Study 18

Continuous Surrogate Measurement of Bedload Sediment Transport Using Hydrophone Installations on the San Joaquin River

Final
2015 Monitoring and Analysis Plan

SAN JOAQUIN RIVER RESTORATION PROGRAM

January 2015

1.0 Continuous Surrogate Measurement of Bedload Sediment Transport Using Hydrophone Installations on the San Joaquin River

Theme(s):
Spawning and incubation
Related Question(s):

- SI-001d: Are gravel surfaces in Reach 1 capable of being mobilized, or are they sufficiently reinforced or embedded, in such a way that a loose and permeable stream bed is insufficient for spawning habitat?
- SI-003b: Is gravel recruitment sufficient for spawning habitat in Reach 1A?
- SI-008: If new spawning habitat is created, or existing spawning habitat rehabilitated, will future sand (fine bedload) quickly infiltrate spawning habitat and reduce the quality (longevity) of spawning habitat? How frequently would gravel improvements be needed?
- SI-015: What are the bed transport rates at various flows? How would this change with the addition of new spawning habitat or rehabilitation of existing habitat? How would you schedule gravel augmentation with different flows and quantities of gravel in the system?
- SI-015a: Is Cottonwood Creek supplying useful spawning gravels to Reach 1?
- SI-015c: At what flows do spawning gravels begin to mobilize in riffles in Reach 1?
- SI-015d: What is the gravel transport rate out of Reach 1?

1.1 Statement of Need

The Fisheries Management Plan (SJRRP, 2010) identifies spawning and incubation as a life stage to be supported for the successful completion of the salmon life cycle. The Spawning and Incubation Small Interdisciplinary Group convened in 2013 and developed several technical questions (and related data gaps) related to restoration activities and management for the spawning and incubation life stage. The primary goal of this study is to collect high temporal resolution sediment transport data which will be used to answer some of these questions. Specifically, the data collected would be used to identify the timing of incipient motion and cessation of gravel mobilization and provide surrogate bedload data, which when calibrated to physical samples, may be used to improve sediment transport estimates.

1.2 Background

Traditional methods for measuring coarse bedload sediment transport by discrete physical sampling tend to be 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 augment discrete physical sampling programs and have 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 may be used to quantify bedload transport rates at high temporal resolution (e.g., minutes to hours) with calibration using physical bedload samples (e.g., Barton et al. 2008) or they may be used as stand-alone measurements to detect the threshold of mobilization and cessation of coarse bed material movement.

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 recordings may be produced by near low-energy impacts and distant high-energy impacts). 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. With the addition of a second hydrophone station and one or two more hydrophones (i.e. 3 to 4 total hydrophones), it may be possible to geo-locate individual sound peaks and spatially map them over time. 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.

Photo by A Powell (12/2013).
Figure 1. Hydrophone Installation on the San Joaquin River (A), Close-up View of Submerged Hydrophone Mounted Near Bank (B)

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, 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 specific knowledge related to bedload response. These three 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 Water Year (WY) 2011 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 2015-17. Three separate types of installations will be evaluated: three stereo hydrophone and one 'Quadraphone' (double stereo) installation co-located at existing bedload sampling locations for measuring coarse bedload transport rates, and three stereo hydrophone and one 'Quadraphone' installation 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.

1.3 Anticipated Outcomes

The study will result in following outcomes:

- Surrogate sediment data for coarse bedload transport which may be calibrated to physical bedload samples. This data would be used to improve transport estimates.

- Identify the timing of incipient motion and cessation of gravel at the riffle sites.

1.4 Methods

Type of Study: field

Reach(es): Reach 1A

Methods

A total of ten hydrophone stations will be deployed for water years 2015 through 2017. Eight of those stations will be installed at six sites along the San Joaquin River (in Reaches 1A) and the remaining two stations will be installed on the two tributaries (Cottonwood Creek and Little Dry Creek) of the San Joaquin River. Of these ten hydrophone stations, five will be calibrated to physical bedload samples (assuming samples will be collected by the USGS and DWR under separate scopes of work) and the other five will be uncalibrated. The calibrated hydrophone installations will be used to quantify sediment transport rates and to estimate bed mobilization and cessation. The un-calibrated hydrophones will be used to estimate bed mobilization and cessation and provide a qualitative estimate of bedload transport.

The calibrated stereo (more than one head) hydrophone installations will be located on the mainstem San Joaquin River at existing USGS and DWR bedload measurement sites: Highway 41, Skaggs Bridge, Lost Lake, and Riffle 38. Though Skaggs Bridge is outside the primary reach of interest, it is a gravel-bedded site and it is the next closest physical bedload sampling site, which will be needed for testing purposes. Previously, one of these sites (Riffle 38) was the focus of a SJRRP mobilization study using painted rocks and radio transmitters (SJRRP 2011). The results from this study may provide some additional corroborating information about incipient motion for various grain sizes.

In addition to the calibrated stereo hydrophone stations, uncalibrated stereo hydrophone stations will be installed at two locations (Riffle 40 and Owl Hollow) on the San Joaquin River to estimate of the threshold of mobilization for coarse bedload particles as well as cessation of transport. Two uncalibrated stereo hydrophone installations will also be located on the two major tributaries: Cottonwood Creek and Little Dry Creek. During flooding, these ephemeral creeks have the potential to transport large volumes of coarse bedload into the mainstem San Joaquin River. An existing tributary sediment study may provide some bedload sediment samples which can be used to calibrate the hydrophone data collected at these two tributary sites.

The following is a summary of the planned hydrophone installation locations (these are also shown in the map on Figure 1):

1. Calibrated, stereo installation at Lost Lake, co-located with DWR bedload monitoring site
2. Uncalibrated, quadraphone (4 heads) installation at Riffle 40
3. Calibrated, stereo installation at Riffle 38, co-located with DWR bedload monitoring site
4. Uncalibrated, stereo installation at Owl Hollow
5. Calibrated, quadraphone installation at Hwy 41 Bridge, co-located with USGS bedload monitoring site
6. Calibrated, stereo installation at Skaggs Bridge (Hwy 145), co-located with USGS bedload monitoring site
7. Uncalibrated, stereo installation at Cottonwood Creek, co-located with USGS Tributary Sediment Monitoring Study
8. Uncalibrated, stereo installation at Little Dry Creek, co-located with USGS Tributary Sediment Monitoring Study

Most of the hydrophone stations will be stereo hydrophone installations (two recording heads) to help minimize potential issues with head placement and the proximity to zones of bedload movement. The two remaining installations will be “Quadraphone” stations, consisting of two stereo hydrophone installations (e.g., two x two recording heads) on each bank of the river to investigate spatial variability of bedload transport and the potential to geo-spatially locate bedload movement.

Two Aquarian model H2a 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 Aquarian hydrophone was field tested alongside another type which was used previously by Barton (2006) and Marineau et al. (2012). The detection distance is also unknown and there is some evidence that it increases with increasing flow depths (Marineau, unpublished data). The audio signal will be routed through a pre-amplifier and then to a computer which will digitally store the audio data.

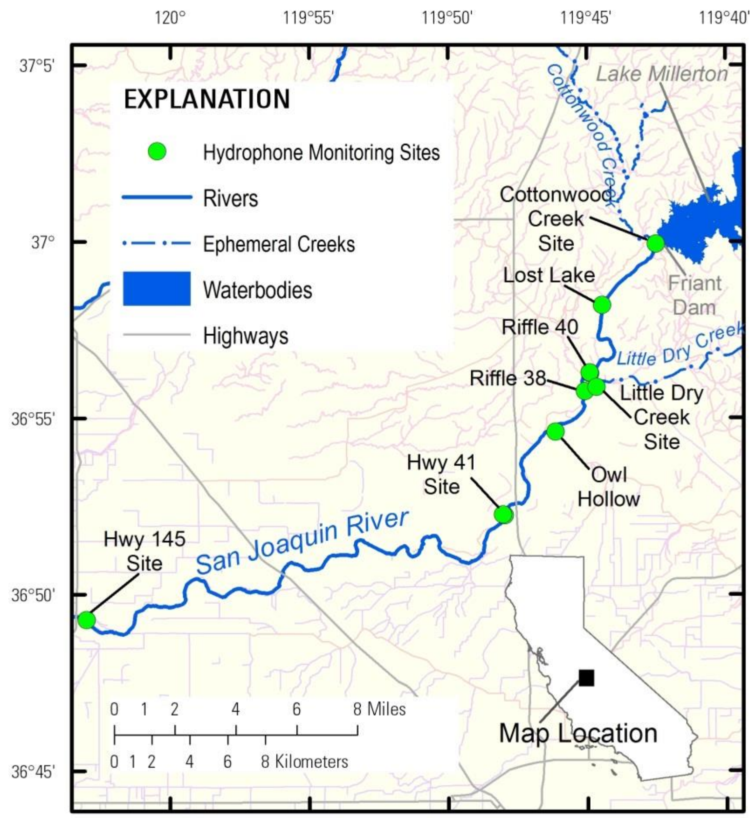

Figure 2. Map Showing Locations of Planned Hydrophone Installations

The audio data will be processed using methods developed previously by Marineau et al. (2012). 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. 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 (Belleudy 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.

Deliverables and Schedule

Field work is anticipated to take place each water year from October until May to June (depending on the exact timing of reservoir releases). Sites will be serviced monthly. Data will be processed at the end of each field season. Deliverables will include preliminary data series for calibrated sites along with a final report with methods, results and interpretations:

1. Preliminary estimates on the timing of the start and stop of coarse bedload. Anticipated delivery date will be summer or fall, depending on the end of any reservoir releases or high-flow events.

2. Preliminary acoustic data, calibrated to physical samples of bedload (pending the collection of physical samples by the USGS and DWR under separate scopes of work). Anticipated delivery date will be dependent on the processing and release of any bedload samples collected.

3. Final report (USGS or journal article) will be prepared documenting the results following the third year of the field study.

1.5 Budget

The total cost estimate is $136,058 for 2015.

Table 1-1. Proposed 2015 Budget

Task	Cost
Labor	$57,767
Travel	$4,735
Equipment and Supplies	$11,200
Subtotal	$73,702
Overhead	$62,356
Total	$136,058

1.6 Point of Contact / Agency Principal Investigator

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1.7 References

Barton, J.S., 2006, Passive acoustic monitoring of coarse bedload in mountain streams." University Park, Pennsylvania State University PhD Dissertation, 107p.

Barton, J.S., Slingerland, R.L., Pittman, S., and Gabrielson, T.B., 2010, Monitoring coarse bedload transport with passive acoustic instrumentation: A field study." in Gray, J. R., Laronne, J. B., and Marr, J. D. G., Bedload-surrogate monitoring technologies: U.S. Geological Survey Scientific Investigations Report 2010-5091.

Batalla, R.J., 1997, Evaluating bed-material transport equations using field measurements in a sandy gravel-bed stream, Arbucies River, NE Spain. Earth Surface Processes and Landforms 22, 121-130.

Belleudy, P., Valette, A., and Graff, B., 2010, Passive hydrophone monitoring of bedload in river beds: First trials of signal spectral analysis. in Gray, J. R., Laronne, J. B., and Marr, J. D. G., Bedload-surrogate monitoring technologies: U.S. Geological Survey Scientific Investigations Report 2010-5091.

Gomez, B., Naff, R.L., and Hubbell, D.W., 1989, Temporal variations in bedload transport rates associated with the migration of bedforms. Earth Surface Processes and Landforms 14, 135-156.

Gray, J.R., Laronne, J.D., and Marr, J.D.G., 2010, Bedload-surrogate monitoring technologies. U.S. Geological Survey Scientific Investigations Report 2010-5091, 37p.

Marineau, M.D., Gendaszek, A.S., Magirl, C.S., Czuba, C.R., and Czuba, J.S., 2012, Surrogate bedload monitoring using hydrophones in the gravel-bedded Cedar River, Washington. In Proceedings of the ASCE Hydraulic Measurements and Methods conference, Snowbird, Utah, USA, August 13-15, 2012.

San Joaquin River Restoration Program (SJRRP), 2010, Fisheries Management Plan: A Framework for Adaptive Management in the San Joaquin River Restoration Program. November.

San Joaquin River Restoration Program, 2011, Annual Technical Report. Available at www.restoresjr.net

United States Geological Survey, 2012, National Water Information System (NWIS), accessed 6/2012, waterdata.usgs.gov/nwis.

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