BUREAU OF RECLAMATION

Final Report No. ST-2024-21092

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

Research and Development Office

Science and Technology

Research Program

U.S. Department of the Interior

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED *(From - To)*
30-09-2024	Research	2021 - 2024

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER RY15412021EN21092
Utilizing Hydrophones to Detect Streambed Mobilization in the Wild and Scenic Reach of the Rio Chama	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 1541 (S&T)
6. AUTHOR(S) Rebecca Braz, Civil Engineer	5d. PROJECT ID NUMBER Final Report ST-2024-21092
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Bureau of Reclamation, Albuquerque Area Office 555 Broadway Blvd NE Albuquerque, NM 87102	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) Reclamation
Science and Technology Program Research and Development Office Bureau of Reclamation U.S. Department of the Interior Denver Federal Center PO Box 25007, Denver, CO 80225-0007	11. SPONSOR/MONITOR'S REPORT NUMBER(S) (if applicable)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Final Report may be downloaded from https://www.usbr.gov/research/projects/index.html

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Wild and Scenic Rio Chama experiences fine sediment inflows that smother the gravel streambed and negatively impact brown trout habitat. Using hydrophones, incipient motion can be detected, and that data correlated to a range of flow rates. These flow rates can be used by water managers in planning environmental flows that remove fine sediments from the coarse, gravel bed of the Chama. Installation of hydrophone equipment and initial data collection has been completed for the conducting proposal work. This project is a collaboration between Bureau of Reclamation and USGS; an interagency agreement has been submitted to transfer funds to USGS.

15. SUBJECT TERMS
brown trout, acoustic sensor, hydrophone, incipient motion, sediment transport, streambed mobilization, Rio Chama, Wild and Scenic Rio Chama

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Rebecca Braz
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
U	U	U			505-462-3663

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, Native Hawaiians, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

Information in this report may not be used for advertising or promotional purchases. The data and findings should not be construed as an endorsement of any product or firm by the Bureau of Reclamation, Department of Interior, or Federal Government. The products evaluated in the report were evaluated for purposes specific to the Bureau of Reclamation mission. Reclamation gives no warranties or guarantees, expressed or implied, for the products evaluated in this report, including merchantability or fitness for a particular purpose.

Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research. Thank you to Mathieu Marineau, Michael Kohn, Mike Harvey, and Mark Stone for your contributions to this work. Thank you to Monastery of Christ in the Desert and Brother Bede for agreeing to host the equipment on your property.

Cover Image – Gravel bar located in the Wild and Scenic Rio Chama near the site where the hydrophones were installed (Rebecca Braz/Bureau of Reclamation).

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

Final Report No. ST-2024-21092

Prepared by:

Upper Colorado Region
Rebecca Braz, Civil Engineer

Peer Review

Bureau of Reclamation
Research and Development Office
Science and Technology
Research Program

Final Report ST-2024-21092

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

REBECCA BRAZ Digitally signed by REBECCA BRAZ
Date: 2025.04.09 08:59:29 -06'00'

Prepared by: Rebecca Braz, PE
Civil Engineer, Bureau of Reclamation

DAGMAR LLEWELLYN Digitally signed by DAGMAR LLEWELLYN
Date: 2025.04.10 08:17:10 -06'00'

Peer review by: Dagmar Llewellyn
Resources Program Group Chief, Bureau of Reclamation

This document has been reviewed under the Research and Development Office Discretionary peer review process, consistent with Reclamation Policy CMP P14. It does not represent and should not be construed to represent the Bureau of Reclamation's determination, concurrence, or policy.

Acronyms and Abbreviations

2D	two-dimensional
BLM	Bureau of Land Management
cm	centimeter
D_{50}	median grain size
D_{90}	representative grain size of the coarse grains in a sample
DOI	U.S. Department of the Interior
ft	foot/feet
ft^3/s	cubic feet per second
FY	fiscal year
kHz	kilohertz
m^3/s	cubic meter per second
mm	millimeter
Monastery	Monastery of Christ in the Desert
N/A	not available; not applicable
NM	New Mexico
Reclamation	Bureau of Reclamation
S&T	Science and Technology
SGN	sediment generated noise
TSC	Technical Service Center
UNM	University of New Mexico
USGS	United States Geological Survey

Symbols

$\approx$	approximately equal to

Contents

Page

Figures

Executive Summary

The stretch of the Rio Chama between El Vado Dam and Abiquiu Dam was designated a Wild and Scenic River in 1988 and is a high-sediment system with a significant amount of fine sand, silt, and clay sediments deposited by inflows from arroyos and bank erosion onto gravel-cobble (coarse) bed material. The fine sediment fills the interstitial spaces within the gravel streambed and adversely impacts the suitability of spawning habitat of the brown trout, a key species in the designation of the Wild and Scenic reach.

Bureau of Reclamation (Reclamation) periodically releases high flow pulses from El Vado Dam for environmental enhancement purposes, including clearing of fine sediment from the streambed to maintain habitat for brown trout and their macroinvertebrate food base. Fine sediments are mobilized, along with coarser sediment, in a threshold event called incipient motion. Incipient motion is said to begin when a flow has enough energy to pick up the median grain size in the streambed (Gregory 2013). Mobilization of the streambed is necessary to not only remove fine sediments on top of the gravels but also the fines in the interstitial spaces.

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 flows decrease by one-third and inter-basin transfer flows by one-quarter over the next century (Reclamation 2013). With less water available in the future for high flow pulses, it is necessary to better understand what flow rates are needed to trigger incipient motion. This knowledge would assist water managers in planning the most effective high flow pulses.

A conducting proposal was developed and submitted for the FY21 Science and Technology (S&T) Program call for proposals. The conducting proposal's timeframe extended from fiscal year (FY) 2021 to FY2024. The conducting proposal sought to use the underwater acoustic sensors, or hydrophones, in a new place, the Wild and Scenic Rio Chama, to test its capabilities and evaluate potential for developing a long-term sediment mobilization monitoring methodology there. Previous research has shown hydrophones to be a viable low-cost and passive method to monitor sediment transport. Mathieu Marineau, a research hydrologist from USGS who worked on a similar study on the Upper Colorado River, agreed to collaborate on this project and bring his experience using hydrophones and analyzing hydrophone data.

Two high streamflow events occurred during the project performance period, one in November–December 2021 and the other in April–May 2023. The sediment generated noise (SGN) levels suggest that coarse sediment transport may have occurred during the high flow pulses, which peaked at 3,350 ft^3/s in 2021 and 3,410 ft^3/s in 2023. The SGN also suggests that bedload began to mobilize when flows exceeded 2,000 ft^3/s.

1.0 Introduction

The 24.6-mile-long segment of 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 when 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 (SRH-2D) (Reclamation 2020) to develop a 2D hydrodynamic model (Gregory et al. 2018). The study found that a streamflow of 56 cubic meters per second (m^3/s), or ≈1,980 cubic feet per second (ft^3/s), would mobilize fine sediments and a streamflow above 100 m^3/s (≈3,530 ft^3/s) would cause "extensive" flushing of fine sediments. Fine sediments were specified as less than 4.76 mm in diameter.

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.

A conducting proposal was submitted for the FY21 Science and Technology (S&T) Program call for proposals. The conducting proposal's timeframe extended from fiscal year (FY) 21 to FY24. The conducting proposal sought to use the underwater acoustic sensors, or hydrophones, in a new place, the Wild and Scenic Rio Chama, to test its capabilities there and evaluate the feasibility of using the hydrophones as a long-term sediment mobilization monitoring methodology.

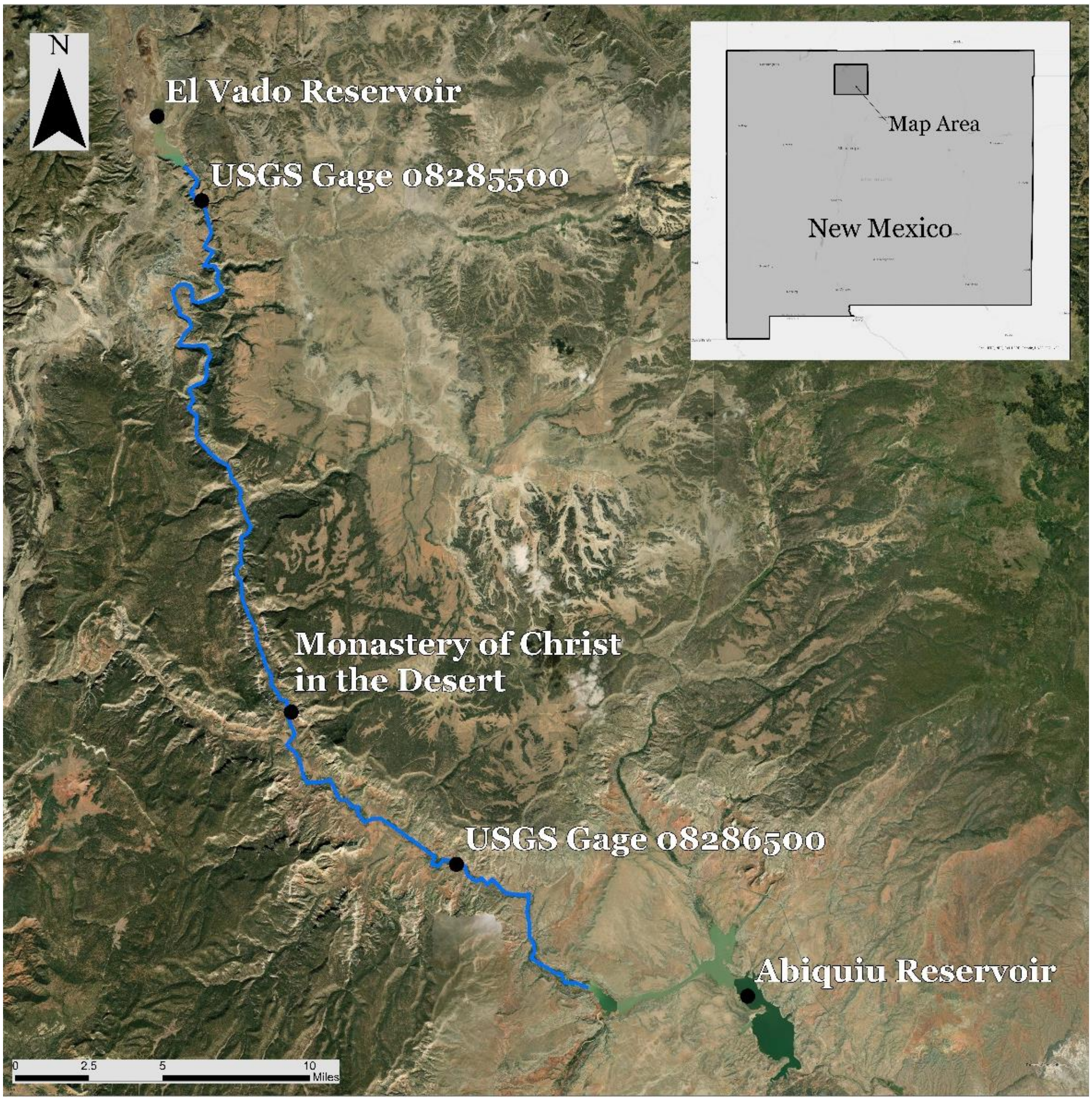

Figure 1.—Map of the Wild and Scenic Rio Chama in northern New Mexico, map created using data from U.S. Geological Survey 2023 and Maxar Technologies 2020.

2.0 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 ideally 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. In fact, inaccessibility except via trail is a requirement of the "Wild" river designation.

There are several sites along this reach of the Rio Chama where streambed data has been collected in the past, including the site where the SRH-2D model was developed by UNM researchers. Inaccessibility via roadway eliminated most of those sites. 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 help with the project. Brother Bede from the Monastery was the main point of contact and provided assistance to the project throughout the performance period.

Two hydrophone stations were installed at the Monastery for three data-collection periods, April through December 2021, April through October 2022, and April through May 2023. 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 median grain size, D_{50}, ranged between 8 and 22.6 mm. The D_{90} ranged between 22.6 and 128 mm, indicating the coarser grain sizes present in the streambed. The hydrophone stations were about 40 to 50 feet apart; the upstream station is referred to herein as BEDE01 and the downstream station as BEDE02.

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 a high streamflow. Each hydrophone was mounted to a piece of rebar that was driven into the streambed (figure 3); 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 2.—Gravel bar at hydrophone monitoring site, photograph taken by Rebecca Braz, 2021.

Figure 3.—Hydrophone mounted to rebar driven in to the riverbank; this is the “upper hydrophone”, the “lower hydrophone” is submerged; photograph taken by Rebecca Braz, 2021.

Figure 4.—A water-resistant case housed the data collector, pre-amplifier, and batteries at each site; the case was secured to a U-channel driven into the floodplain about 10 feet from the river's edge; photograph taken by Rebecca Braz, 2021.

Each data-collection period included periods of relatively low streamflow (approximately 100 ft^3/s) which were not expected to initiate incipient motion. In late November through early December 2021, a high streamflow pulse was released from El Vado Dam. A peak streamflow of 3,350 ft^3/s was measured (figure 5), which was approximately equal to the streamflow rate predicted to cause extensive flushing of fine sediment (Gregory et al. 2018). In May 2023, another high streamflow event occurred where the hydrophones experienced a peak of 3,410 ft^3/s (figure 6). The data collectors and batteries were removed from the site during the May 2023 peak because the river had started to overbank and was threatening to submerge the cases. The water-resistant cases provide adequate protection from the elements during most conditions but cannot be submerged.

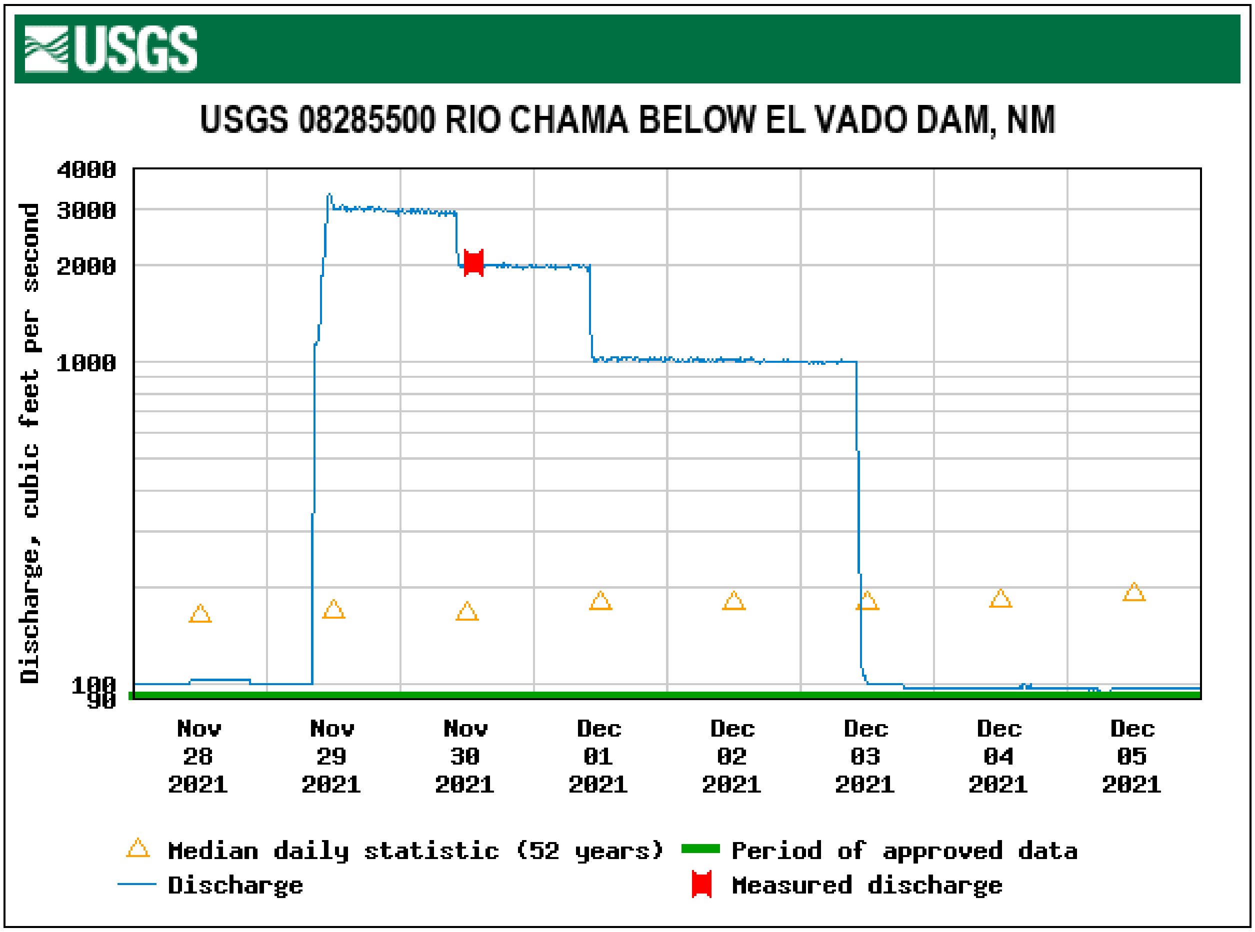

Figure 5.—Hydrograph at U.S. Geological Survey streamgage 08285500 (Rio Chama Below El Vado Dam, NM; U.S. Geological Survey, 2023) during the 2021 high streamflow pulse release.

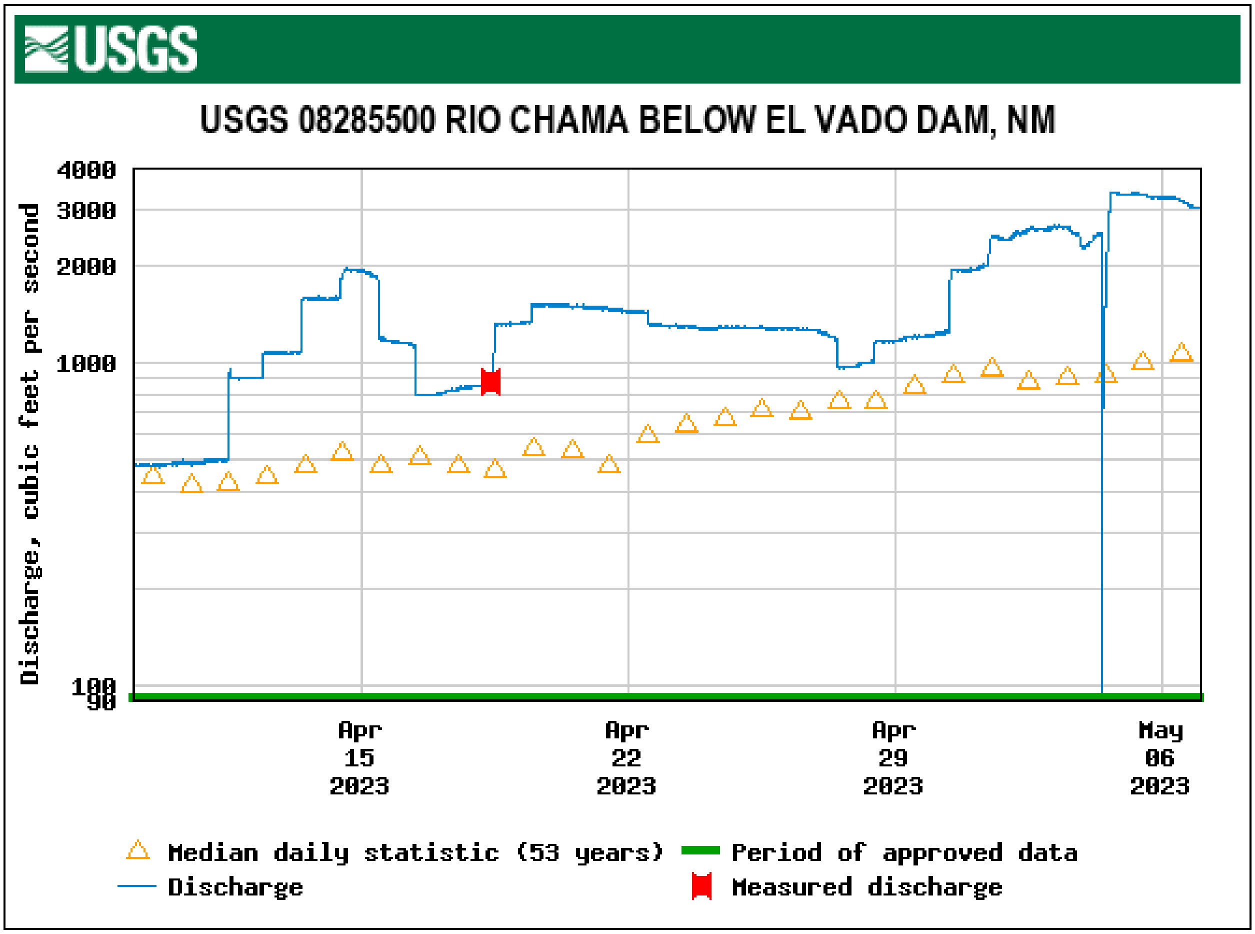

Figure 6.—Hydrograph at U.S. Geological Survey streamgage 08285500 (Rio Chama Below El Vado Dam, NM; U.S. Geological Survey, 2023) during the 2023 high streamflow.

3.0 Data Processing

Audio data files are first processed in MATLAB using a similar methodology to what is described in Marineau et al. (2017). See Marineau et al. (2025) to access the code. 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 between 2–10 kHz is calculated, 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 7 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 7 shows that changes in sound levels primarily occur below 10 kHz at all ranges of bedload transport.

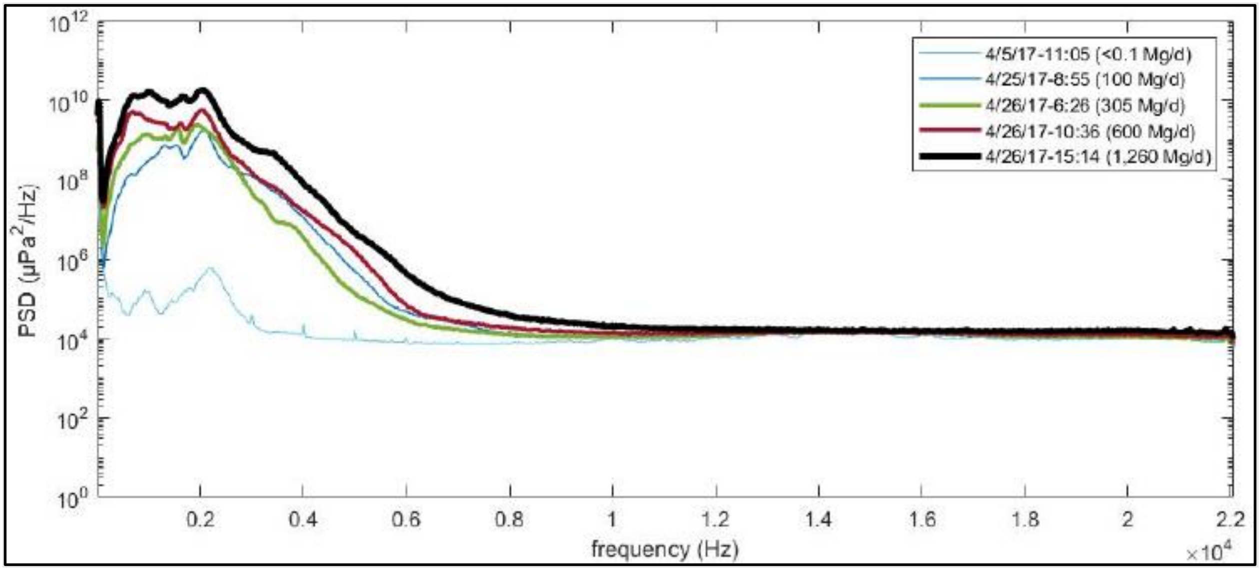

Figure 7.—Examples of power spectral density (PSD) estimates under different streamflow and bedload transport conditions from a previous study on the Trinity River (Marineau et al. 2019).

The second audio processing method is 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.

Figures 8 and 9 show two examples of plots of the digital sounds for two different .wav files collected from the Rio Chama hydrophone site. The first (figure 8) 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 9) 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 10).

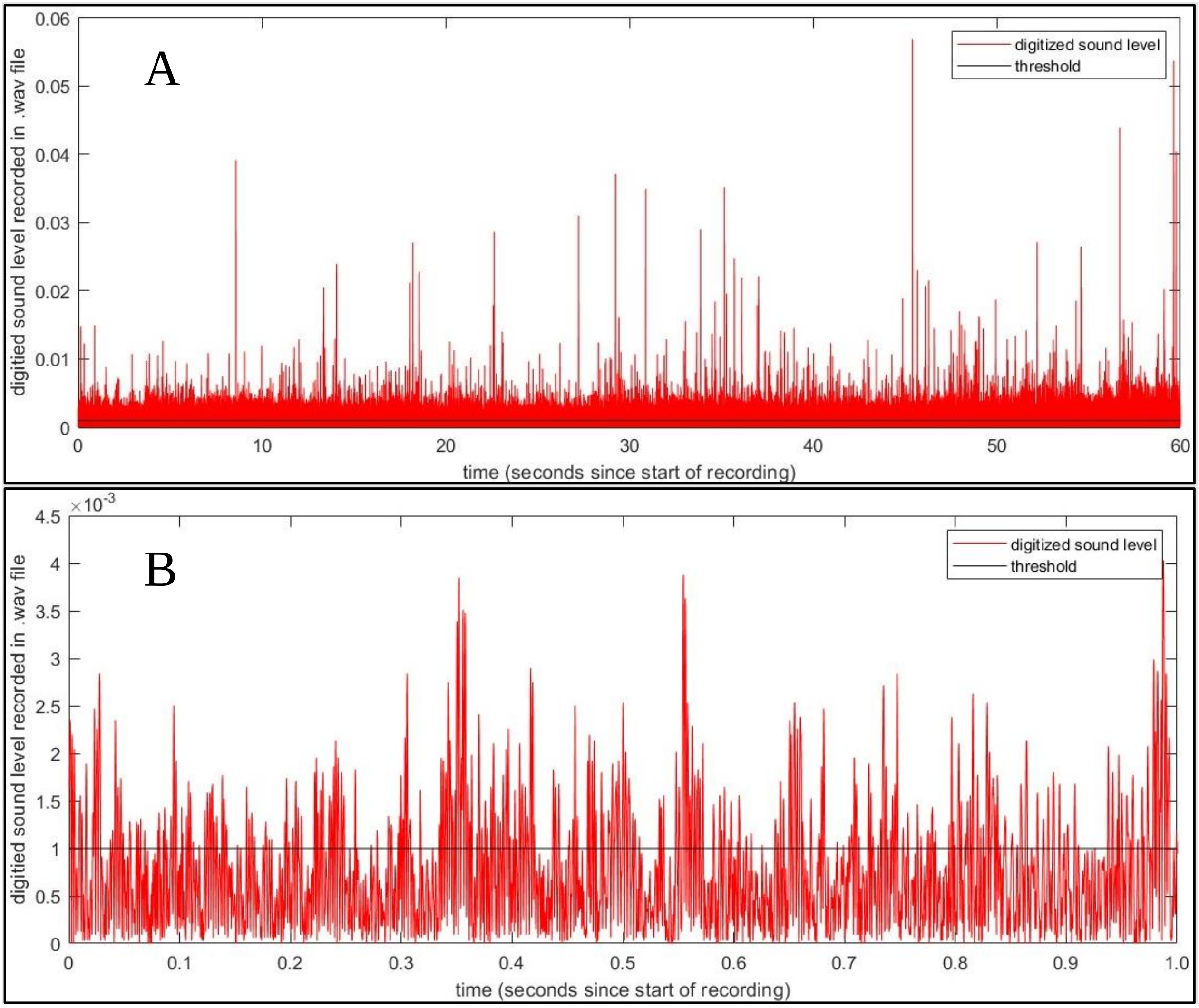

Figure 8.—Plots of digitized audio recording (from .wav file) from 11/30/2021 at 12:45 (Mountain Standard Time) at BEDE01 near peak of sediment-generated noise (SGN). 'A'-plot shows full 1-minute recording, 'B'-plot shows a closeup of the first second. A threshold is also shown overlaid on the time series.

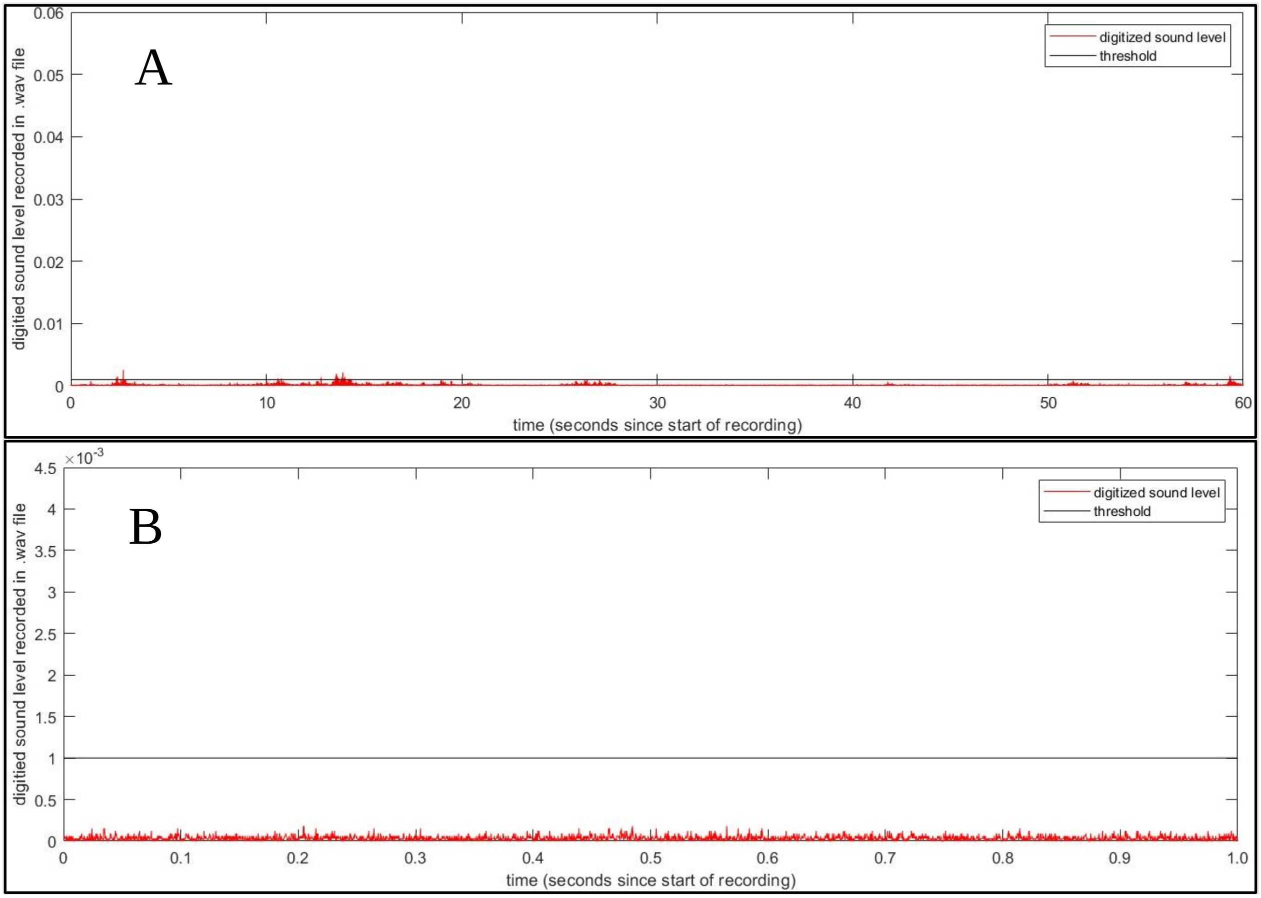

Figure 9.—Similar plots as figure 8, but from a low-streamflow (quiet) period, with little or no detectable sediment-generated noise. The same threshold is used through the entire time series for a plot. The 'A'-plot is a 1-minute recording collected on 12/30/2021 at 9:00 (Mountain Standard Time), the 'B'-plot is from the same recording but is a closeup of the first second of that recording.

4.0 Results and Conclusions

Audio recordings were successfully collected using hydrophones for approximately 8.5 days during the November–December 2021 streamflow releases, and approximately 15 days during the April–May 2023 releases. Time series of SGN for each streamflow release are shown in figures 11 and 12. Several recordings were aurally reviewed to confirm that the sounds were consistent with SGN recordings collected in other studies, such as the Trinity River, though overall sound level was lower (i.e., quieter).

Figure 12 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 high flow event.

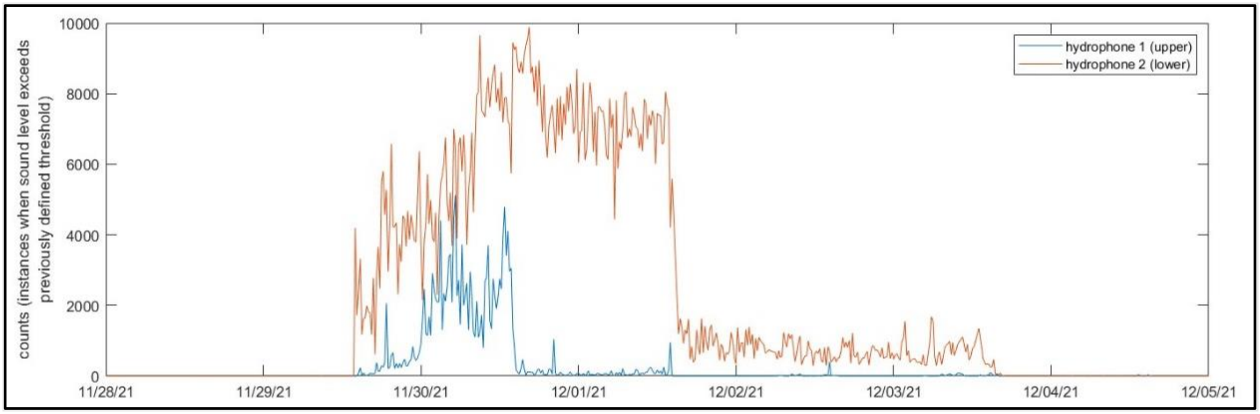

Figure 10.—Time series of "counts" when sound level exceeded the previously defined threshold during the 2021 high flow. This is used as an indicator of how many particle impacts are detected near the hydrophone in each 1-minute audio recording.

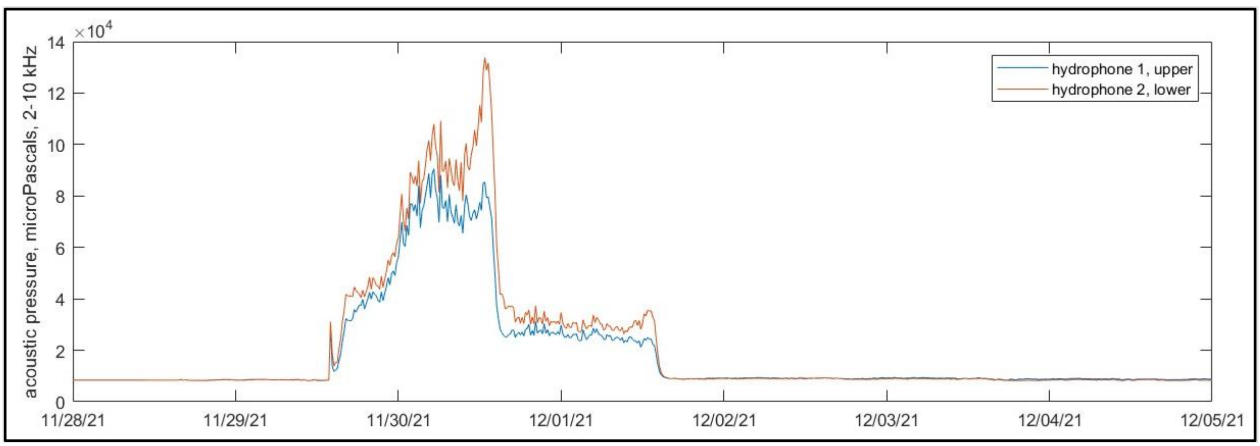

Figure 11.—Time series of sediment-generated noise (SGN) between 2-10 kHz at the hydrophone study site for the Rio Chama, New Mexico during the 2021 high flow.

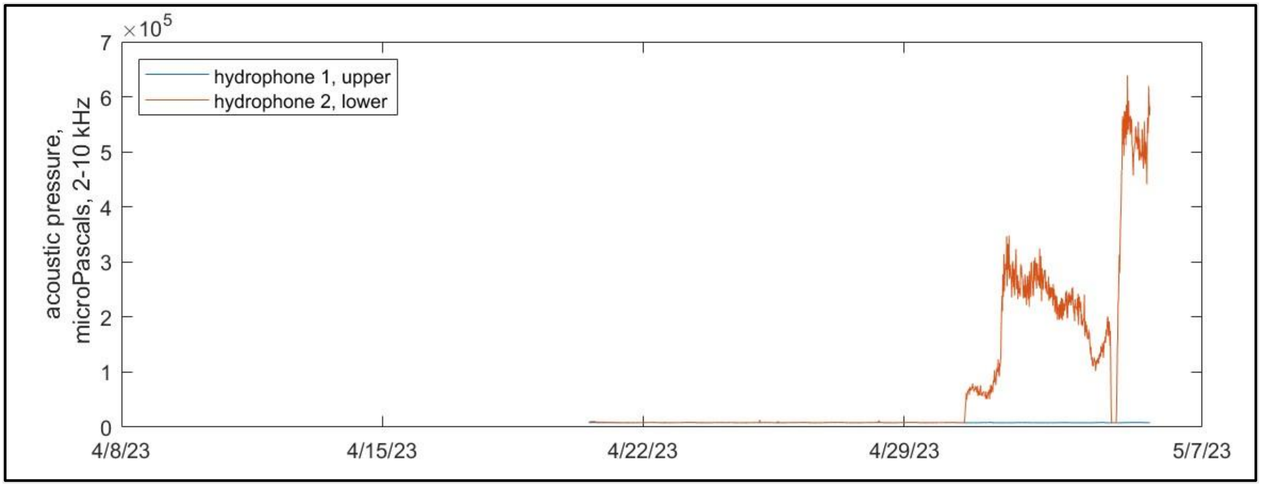

Figure 12.—Time series of sediment-generated noise (SGN) between 2-10 kHz at the hydrophone study site for the Rio Chama, New Mexico during the 2023 high flow. The x-axis limits are set to align with those on the hydrograph plot in figure 6.

The SGN levels (figures 11 and 12) would suggest that coarse sediment transport may have occurred during the high flow pulses, which peaked at 3,350 ft^3/s in 2021 and over 3,400 ft^3/s in 2023. During the 2021 release, the flows were rapidly increased from 100 ft^3/s to the peak flow. A precise flow level in which the noise and bedload transitioned from quiet, low or no transport periods to louder, presumably bedload transport periods, could not be determined. However, the hydrograph pattern in the 2023 flow release was a complex step-increase pattern that allowed a bit more interpretation in the SGN data. The flows nearly reached 2000 ft^3/s around April 15, but the SGN was very low, suggesting low or no transport. Around April 30, flows were ramped up again, increasing above 2,000 ft^3/s, until they reached around 3,400 ft^3/s on May 4 (figure 6). The SGN increased when flows exceeded 2,000 ft^3/s. Flows continued to increase to around 4,400 ft^3/s, but acoustic data were not available beyond May 5. 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. This is generally consistent with the findings using hydrophones which suggested bedload began to be mobilized when flows exceeded 2,000 ft^3/s.

The audio data collected in this study which suggest bedload mobilization and transport were not entirely conclusive without some secondary evidence of bedload transport, such as physical bedload samples, use of pit tags, painted rocks, or measurements of channel change. The data were also insufficient to determine the magnitude of bedload transport. In other words, bedload could not be quantified with the audio data alone. Physical bedload samples would be required to develop a relation between bedload measurements and acoustic data.

5.0 Future Considerations

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.

Evaluating hydrophone datasets collected with concurrent bedload measurements could also help refine this method. 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. Any future hydrophone data collection should be paired with another method of bedload transport monitoring method, such as physical bedload samples, use of pit tags, painted rocks, or measurements of channel change. These monitoring methods would require additional visits to the Rio Chama aside from installing and maintaining the hydrophones. This additional time requirement should be carefully considered in future monitoring plans.

Hydrophone data that indicates the presence or absence of bedload transport could help inform decision making about environmental flows but only represent one piece to the broader puzzle of how these 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. This scenario was observed during and after the 2021 high flow pulse. Other sediment management measures should be explored to help improve the sustainability of spawning habitat.

6.0 References

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

Bureau of Land Management (BLM). 1992. "Rio Chama instream flow assessment December 1992." https://archive.org/details/riochamainstream7843fogg.

Bureau of Reclamation (Reclamation). 2013. "West-wide climate risk assessment: Upper Rio Grande impact assessment." https://www.usbr.gov/watersmart/baseline/docs/urgia/URGIAMainReport.pdf.

_____. 2020. "SRH-2D." https://www.usbr.gov/tsc/techreferences/computer%20software/models/srh2d/index.html.

Geay, T., P. Belleudy, C. Gervaise, H. Habersack, J. Aigner, A. Kreisler, H. Seitz, and J.B. Laronne. 2017. "Passive acoustic monitoring of bed load discharge in a large gravel bed river." Journal of Geophysical Research: Earth Surface Volume 122, https://doi.org/10.1002/2016JF004112.

Gregory, A. 2013. "Incipient motion of mixed sediment load on the Rio Chama [Master's thesis, University of New Mexico]." UNM Digital Repository. https://digitalrepository.unm.edu/ce_etds/83/.

Gregory, A., M. Stone, and R.R. Morrison. 2018. "Assessing the hydrogeomorphic effects of environmental flows using hydrodynamic modeling." Environmental Management Volume 62. https://doi.org/10.1007/s00267-018-1041-6.

Kohn, M.S., M.D. Marineau, L.A. Hempel, and R.R. McDonald. 2020. "Incipient bed-movement and flood-frequency analysis using hydrophones to estimate flushing flows on the upper Colorado River, Colorado, 2019." U.S. Geological Survey Scientific Investigations Report 2020–5069, 39 p., https://doi.org/10.3133/sir20205069.

Lorang, M., and D. Tonolla. 2014. "Combining active and passive hydroacoustic techniques during flood events for rapid spatial mapping of bedload transport patterns in gravel-bed rivers." Fundamental and Applied Limnology. Volume 184 No. 3. https://doi.org/10.1127/1863-9135/2014/0552.

Marineau, M.D., S.A. Wright, and D. Gaeuman. 2017. "Estimating bedload transport along the gravel-bedded Trinity River using in-situ and boat-mounted hydrophones." Conference proceedings for ASCE Hydraulic Measurements and Experimental Methods, Durham, NH, July 9-12, 2017, 6p.

Marineau, M.D., S.A. Wright, D. Gaeuman, C.A. Curran, K. Stark, J. Simeon, and E. Schenk. 2019. “Overview of five recent bedload monitoring field experiments using hydrophones.” Conference proceedings at SEDHYD Reno, Nevada, 14p.

Marineau, M.D., Ely, C.P., 2025, Matlab code to count acoustic impulses from coarse sediment particle collisions during sediment transport in rivers, U.S. Geological Survey Software Release, https://doi.org/10.5066/P13GQRSF.

Maxar Technologies. 2020. “Maxar (Vivid) imagery captured 2 years 5 months ago, on Oct 18, 2020.” Accessed at https://www.arcgis.com/apps/mapviewer/index.html?webmap=c03a526d94704bfb839445e80de95495

Senate Bill 850, 1988. “A bill to amend the Wild and Scenic Rivers Act to designate a segment of the Rio Chama River in New Mexico as a component of the National Wild and Scenic Rivers System.” Accessed at https://www.congress.gov/bill/100th-congress/senate-bill/850 on 3/24/2023

U.S. Geological Survey. 2023. “USGS water data for the nation: U.S. Geological Survey National Water Information System.” Accessed on March 23, 2023 at https://doi.org/10.5066/F7P55KJN.