during a 17 $m^3 s^{-1}$ (600 $ft^3 s^{-1}$) event, but later samples at more than twice the discharge only contained grains less than 8 mm (USGS 2012) and had a smaller bedload transport rate than the smaller flow (3000 kg d^{-1} compared to 3400 kg d^{-1}) (USGS 2012). Additional transport data from bedload sampling at Ledger Island collected during high discharge events in WY2011 indicates that even for this relatively low-slope site, large particles (up to 115 mm) can be transported, though at relatively low transport rates (SJRRP 2011). Gravel tracer data from two riffles in Reach 1A also show significant mobilization even at low flows, with large differences between heads and tails of riffles, with the heads of riffles only being mobilized during the largest flows in WY2011 (SJRRP 2011). All of the above factors suggest that hydrophones, with their ability to provide increased temporal resolution and possibly spatial resolution of bedload data, would be a valuable addition to the objectives of the SJRRP.

Objectives

The objective of this study is to evaluate the use of hydrophone stations for estimating coarse bedload sediment transport dynamics at high temporal resolutions (e.g. hourly or finer) on the mainstem San Joaquin River downstream of Friant Dam for water years 2013 and 2014. Three separate types of installations will be evaluated: two stereo hydrophone installations and one ‘Quadraphone’ (double stereo) installation co-located at existing bedload sampling locations for measuring coarse bedload transport rates, and two stereo hydrophone installations located at riffle sites for estimating thresholds of coarse bedload mobilization and cessation. Each type of hydrophone installation will be evaluated for its accuracy in estimating coarse bedload transport rates and bed mobilization using data collected by other studies funded by the SJRRP. In particular, the hydrophone data will be evaluated for the ability to ‘tune’ the hydrophone response to the relative low rates and low bedload grain sizes present on the San Joaquin River. In addition, the ‘Quadraphone’ installation will be assessed for the potential to spatially locate bedload movement within the stream, using calibrated time-of-travel techniques.

Methods

Three stereo hydrophone stations and one ‘Quadraphone’ station (a double stereo hydrophone) will be installed on the mainstem San Joaquin, as well as one stereo hydrophone station on Little Dry Creek, a major tributary. One of the mainstem stereo hydrophone stations and the ‘Quadraphone’ station will be co-located with existing bedload sampling operations, with one station at the Highway 41 gage, and another station at either the Skaggs Bridge gage or at the Ledger Island bedload sampling site (the site of occasional high-flow coarse bedload sampling). Locating the second hydrophone site in close proximity to Friant Dam would be preferred, at a site such as Ledger Island, due to the importance of this reach for salmon spawning and because of the potential for collecting bedload data that will be useful for future planned gravel augmentation projects.

One stereo hydrophone station will be installed on Little Dry Creek, the major tributary to the San Joaquin River that enters the river ~11 km downstream of Friant Dam. Little Dry Creek has no water for the majority of the year but when floods occur, there is a high likelihood of transporting large volumes of coarse bedload towards the mainstem San Joaquin River. The bedload data for calibration of the Little Dry Creek hydrophone station will be provided from an existing tributary sediment study by the authors that will be active through WY2013. If necessary, additional bedload sampling will be collected on Little Dry Creek in WY2014 to calibrate the hydrophones as part of the present proposal.

In addition to the stereo hydrophone stations co-located with bedload sampling sites, two stereo hydrophone stations will be installed at important riffles to evaluate the estimation of the threshold of motion for coarse bedload particles as well as cessation of transport. Most likely the two riffles chosen will be Riffle Cluster 38 and Riffle Cluster 40 due to the prevalence of existing sediment data at those sites that could be used for comparison (SJRRP 2011). Other sites would be possibilities if requested by the SJRRP staff.

Figure 1a,b. Hydrophone installation on the Cedar River, Washington. a.) interior of the installation enclosure showing the digital timer, computer, geophone battery and charger; b.) location of the hydrophone installation (the pipe containing the cable to the hydrophone receiver is underground). Photo by M. Marineau (2/2011).

Two Geospace model MP-18 hydrophones will be installed at each stereo hydrophone station (Figure 1a,b), with the two hydrophones preferably installed within ~15 m of each other. The ‘Quadraphone’ will consist of two stereo stations located ~20 m apart and on opposite sides of the river. The Geospace hydrophone model has been shown by Barton (2006) and Marineau *et al.* (2012) to be capable of detecting coarse bedload movement up to 15-20 m from the hydrophone, which is a distance approximately the width of the low flow channel in the gravel-bedded portion of the San Joaquin River. The audio signal will be routed through a pre-amplifier and then to an energy efficient computer which will digitally store the audio data. To reduce battery consumption and extend deployment times, a digital timer will be used to limit computer on-time to five minutes per hour. The total equipment and materials cost of one stereo hydrophone station is approximately $1,600. Table 1 provides an itemized list of the equipment and materials used to build and install one such station.

The audio data will be processed using methods developed previously by Marineau *et al.* (2012). The acoustic signals will be first transformed to the frequency domain using a fast Fourier transform (FFT). The values of acoustic intensity will then be averaged between a range of frequencies. Collisions of gravel- and cobble-sized (up to 120 mm) bed particles have been shown to produce audio waves with frequencies between 600 and 3,700 Hz (Belluedy *et al.* 2010). The mean acoustic intensity will be calculated between these frequencies, measured in decibels (dB) and used as an indicator of bedload. Where physical bedload samples are collected, the mean acoustic intensity will be calibrated using the measured bedload transport rates. If sites are located where physical bedload samples are not collected (e.g. riffle sites), the audio data will be used to qualitatively assess if coarse bedload movement occurred and will be used to identify the timing of the start and stop of bedload movement.

To assess the possibility of using the 'Quadraphone' station to geo-spatially locate bedload movement, the location of each hydrophone receiver will be surveyed by RTK GPS or total station to determine its coordinate location. In addition, a general survey of the nearby bed topography will be performed. To calibrate the timing of the hydrophones relative to the spatial location, a pipe or other sound-generator (e.g. artificial rock impacts) will be used with time-of-travel techniques to calculate the possible geo-spatial location of the sound source (following Marineau *et al.* 2012). Using time-of-travel techniques to determine spatial location of energy sources have been well developed in the geologic literature for seismography and near-surface tomography with numerous textbooks and articles on the subject (e.g. Shearer 2009, Trifu 2010). Time-of-travel techniques using hydrophones also have been used to track fish in three dimensions (e.g. Goodwin *et al.* 2006)

Anticipated Results

We anticipate that we will be able to provide coarse bedload transport rates at high-temporal resolution of (e.g. hourly or finer) for the San Joaquin River at the hydrophone sites co-located with the existing bedload sampling locations, as well as parameters that will tune the hydrophones specifically for the San Joaquin River. In addition, we will be able to provide data on mobilization and cessation at the riffle sites as well as the hydrophone parameters most applicable to the San Joaquin. For the spatial location of the occurrence of bedload transport using individual rock impacts, we are hopeful that we will be able to locate the impacts, though it should be noted that the geo-spatial location method is an experimental method that may not produce useful results. However, even if the geo-spatial bedload location technique does not work, the hydrophone station still can be used for quantifying bedload movement similar to the other hydrophone installations.

Deliverables

The results of this study will be prepared as a peer-reviewed journal article for submission to a relevant geomorphology journal. The results also will be presented at a national science conference, such as the American Geophysical Union Fall Meeting in San Francisco. In addition, we anticipate one or more presentations of the results to the San Joaquin River Restoration Program Sediment Working Group or other SJRRP groups.

Budget

The estimated budget for this project over WY2013 and WY2014 is tabulated in Tables 1 and 2.

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Table 1. Itemized cost estimate for one stereo hydrophone station				
Item	**Qty**	**Unit Price**	**Cost**	**Details**
Hydrophones	2	$ 125.00	$ 250.00	Geophone model MP-18-200
Computer	1	$ 213.00	$ 213.00	ASUS Eee Box B202
RAM card	1	$ 39.00	$ 39.00	2GB RAM, CDW #967338
Audio preamplifier	1	$ 99.00	$ 99.00	USB Duo (2-channel) Preamplifier
SD Card for OS and data	1	$ 47.00	$ 47.00	16GB SD Card, CDW #1780355
Programmable 12V Timer	1	$ 89.00	$ 89.00	Brazix #SKU: 053-082BR-15A
Flexible conduit (100' roll)	1	$ 100.00	$ 100.00	Used to protect audio cables
12V deep cycle batteries	2	$ 153.00	$ 306.00	1 at site, and 1 backup
Misc wiring	2	$ 20.00	$ 40.00	Audio conn., wire, etc.
PVC piping	2	$ 20.00	$ 40.00	PVC pipe, end caps
Cement and rebar	1	$ 80.00	$ 80.00	To secure hydrophone near bed
Metal box	1	$ 150.00	$ 150.00	House computer and battery
Desiccant packs	1	$ 21.00	$ 21.00	4-pack of 40 gm desiccant silica gel
Subtotal			*$ 1,474.00*	
Shipping and handling, approx.			$ 150.00	
Total Direct Costs			***$ 1,624.00***	

Table 2. Proposed Budget for U.S.G.S. Hydrophone Study on San Joaquin River, WY2013 and WY2014.

Item	Qty	Unit Price	Cost	Details
Equipment costs				
Stereo hydrophone stations	6	$ 1,624.00	$ 9,744.00	4 x stereo hydrophones, 1 x ‘Quadraphone’
Backup hydrophone equipment, field gear and survey DGPS rental	1 (x2 years)	$ 1,050.00	$ 2,100.00	Equipment for repair, field tools and RTK GPS rental
Indirect costs	na	na	$ 10,281.00	Overhead
Travel costs				
Per diem, lodging	3 x 2-day trips; 4 x 1-day trips (x2 years)	2-day trip (2 people) = $710; 1-day trip (2 people) = $122	$ 5,236.00	Travel to install, survey and maintain hydrophone stations
Fuel	7 trips per year (x2 years)	$95 / trip	$ 1,330.00	Fuel
Indirect travel costs	na	na	$5,699.00	Overhead

Table 2 continued on next page.

Table 2. (continued)				
Item	**Qty**	**Unit Price**	**Cost**	**Details**
Labor				
Hydrologist (Marineau)	240 hours (x2 years)		$ 23,773.00	
Research Hydrologist (Minear)	80 hours (x2 years)		$ 9,505.00	
Research Hydrologist (Wright)	40 hours (x2 years)		$ 5,816.00	
Field Tech	80 hours (x2 years)		$ 9,587.00	
Indirect Costs	na	na	$ 42,254.00	Overhead
Conference and Publishing Costs				
Publishing costs	20 page article	$80.00 / page	$1,600.00	Average publishing cost at a peer-reviewed journal
Conference registration, travel, per diem, lodging	1 person attending	$ 1,300.00	$ 1,300.00	Attendance at AGU fall meeting in San Francisco
Indirect Costs	na	na	$ 2,478.00	Overhead
Total Direct Costs			$ 69,991.00	
Total Indirect Costs			$ 60,712.00	
Total Cost			**$ 130,703.00**	