Monitoring Sediment Transport in an Ephemeral Stream

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14. ABSTRACT
This document covers three-years of a research effort that began in 2013. The primary tasks accomplished in the three-year period from FY18-FY20 include the collection of hydrologic, hydraulic, and sediment flux data at the newly constructed Arroyo de los Pinos Research Station, the preliminary analysis of said data, completion of two Master of Science (M.S.) theses, commencement of a third M.S. thesis, commencement of a PhD dissertation, the presenting of information at many conferences, and the submission of an article to a peer-reviewed technical journal.

The research focuses on physical measurements of sediment flux and surrogate techniques in order to establish a relationship between the two in an ephemeral stream environment. This relationship is necessary because: standard methods for estimating sediment yield are derived from perennial systems and are inapplicable to ephemeral systems; the nature of ephemeral streams (infrequent and short-lived) means that standard data collection methods are insufficient; and 30% of the world's inhabited land surface is made up of desert climates and is home to approximately 2 billion people and this research will help fill the gap in scientific knowledge such that management of desert channel networks (including the semi-arid southwestern United States) will be improved.

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prepared by

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Cover Photo: Aerial Image of the Arroyo de los Pinos Research Station collected by Sharllyn Pimental piloting a UAV.

Peer Review

Bureau of Reclamation
Research and Development Office
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Final Report ST-2020-1871-01

Report Title

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Acronyms and Abbreviations

AAO	Albuquerque Area Office
ADV	acoustic doppler velocimeter
BAA	broad agency announcement
BGU	Ben Gurion University of the Negev
Corps	United States Army Corps of Engineers
D90	90th percentile of a grain size distribution
dB	decibels
DEES	Department of Earth and Environmental Science
ERDC	Engineer Research and Development Center (Corps)
FY	fiscal year
GSD	grain size distribution
GFZ	German Research Center for Geosciences
HEC-RAS	Hydrologic Engineering Center River Analysis Software
Hz	Hertz
IRIS	Incorporated Research Institutions for Seismology
kg	kilogram
kg/s/m	kilogram per second per meter
LiDAR	light detection and ranging
LSPIV	large scale particle image velocimetry
m	meter
mg/l	milligrams per liter
mi^2	square miles
min	minute
MIPR	military interdepartmental purchase request
mm	millimeter
MoBeD	mobile bed discharge gage
M.S.	Master of Science
NMT	New Mexico Institute of Mining and Technology
NSF	National Science Foundation
PhD	Doctor of Philosophy
R^2	r-squared, coefficient of determination
Reclamation	Bureau of Reclamation
RUSLE	Revised Universal Soil Loss Equation
S&T	Science and Technology
SSC	suspended sediment concentration
SSCAFCA	Southern Sandoval County Arroyo Flood Control Authority
SVR	surface velocity radar
UAV	unmanned aerial vehicle
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTC	Coordinated Universal Time

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Executive Summary

This document covers the recent three-years of a research effort that began in 2013. The primary tasks accomplished in the three-year period from FY18-FY20 include the collection of hydrologic, hydraulic, and sediment flux data at the newly constructed Arroyo de los Pinos Research Station, the preliminary analysis of said data, completion of two Master of Science (M.S.) theses, commencement of a third M.S. thesis, commencement of a PhD dissertation, the presenting of information at many conferences, and the submission of an article to a peer-reviewed technical journal.

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1. Introduction

A significant portion of Reclamation's purview is referred to as the "arid southwest" of the United States. This region receives little precipitation on an annual basis (Figure 1), and the precipitation that does fall tends to occur during summer monsoon events, which are characterized by flashy, sometimes intense, rainstorms. The landscape is generically similar to other parts of the country; mountains, valleys, and streams. The main differences for the arid southwest are that many streams (especially tributaries) are dry most of the year, the vegetation is sparse, soil formation is low, rock weathering is high, and there is an abundance of sediment available to be moved into streams and thus to continue downstream when there is a rainstorm event.

The purpose of this research is to better understand the quantity of sediment that is transported in these ephemeral streams during monsoon events. River maintenance and other in-channel projects that Reclamation engages in – whether for water delivery, public safety, habitat restoration, or other – need to be designed and implemented with a knowledge of river processes and channel morphology to ensure project success. River morphology and channel processes are essentially the design parameters which need to be considered for many in-river or riverside Reclamation projects, just as snow, wind, and earthquake loads need to be considered by a structural engineer. For a river, process and morphology are a result of the magnitude and timing of water and sediment delivery to the channel. A method to adequately quantify sediment delivery from ephemeral tributaries in a reliable and cost-effective manner does not exist.

Existing methods for estimating sediment load from ephemeral streams typically consists of coupling a soil loss equation for the wash load with a sediment transport equation for the bed material load. Soil loss equations can have vastly different results depending on the assigned parameters (there are six user-defined parameters for the USLE and RUSLE). Sediment transport equations, although formulated to represent the physics of sediment transport, are typically calibrated and or assessed using data from perennial, not ephemeral, streams. Since monsoon events are so short-lived ('flashy'), mobilizing to a site and performing industry-standard data collection techniques (reliable yet time consuming) means a dearth of data exist for sediment flux in ephemeral streams. Aside from the logistical challenges of accessing an ephemeral stream during a short-lived storm event, the cost of instrumenting many tributary streams for sediment monitoring is exorbitant. The goal of this research is to determine if acoustic instruments can be used as a surrogate for physical measurements to improve the accuracy of sediment flux estimates relative to existing methods in a more economical feasible way.

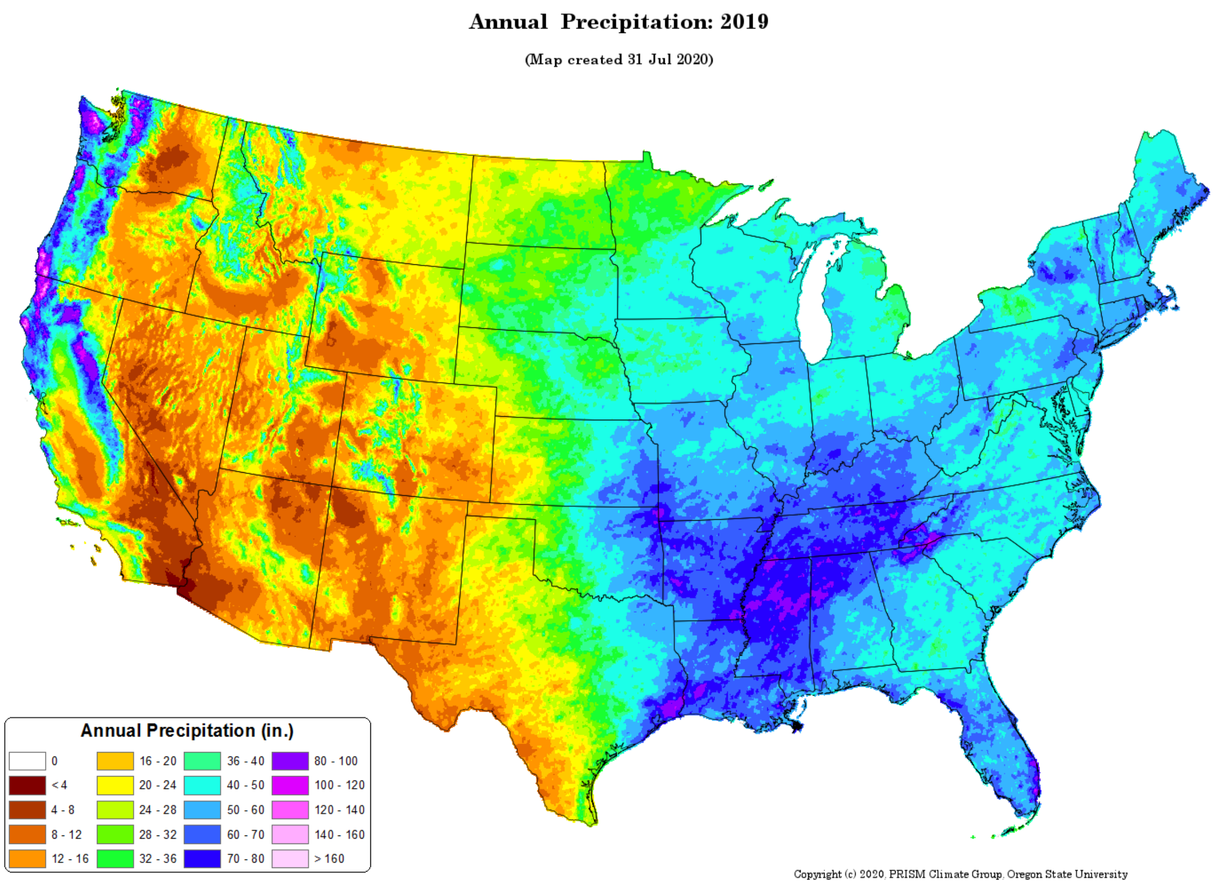

Figure 1 Annual precipitation for the contiguous United States, demonstrating Reclamation's purview contains the driest portions of the country. (https://prism.oregonstate.edu/recent/)

2. Previous Work

This report documents a three-year window covering FY18, FY19, and FY20 under the S&T Project ID 1871. The larger research effort on this project began earlier, however.
A scoping project (S&T Project ID 2180) was completed in FY13 (Varyu, 2013) and was initiated primarily on two efforts being done for Reclamation's Albuquerque Area Office. One effort was the Maintenance Plan and Guide (Reclamation, 2012) which was a sweeping, long-term assessment of the Middle Rio Grande, it's history, the drivers and controls of the system, the observed geomorphic trends over time, and an evaluation of maintenance strategies that were appropriate for various reaches of the river. Another effort was the development of a sediment budget (Varyu, 2014), where channel hydraulics, sediment samples, USGS gage data, and sediment transport equations were compared to changes in channel geometry. The common observation during both efforts was that the timing, volume, and size of sediment entering the Rio Grande from ungaged, ephemeral tributaries, was a major source of uncertainty. The scoping project consisted of a literature review and the conceptual design of a data collection site that could be constructed to collect the data required to estimate sediment flux rates during an ephemeral storm event. The conceptual design was based on information gathered during the literature review, which demonstrated that this issue

of sediment flux (especially bed load flux) in ephemeral streams is not unique to the United States, and research was being conducted in various European and Asian locations, and limited research on the topic had been or was being conducted in the United States. The final report associated with Project ID 2180 can be found on the Reclamation website (https://www.usbr.gov/research/projects/download_product.cfm?id=804).

A subsequent three-year conducting S&T Proposal (ID 9781) occurred during FY15, FY16, and FY17. The primary tasks completed during this time period include site selection, establishing partnerships, collecting initial data for baseline conditions and to be used for design, designing the data collection facility, and construction of the facility. It needs to be noted here that the Albuquerque Area Office funded the construction of the facility, a cost of approximately $400,000. The ephemeral stream selected is the Arroyo de los Pinos – a tributary to the Rio Grande – and is located near Socorro, NM. The final report documenting the work conducted in association with S&T Proposal 9781 can be found on the Reclamation website (https://www.usbr.gov/research/projects/download_product.cfm?id=2667). A description of the site is contained in this reference. For convenience, a brief review of the site follows.

The Arroyo de los Pinos drainage basin is approximately 12.3 square miles (mi^2) and drains the highlands east of the Rio Grande (Figure 2). The geology includes volcanic, shale, sandstone, limestone in the upper watershed and clastic and alluvium closer to the mouth. The bed material of the Arroyo de los Pinos near the research station is about one-third sand and two-thirds gravel, and the bed slope is 1.3%.

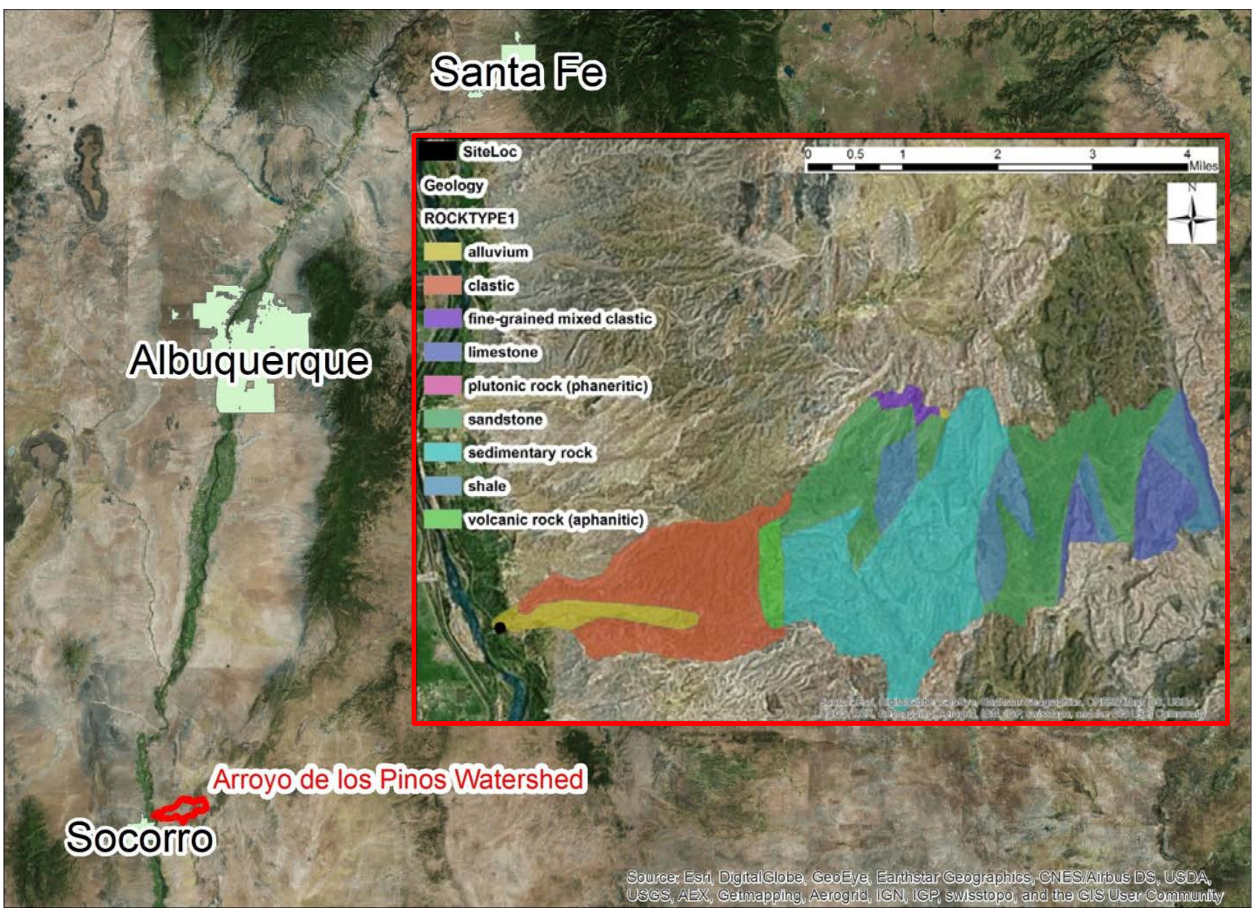

Figure 2 Location map of the Arroyo de los Pinos, with an inset map characterizing the basin geology.

3. Ongoing Research

The work associated with this S&T Project (ID 1871) is the collection and analysis of data obtained during monsoon events at the site. Appendix A provides a photolog of the site and the instruments deployed to conduct data collection. The design of the research station and the instruments deployed aim to answer the research questions as defined in the original proposal:

> Is there a strong statistical regression between surrogate measurements and definitive (direct) measurements of sediment transport in ephemeral systems? Which surrogates are the most reliable to predict the discharge of bedload (e.g., seismic or acoustic)? What characteristic of the surrogate is most informative (e.g. total acoustic power or number of impacts for acoustic amplitude; at what frequency for seismic)? Can multiple calibrated turbidity sensors account for sandy suspended sediment concentrations (SSC) to determine suspended load? Can LSPIV be useful to determine water velocity and discharge in flash-flood environments as shown elsewhere?

3.1. Data Collection Methods and Techniques

Data collected during storm events at the primary location includes flow depth, flow velocity, physical measurements of bedload flux, surrogate (acoustic) measurements of bedload flux, physical measurement of SSC, grain size distribution (GSD) of SSC, and surrogate (optical) measurements of SSC.

A network of rain gages throughout the drainage basin (including one at the research station) monitor precipitation during storm events, and a network of pressure transducers are used to estimate the flow coming from various channels upstream of the primary research station site. Repeat UAV flights provide LiDAR data between monsoon events to help quantify changes in Arroyo de los Pinos channel form and elevation. Further, the prograding delta fan at the confluence with the Rio Grande and subsequent erosion is being investigated and assessed vis a vis Rio Grande flow rates. This effort is somewhat tangential to the primary research questions, but is in fact important in understanding the delivery of sediment to the trunk system (the Rio Grande), which was indeed the impetus of this research.

An associated research effort – funded by the National Science Foundation (NSF) – involves the deployment of an array of seismic sensors at the Arroyo de los Pinos site to assess the feasibility of using this technology as a surrogate to monitor bedload in an ephemeral stream. The inclusion of seismic devices is one of the research questions, and a single node has been on site since the 2018 season. Developments in the field of seismic sensors since the S&T proposal was written have shown that an array of nodes are more promising than a single node. The collection and analysis of the seismic portion of this research is being carried out by our partners at New Mexico Tech under the NSF program. A figure demonstrating the array of deployed seismic nodes is in Appendix A.

Similarly, a passive acoustic surrogate system – developed and being tested by the California Water Science Center branch of the USGS – is deployed on site as well. These associated research efforts will not be discussed further but are mentioned to demonstrate the interest in this topic by various agencies and scientists, to introduce some of the partnerships developed around this effort, and to validate the value of the research being conducted at the Arroyo de los Pinos.

There were several substantial storm events during the summer and fall of 2018, which was fortunate and more than expected. Based on input provided by local landowners, a typical monsoon season will yield one or two floods per year, if any at all. Unfortunately, the 2019 monsoon season was one of those that yielded no storm events. There was a small storm on November 22nd, 2019 that yielded very little bed load and was too shallow for suspended sediment to be sampled. As of the writing of this report, the 2020 season has had three events, and there may be more before the season is over. Table 1 summarizes the storm events that have been monitored at the Arroyo de los Pinos Research Station since construction and as of development of this report (the November 2019 event is not included due to the small nature of the storm and minimal usable data was collected).

Table 1 Data collected during flow events at the Pinos Research Station.

	2018					**2020**		
Parameter	**7/16**	**7/26**	**8/9**	**8/24**	**9/1**	**7/23**	**7/24**	**9/1**
Water Depth	X,M	X	X,M	X,M	X,M	X,M	X	X
Bedload Flux	X,M	X	X,M	X,M	X,M	X,M	X	X
Acoustic	X	X	X	X	X	X	X	X
Seismic	X	X	X	X	X	X	X	X
Hydrophone		X*	X*	X	X	X*		
Turbidity	X	X		X		X	X	X
Suspended Sediment	X,M		X,M	X,M	X,M	X,M	X	M
Velocity	M		M	M	M	X,M	X, M	X

X = collected automatically; M = collected manually

** only one of two units recorded*

3.2. Data Analysis and Research Implications

The analysis of the data from the Arroyo de los Pinos Research Station, just like the data collection, is ongoing. The lack of storm events in 2019 limited the opportunity for the research effort to yield definitive results. Similarly, as of the writing of this document, the 2020 monsoon event is still occurring, and the events that occurred during this past July and August have data that is still being processed in preparation for analysis.

3.2.1 Bedload: Direct and Surrogate Measurements

For the bedload, a theoretical particle moving along the stream bed – rolling, sliding, saltating – would strike the housing for the microphone (pipe or plate), an acoustic signal would generate a small electrical pulse as a result of the contac, then continues downstream and fall into the slot sampler.

The answer to the primary research question – whether there is a strong statistical regression between surrogate measurements and definitive (direct) measurements of sediment transport in ephemeral systems – is, "not yet". A more substantive answer would have been available had there been storm events of appreciable magnitude in 2019. The current relationship between acoustic signal (impulses per minute) and bed load flux (kg per second per meter) is presented in Figure 3. This plot includes all available data for the left and right samplers, which each have a pipe microphone immediately upstream. The color-coded dots correspond to the D90 of the sediment in the slot samplers (the D90 is a percentile, e.g. 90% of the sampled sediment is smaller than this grain size). The data do not qualitatively appear to have any correlation and quantitatively have a regression coefficient R^2 of 0.32. Improvements to this regression are being actively explored, including investigating the acoustic amplification of the signal and considering other metrics of the GSD.

Figure 4 presents an example of different amplifications of the acoustic signal for the July 26, 2018 storm event. These amplifications are recorded during the storm event and are not derived in post-processing. The figure demonstrates more pulses being registered at higher amplifications. What is not shown in the figure are the higher amplifications (P256, P512, P1024) that are saturated; the amplified acoustic signal is confused by noise (there is a low signal-to-noise ratio) and data are not reliable.

The next step in improving the regression between acoustic response and bedload flux is to attempt to correlate different grain size categories to different acoustic amplifications. For example, the P128 amplification has ~350 pulses/min near time 00:00. Assume this represents all bedload that is very fine gravel (2-4 mm) and larger. Similarly, assume that fine gravel (4-8 mm) and larger is represented by the 175 pulses/min counted by the P64 amplification. Thus, there is 175 pulses/min (350-175) representing only the very fine gravel portion of the bedload. Then, the sediment flux for various grain sizes can be apportioned based on pulse counts using different amplifications.

Seismic devices are extremely sensitive instruments that can detect minor vibrations. Additionally, they can also detect a vehicle that drives by at a distance up to ¼ mile. Conceptually, these devices sense any and all vibration/sound within a given radius, and part of the challenge of these devices is separating vibrations caused by bedload with other signals (e.g. precipitation, turbulence in the flowing water, natural resonant frequency of the concrete sill, etc.). Figure 5 (top) presents spectrograms of the July 26th, 2018 flood event. The processing of these signals and comparing to the acoustic pipe microphone data provides the relationship shown in Figure 5 (bottom). Both plots are from Dietz (2019). The data analysis from this single seismometer is promising. The relevant potential information obtained from the array of seismometers (Figure AA- 11) as part of an NSF research grant is tremendously exciting.

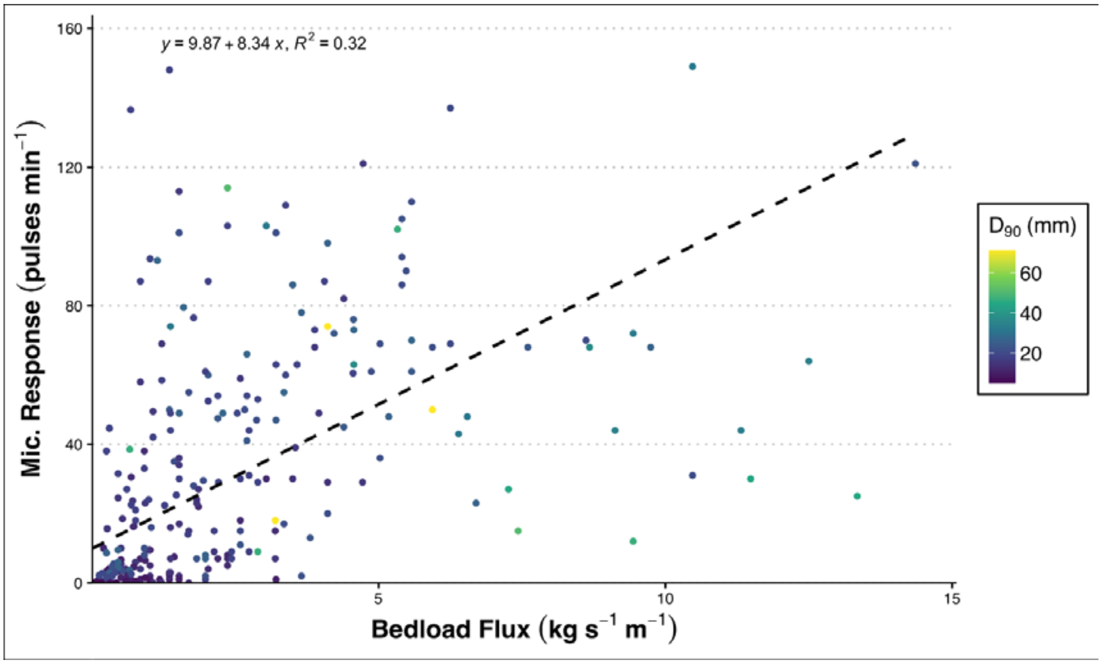

Figure 3. Initial correlation between pipe microphone response and bedload flux. Color coded dots represent different sediment sizes.

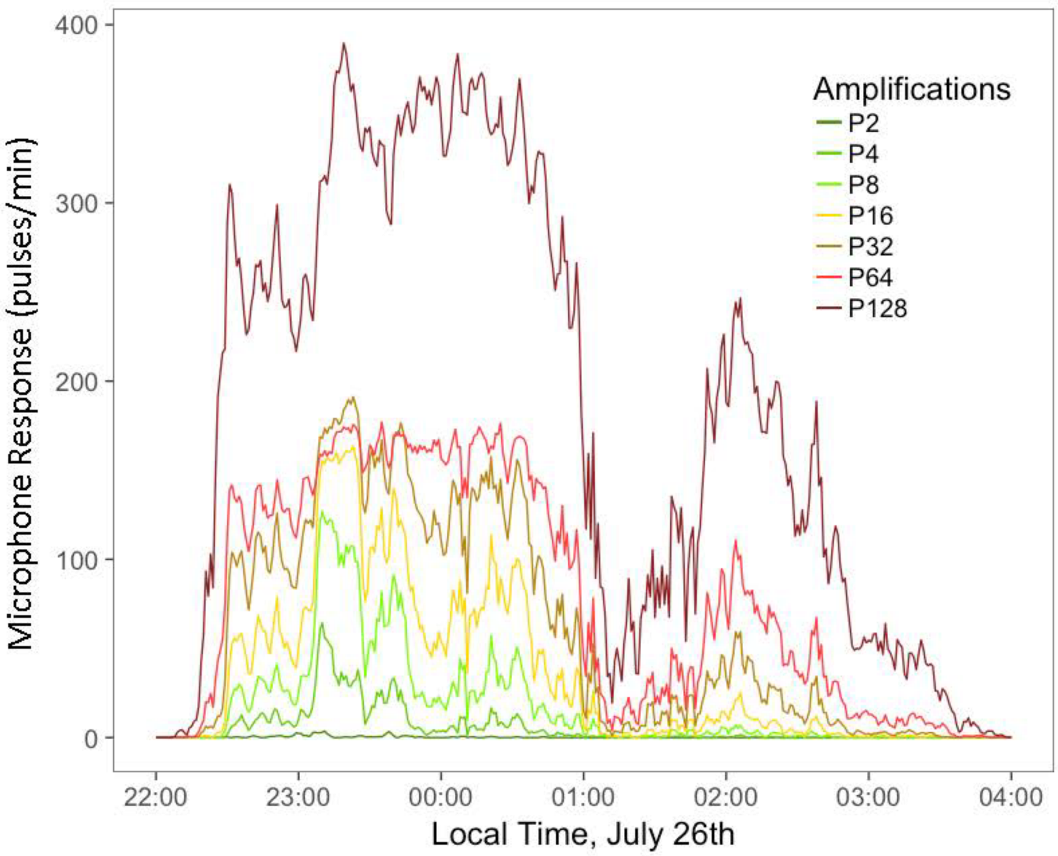

Figure 4. Time series of microphone response (in pulses per minute) during the July 26th, 2018 event at different amplification levels

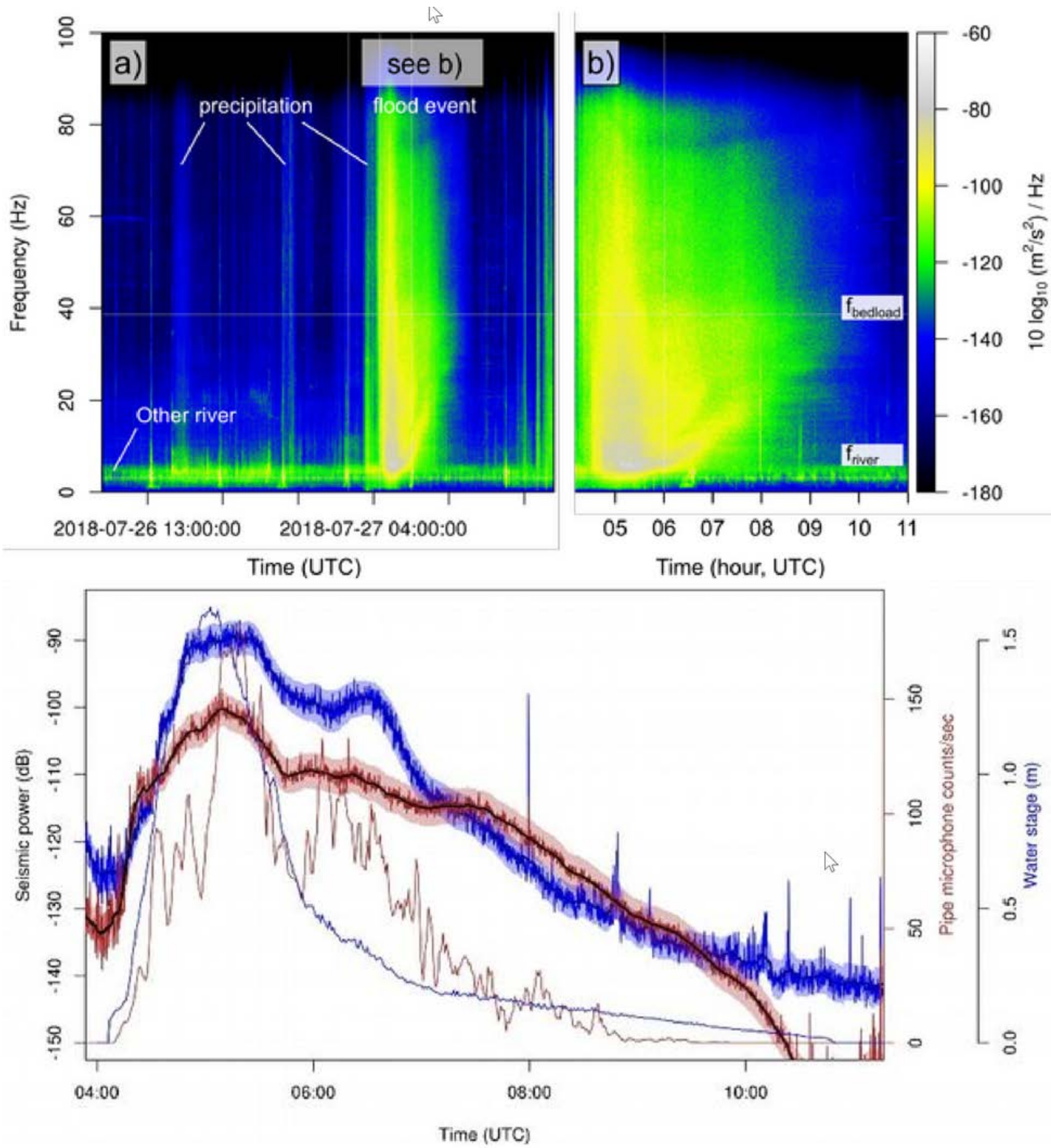

Figure 5 Seismic data collected during the July 26, 2018 event. Top Left: time series using color to map signal intensity at various frequencies and showing that precipitation is present in the data. Top Right: similar to top left except focusing on the time period of the flood event. Bottom: time series of seismic power, pipe microphone response, and water stage. The banded series are plotted on the left axis and represent power (dB) at different frequencies; a first approximation of those to be used for developing relationship to water (blue) and sediment (red) flux. Figures are from Dietz (2019).

3.2.2. Suspended Load: Direct and Surrogates

The established theory (Rasmussen et al. 2009) for suspended load is that higher concentrations of sediment increase the backscatter and attenuation of light, therefore optical measurements (turbidity) can predict concentration. The relationship between turbidity and SSC can vary widely depending on local site conditions, GSD of the suspended material, mineralogical content, particle shape, and concentration of organic matter. Correlation between direct and surrogate measurements for a given location can usually be improved with site-specific calibration. Figure 6 (top) presents the calibration of the instruments deployed at the Arroyo de los Pinos (Confab 950 turbidimeter) to samples developed using native material bank deposits mixed with known quantities of water to develop various concentrations.

The research question at hand is not so much the relationship between surrogate and physical measurements of suspended sediment, but rather if multiple calibrated turbidity sensors can account for SSC rich in sand. As mentioned, the GSD can affect instrument calibration, and typically suspended load in perennial streams are made up largely of silt- and clay-sized material. In contrast, ephemeral streams can have suspended sediment rich in the sand fraction. Sand sized material (especially coarser sand), in contrast to the silt and clay fraction, has a vertical concentration profile where higher concentrations are found near the bed and lower concentrations near the surface; silts and clays (and to a lesser extent very find sand) tend to have a more uniform vertical profile. To complicate matters, typical turbidimeters are not as sensitive to changes in sand-sized sediment concentrations as they are to fine-sized concentration changes. This research deployed pump samplers at two elevations to improve the understanding of the vertical concentration profile of suspended material.

Figure 6 (bottom) presents a plot of SSC during the July 16th, 2018 flood event obtained from the lower pump sampler, the upper pump sampler, and a DH-48 depth integrated manual sampler. Plots from other events show the similar behavior of higher concentrations at the lower sampler while the depth integrated sampler (which samples more of the water column, specifically above the elevation of the higher pump sampler) has a lower concentration than the upper and lower pump samplers. The data presented are all on the falling limb of the hydrograph; the flood bore arrived very quickly and the hydrograph peaked while the system was coming online in preparation to collect data. Even though there is variation between the upper (45 cm above the bed) and lower (10 cm above the bed) SSC, the difference is less than expected. This can be explained by the GSD of the sampled suspended sediment. During the 2018 monsoon season, 40% of the suspended material was silts and clays (<0.0625 mm) and 25% was very fine sand (0.0625-0.125 mm). This means that nearly two-thirds of the material in suspension is in the range expected to be carried evenly in the vertical dimension by turbulent eddies. In comparison, samples of the dry riverbed demonstrate approximately 5% silt and clay material and approximately the same amount of very find sand (0.0625-0.125 mm). The amount of fine material in the suspended sediment was surprising because, based on the nature of ephemeral streams, the assumption made was that any fine material in suspension would deposit on the bed during the flood recession. For reference, it is not uncommon for perennial streams to have a marked difference between bed material GSD and suspended material GSD, largely due to the continual streamflow that continues to carry the silts and clays downstream. However, for an ephemeral stream lacking continuous streamflow, where else would the suspended silt and clay material go other than to deposit on the bed during flood recession? One theory is that the fine material dries out and is removed from the bed by aeolian transport between storm events, but this theory has not been tested.

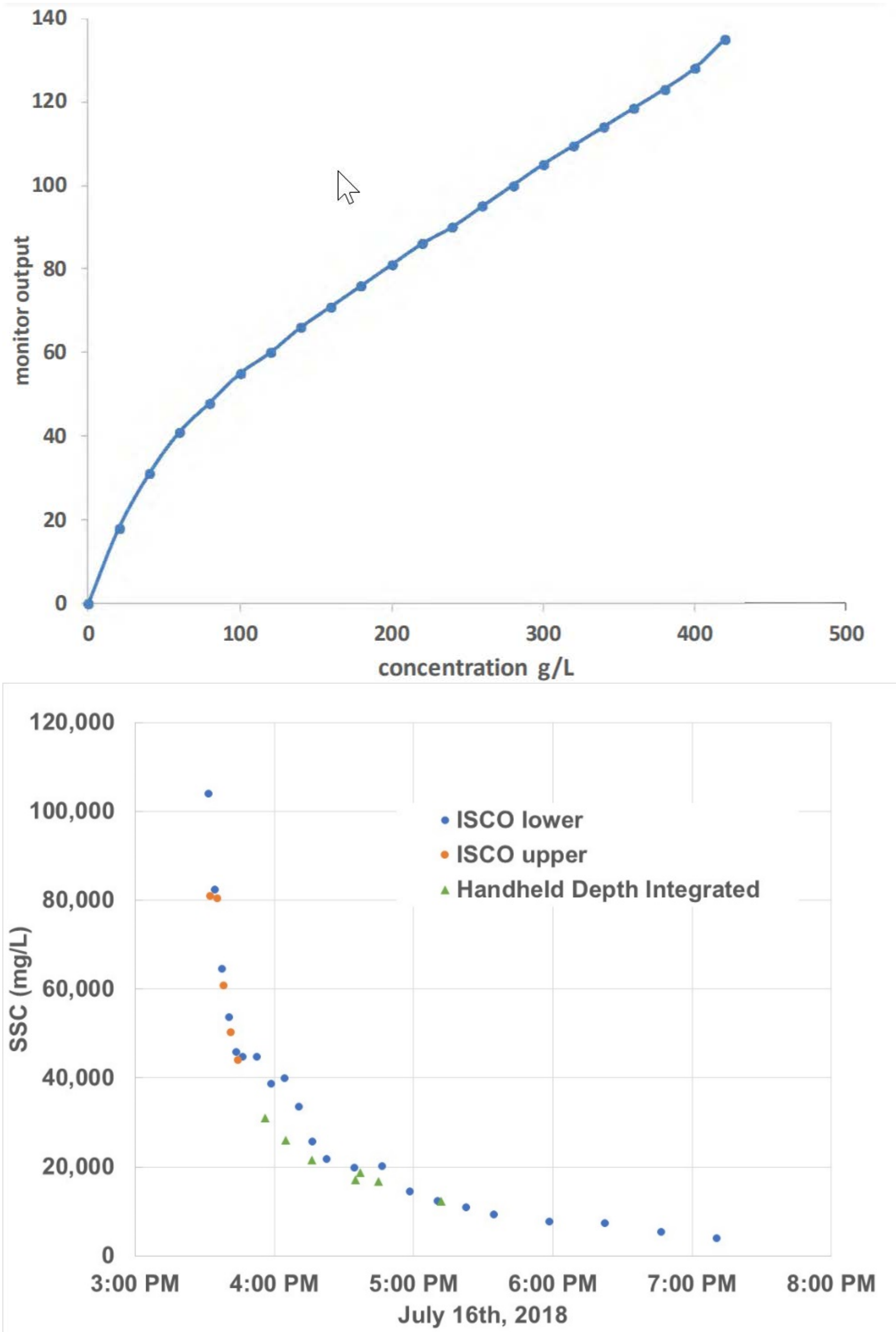

Figure 6 Suspended load data. Top: calibration curve of the Confab 950 turbidity meter. Bottom: comparing SSC collected by the upper pump sampler, the lower pump sampler, and the handheld depth-integrated sampler.

3.2.3. Velocity Measurements.

A camera for Large Scale Particle Image Velocimetry (LSPIV) was deployed in preparation for the 2019 monsoon season. The camera did obtain imagery from the three events during the 2020 season, but no data has been processed from the LSPIV yet as there were no flow events in 2019. In addition to LSPIV, velocity measurements were made with a surface velocity radar (SVR) instrument and a hand-held acoustic doppler velocimeter (ADV). The SVR is a non-contact instrument that can measure the surface velocity (as does the LSPIV) and the ADV involves wading in the river and being able to measure velocity at different depths to obtain a depth-averaged velocity. The SVR provides a surface velocity for a relatively small location as compared to the LSPIV, which provides surface velocity for the domain of the imagery. Comparing the LSPIV results at the same location as where the SVR measurements were made will allow for an assessment of LSPIV accuracy, and a comparison of both surface velocity measurements to ADV measurements will allow for knowing the ratio of surface velocity to depth-averaged velocity, such that an estimate of discharge can have improved accuracy.

4. Partnerships

The strength of this research lies with the partnerships that have been developed surrounding the research.

- **Albuquerque Area Office (Reclamation)**. AAO has been instrumental in the design, permitting, contracting, and construction of this site. The staff at the AAO have been involved going back to site selection during the previous S&T project (9781), provided funding for the PI of this research project, developed the project description, created the design drawing required for construction, conducted all NEPA related investigations and documentation, obtained necessary land access and permitting, completed the contracting to hire the construction company, and will perform necessary QAQC as construction progresses. They also repaired the Pinos Research Station after a significant flood event (July 2018) damaged the gabion baskets on the left bank of the channel.
- **New Mexico Institute of Mining and Technology (NMT).** Both the Department of Earth and Environmental Science (DEES) as well as the Seismic Observatory are providing in-kind services towards this project. The DEES have been, and will continue to be, the on-site manager and instrumentation steward, ensuring the site is functional and prepared for data collection during storm events, as well as managing data collected and recorded at the site. Manual sediment sampling during runoff events were conducted by DEES, which help to validate the automated data collection systems. Reclamation has provided funding to NMT through a Cooperative Agreement to partially fund multiple graduate student (co-supervised by Dr. Daniel Cadol) in this department. The NMT Seismic Observatory (Dr. Sue Bilek) is involved in the deployment of seismic devices that can be used to collect additional surrogate data during a bedload-moving runoff event. This is a relatively new application of seismic devices and the department continues to coordinate with the GFZ and IRIS. NMT has hosted Dr. Jonathan Laronne (BGU) during the summers of 2016-2019 while he teaches the students regarding sediment transport theory, on-site data collection

techniques, and data analysis. Dr. Laronne is co-supervisor to all the graduate students working on the Arroyo de los Pinos Research Station.

- **Local landowners.** Several local landowners have shown an interest in, and are supportive of, the project. One notable landowner is Mr. Bill Holms, who is not only supportive of the project but is also providing portions of his property for access to the Pinos Research Station.
- **Ben Gurion University of the Negev (BGU).** Dr. Laronne is one of the premier researchers in the field of surrogate measurements of bedload transport. Dr. Laronne designed the instrumentation and construction specifically for the flashy nature and sediment size distribution of this site to ensure that project goals are achieved. Helping to identify the monitoring reach in previous visits, he spent the summers of 2016-2019 in Socorro to oversee see the design process through construction (S&T Project ID 9781) as well as providing ongoing mentorship and to co-supervise graduate students.
- **U.S. Army Corps of Engineers (Corps), Albuquerque District**. The Corps has contributed significant funding to this project ($100,000) over the last three years. This is in addition to the $55,000 contributed to the project in FY17 (S&T Project ID 9781). The Corps continues to partner with Reclamation on this research effort; a proposal has been submitted by Jonathan Aubuchon (Regional Sediment Specialist, Albuquerque District) to their internal research office to further the Corps involvement.
- **Rishin Hydrotech.** Mr. Michinobu Nonaka continues to provide upgrades and repairs to the pipe and plate microphones he designed and supplied to the project under S&T Project 9781. His knowledge continues to guide methods that push the envelope of smallest detectable grains that can be detected by these types of instruments.
- **Yamma & Ayyeka Companies.** A state-of-the-art hydraulic-hydrologic transmitting system based on US, Japanese, German, UK, Australian and Israeli components has been assembled by these groups at the direction of Yaniv Munwes. All data (except seismic) is transmitted via cellular signals so that the system can be monitored remotely and data, including bedload discharge, can be observed in real time. Mr. Munwes continues to provide support and training on proper care and operation of the system. He made a site visit to the Arroyo de los Pinos during the summer of 2019 to check on the system and interact with the student's and advise them to improve their practices and maintenance of the system. This visit in 2019 and his time was covered by his own care for the project and not funded by U.S. government.
- **GFZ German Research Center for Geosciences.** The use of seismic devices as a means to collect surrogate bedload data is a relatively new field. Jens Turowski with the GFZ is a leader in this field, conducting research and publishing papers on the topic. He and his colleague Michael Dietze have been involved in designing the system currently deployed at the site. Dr. Dietze has provided an initial analysis of the single-node seismic data collected in 2018 and is currently working on the data collected in 2020.
- **University of Grenoble Institute of Environmental Sciences / CNRS.** Florent Gimbert is also a leader in the field of seismic devices being deployed to sense bed load transport in fluvial systems. He helped design the network of seismic devices currently deployed at the site (funded by NSF) and co-authored a SedHyd paper (see Section 4).
- **The Incorporated Research Institutions for Seismology (IRIS).** This consortium of universities across the U.S. is dedicated to seismological data acquisition, management, and distribution. They are working with NMT, GFZ, and the University of Grenoble under the

NSF-supported research regarding the array of seismometers deployed at the Arroyo de los Pinos in assessing the performance of using this technology as a surrogate measure of bedload.

- **United States Geological Survey.**
    - California Water Science Center. A portable hydrophone system has been developed by scientists in this group, and they are testing it in a variety of streams. Dr. Mathieu Marineau worked with NMT in deploying one of their systems at our site, to expand the range of conditions to which their system is exposed, evaluating its applicability to an arid, ephemeral drainage basin.
    - New Mexico Water Science Center. Unique measurement systems for deployment in local drainage basins have been devised by this office in the past. Designing a system for this research site is ongoing.
    - The USGS Office of Surface Water has shown interest in collaborating in this long-term project. Representatives of the OSW attended the stakeholder/partner meeting during the last week in October 2017.
- **New Mexico Bureau of Geology**. Repeat micro-gravity surveys of the drainage have been conducted to inform infiltration rates and groundwater recharge processes.

5. Conference Proceedings, Theses and Publications

The work being done at the Arroyo de los Pinos has been represented at a variety of conferences in the last few years. Two Master of Science (M.S.) theses have been completed, another is currently being developed, and a PhD doctoral thesis is also being developed. An article is currently being prepared for inclusion in a peer-reviewed technical journal and will be ready by the end of this calendar year. A list of conference papers, theses, and publications funded by the Arroyo de los Pinos research is presented. All proceedings from SedHyd 2019 are available on the website (https://www.sedhyd.org/2019/proceedings/).

Cadol, D., Stark, K., Laronne, J.B., Varyu, D. & Richards, M., 2019. "Bedload flux and characteristics from flash floods in the Arroyo de los Piños, NM – initial results" SedHyd2019, Federal Interagency Sedimentation and Hydrologic Modeling Conference. June 2019, Reno NV.

Dietze, M., Gimbert, F., Turowski, J.M., Stark, K., Cadol, D. & Laronne, J.B., 2019. "The seismic view on sediment laden ephemeral flows – modelling of ground motion data for fluid and bedload dynamics in the Arroyo de los Piños" SedHyd2019, Federal Interagency Sedimentation and Hydrologic Modeling Conference. June 2019, Reno NV.

Laronne, J.B., Stark, K. Cadol., D., Varyu, D. & Richards, M., 2019. "Initial analysis of suspended sediment concentrations during flash floods on the Arroyo de los Piños, NM" SedHyd2019, Federal Interagency Sedimentation and Hydrologic Modeling Conference. June 2019, Reno NV.

Marineau, M. et al., 2019. "Portable Hydrophone System" SedHyd2019, Federal Interagency Sedimentation and Hydrologic Modeling Conference. June 2019, Reno NV.

Pimentel, S. (2021). Changes in bed morphology and sedimentology of confluences of ephemeral tributaries and the Rio Grande. New Mexico Institute of Mining and Technology (in production).
Richards, M. (2020). Rainfall-runoff relationships in the Arroyo de los Pinos Socorro New Mexico. New Mexico Institute of Mining and Technology (unpublished thesis). 85p.
Richards, M., Cadol, D., Laronne, J.B., Stark, K., Brown, S., "Rainfall-runoff relationships at the Arroyo de los Piños, Socorro, New Mexico" AGU Fall Meeting 2019
Richards, M., Cadol, D., Laronne, J.B., Stark, K., Varyu, D., "SedHyd2019, Federal Interagency Sedimentation and Hydrologic Modeling Conference. June 2019, Reno NV.
Richards, M., Cadol, D., Stark, K., Laronne, J.B., Varyu, D., "Rainfall-Runoff Relationships Complementing Previous Sediment Transport Studies at the Arroyo De Los Piños, Socorro, New Mexico" 2019 New Mexico Geologic Society Spring Meeting
Stark, K. (2018). A two-year study of flash flood characteristics in New Mexican and Israeli ephemeral channels. New Mexico Institute of Mining and Technology (unpublished thesis). 63 p.
Stark, K., "Evaluating the Grain Size of Bedload Transported from Arroyos into the Rio Grande". 2019 Middle Rio Grande Endangered Species Collaborative Program Symposium
Stark, K., Cadol, D., Laronne, J.B., Varyu, D., Halfi, E., Richards, M., "How sand travels – first field measurements from a sand-rich gravel bedded ephemeral channel" AGU Fall Meeting 2019
Stark, K., Cadol, D., Laronne, J.B., Varyu, D., "Event-Scale Geomorphic Change Evaluated Alongside Sediment Transport Measurements in a Flood-Driven Ephemeral Channel" GSA Annual Meeting 2019
Stark, K., Cadol, D., Laronne, J.B., Varyu, D., Halfi, E., Richards, M., 2019. "Initial Calibration of Acoustic Pipe Microphone Sensors to Monitor Bedload During Flash Floods in the Arroyo de los Piños, NM.," SedHyd2019, Federal Interagency Sedimentation and Hydrologic Modeling Conference. June 2019, Reno NV.
Stark, K., Cadol, D., Laronne, J.B., Richards, M. "Sediment Flux and the Acoustic Characteristics of Bedload in the Arroyo De Los Piños, NM" 2019 New Mexico Geologic Society Spring Meeting
Stark, K., Cadol, D., Laronne, J.B., Varyu, D., 2018 "Initial Evaluation of the Effect of Grain Size on Novel Bedload Monitoring Methods in Ephemeral Channels" AGU Fall Meeting 2018
Stark, K., Cadol, D., Laronne, J.B., Varyu, D., Richards, M., 2018 "Initial calibration of acoustic pipe microphone sensors to monitor bedload during flash floods in the Arroyo de los Piños, NM" 2018 NM Water Resources Research Institute Water Conference. October 2018, Las Cruces, NM
Stark, K., Cadol, D., Laronne, J.B., Varyu, D., Richards, M., 2018 "Novel bedload monitoring technologies applied to during flash floods in ephemeral tributaries of the desert Southwest" 2018 Binghamton Geomorphology Conference. October 2018, Syracuse, NY
Stark, K., Cadol, D., "Evaluating Sediment Transport in Flood-driven Ephemeral Tributaries" 2018 New Mexico Geologic Society Spring Meeting
Stark, K., Cadol, D., Laronne, J.B., Varyu, D., Gimbert, F., 2017 "Evaluating Sediment Transport in Flood-driven Ephemeral Tributaries Using Direct and Acoustic Methods" AGU Fall Meeting 2017
Stark, K., Laronne, J.B., Cadol, D.,Varyu, D. (2020). Direct, continuous measurements of sediment transport from a sand-rich gravel-bed ephemeral river (in production)
Varyu, D., Laronne, J.B., Cadol, D., Padilla, R., Lampert, A., Stark, K., Scissions, S., AuBuchon J.A., Munwes, Y., 2019. "Monitoring the Transport of Sediment in an Ephemeral Stream"

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6. Summary, Conclusions, and Next Steps

A world-class facility for monitoring sediment transport in an ephemeral stream exists in the Arroyo de los Pinos watershed in Socorro, New Mexico. The site has been developed and constructed using public funds from the federal level and graduate student funding has been provided at both the state and federal levels. The importance of this research is demonstrated by the partnerships developed and the collaboration across many federal, state, and local entities, both public and private.

A new three-year research proposal has been submitted to Reclamation's Science and Technology Program where sediment flux monitoring would continue, and an additional partnership would be entered into with the Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA). Multiple discussions have occurred with SSCAFCA already, and the project is looking to utilize existing infrastructure to deploy additional instruments that can be used to test hypothesized sediment flux rates based on local site conditions.

The Albuquerque District of the Corps of Engineers has submitted a research proposal to fund the deployment of a mobile bed discharge (MoBeD) gage at the Arroyo de los Pinos and process the collected data. This is a single-year proposal with a funding amount request of $176,000, which includes a MIPR to the USGS for $60,000.

New Mexico Tech has submitted a proposal for funding consideration to the ERDC Broad Agency Announcement (BAA). The proposal amount to the BAA is approximately $300,000, and similar to the Reclamation S&T proposal, would largely go to graduate student tuition for performing specific tasks, including validating HEC-RAS sediment transport modules with data collected at the Arroyo de los Pinos Research Station.

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Appendix A

Photolog of data collection instrumentation.

Figure AA-1 Overview of the sediment research station at the Arroyo de los Pinos. Flow direction is left to right. Concrete sill contains three Reid-type slot samplers, three active acoustic devices (two pipe microphones and one plate with microphone and geophone), and two blockouts for additional instruments. A red stilling well on the right bank contains additional instruments (see below). A concrete vault (not shown) houses the data loggers, batteries, pump samplers, and other equipment.


Figure AA- 2 Left: Pipe microphone upstream of Reid-type slot sampler. This is the left sampler, and right sampler is similar. Right: Plate with microphone and geophone upstream of center sampler. All slot sampler openings have adjustable widths.


Figure AA- 3 Right bank of the sediment research station. Two perforated pipes protruding from the stilling well are each oriented downstream and house the an optical turbidimeter and the intake end of suspended sediment sampler. Two pipe microphones downstream of the stilling well (one vertical, one horizontal) are positioned in investigate the vertical concentration profile of suspended sediment. A pressure transducer is mounted inside the stilling well to measure stage during storm events.

Figure AA- 4. Crane and gurney system for removing the inner metal box from the recessed concrete vault. Each metal box sits atop a pressure pillow that monitors the rate at which each box fills during a storm event. Kyle Stark operating equipment.

Figure AA- 5 Side door of inner metal box is open, exposing the bed load deposited during a storm event. Sediment is sampled in layers and grain size distributions are performed on each sample. After samples are collected, boxes and vaults are cleaned, boxes replaced in vault, cover is installed, and box is filled with water in preparation for next storm event.

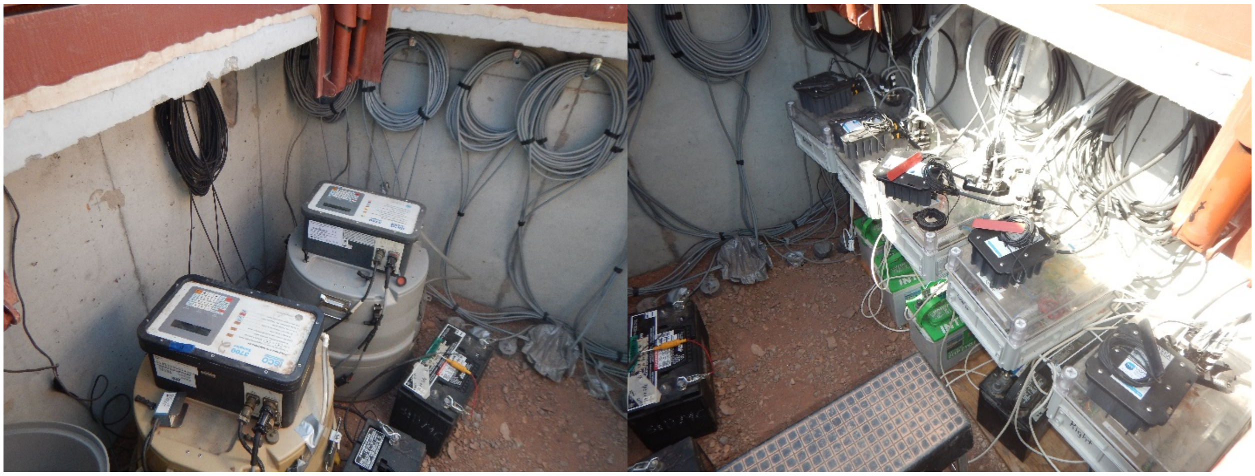
Figure AA- 6 Inside the concrete vault on the high right bank. Left: ISCO pump samplers collect suspended sediment samples. Right: batteries and data collectors for pressure pillows, acoustic devices, and pressure transducers.


Figure AA- 7 Up-basin instrument deployment. Left: Pressure transducer to measure flow depth in an up-basin channel installed by Madeline Richards. Right: weather stations for measuring precipitation and wind speed.

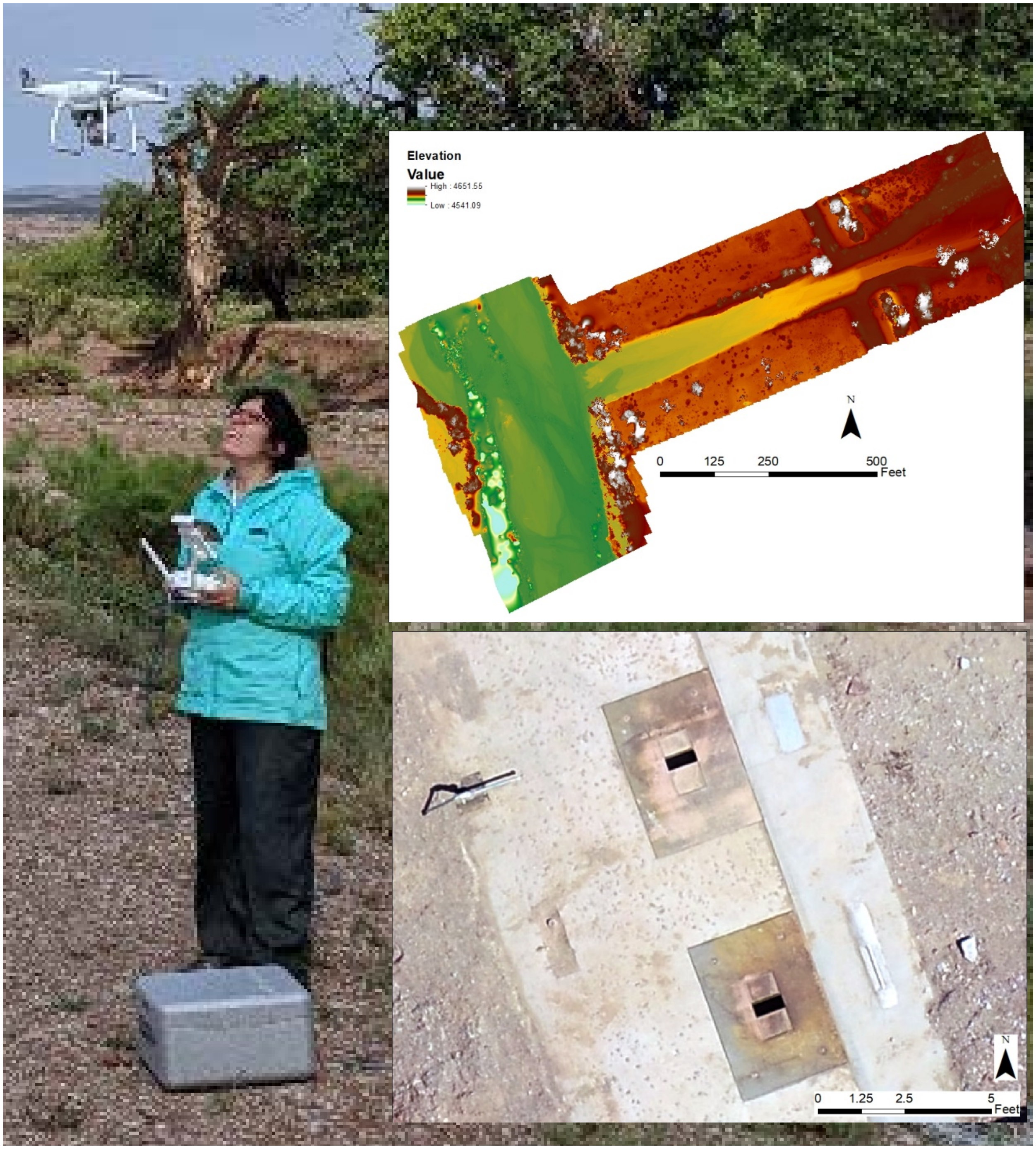

Figure AA- 8 Drone flights collect imagery and LiDAR data to develop a Digital Elevation Model (DEM) after each flood event. Sharllyn Pimental operating drone. Top inset: digital elevation model of the Arroyo de los Pinos confluence with the Rio Grande. Bottom inset: high resolution imagery showing the left and center slot samplers.

Figure AA- 9 The July 26th, 2018 was estimated to be a 25-year return interval storm (Lampert and Everetts, 2018). A 'turndown' section of the concrete sill was designed to protect the facility from a headcut propagating from the downstream, which is exactly what happened during this storm (top). The gabion baskets on the left bank were damaged, and the AAO provided a grouted riprap fix (bottom).

Figure AA- 10 Relevant instrument deployments at the Arroyo de los Pinos from associated researcher. Top Left: Passive acoustic hydrophones mounted on both banks as directed by Matthieu Marineau, California Water Science Center (USGS); the left bank deployment is shown with Kyle Stark, PhD student after installation. Top Right: One seismic measuring device (node) that is part of a ~30-devices array. Bottom: array of deployed seismic nodes at the site. Background image does not show the Research Station, which is located near nodes 2113 and 2114.