Utilizing Hydrophones to Detect Streambed Mobilization in the Wild and Scenic Reach of the Rio Chama

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Introduction

The Rio Chama between El Vado Dam and Abiquiu Dam in northern New Mexico was designated a Wild and Scenic River in 1988 (Senate Bill 850 1988). The Rio Chama receives a substantial amount of fine sand, silt, and clay sediments supplied by reservoir releases, arroyo tributary streamflows, and bank erosion. Fine sediment deposits onto the gravel-cobble (i.e., coarse) bed material and fills the interstitial spaces within the gravel streambed. This sediment load may adversely impact the suitability of spawning habitat of brown trout (*Salmo trutta*), a target management species in the designation of the Wild and Scenic reach (BLM 1992).

Bureau of Reclamation (Reclamation) periodically releases high streamflow pulses, or flushing flows, from El Vado Dam for environmental enhancement purposes. One such purpose is clearing fine sediment from the coarse gravel-cobble streambed to maintain spawning habitat for brown trout and their macroinvertebrate food base. The threshold for the mobilization of fine sediments along with coarser sediments is called incipient motion. Incipient motion is said to begin when a streamflow has enough energy to mobilize the median grain size (the D_{50}) in the streambed (Gregory 2013). Mobilization of the streambed is necessary to remove fine sediments on top of the gravels and in the interstitial spaces of the coarse gravel-cobble streambed.

The Rio Chama receives a combination of native water and inter-basin transfer water from the San Juan-Chama Project. Because of climate change, the Rio Chama is projected to see native water streamflows decrease by one-third and inter-basin transfer streamflows decrease by one-quarter over the next century (Reclamation 2013). With less water available in the basin in the future for flushing flows, it is necessary to better understand what streamflow rates are needed to trigger incipient motion. This knowledge would assist water managers in planning effective flushing flows.

A recent research effort on incipient motion in this reach of the Rio Chama was conducted by researchers at the University of New Mexico (UNM) using Reclamation's Sedimentation and River Hydraulics-Two Dimension (Reclamation 2020) to develop a 2D hydrodynamic model (Gregory et al. 2018). The study found that streamflows at 56 cubic meters per second (m^3/s), which is ~1,980 cubic feet per second (ft^3/s), would mobilize fine sediments (classified as sediments less than 4.76 mm in diameter), and streamflows above 100 m^3/s (~3,530 ft^3/s) would cause "extensive" flushing of fine sediments.

Previous research has shown hydrophones to be a viable method to passively monitor sediment transport (e.g., Geay et al. 2017; Marineau et al. 2019) and potentially as a method to identify incipient motion (Kohn et al. 2020). Because incipient motion is a threshold event, the hydrophone recordings can capture the transition from a "quiet" stream prior to incipient motion versus a "loud" stream during streambed mobilization. Correlating these transitions to changes in bedload transport rate in the river would indicate what streamflow rates initiate sediment transport. The goal of our study is to expand the applicability of underwater acoustic sensors, or hydrophones, to the Wild and Scenic reach of the Rio Chama to test their capabilities in this hydrologic system and potentially develop long-term sediment mobilization monitoring methodology.

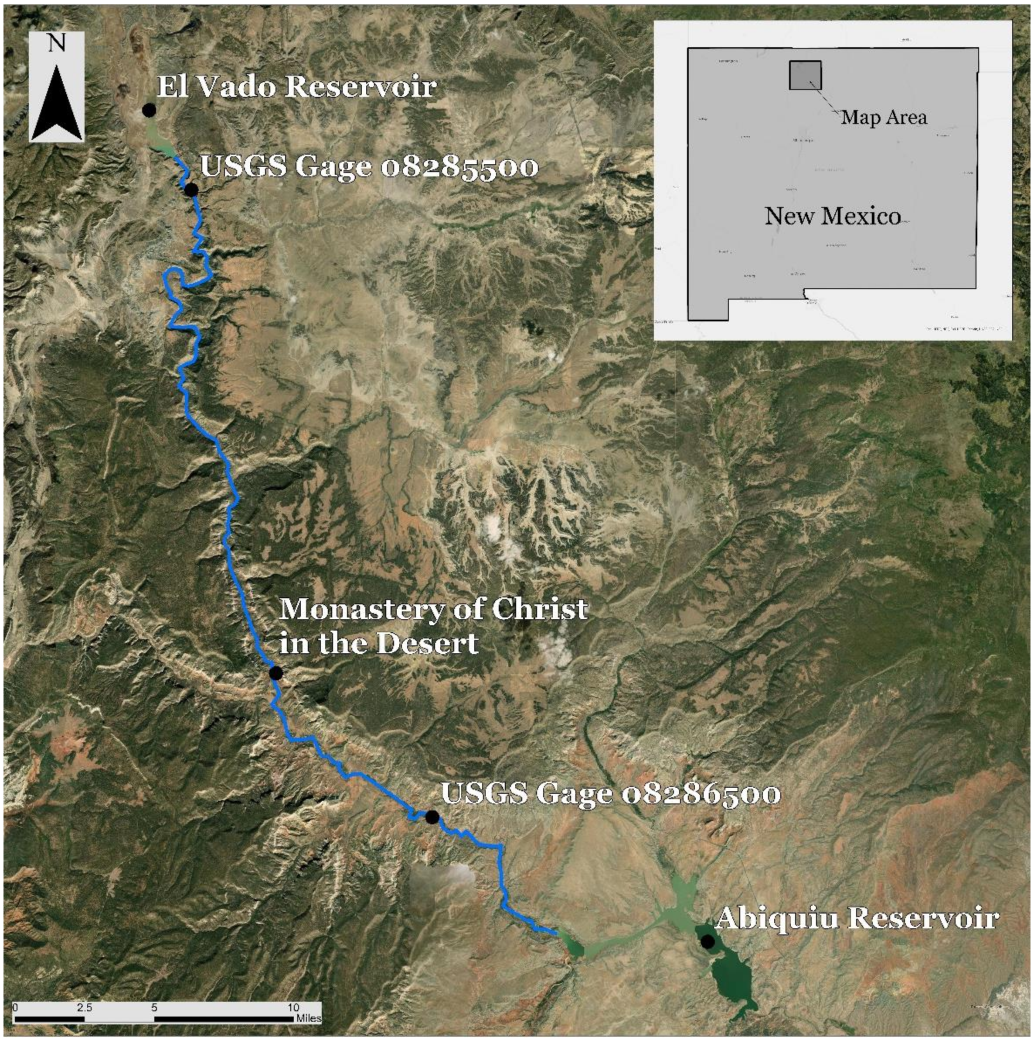

Figure 1. Map of the Wild and Scenic Rio Chama in northern New Mexico (U.S. Geological Survey 2023; Maxar Technologies 2020)

Data Collection

A major consideration of the feasibility of this project was ease of access to the study reach. The hydrophone equipment would require regular visits to replace batteries and download data, which means the site would need to be accessible via roadway. Roadway access to the Wild and Scenic reach of the Rio Chama is limited because the river runs through a canyon for much of its length. The issue of cow trespass also eliminated one potential site because cows crossing the river could damage the hydrophone equipment. Ultimately, the Monastery of Christ in the Desert (Monastery) (Figure 1) was selected as the project site because of relative ease of access, minimal chance of animal or human disturbance to the equipment, and the Monastery’s willingness to provide assistance for the project.

Two hydrophone stations were installed at the Monastery for two data-collection periods, April through December 2021 and April through October 2022. Both the hydrophone stations were installed on the left (east) bank of the Rio Chama near a gravel bar (Figure 2) just upstream of the Rio Gallina. This location was chosen because the gravel signified that there were coarse grains in this area that could potentially be mobilized during a high streamflow event. Several pebble counts were taken around the gravel bar throughout the data-collection period. The D_{50} ranged between 8 and 22.6 mm and the D_{90} between 22.6 and 128 mm. The hydrophone stations were about 40-50 feet apart; the upstream station is referred to herein as BEDE01 and the downstream station as BEDE02.

Figure 2. Gravel bar at hydrophone monitoring site, photograph taken by Rebecca Braz, 2021

Each station consisted of two Aquarian H2a-XLR hydrophones, one installed on the streambed to be submerged continuously (referred to as the "lower hydrophone") and the other installed halfway up the bank (referred to as the "upper hydrophone") as a backup if the lower hydrophone became buried during high streamflows. Each hydrophone was mounted to a piece of rebar that was driven into the streambed; the hydrophones were placed so that they were pointing toward the middle of the river, with the hydrophone heads located approximately 25 cm above the streambed or bank. Another piece of rebar was driven at an angle just upstream of the hydrophone to limit debris catching on the hydrophone. The hydrophones converted sound pressure waves into an analog electrical signal, which was digitized using an Art Technologies Art Dual USB preamplifier. The digital signal was stored in 1-minute .wav files at 44.1 kHz using a Raspberry Pi computer. The audio recordings were made at a 15-minute sampling interval to correspond to the recording interval of streamgages in the study reach.

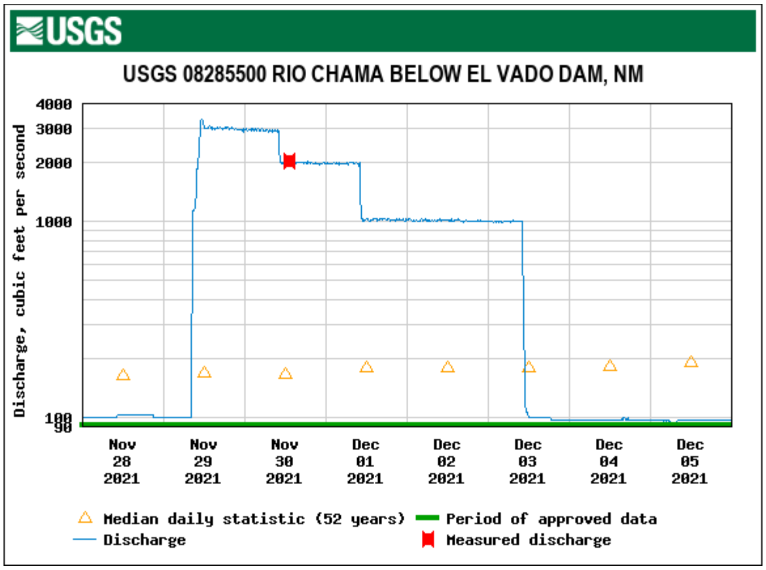

Figure 3. Hydrograph at U.S. Geological Survey streamgage 08285500 (Rio Chama Below El Vado Dam, NM; U.S. Geological Survey, 2023) during the 2021 high streamflow pulse release

Both data-collection periods included relatively low streamflows (approximately 100 ft^3/s), but in late November through early December 2021, a high streamflow pulse was released from El Vado Dam. A peak streamflow of 94.9 m^3/s (3,350 ft^3/s) was measured (Figure 3), which was approximately equal to the streamflow rate predicted to cause extensive flushing of fine sediment (Gregory et al. 2018). Thus far, data processing has focused on the audio recording taken during the November-December 2021 high streamflow pulse because the other time periods did not have streamflows expected to have moved coarse sediment.

Data Processing

Audio data files were first processed in MATLAB using a similar methodology described in Marineau et al. (2017). Each 1-minute audio file is processed using a Fast Fourier Transform to determine the sound level, in micropascals, between 0 and 22.05 kHz. Then the mean value was calculated between 2-10 kHz, which has been found to correspond with sounds generated by the collisions of gravel and cobbles (Gaey et al. 2017). The underwater sound spectrum below 1 kHz often contains streamflow or turbulence noise which is unrelated to bedload or mixed with sediment-generated noise (SGN) (Gaey et al. 2017); therefore, 2 kHz was selected as the lower cutoff frequency. Figure 4 shows example power spectral density plots produced from recordings at different streamflows in a previous study on the gravel-bedded Trinity River (Marineau et al. 2019). The example in Figure 4 shows the changes in sound levels primarily occur below 10 kHz at all ranges of bedload transport.

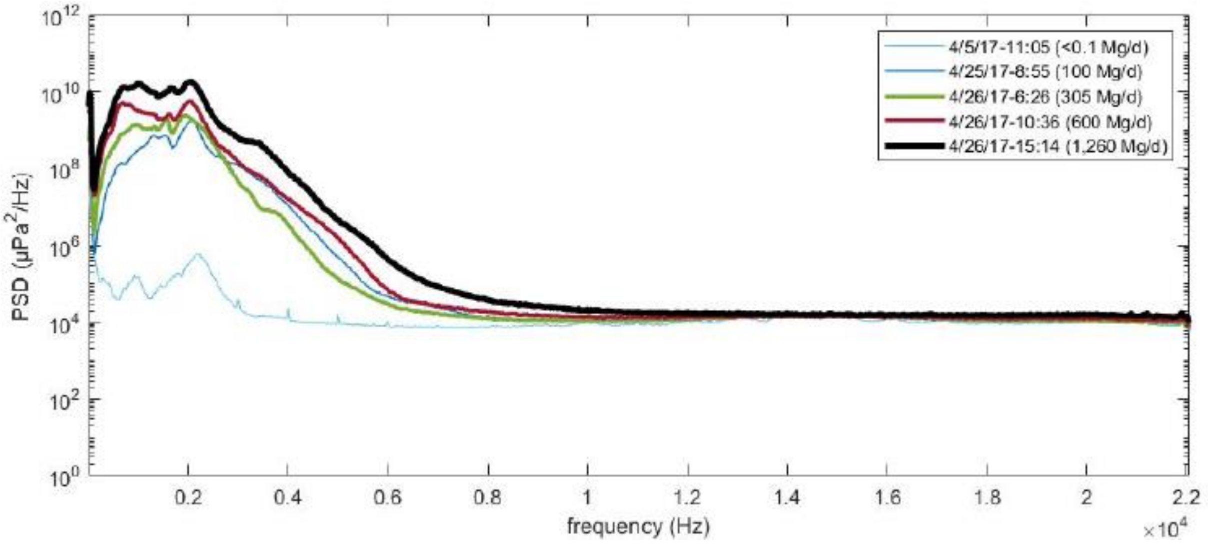

Figure 4. Examples of power spectral density (PSD) estimates under different streamflow and bedload transport conditions from a previous study on the Trinity River (Marineau et al. 2019)

The second processing method was to identify incipient motion using an automated method of audibly “counting” the impacts of gravels and cobbles by identifying sounds which exceed a background threshold level. Several selected audio recordings were also aurally reviewed to confirm presence or absence of sounds thought to be sediment-generated noise. The method of counting impact sound which exceed a background level was proposed by Belleudy et al. (2010). A preliminary sound level threshold was determined from the entire set of audio files and was calculated by determining the 25th percentile of the values in the digital .wav files for the entire time series. Digital .wav files stored audio data as 16-bit signed data on a scale of –1 to 1. For this analysis, absolute values were used. These data and the threshold value could be converted to decibels, but the purpose was to determine when a threshold is exceeded.

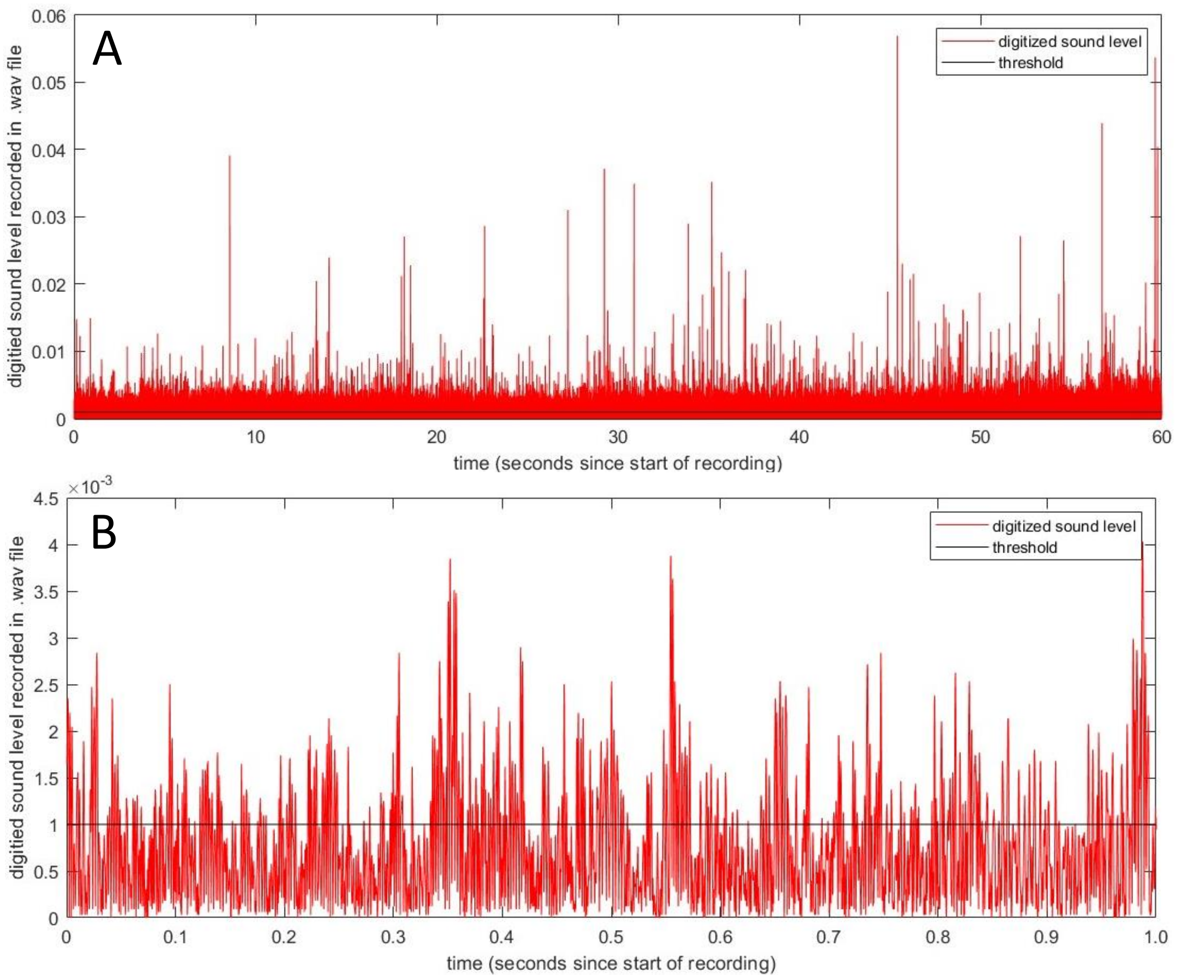

Figure 5. Plots of digitized audio recording (from .wav file) from 11/30/2021 at 12:45 (Mountain Standard Time) at BEDE01 near peak of sediment-generated noise (SGN). 'A'-plot shows full 1-minute recording, 'B'-plot shows a closeup of the first second. A threshold is also shown overlaid on the time series.

Figures 5 and 6 show two examples of plots of the digital sounds for two different .wav files collected from the Rio Chama hydrophone site. The first (Figure 5) corresponds to one of the noisiest recordings, which would likely indicate the highest bedload transport rates of the November-December 2021 event. The second (Figure 6) is from a quieter period after the recession of the high streamflow. The purpose of showing these figures was to illustrate the extent to which sound levels exceed the threshold value. The next step in the processing was to count how many times the sound level exceeded the threshold in each of the 1-minute audio recordings for the entire dataset. The "counts" were assumed related to particle impacts that are detected in the area around the hydrophone. The "count" number was then plotted on a new time series (Figure 7).

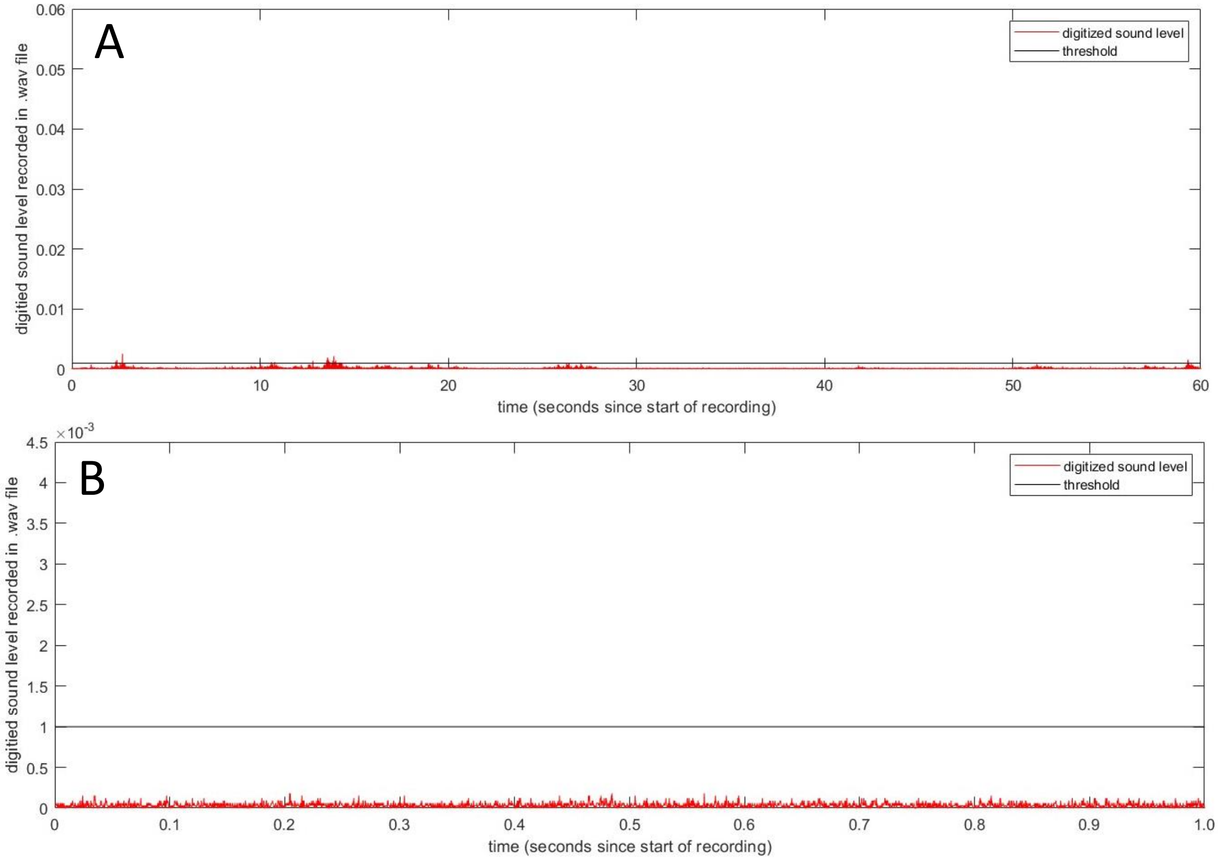

Figure 6. Similar plots as figure 5, but from a low-streamflow (quiet) period, with little or no detectable sediment-generated noise. The same threshold is used through the entire time series for a plot. The 'A'-plot is a 1-minute recording collected on 12/30/2021 at 9:00 (Mountain Standard Time), the 'B'-plot is from the same recording but is a closeup of the first second of that recording.

Preliminary results

Audio recordings were successfully collected using hydrophones for approximately 8.5 days during the November-December 2021 streamflow releases. Figure 7 shows a time series of SGN for one of the hydrophone-recording stations. Several recordings were aurally reviewed to confirm that the sounds are consistent with SGN recordings collected in other studies, such as the Trinity River, though overall sound level was lower (i.e., quieter). The SGN levels (Figure 7) would suggest that some coarse sediment transport occurred during the high flow pulse, which peaked at 3,350 ft^3/s. Similar transport of coarse sediment during a high flow pulse was observed in the UNM study (Gregory et al. 2018), which modeled that "extensive" flushing would occur at flows greater than 3,530 ft^3/s. Figure 8 shows counts per 1-minue audio period, with counts referring to the number of times per minute that the sounds exceeded the sound threshold defined earlier. Larger "count" numbers would indicate more gravel and cobble collisions were occurring. The "lower" hydrophone was closer to the bed, while the upper hydrophone was located farther up the bank and was likely not fully submerged during the entire reservoir release event.

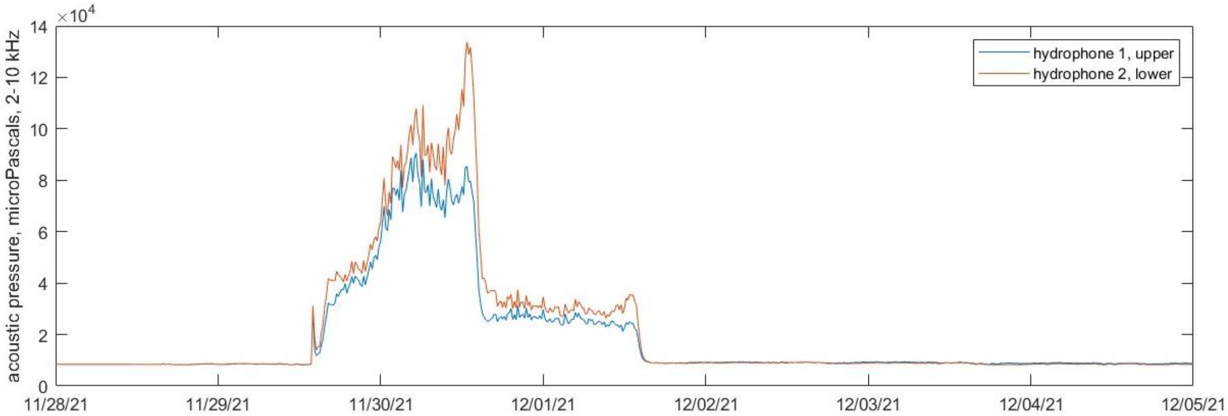

Figure 7. Time series of sediment-generated noise (SGN) between 2-10 kHz at the hydrophone study site for the Rio Chama, New Mexico

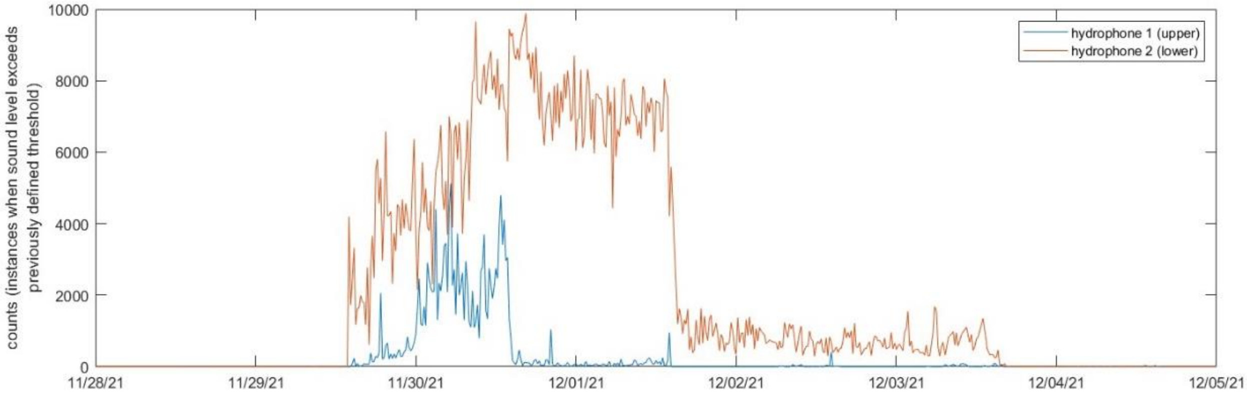

Figure 8. Time series of "counts" when sound level exceeded the previously defined threshold. This is used as an indicator of how many particle impacts are detected near the hydrophone in each 1-minute audio recording.

Discussion and Ongoing Work

There are spatial limitations to the applicability of these conclusions because only one site was used along the 24.6-mile segment of the Wild and Scenic Rio Chama. Deploying hydrophones in other parts of the river would be difficult because of limited roadway access for much of the river. Nevertheless, more hydrophone data throughout the river could be used to inform decisions about intensities of environmental streamflows. Boat-mounted hydrophones were used previously (Lorang and Tonolla 2014; Marineau et al. 2017; Kohn et al. 2020) to collect data during high-streamflow events on the upper Colorado River and could be used on the Rio Chama during future flushing flow releases.

Additional data would help better define a valid "threshold" for the particle impact counting step. A threshold too high would underestimate sediment movement, but a threshold too low would overestimate sediment movement. Evaluating hydrophone datasets collected with concurrent bedload measurements could also help refine this method.

Hydrophone data that indicate the presence or absence of bedload transport could help inform decisions about environmental streamflows but only represent one piece to a broader puzzle of how management decisions could affect brown trout spawning habitat on the Rio Chama. For example, reservoir releases could provide the water that is needed to mobilize sediment, but those same releases may also supply additional fine sediments. Other sediment management measures could be explored to help improve the sustainability of spawning habitat.

U.S. Geological Survey Non-Endorsement Disclaimer

Provisional Data Disclaimer

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