RECLAMATION

Managing Water in the West

Field Deployment of a Continuous Suspended Sediment Load Surrogate

Research and Development Office
Science and Technology Program
Final Report ST-2016-7839-1

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Mission Statements

Protecting America's Great Outdoors and Powering Our Future

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

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Rivers have captured our imagination for centuries. The relationship between the movement of water and sediment create complexities that refresh our souls, pique our interest, and demand our attention. The study and understanding of complexities, such as sediment transport, requires the collection of data. Over the decades, the techniques for collecting sediment data have been refined and more recently surrogate techniques have expanded the temporal range of the collected data. One of the more promising surrogate technologies is active acoustics, which have been successfully tested in a variety of fluvial environments, including gravel and sand bed rivers, where morphological changes are minimal. Application of this technology to shallow sand bed rivers though has been limited to areas where the local geology provides a sufficient flow depth at various discharge stages and the local morphology is stable. A site was identified on the Middle Rio Grande that provided the opportunity to explore the robustness of the developed technology in recording continuous suspended sediment data in an environment where the morphology is not stable. Challenges were present in implementation of the developed technology, but with some caveats the developed technology can be utilized in shallow sand rivers with changing morphology.

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Field Deployment of a Continuous Suspended Sediment Load Surrogate

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Notices

The opinions and results described in this report do not necessarily represent the official views of the U.S. Army Corps of Engineers, the U.S. Geological Survey, the University of Mississippi, or the Bureau of Reclamation. Mr. Jonathan AuBuchon, though currently employed by the U.S. Army Corps of Engineers, initiated and conducted this research through conception and field deployment. Dr. Posner took over as PI and helped evaluate the collected data and complete the final report.

Acronyms and Abbreviations

AAO – Albuquerque Area Office

ARS-NSL – Agricultural Research Service National Sedimentation Laboratory

cfs – cubic feet per second

cm – centimeter

dB – decibels

D_{50} – median grain size for which 50% of the mass is finer

DSP – digital signal processor

EDI – Equal Discharge Interval

EWI – Equal Width Interval

ft – feet

FISP – Federal Interagency Sedimentation Project

g – gram

GCMRC – Grand Canyon Monitoring and Research Center

HDD – Hard disk drive

HEC-RAS – Hydrologic Engineering Center's River Analysis System

L – liter

lbm – pounds mass

lb(s) – force-pound(s)

MHz – MegaHertz

mm – millimeter

µm – micrometer

MRG – Middle Rio Grande

MS – Mississippi

NCPA – National Center for Physical Acoustics

NM – New Mexico

NMWSC –New Mexico Water Science Center

RGSM – Rio Grande Silvery Minnow

sec – second

SD – secure digital flash memory card

SC – suspended sediment concentration

TSD – Technical Service Division

USACE – U.S. Army Corps of Engineers

USB – universal serial bus

USDA – U.S. Department of Agriculture

USGS – United States Geological Survey

Executive Summary

Sediment plays an important ecological function in water bodies throughout the United States. Too much or too little sediment can cause problems on riverine systems that not only impair the riverine ecosystem, but also engineering systems, such as dams, reservoirs, water diversions, etc. For this reason the transport of sediment in rivers (how much, when, where, etc.) is a critical question for managers concerned with river restoration, irrigation and water diversion projects, water storage, and water quality (Fripp, Visser and Hoeft 2019, Kuhn, Tracy and Walker 2019, Leonard, et al. 2019, Travis, Basyal and Wahlin 2019). To understand the relationship between water and sediment requires the collection of data, facilitating a greater understanding of the system being managed. How sediment is transported in rivers, through irrigation facilities, and into and through reservoirs is a growing area of interest for Reclamation and other managers of large reservoirs (Hajimirzaie, Ansar and Zeng 2019, Raitt 2019, Randle, et al. 2019, Shvidchenko and Hall 2019, Wegner 2019, Crouch, et al. 2019).

Active acoustic measurements have been successfully utilized for suspended sediment measurements on larger fluvial systems (Wood and Teasdale 2013, Topping, Wright and Griffiths, et al. 2015, Topping and Wright 2016) where the influences of the bed morphology are not as influential on the suspended sediment concentrations. Testing on shallow, sand bed rivers (10 feet or less) though has been limited to areas where the local geology provides a sufficient flow depth at various discharge stages. The objective of this research endeavor was to see if current acoustic configurations would work in shallow, sand bed rivers where bed adjustments can occur which may affect acoustic measurements.

The research proposed a test site on the Middle Rio Grande (MRG) near San Acacia, NM and provided options to explore testing on other fluvial systems (such as the San Juan River) if testing at the San Acacia site went well. Two different active acoustic setups were utilized at the San Acacia site. A single frequency acoustic system (20 MHz) for collecting suspended sediment concentrations for fines (suspended sediment < 0.0625 mm) was developed by University of Mississippi, National Center for Physical Acoustics (NCPA) for a long term deployment at this site. A dual frequency method was also implementedat the site with 1 MHz and 2 MHz devices manufactured by AquaDopp. These three acoustic instruments were calibrated using physical suspended sediment measurements collected at the existing U.S. Geological Survey (USGS) gaging station at San Acacia (ISCO® pump samples and cross sectional Equal Width Interval (EWI) samples).

While ideally the acoustic instruments would be inundated throughout the year, if the instruments collected floating debris, were buried by the bed sediment, or the acoustic signal encountered interference with bed or water surfaces in close proximity to the device as the stream bed aggraded or water surface lowered then data collection would be limited. Expertise from the USGS New Mexico Water Science Center (NMWSC) was utilized in the final mounting design, to situate the instruments a certain distance from the right bank (looking downstream) and a set height above observed base flows. While this positioning would not allow data collection during low flow periods, it was felt to be more desirable for this research to be able to continuously collect the suspended sediment information during the larger discharge events, when it is known, anecdotally, that the sediment on the bed is active.

The AquaDopps were installed in April 2016 and operated more or less continuously until the conclusion of this research in July 2019. The NCPA acoustic instrument was installed in July 2017 and operated intermittently through July 2019. Both instruments were found to be good estimators of the suspended sediment concentrations, providing a more temporally robust dataset than would have been collected with only the physical measurements.

From the collected suspended sediment measurements, a better understanding of the timing, magnitude, and duration of the suspended sediment on the MRG at San Acacia, NM was developed. From the collected acoustic information it was observed that more sand sized particles are moved during the spring snow-melt runoff than at other time periods. From the collected acoustic information, there appears to be a continuous discharge threshold of around 1,500 cfs to mobilize the sand particles. Fine particles tend to dominate during the rest of the year and are also dominant on the rising and falling limb of the spring snow-melt runoff. Suspended sediment concentrations tend to peak before the discharge peak (clockwise hysteresis) on the two spring snow melt runoffs observed between 2016 and 2019. Monsoon flows showed more variability with discharge of the suspended sediment measurements. Both clockwise (sediment peak before the discharge peak) and counterclockwise hysteresis (sediment peak after the discharge peak) were observed in the collected monsoon event data. Collected base flow information suggested higher suspended sediment concentrations in January than February.

Acoustical measurements (AquaDopps) also provided median sand suspended sediment size information, revealing a larger scatter during base flow events (November through February), on the rising and falling limbs of the spring snow-melt runoffs, and during monsoon events. During the two spring snow-pack runoff events observed during this research period, the median sand size was around 0.15 mm. Because of the differentiation of particle size, the AquaDopps also provided the ability to assess sediment load contributions. The sand fraction of the suspended sediment load contribute more to the cumulative suspended sediment load during the spring snow-melt runoff and the fines (suspended sediment fraction less than 0.0625 mm) contribute more during the monsoonal events. A more or less constant (straight line) transport of fine suspended sediment was also observed during the entire year outside of the monsoon season, which tends to have a markedly steeper slope.

In this regard the acoustic instruments, especially the AquaDopps, installed at the San Acacia site indicate that the developed acoustic technology on larger river systems is applicable on shallow, mobile bed systems like the MRG. The collected data was not always continuous though, often a result of the mounting decision. Large time periods exist when there is minimal flow in the river and the acoustics were above the water surface elevation and thus no information could be collected. This is a limitation of the use of acoustics on shallow, mobile bed fluvial systems that precludes the data collection to periods above a given discharge.

Even when the AquaDopps are submerged, no data may be collected if an insufficient horizontal collection distance is acquired prior to the outgoing acoustic signal reflected by a shallow water covering or a depositional bed form that raises the channel invert. This may be one of the reasons the AquaDopps didn’t collect data during hydrologic events that had a water surface elevation that was known to have submerged the instruments. While there were some limitations with the AquaDopps in the collection of longer duration discharges (most notably the 2019 spring snow-melt runoff), the flashy, short duration monsoon events were also problematic. Only a fraction of the monsoon events were captured, and those that were captured by the AquaDopps often underrepresented the suspended sediment concentration observed from the collected physical measurements.

The NCPA acoustic instrument only collected data from 13 events between 2017 and 2019. Power issues and file storage protocols were the primary reasons that additional data was not collected. In many cases, the collected NCPA acoustic data could be compared to physical samples and often to the AquaDopps. Estimated suspended sediment concentration from the NCPA acoustic instrument correlated well with the trends of the physical samples, though often over-estimated the suspended sediment concentrations. Different gradations of sediment in suspension passing by the instrument than what was present during the calibration process may be responsible for this over-estimation. Other possible reasons for this include: the system getting buried, debris collecting on the apparatus, and system malfunctions due to intermittent power. Due to issues experienced with the NCPA acoustic instrument, efforts were focused on improving the design rather than on deployment to another fluvial system.

When acoustic systems were functioning, the active acoustics provided a good estimator of the in-situ suspended sediment concentrations. The additional temporal resolution provided the ability to better understand the transport of suspended sediment on the MRG at San Acacia. In fact, utilization of the suspended sediment measurements from the acoustics indicates that traditional methods of estimating the suspended sediment from discharge measurements may under predict the cumulative suspended sediment load and the sediment concentrations during larger flow events, while over predicting the suspended sediment moved during low flow periods. This provides additional insight into the timing of sediment movement that is important in the creation of transitory sediment features, like low elevation bars, where the Rio Grande Silvery minnow (RGSM) have been found (Dudley and Platania 1997, Mortensen, et al. 2019).

In the long term, more continuous acoustic data sets and accompanying physical samples will provide an understanding of the sediment transport in the river better than the discrete information currently acquired. This research encompassed a 2.5 year monitoring effort, for which both spring snow-melt runoffs and monsoon events were observed. More events measured at the San Acacia site will enhance the predictive capabilities of the active acoustics by providing a larger dataset as well as greater suspended sediment concentration ranges for which to calibrate the instruments. Moreover, deployments at other sites on the MRG will provide additional insight into the movement of suspended sediment within the system. And deployments on other fluvial systems, such as the San Juan River or the Platte River, would provide more robust data collection methods, better mounting configurations, and potentially more general sediment active acoustic models.

Issues still needing to be resolved for the NCPA acoustic data collection to provide more continuous data sets primarily involve file download time and overall data acquisition stability. There are several potential work arounds that have been suggested, but all of these need to be investigated, programmed, and tested in the field. Currently the NCPA acoustic instrument is set to measure only fines (particles less than 0.0625 mm). It is possible that the NCPA acoustic system could be modified to measure suspended sand-sized particle concentrations. This could be accomplished by adding an orthogonal transducer in the down-facing position. This would be in addition to the original 20 MHz transducer and the 10 MHz transducer added to modify the NCPA acoustic instrument during the research period. The new transducer would operate at a lower frequency (i.e. 1 MHz) and could measure the backscattered signals from the larger silt and sand sized grains. Using these three frequency approach, the calibrated acoustic surrogate device would allow researchers to measure clay, silt, and sand grains in the same water column.

For the AquaDopps, additional exploration of why data was not collected when the instruments were covered with water would help to develop more robust data processing steps. Exploration of the infrequent monsoon data collections and the observed under representation of the monsoonal suspended sediment concentrations would also be useful. It may be that there is an upper bound on the suspended sediment concentrations that can be measured from the AquaDopps.

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Background

Sediment plays an important ecological function in water bodies throughout the United States. Too much or too little sediment can cause problems on riverine systems that not only impair the riverine ecosystem, but also engineering systems, such as dams, reservoirs, water diversions, etc. For this reason the transport of sediment in rivers (how much, when, where, etc.) is a critical question for managers concerned with river restoration, irrigation and water diversion projects, water storage, and water quality (Fripp, Visser and Hoeft 2019, Kuhn, Tracy and Walker 2019, Leonard, et al. 2019, Travis, Basyal and Wahlin 2019). To understand the relationship between water and sediment requires the collection of data, facilitating a greater understanding of the system being managed. How sediment is transported in rivers, through irrigation facilities, and into and through reservoirs is a growing area of interest for Reclamation and other managers of large reservoirs (Hajimirzaie, Ansar and Zeng 2019, Raitt 2019, Randle, et al. 2019, Shvidchenko and Hall 2019, Wegner 2019, Crouch, et al. 2019).

Reclamation's mission is the management of water and related resources. Dams, levees, and canals, have all been built to store and deliver water to Reclamation's stakeholders. And the operational life and management cost of these facilities is often affected by sediment (Randle, et al. 2019, Wegner 2019). Reclamation's vision also includes the protection and preservation of the natural ecosystems, which is also dependent upon the management of sediment (Leonard, et al. 2019). These concepts are embodied in mission areas 1 (Protecting America's Landscapes) and 2 (Sustainably Manage Energy, Water, and Natural Resources) of the Department of Interior's Strategic Plan (DOI 2011). Moving forward on how to best address these concepts raises the question of how to manage sediment – a question that is best answered with both temporally and spatially robust data sets that provides a greater understanding of the quantity, type, and timing of the sediment moving in a system. An ideal supported by the Department of Interior's Strategic Plan (mission area 6 – Provide a Scientific Foundation for Decision Making).

Direct sampling methods have been developed over the decades to fill this data need (Davis 2005, Edwards and Glysson 1998, Gray and O'Halloran 2015, Gray and Simoes 2008), but they are costly and it is difficult to obtain the temporal resolution needed to answer many questions. Conventional samplers using equal discharge interval (EDI) or equal width interval (EWI) methods are the best, but these are expensive because of the required labor. It is also difficult to obtain sufficient temporal data points when the discharge stage is changing rapidly because of the man-hours needed. Single point pump samples offer a viable alternative, but may not capture the diversity of suspended sediment transport, especially in sand bed rivers because of non-uniform mixing throughout the cross section. This leaves a gap in the understanding that has historically been filled by using streamflow as a surrogate measurement for sediment transport and creating rating curves to estimate the sediment transport. This relationship, however, is typically poorly correlated, with 1-3 orders of magnitude difference between a best fit rating curve and the collected samples (MEI 2002).

Over the decades, the techniques for collecting sediment data have been refined and more recently surrogate techniques have expanded the temporal range of the collected data. In the last decade, indirect measurements, such as light (Rasmussen et. al., 2009), sound (Topping and

Wright, 2016), or density (Brown et. al., 2015) have shown promise in providing better correlations with sediment transport. When these indirect measurements are paired with the strategic collection of direct physical samples, significantly more information is collected at a fraction of the cost of a similar physical sampling program, providing a greater understanding of how sediment moves. This in turn leads to better decisions regarding engineering design, reservoir life cycle estimates, ecosystem rehabilitation design, etc.

Field research in sound surrogates, specifically active acoustics, has shown considerable promise over the last decade using commercially available equipment. The available acoustical instrumentation was originally designed for discharge measurements, but devices that have strict internal power regulation can also provide meaningful suspended sediment information. Research work on the Clearwater and Snake Rivers (Wood and Teasdale 2013) demonstrated good correlations between measured and acoustically estimated sediment concentrations (9-10 % differences). The work also helped reveal a much more in depth understanding of the timing, magnitude, and duration of the high sediment loads in those systems than was possible with previously collected data sets. Research on the Colorado and other rivers (Topping, Wright and Griffiths, et al. 2015, Topping and Wright 2016) has also demonstrated a good correlation between suspended sediment concentrations measured with conventional methods and those measured with multi-frequency acoustic. The data collected on the Colorado River provided a suspended sediment data set that while not as accurate as the EDI or EWI methods, was more accurate than the single-frequency acoustic measurements or point pump samples while also providing a much-increased temporal resolution. The ability to continuously measure sediment transport has provided a greater understanding of the sediment flux in the dynamic Colorado River environment. The field of active acoustics for suspended sediment measurements has also been progressing in the laboratory setting through the development of systems designed to measure the attenuation of an acoustical signal through a suspended sediment fluid (Carpenter, Goodwiller, et al. 2014). Recent work by the University of Mississippi's NCPA during a short term field deployment has shown that these have potential promise to increase the accuracy and temporal resolution of sediment transport measurements (Carpenter, Wren, et al. 2015). These more robust temporal datasets provide real-time insight into a river's fluvial response to sediment-management strategies. The acoustic surrogates also have several advantages over manual physical sampling techniques. Hazards such as night-time darkness and storm event flooding pose difficulties for the direct, physical measuring of suspended sediments. The acoustic technology provides access to fluvial systems for near continuous monitoring that minimizes need and hazards of having a person present during these events.

The majority of acoustical testing on sand bed rivers has been in large rivers (like the Colorado or the Green) that have sufficient depth of flow to separate out the effects of bed load and suspended load. Testing on shallow, sand bed rivers (10 feet or less) though has been limited to areas where the local geology provides a sufficient flow depth at various discharge stages. These conditions allow for a fixed monitoring platform, which provides protection from floating debris, such as logs. The current configuration though does not account for bed adjustments that occur on shallow, sand bed rivers, such as the MRG near Albuquerque, NM. Will the developed acoustical technique still work in these situations? Can these acoustical setups capture continuous suspended sediment load information over the range of expected discharge stages? The use of a floating platform potentially may address concerns from morphological adjustments, but there are still the floating debris concerns. The MRG provides an ideal testing ground to explore the application of developed active acoustic techniques to a shallow, sand bed river with changing morphology due to the existing traditional sediment sampling that is ongoing at many MRG gaging sites.

To investigate the applicability of active acoustics in a shallow bed river with changing morphology, Reclamation initiated a collaboration with the NCPA and the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) and the NMWSC to expand their developed active acoustic techniques to an application on a shallow sand bed river. The selected field site is at an existing USGS water and sediment discharge gaging station – "Rio Grande Floodway at San Acacia, NM" USGS gage 08354900. This gaging station was chosen due to quality and quantity of sediment data already being collected and also because there are two unregulated, tributaries upstream that have the potential to bring in high suspended sediment values (> 30,000 mg/L) (Brown, Gray and Hornewer 2015, Griffin and Friedman 2015). Testing on the MRG also has specific local interest due to the additional responsibility imparted to Reclamation from the Flood Control Acts of 1948 and 1950 to manage sediment on the Rio Grande through the Middle Valley (Velarde, New Mexico to Caballo, New Mexico). The San Acacia site on the MRG is located in an area with uncontrolled sediment input from tributaries, and is a well-known critical area for the endangered RGSM. Understanding the timing, magnitude, and duration of the sediment load pulses to this system may also provide insight that can be correlated to the creation of transitory sediment features, like low elevation bars, where the RGSM have been found (Dudley and Platania 1997, Mortensen, et al. 2019).

Expanding the developed acoustical technology to be applicable on other sand bed rivers, like the MRG, the Platte River, and the San Juan River is the next step. This is especially relevant on shallow, sand bed rivers where sediment management options are being discussed to prolong reservoir life, improve ecological rehabilitation projects, and help with the recovery of endangered species.

Site Installation

Initial Proposal

In the initial proposal, NCPA proposed to test a single frequency system (20 MHz) for collecting suspended sediment concentrations of the silt and clay particles using a floating platform (pontoons) to minimize the disturbance effects from the adjustable sand bed on the MRG. Sediment measurements (ISCO® pump samples and cross sectional EWI samples) were proposed to initially calibrate the instrument and provide an assessment of how well the acoustic measurement compares with the direct physical samples. While there is sediment data currently collected at the San Acacia USGS gage station, additional physical samples were planned to be collected during the initial calibration phase.

The GCMRC, in collaboration with the NMWSC, proposed the installation of a dual frequency (1 MHz and 2 MHz), fixed platform (aluminum mount) acoustic system, similar to that in use on the Colorado River within the Grand Canyon. This has been effective on other systems to minimize concerns from floating debris.

Site Visits

A site visit to the San Acacia gaging station occurred in early spring 2016 between the NMWSC and Reclamation. Three potential locations were identified at the San Acacia site, as shown in Figure 1:

- Installation at the cableway (where the EWI samples are collected)
- Installation at the staff gage (correlates with the location of the discharge measurements and at the time the location of the daily ISCO® pump samples)
- Installation on an older stilling basin, which is used for event based ISCO® pump samples.

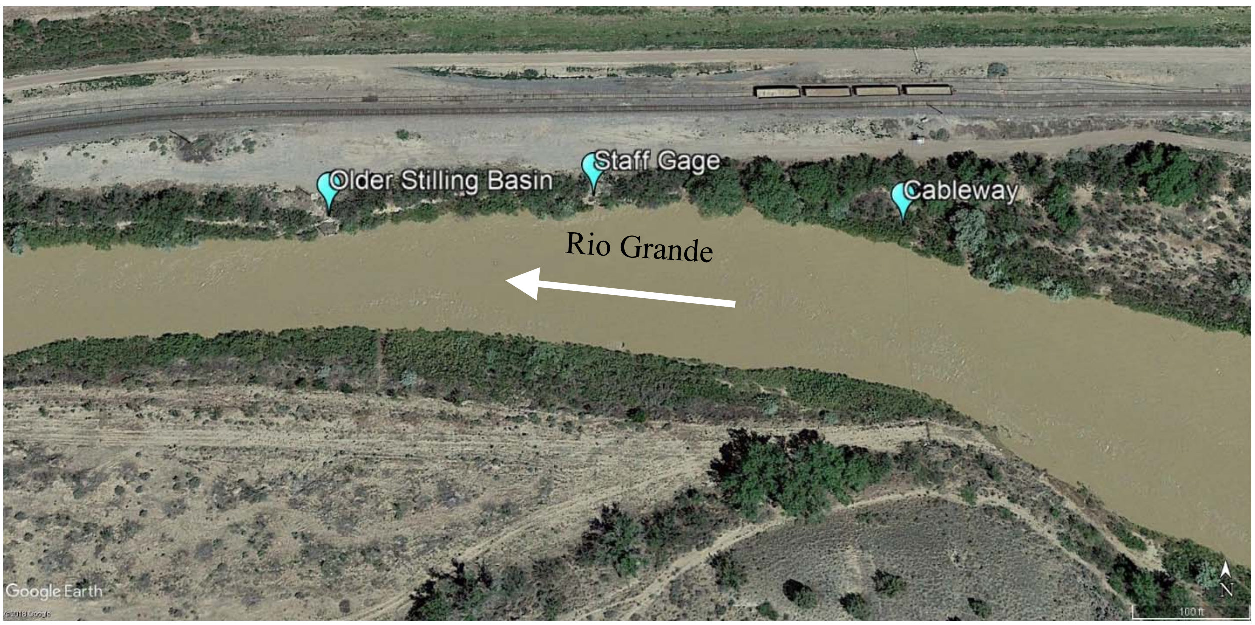


Figure 1. Potential site locations for locating acoustic sediment instruments at the USGS San Acacia gaging station. Image was created in Google Earth Pro (version 7.3.2.5776) using the 2017 MRG aerial imagery.

Two different mounting options (fixed and floating platform options) were investigated. The fixed platform required a solid, rigid mount. A system, such as that shown in Figure 2, was originally envisioned for anchoring at least the GCMRC acoustics. The upper half of the boom featured in Figure 2 is bolted to a solid structure, such as a rock wall, and then a hinge allows the lower part to be lowered into the water column to a set depth. Two bolts in the boom allow the structure to be locked in place, allowing the acoustic instruments to be in a fixed location. The acoustics are mounted on the lower L shaped flange shown at the bottom of Figure 2. The envisioned mounting system is elegant and works for surfaces that provide a solid foundation parallel to the river flow. Unfortunately the only solid surface at the San Acacia site was the older stilling basin (see Figure 3 and Figure 4), which provided a curved or angled mounting structure, neither of which optimally worked with the envisioned GCMRC mount.

The lack of solid mounting structures essentially ruled out the first two locations. The third location, while providing a solid support, also had structural (no face parallel to the flow), sedimentation (observed fill and scour), and debris (see Figure 5) issues. At the site visit, the NMWSC staff who maintain the San Acacia gaging site mentioned that anything mounted close to the structure (within a foot or two) would be subject to waves of deposition and scour due to changes in the sand bed morphology. They also mentioned that anything floating on the surface would be subject to debris, ruling out a floating platform.

The cross section of the MRG through this reach is incised (see Figure 6), with flows very rarely making it onto the floodplain (see Figure 7). The channel is single thread through this reach of the MRG and has a sand bed. Two upstream tributaries (Rio Salado and Rio Puerco) can bring in significant sediment loads ranging from fines to gravels and cobbles. Large spring snow melt runoffs can also mobilize upstream sediment supplies and transport sand and finer material downstream. The difficulty of the mobile bed morphology is compounded by the range of discharges at this gaging station (in the last decade, flows have been measured ranging from near 0 to 10,000 cfs). At the lower discharge range the water is only inches deep, while at the higher discharge range it is approaching the ten foot mark.

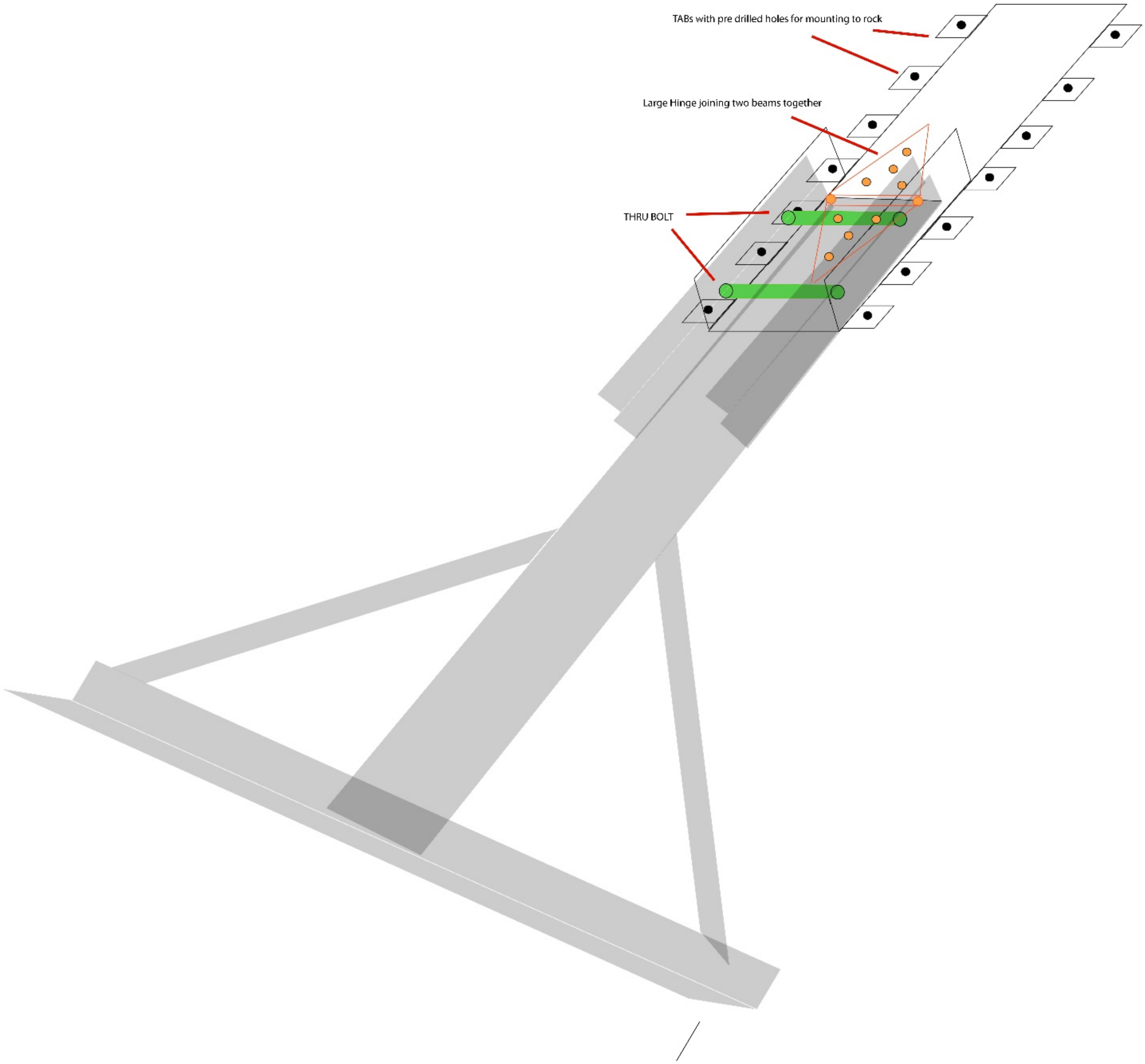


Figure 2. Sketch of a boom mount used by GCMRC on the Green River in Canyonlands National Park.

Figure 3. USGS Gaging Station at San Acacia circa 1953, looking upstream. This site was used as the gaging location from 1953 through 1965, when due to settlement of the abutment the location was discontinued. In 1990 the old well house structure was officially removed, leaving only the abutment (Survey 2012).

Figure 4. USGS San Acacia gaging station, old stilling basin structure (with the well removed). Photograph taken by J. AuBuchon on April 20, 2016.

Figure 5. USGS San Acacia gaging site, looking upstream from the old stilling basin structure. Rock used to stabilize bank. Note debris caught in the vegetation above the rock toe. Photograph taken by J. AuBuchon on April 20, 2016.

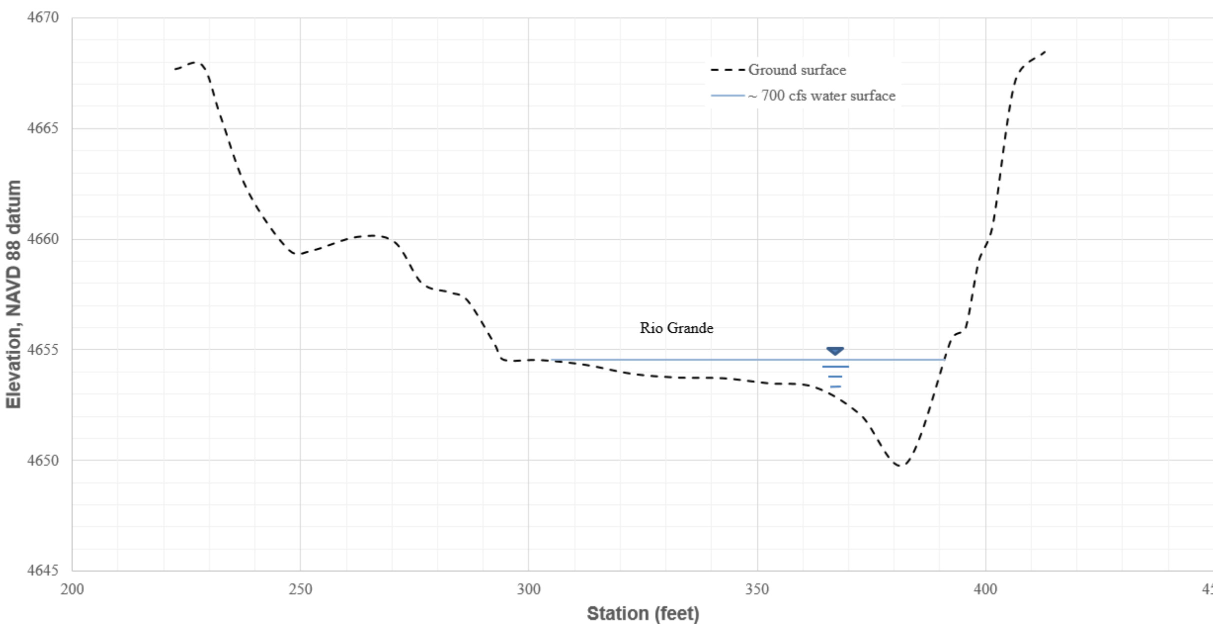


Figure 6. Typical cross section on the Rio Grande near the San Acacia USGS gaging station. Cross section is shown looking downstream, with stationing from left to right.

Figure 7. USGS San Acacia gaging site, looking upstream from the old stilling basin structure from top of right bank. Floodplain on left bank (see arrow) has limited vegetation, indicative of infrequent inundation. Photograph taken by J. AuBuchon on April 20, 2016.

Installation

Placing an instrument low to take advantage of most of the flows leaves the equipment susceptible to sediment burial, while positioning equipment too high leaves them high and dry when the bed scours and also susceptible to floating debris. Because of their familiarity with the site, the NMWSC staff described their ideal measurement site as being about ten feet out from the old stilling basin in the channel thalweg and just below the water surface elevation at the time of the site visit (gage recorded a flow of 700 cfs). While this design would minimize sediment burial of the instruments, it would also require sacrificing data collection at discharges lower than about 500 cfs.

Reclamation's Albuquerque Area Office (AAO), Technical Service Division (TSD) used force diagrams to estimate the hydraulic forces acting on a structure that was sticking out into the water column. Hydraulics (mean velocity and water surface elevations) were estimated using a 1-dimensional numerical hydraulic model (HEC-RAS). A high flow (50 year design event) and a low flow (700 cfs) were used to evaluate the structural design based on a hydrologic analysis of the stream gage at San Acacia (Wright 2010). Forces used in the calculation of the structural design include structural weight, hydrostatic head, buoyancy force, and drag force, as defined in Equation 1, Equation 2, Equation 3, and Equation 4, respectively.

The design for the structure took advantage of the old stilling basin structure as an anchor, as shown in the plan and section views (see Figure 8 and Figure 9). The final mounting structure accounted for the angular mounting structures and was designed to avoid sediment burial while still allowing for collection of data (submerged condition) under most flow conditions.

Equation 1. Structural weight

$$W = \rho_{structure} * Vol$$

Where W = weight (lb), $\rho_{structure}$ = density of steel (~ 494.2 lbs/ft^3), and Vol = volume of solid mass (ft^3).

Equation 2. Hydrostatic head (Olson and Wright 1990).

$$F_h = \gamma_w * h * A$$

Where F_h = hydrostatic head, γ_w = unit weight of water (62.4 lbs/ft^3), h = height of water column acting at centroid of mass, and A = area of structure being acted upon (ft^2).

Equation 3. Buoyancy force

$$F_b = \gamma_w * Vol_{disp}$$

Where F_b = buoyancy force (lb), γ_w = unit weight of water (62.4 lbs/ft^3), and Vol_{disp} = the submerged structure volume.

Equation 4. Drag Force (Olson and Wright 1990)

$$F_d = 0.5 * C_f * \frac{\gamma_w}{g_c} * Vel^2 * A$$

Where F_d = skin-friction drag (lb), C_f = drag coefficient (1.2), γ_w = unit weight of water (62.4 lbm/ft^3), gc = gravitational factor or mass conversion factor (32.174 lbm-ft/(lbf-sec^2) (Lindeburg 1999), Vel = average channel velocity (ft/sec), and A = area upon which the flow acts (ft^2).

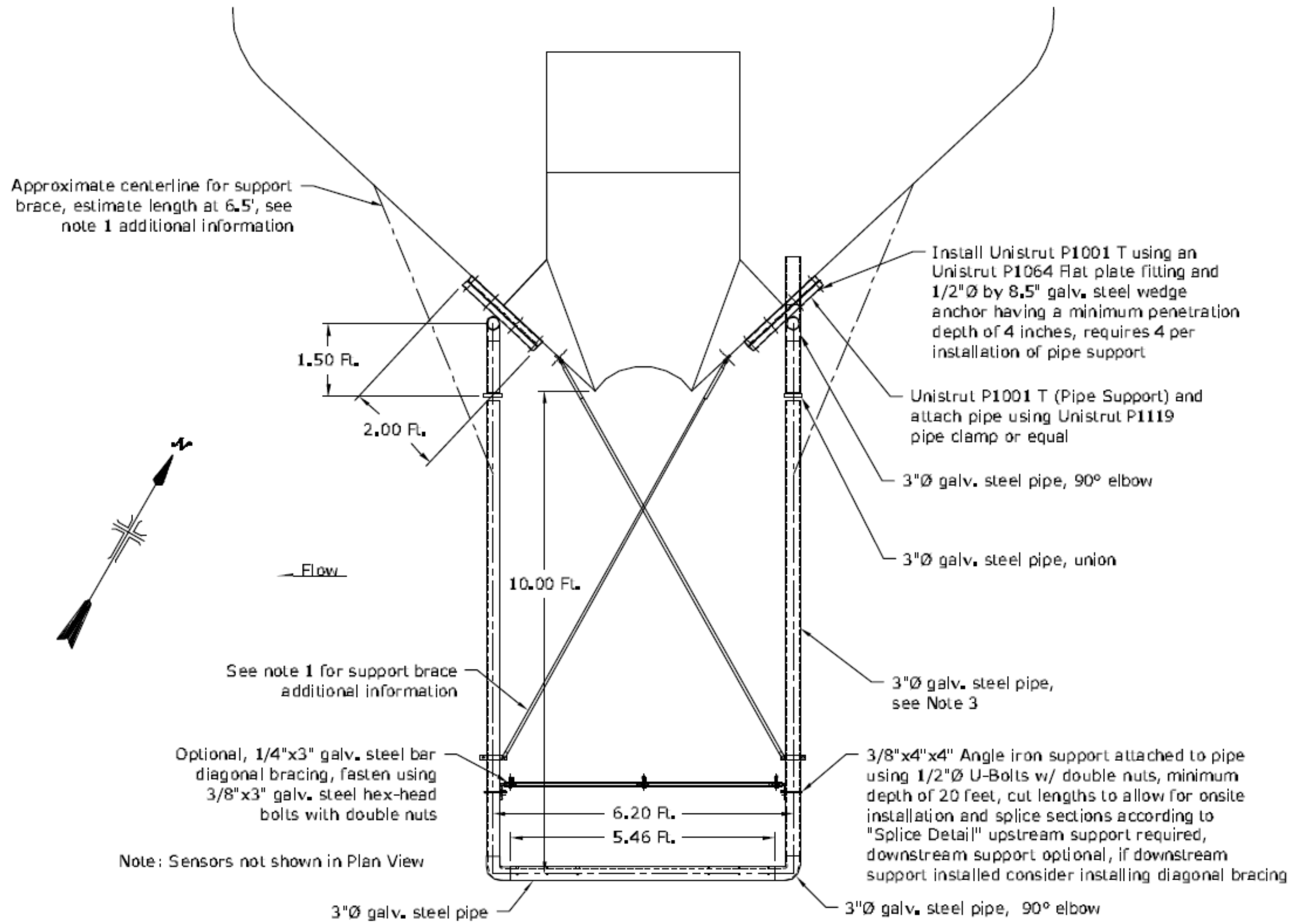


Figure 8. San Acacia USGS acoustic mounting structure, plan view (C. Everetts and R. Bernal 2016).

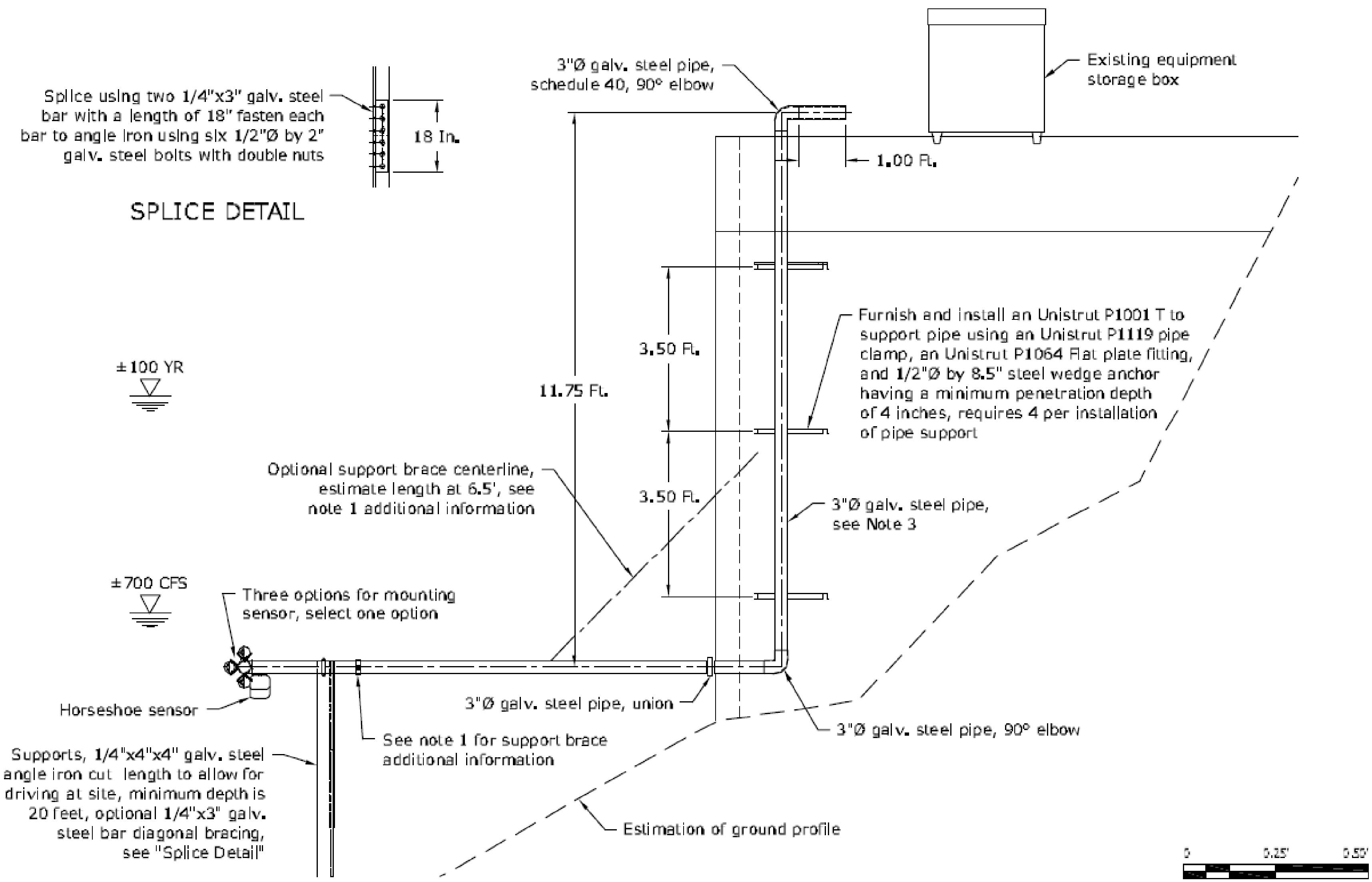


Figure 9. San Acacia USGS acoustic mounting structure, section view (C. Everetts and R. Bernal 2016).

In the fall of 2016, the NMWSC installed the structure (see Figure 10). In the same time period NMWSC and GCMRC attached the two AquaDopps to the structure, as shown in Figure 11, and installed the electronic equipment to monitor and record suspended sediment measurements (see Figure 12).

Figure 10. Installation of acoustic mounting structure at USGS San Acacia gaging station, looking down from top of old stilling basin structure. Photograph taken September 2016 by J. AuBuchon.

Figure 11. Installation of AquaDopps by NMWSC and GCMRC, looking towards river right bank Photograph taken September 2016 by J. AuBuchon.

Figure 12. Installation instrumentation in KNAACK toolbox for the AquaDopps (left side of picture. Right side is ISCO sediment pump sampler). Photograph taken September 2016 by J. AuBuchon.

A third active acoustical device, developed by the NCPA, was installed in July 2017 (see Figure 13 and Figure 14). The NCPA acoustic instrument and electronic control box are featured in Figure 15.

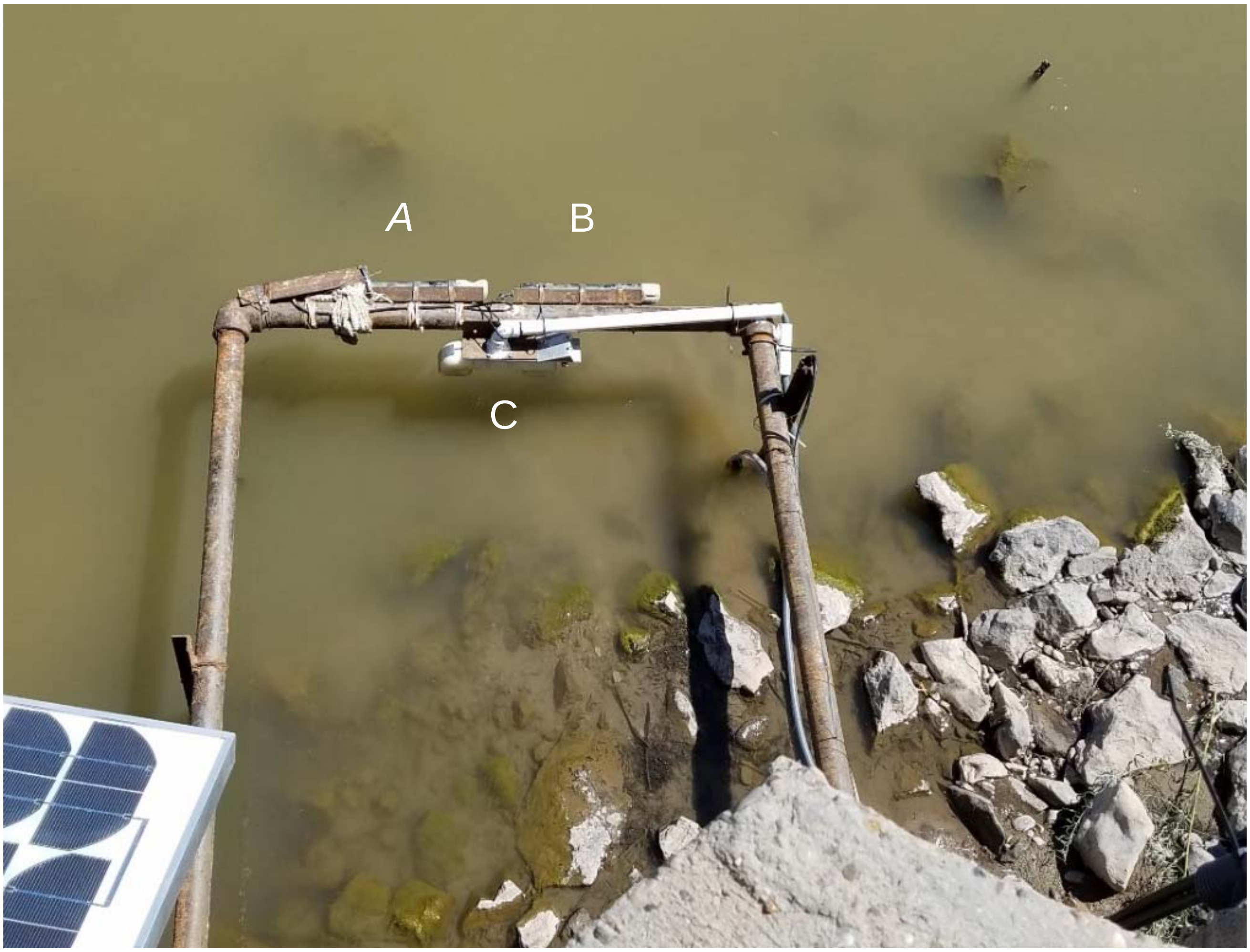


Figure 13. Active acoustic installations on the Rio Grande at San Acacia: A) 1 MHz and B) 2 MHz AquaDopp acoustical probes and C) NCPA 20 MHz acoustical instrumentation. Photograph taken by W. Carpenter (NCPA) on July 24, 2017.

Figure 14. J.D. Heffington (NCPA) and Tyson Hatch (NMWSC), discuss details of the NCPA 20 MHz acoustical instrumentation (C). Previous AquaDopp acoustical probe installations on the Rio Grande at San Acacia are also visible: A) 1 MHz and B) 2 MHz. Photograph taken by J. Brown (NMWSC) on July 24, 2017.

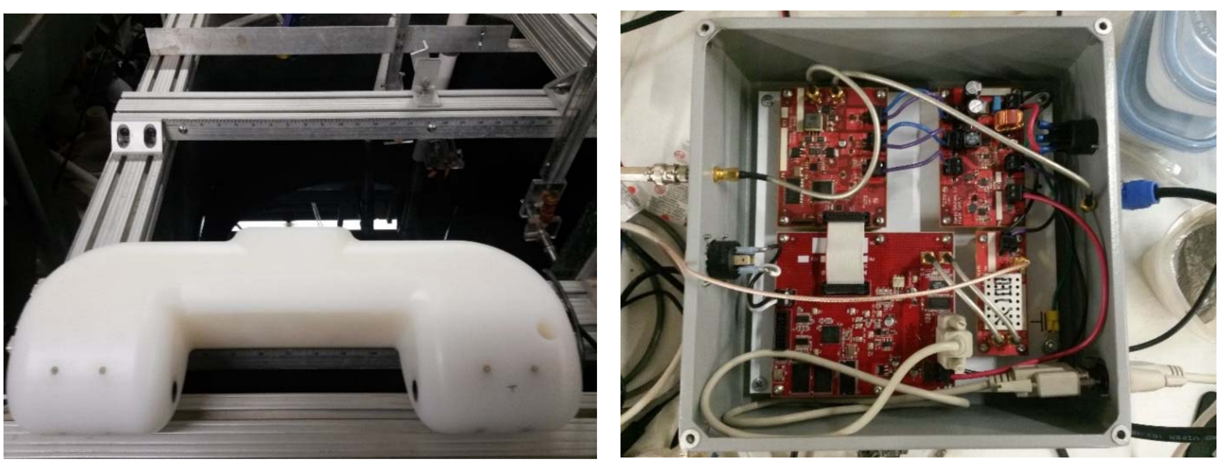


Figure 15. Ole Miss acoustical instrumentation. Photograph on the left is the transducer and casing. Photograph on the right is the data acquisition box. Photographs taken by W. Carpenter on October 21, 2016.

Field Troubleshooting

Initial proposal

Initially it was thought that the installation of the systems would occur rapidly and that the first few months to a year would involve the calibration of the active acoustics. After this period, it was desired to collect continuous field data between 6 months and two years to assess the viability of applying active acoustics in a shallow, sand bed river after an initial calibration period. The AquaDopps were expected to run for an additional 2 years beyond the initial calibration period. The NCPA acoustic instrument was envisioned to involve a 6-8 month testing window at the San Acacia gaging site after a check on the calibration. If this was successful the NCPA acoustic instrument was envisioned for application in another shallow, sand bed system (the USGS gaging station at Hogback Canal near Waterflow, NM on the San Juan River in northwestern New Mexico – chosen because of its importance as the proposed pumping location for the Navajo-Gallup pipeline). Poor initial field results would require a longer testing window at the San Acacia gaging station and potentially modifications of the NCPA acoustic instrument.

To help with the calibration of the instruments, physical sediment measurements (ISCO® pump samples and cross sectional EWI samples) were collected. These were intended to calibrate the instrument and provide an assessment of how well the acoustic measurement compares with the direct physical samples. The collection of suspended sediment samples during the initial calibration phase was designed to add physical samples beyond the normally collected suspended sediment samples at the San Acacia gaging station. All collected physical samples were assessed for suspended sediment concentration (SSC) and also gradation analyses (sand/fine split in per cent finer than 0.0625mm). Select samples were also analyzed by GCMRC for a full suspended sediment gradation analysis (1/4 phi resolution).

The collected acoustical data was originally perceived to be stored via electronic memory storage on site and periodically downloaded during routine gaging station maintenance visitations by the NMWSC. The data would then be transmitted to the NCPA and GCMRC for calculating a regression relationship between signal attenuation and backscatter with the suspended sediment concentration (Topping, Wright and Griffiths, et al. 2015). Collected data was envisioned to be made available to the general public once the regression model was developed by taking advantage of existing data dissemination utilities in use by the USGS (Domanski, et al. 2015, Oms, et al. 2015).

Initial years (September 2016 to December 2017)

The hydrograph as recorded at the San Acacia gaging station for the first year or so of deployment is shown in Figure 16. During the end of September 2016, when the AquaDopps were installed, the discharge in the Rio Grande was below the median daily flow, based on 45 years of collected discharge data. This facilitated the installment of the mounting structure and the installation of the AquaDopps. A rainfall-runoff event during this period of low flows (early October 2016) caused debris to get caught on the mounting structure, as shown in Figure 17 and

Figure 18. The peak flow was around the submergence discharge for the mounting structure and the structure ended up catching significant debris. While the accumulated material was undesirable, the structure did stay intact and the AquaDopps were not buried in sediment. Angle iron attached on the upstream end of the structure protected the AquaDopps from damage.

Discharges after November 2016 were large enough to submerge the AquaDopps and allow for continuous monitoring of the data, except for periods in July and September/October 2017. Originally the NCPA instrument was expected to be installed in the late March/early April time frame. The 2017 spring snow melt runoff was larger than expected and caused flows to rise significantly above the height of the mounting structure. This delayed installation of the NCPA instrument until the flows receded in July 2017.

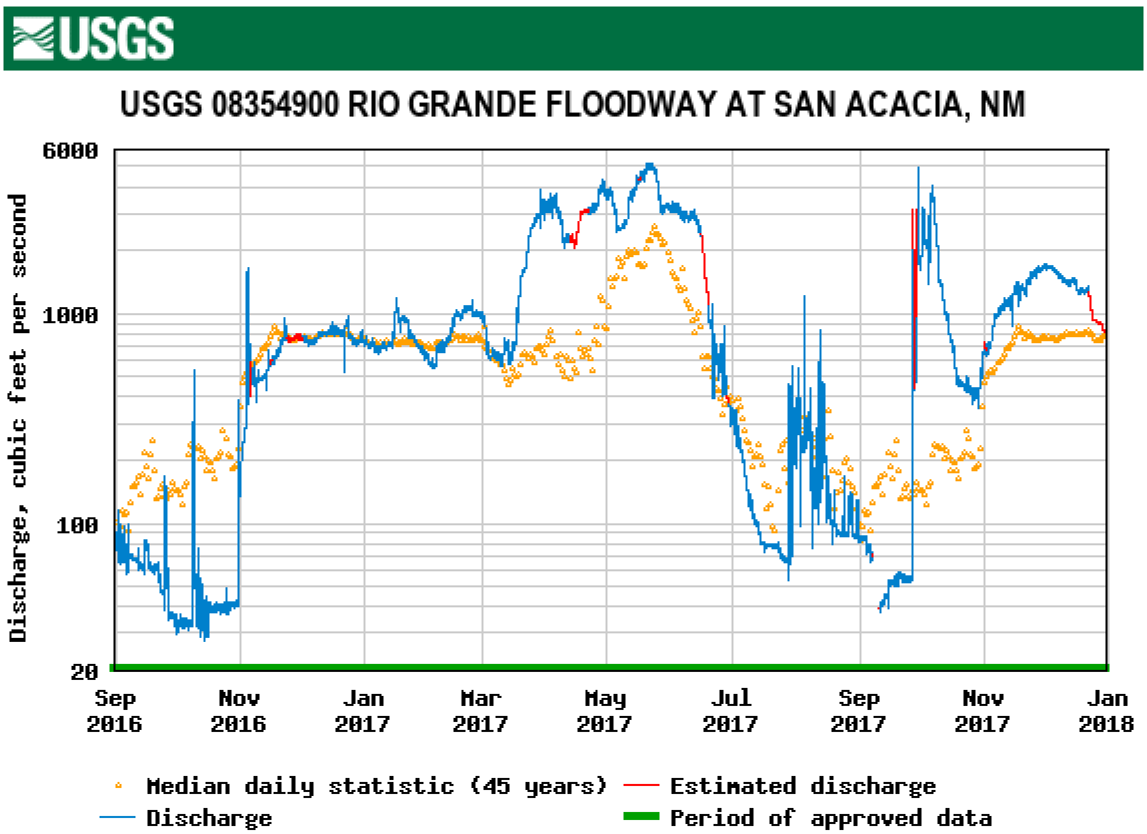


Figure 16. Daily average discharge values at the USGS San Acacia gaging station (# 08354900) between 1 September 2016 and 31 December 2017.

Figure 17. Debris and sediment left from storm surge on uncontrolled tributaries upstream of the USGS San Acacia gaging station. This material was subsequently cleared away by NMWSC. Photograph taken by T. Austring, NMWSC, on October 13, 2016.

Figure 18. Debris and sediment left from storm surge on uncontrolled tributaries upstream of the USGS San Acacia gaging station. Shown is the 1 MHz AquaDopp and the upstream angle iron that protected it. Photograph taken by T. Austring, Albuquerque USGS office, on October 13, 2016.

Development of the NCPA acoustic instrument

Unlike the AquaDopps, the NCPA 20 MHz acoustic instrument was custom-built. The work at San Acacia built upon previous research (Carpenter, Chambers, et al. 2009) that investigated the ideal distance between two 20 MHz transducers in a transmit-receive configuration able to measure the widest range of concentrations of a particle size range smaller than 100 microns in suspension. Researchers used the attenuation for each particle classification and made comparisons to the theoretical attenuation curves (Urick 1948, Sheng and Hay 1988) for scattering (Landers 2010), and a model for estimating concentration was created assuming spherical-sized particles. The calibration curve, Equation 5, is valid for silt-sized particles (D_{50} = 20 µm).

Equation 5. Calibration curve for silt-sized particles (NCPA)

$$\alpha_s = SSC_v * k(\gamma - 1)^2 * \left(\frac{s}{s^2 + (\gamma + \tau)^2}\right) + \frac{k^4 * a_s^3}{5 * (1 + 1.3\,k^2 a_s^2 + 0.24\,k^4 a_s^4)} * \frac{8.686}{2}$$

where,

α_s is a coefficient of attenuation, measured in $\left({}^{dB}/_{cm}\right)$

SSC_v is the volumetric sediment concentration (*SSC* divided by the sediment density)

k is the wave number, $k = \frac{2\pi}{\lambda}$, where λ is the wavelength in cm

γ is the specific gravity of the sediment

a_s is the sediment radius in cm

$$s = \left[\frac{9}{4\beta a_s}\right] * \left[1 + \frac{1}{\beta a_s}\right]$$

$$\tau = \left[0.5 + \frac{9}{4\beta a_s}\right]$$

$\beta = \left[\frac{\omega}{2\nu}\right]^{0.5}$, $\omega = 2\pi f$ and ν is the kinematic viscosity of the water.

Over a range of clay and silt sized particles, it was shown that the modified Urick-Sheng-Hay fit suggests a detection threshold of 0.028 dB/cm as shown in Figure 19.

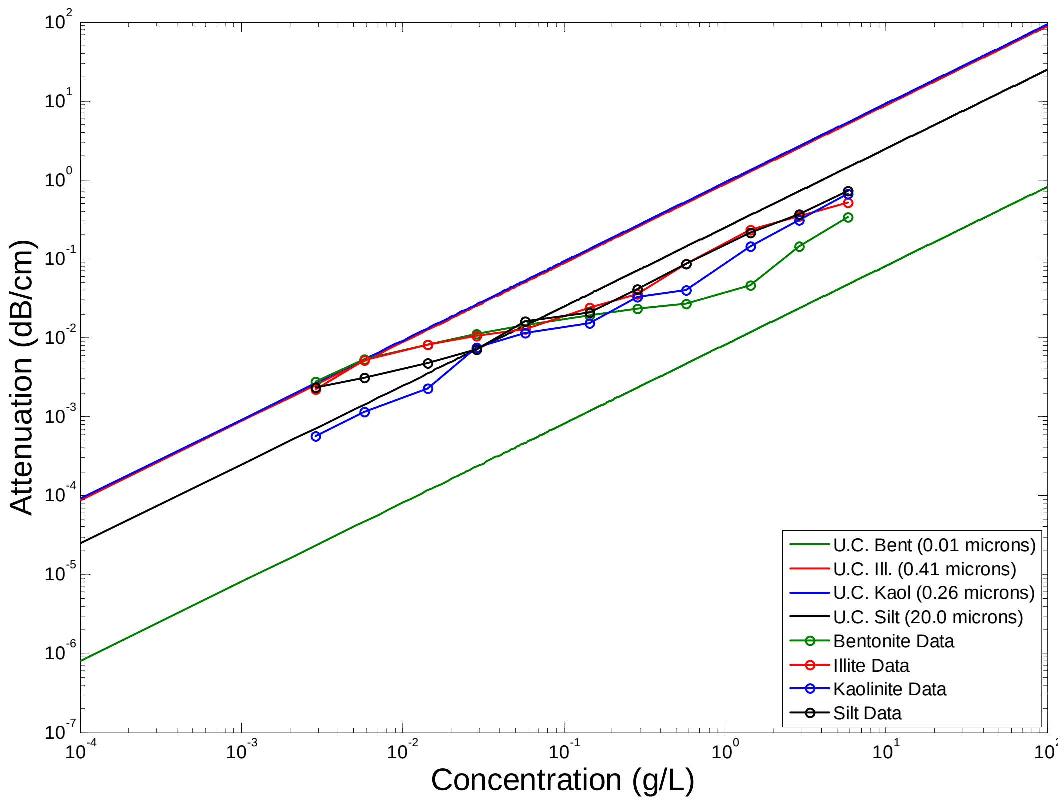


Figure 19. Urick-Sheng-Hay fit of 20MHz attenuation data (NCPA)

(Carpenter, Goodwiller, et al. 2014) investigated using a combination of acoustic backscatter and attenuation in the laboratory recirculation tank to discriminate between known sizes of suspended clays and silt. It was found that a multi-frequency measurement of backscatter from 10 MHz signals and attenuation from 20 MHz signals allows for the discrimination of particle size, as shown in Table 1.

Table 1. Summary of backscatter and attenuation measurement used to discriminate particle size

10 MHz BACKSCATTER	20 MHz ATTENUATION	PARTICLE
High (> 1dB)	High (> 2dB)	SILT
Low (0 - 1dB)	High (1 - 2dB)	CLAYS
Low (~ 0dB)	Low (0 - 1dB)	MINIMAL SED.

These results led to the construction of a prototype through grants from the U.S. Department of Agriculture (USDA) and the Federal Interagency Sedimentation Project (FISP). The prototype monitored suspended sediment transport using single frequency attenuation as a surrogate measurement technique. The suspended sediment monitoring system consists of two transducers mounted inside of a machined polyethylene housing with 18 centimeter spacing. This spacing optimized the detectable range for silt sized particle (D_{50} = 20 mm) from 0.15 g/L to 6 g/L.

A fieldable, short-term deployment prototype was calibrated and deployed to Harris Bayou in Alligator, Mississippi at a USGS gauging station. At that time, the acoustic prototype was only deployed for short durations (less than 4 hours) and a more robust design was needed. Following modifications for a longer field deployment, several laboratory experiments were conducted in order to calibrate the new system. From the previous year of research, it was shown that the transducer internal material depended on ambient temperature. A thermocouple was paired with the prototype logging temperature simultaneously and this method was tested in the laboratory. See Figure 20 for calibration curve correlating ambient temperature and acoustic attenuation to sampled concentration.

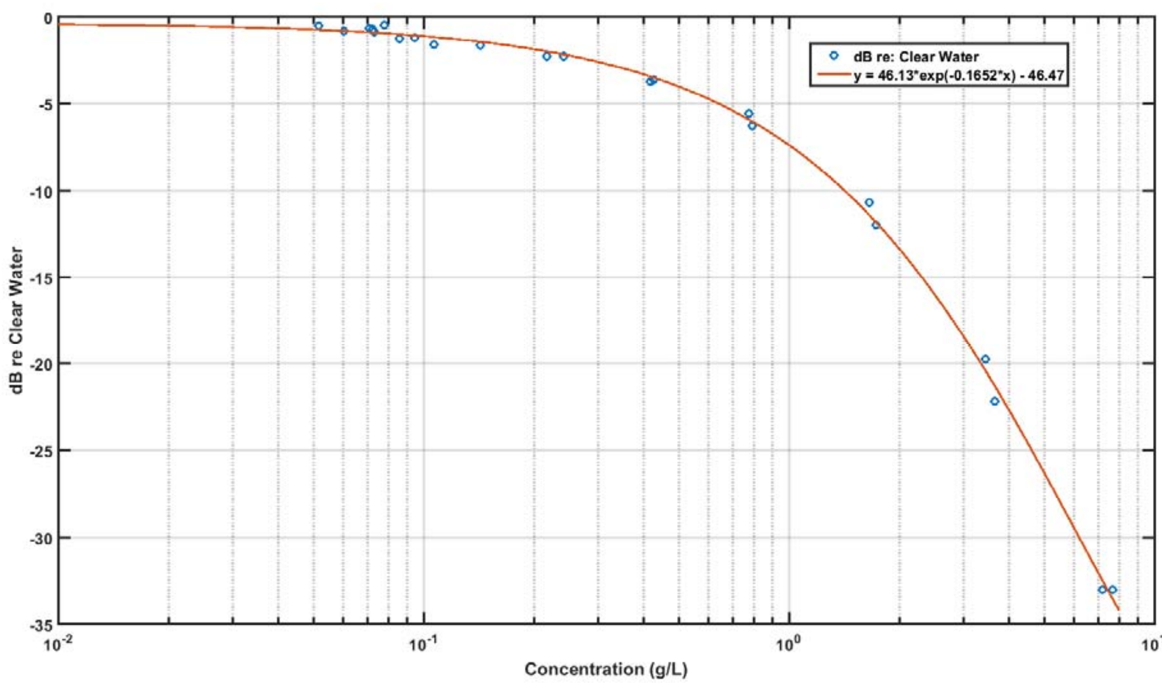


Figure 20. Fit of temperature adjusted attenuation signal relative to clear water 9dB) vs. measured concentration (g/L).

In January 2017, a preliminary long-term field deployment was tested in Goodwin Creek watershed nearby Batesville, MS (Figure 21 and Figure 22) in conjunction with USDA Agricultural Research Service National Sedimentation Laboratory (ARS-NSL). Acoustic signals were incorporated with co-located temperature measurements for calibration purposes. This deployment was largely necessary to observe the rugged ability of the prototype and the peripheral hardware in an ephemeral channel, as well as testing the power consumption.

Figure 21. Deployment of prototype at Goodwin Creek watershed (Photograph by W.O. Carpenter, January 2017).

Following successful laboratory calibration and field deployment at Goodwin Creek, MS, the acoustic surrogate suspended sediment monitoring field prototype was refined for long-term deployment. While the instrument was ready by mid to late spring 2017, deployment did not occur until July due to the high flows on the MRG, which limited accessibility to ensure proper attachment to the mounting structure.

In July 2017, NPCA, installed a long-term monitoring system on the Rio Grande Floodway at San Acacia, NM USGS site in conjunction with the assistance of researchers from Reclamation and NMWSC. The San Acacia USGS gage site allowed NCPA researchers access to correlate USGS measurements to the NCPA acoustic surrogate prototype. Figure 23 illustrates the deployment at the San Acacia site. The instrument is designed to transmit the 20 MHz acoustic pulse and record the received attenuated amplitude to correlate to suspended sediment concentration. The data acquisition computer in communication with the deployed prototype is co-located with USGS physical suspended sediment sampling equipment (ISCO® samplers). Binary data is collected for 60 seconds followed by roughly 20 seconds of downloading time before repeating the cycle. The transducer cables are traced onshore to a custom built DSP (digital signal processor) with amplifier, batteries, and is interfaced with a laptop computer in the current configuration. A float switch mechanism was also installed to trigger data collection of the NCPA acoustic surrogate prototype. The float switch mechanism prevents the transducers in the NCPA acoustic surrogate prototype from firing in the air, which would lead to overheating and cracking of the transducer element.

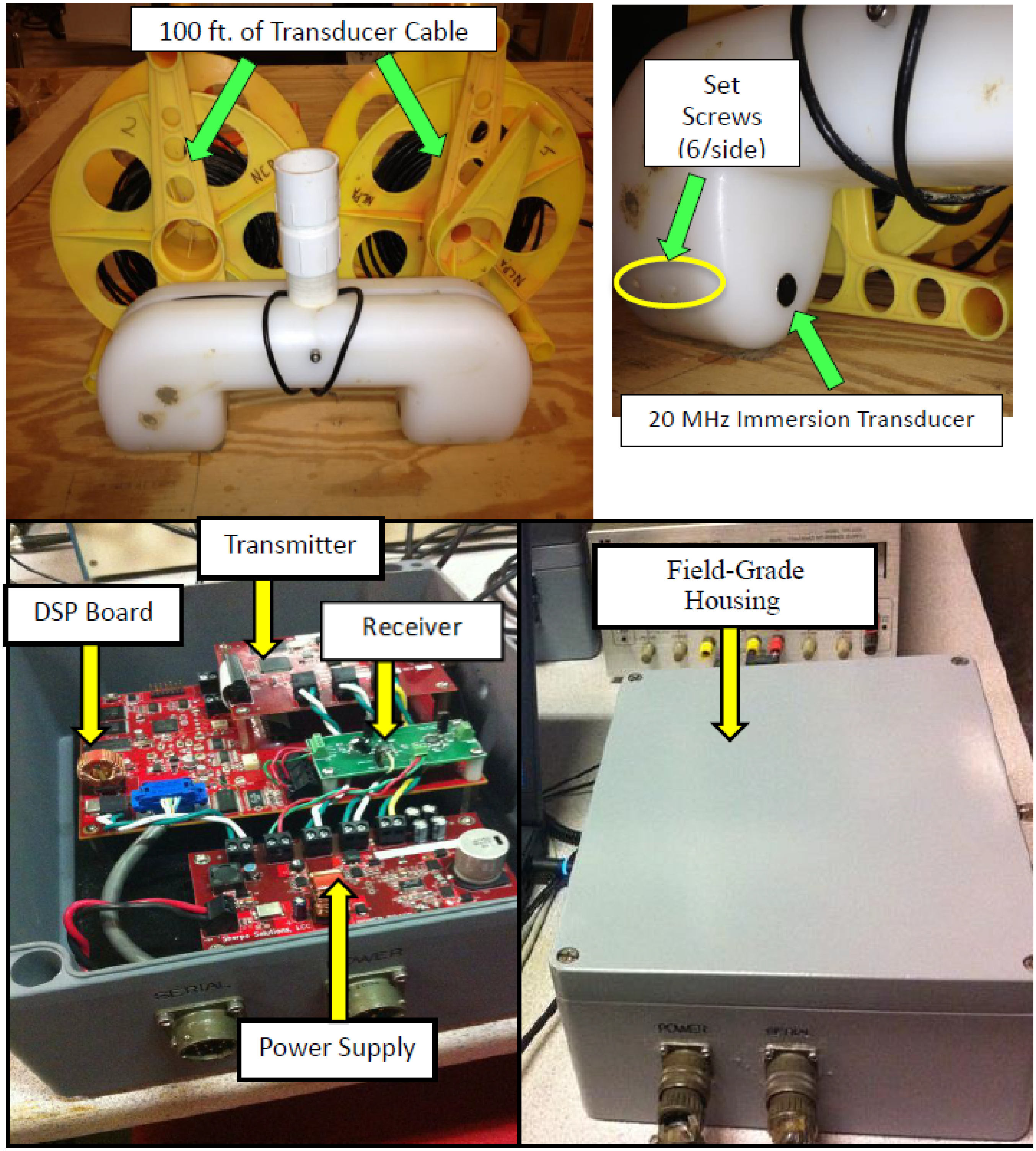


Figure 22. Suspended sediment monitoring system modified for placement at Goodwin Creek, MS. Photographs taken by W.O. Carpenter, NCPA.

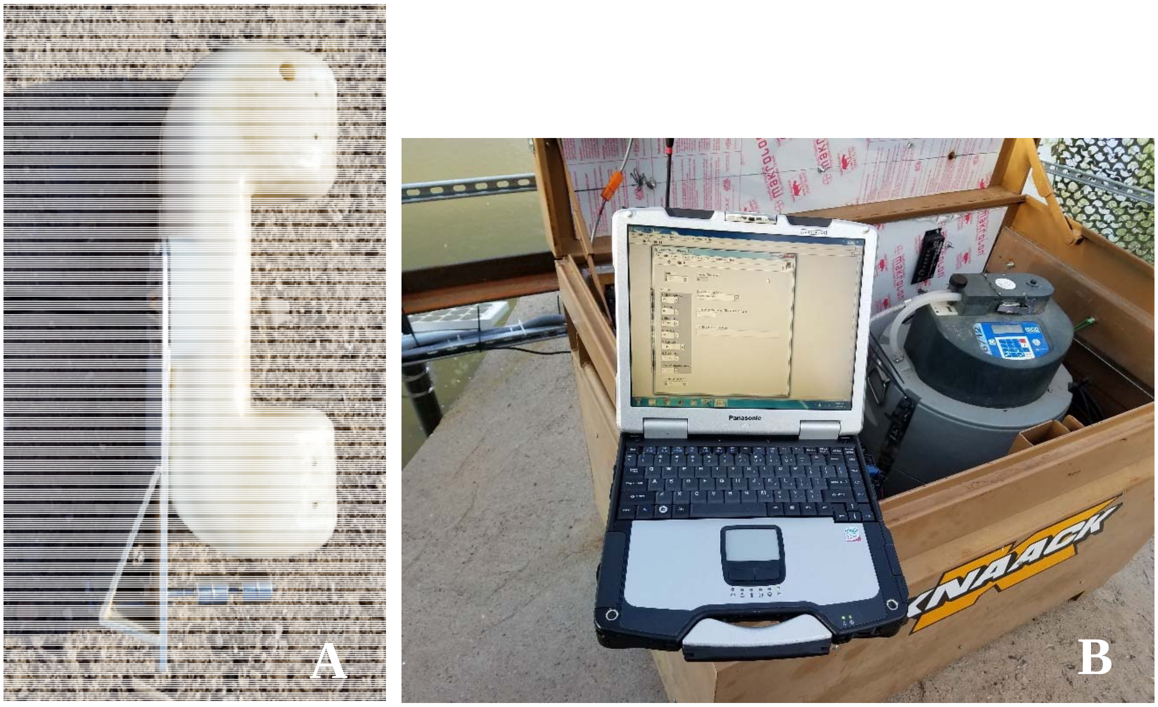


Figure 23. Photographs of A) close-up of the deployed transducer casing and B) laptop display of prototype output and housing enclosure for ISCO® pump sampler and power.

Field data from multiple sites is desired to optimize the acoustic system to endure long-term deployments at fixed stations of interest. By comparing the acoustic signals from deployments in Mississippi and New Mexico with varying particle distributions, NCPA hoped that a more universal calibration could be made. The limited field data from Mississippi had shown promising trends between various acoustic parameters and suspended fine sediment transport. It is hoped therefore that with the longer field deployment at San Acacia, a reliable method of determining suspended sediment transport can be attained and long-term trends of suspended sediment can be observed. The MRG tends to move more sand and larger particles during the snow-melt runoff in the spring. Finer sediment is typically mobilized during the monsoon period, typically running from July through September. The flashy nature of these events makes them more difficult to measure. Moreover, these flashy events historically carry suspended sediments greater than 0.5 g/L, which is outside the range of many acoustic devices yet well within the range of detection of the acoustic surrogate system proposed by NCPA (Carpenter, Chambers, et al. 2009), see Figure 24.

By improving the deployment techniques and mounting methods, the available deployment windows could also be widened, thus improving the diversity of field data available. The end product required significant changes from its current design to be an effective tool for long-term deployment at the San Acacia gaging station. The new setup had to withstand floating debris as well as accumulation of debris on the device with additive forces that may result in destruction of anchoring. The materials would also need to be able to withstand intense solar radiation during summer months, as streamflow at these sites (in between flashy storm flow events) regularly becomes so low that the equipment would be above the water surface. In addition, there was the potential for vandalism. Given the remote location of this gaging station and access behind a locked gate, vandalism wasn't expected to be a significant concern.

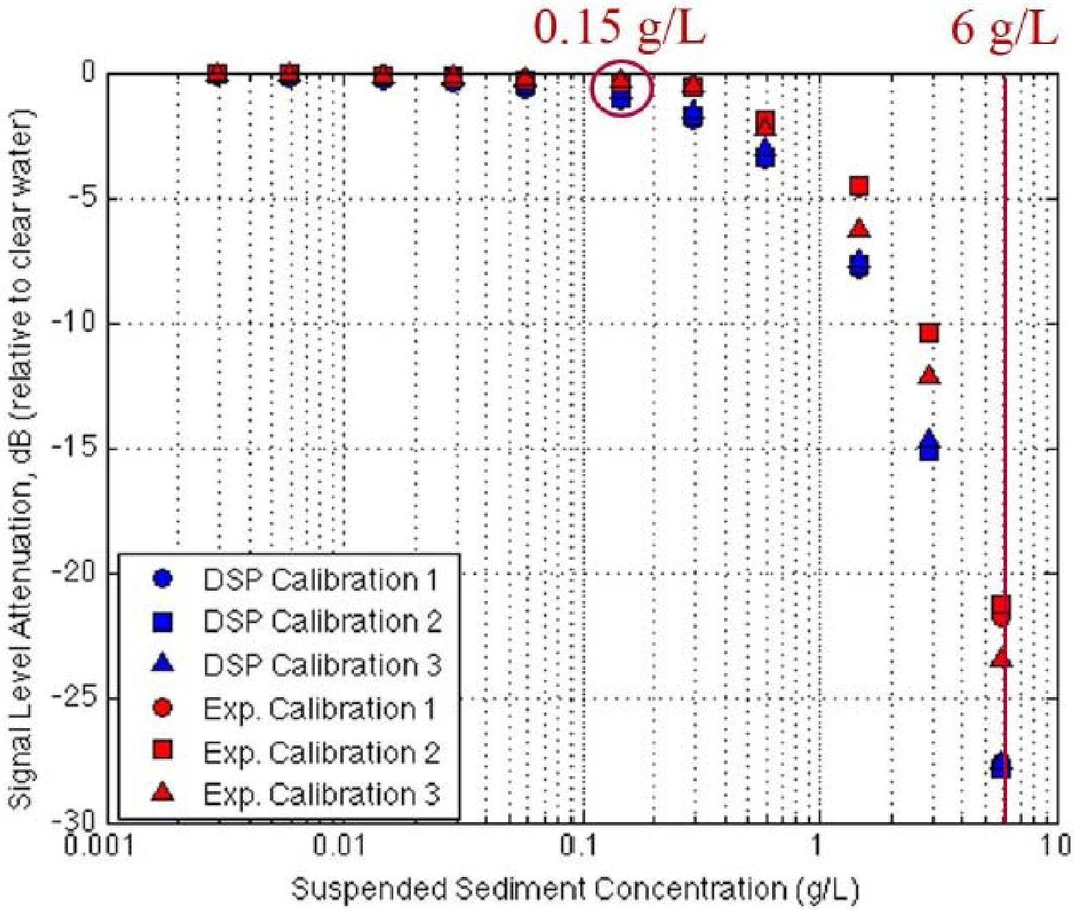


Figure 24. Laboratory calibration of the NCPA acoustic device, as arranged for the Goodwin Creek deployment. The detectable range for silt sized particle (D_{50} = 20 mm) ranged from 0.15 g/L to 6 g/L using the current 18 cm spacing.

While the original installation was perceived as a single instrument, one potential complement considered was to place a turbidity probe to provide a concurrent comparison to the physical ISCO® pump samples. It was desired to have some months of deployment before this option was considered.

Calibration of the NCPA acoustic instrument

Following installation, the San Acacia, NM gauge station at the Rio Grande Floodway (USGS 08354900) experienced some monsoonal events in early October 2017. This moved some finer material into the system for which the NCPA acoustic probe was designed to monitor (silts/clays). Unfortunately, the acoustically acquired NCPA data sets were limited by power outages at the site. To rectify the power outages, additional solar panels were added to the site by the NMWSC personnel to increase charging capacity. At this same time, fuses were replaced in the float switch mechanism to trigger data collection. A larger battery was also added to accommodate the high draw from the additional acoustic equipment installed at the site.

To calibrate the NCPA acoustic instrument for the San Acacia gaging location, specific concentration data released by NMWSC from 11/22/2017 to 11/29/2017 was compared to acoustically collected data from the NCPA acoustic instrument to generate the relationship. The San Acacia gaging site collects suspended sediment data from a co-located ISCO® pump sampler at the same point in the river. The ISCO® collected samples occur daily at 14:00 local Mountain time during the winter and 20:00 local Mountain time during the summer/monsoon season. Specifically, the 70331 parameter (suspended sediment, sieve diameter, percent smaller than 0.0625 mm) and the 80154 parameter (suspended sediment concentration, mg/L) are used to determine the concentration of fine suspended particles (less than 0.0625 mm). The NMWSC obtains these point samples through both an event triggered sampling and/or daily sampling. The intake hoses for both are co-located with the NCPA acoustical instrument, facilitating the ability to correlate the data. ISCO® pumps are used to extract the samples from the intake hoses. The collected daily point samples represent a raw concentration, representing the suspended concentration at the ISCO® pump intake (mg/L). The collected suspended sediment samples were wet sieved followed by a dry sieve, calibrated laser diffraction to get a suspended sediment concentration for each grain size distribution. Concentration analysis from the wet sieve was performed at NMWSC and grain size distribution analysis was performed by GCMRC. The suspended sediment concentration data provided by the USGS daily sampler was used to create a fit to the acoustic measurements collected at San Acacia. In order to provide a correlation with the NCPA instrument, which is designed to measure the fine sediment fraction (suspended sediment less than 0.0625 mm in size), the suspended sediment concentration reported by NMWSC must be adjusted. The adjusted suspended sediment percentage is calculated by multiplying the dry sieve (SED02) from the 70331 parameter and total suspended sediment concentration from parameter 80154, as shown in Equation 6.

Equation 6. Adjusted suspended sediment concentration (NCPA)

$$SSC_{adj} = \%SSC_{<0.0625mm} \times SSC_{total}$$

Where:
SSC_{adj} is the adjusted suspended sediment concentration (mg/L)
$\%SSC_{<0.0625mm}$ is the percentage of material less than 0.0625 mm diameter
SSC_{total} is the suspended sediment concentration sample collected by the ISCO intake (mg/L)

For the fit, the adjusted suspended sediment concentration was used to create a relationship to the received acoustic signal, as shown in Figure 25. The concentration range shown in Figure 25 was chosen to calibrate to the lowest end of the detectable threshold. The correlation was established between the acoustic measurements and suspended sediment concentration for grain sizes under 62.5 microns. Note that for most of the flow events (except for the spring snow-melt runoff events) the fines are a very large percentage of the entire measured suspended sediment concentration.

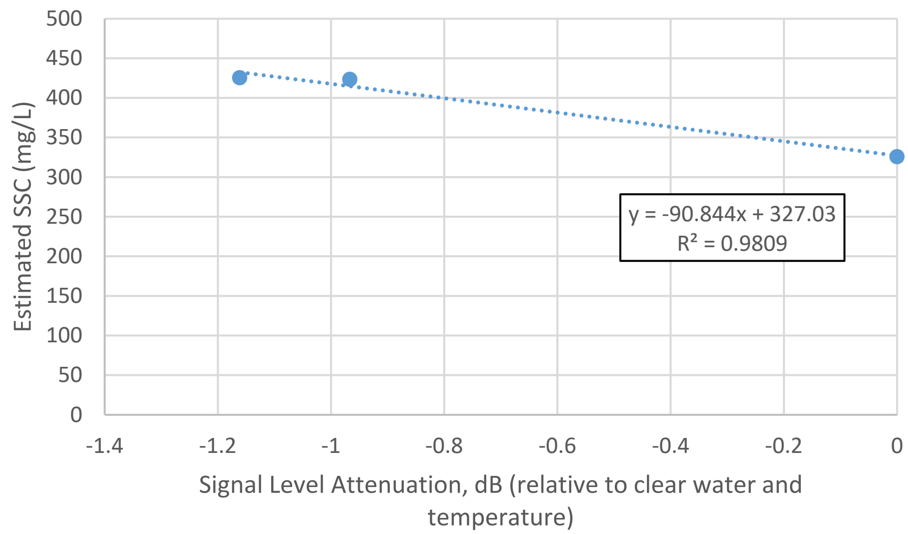


Figure 25. NCPA acoustic correlation fit of 11/22/2017 – 11/29/2017 suspended sediment concentration data for grain sizes under 62.5 microns. The low end of the detectable range is 325 mg/L.

The NCPA instrument is set up to record a receiving signal every minute. Due to power and other issues discussed later, the data was not able to be collected over the entire project duration. The table below shows the error of the fit from 11/22/17-11/29/17 (Table 2). The *DSP #* is a device-specific unit that is a measure of acoustic amplitude on the receiving transducer. The value is also a function of the signal strength generated by the NCPA acoustic instrument. Adjusted suspended concentration (mg/L) is the adjusted USGS physical measurement. Estimated suspended concentration from model (mg/L) is the predicted suspended concentration using the DSP # in a linear fit (R^2=0.881).

Table 2. Summary of error between physically measured concentrations vs. concentrations approximated using acoustic surrogate technique

Date	DSP #	Adj. Conc. (mg/L)	Est. Conc. from model (mg/L)	% Error
11/23/2017	803.38	486	491	1.01%
11/24/2017	807.61	498	489	1.90%
11/25/2017	825.62	474	479	1.12%
11/26/2017	--	446	--	No acoustic data
11/27/2017	800.73	460	493	7.16%
11/28/2017	883.95	450	449	0.25%

A few disclaimers should be noted regarding these results. First and foremost, the USGS data, used in this analysis, is provisional and subject to change. However, the data can be adapted to these changes as they are reported. Secondly, the concentration range of the daily sampler used for the correlation was narrow, roughly 450-500 mg/L which does not encompass the entire working range of the acoustic device. So, as higher or lower suspended sediment concentrations are observed by the NCPA instrument, the fit may change to account for a wider concentration range. Historically, USGS has measured events with suspended sediment concentrations close to 20,000 mg/L, so once collection problems are resolved, it can be possible to obtain a better correlation at the site. In general, the caveat of using this technique is the estimated concentrations may be off when changes occur in the composition of the particles comprising the suspended sediment concentration after the time frame of the correlation.

Extrapolating this model for use with other data, the model was applied to NCPA collected data between 11/22/2017 - 11/29/2017 and 10/30/2017 – 11/3/2017 as shown in Figure 26 and Figure 27, respectively. Both figures show continuous (15 minute) acoustic data collected from the AquaDopps and the instantaneous discharge measurements (15 minute) at the San Acacia gaging station. The NCPA acoustic instrument is designated as "telephone" in Figure 27. For 11/22-29/2017 physical measurements, the daily ISCO® pump samples were getting erratic concentrations, likely an indication of intermittent burial as sediment was moving through the system once main stem flows picked up after the irrigation season. The event ISCO® pump sampler, however, was performing adequately. USGS noted some pump sampler problems for 10/30, 10/31, and 11/1, but there was a daily sample collected on 11/2. As discussed earlier, the signal strength of the receive transducer is a function of the transmission strength of the transmitted signal. The cyclical degradation of the signal strength as observed in Figure 26 could be due to the reliance on solar power and batteries. This might explain night data collections with a weakened transmission signal and daytime data collections showing stronger received signal strengths. A more stabilized power signal could test this hypothesis.

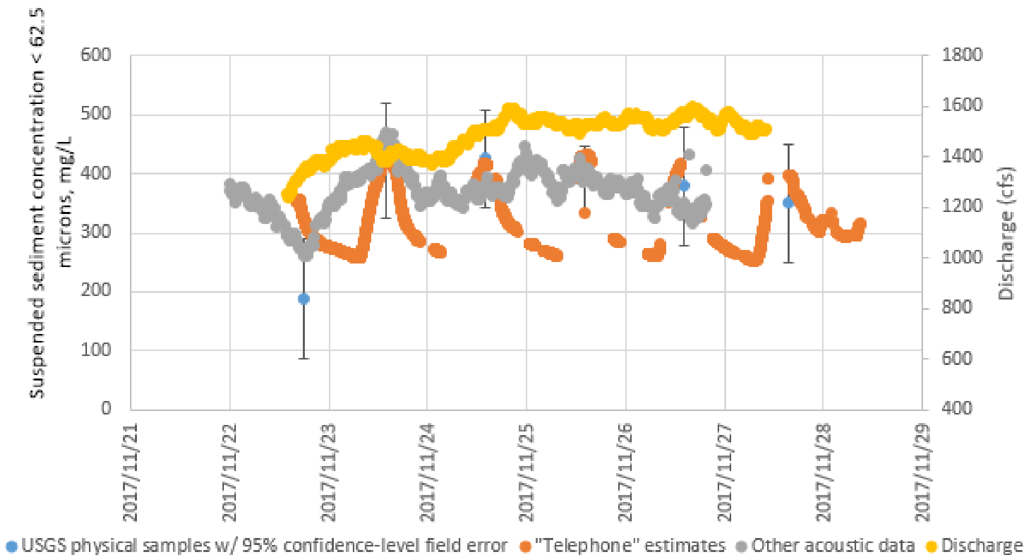


Figure 26. 22 November 2017 through 29 November 2017 measurement of fine suspended sediment concentration from the NCPA acoustic instrument ("Telephone" estimate) compared to acoustic surrogate estimates of fine suspended sediment concentration for the AquaDopps. Also shown is instantaneous discharge reading from the San Acacia gaging station.

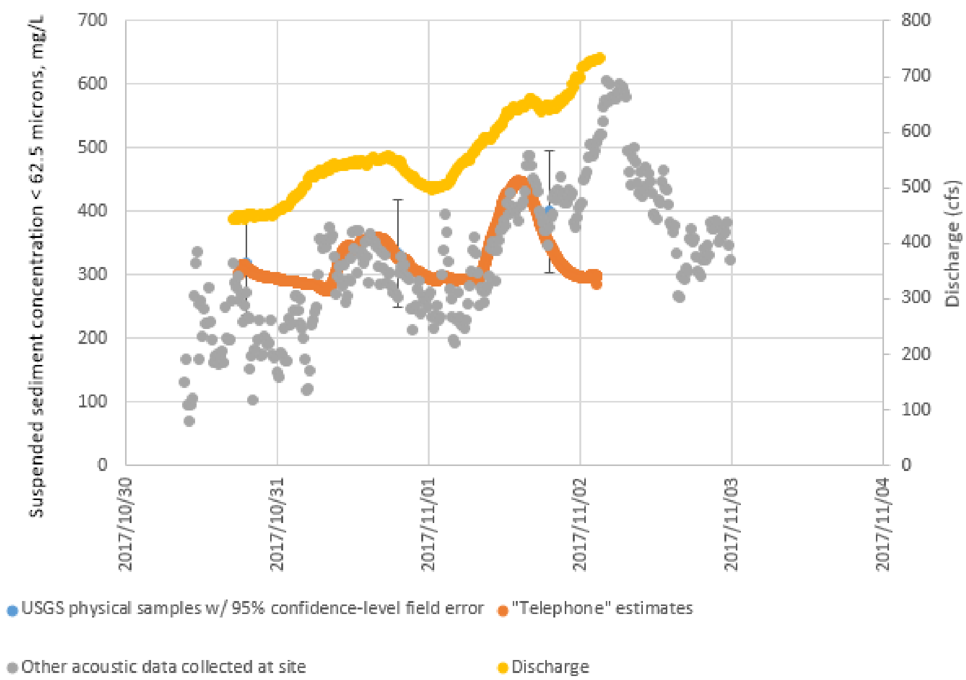


Figure 27.30 October 2017 through 3 November 2017 measurement of fine suspended sediment concentration from the NCPA acoustic isntrument ("Telephone" estimate) compared to acoustic surrogate estimates of fine suspended sediment concentration for the AquaDopps. Also shown is instantaneous discharge reading from the San Acacia gaging station.

Calibration of the AquaDopps

Calibration of the AquaDopps was performed by the GCRMC and followed the general procedures listed below; the comprehensive calibration procedure can be found in Appendix 7 (Topping and Wright 2016).

For each frequency instrument:

- Determine which beams to use and the maximum number of cells to employ in the calculations. (Want to avoid beams that have interference from submerged objects, like a sand bar or the opposite bank while using the maximum number of cells). If two beams are used, average the acoustic signal strengths of corresponding cells.
- Determine the effective noise floor. The effective noise floor is the noise recorded by the instrument plus an iteratively determined noise-floor offset.
- Calculate fluid-corrected backscatter in decibels (dB) for each cell where the acoustic signal strength is greater than the effective noise floor (equation 24 in Topping and Wright, 2016).
- Calculate the sediment attenuation coefficient and the beam-averaged backscatter
    - Use a least-squares linear regression between the fluid-corrected backscatter and distance along the acoustic beam to find the sediment attenuation coefficient (in dB/m).
    - Compute relative backscatter in each cell (equation 25 in Topping and Wright, 2016). Relative backscatter is the fluid-corrected backscatter plus the decibels lost from sediment attenuation.
    - Average the relative backscatter in each cell to determine the beam-averaged backscatter.
- Evaluate whether there are non-uniform flow conditions that affect the distribution of suspended sediment.
- Determine the sediment attenuation and beam-averaged backscatter values associated with laboratory processed suspended-sediment samples.
- Perform a regression analysis for the sediment attenuation coefficient and suspended-silt-and-clay measurements.
- Perform a regression analysis between the beam-averaged acoustic backscatter and the laboratory processed suspended-sand concentrations for conditions dominated by sand. This relationship is developed with only suspended-sand measurements that have a median grain size (D_{50}) that falls within a quarter phi size class according to the Wentworth scale (Wentworth 1922) of the reference D_{50}. The reference D_{50} is the median sand grain size observed for all laboratory processed EWI or EDI samples rounded to the nearest quarter phi size class.
- Calculate the excess backscatter while iteratively solving for the median grain size (D_{50}) and geometric sample standard deviation of the silt and clay particles using both frequencies of AquaDopps.
- Evaluate the quality of the calibration by comparing theoretical and measured values of the log of the ratio of the silt and clay suspended sediment concentration to sand-suspended sediment concentration. Poor relationships may indicate the presence of

physical processes that substantially shift the developed relationships with stage. In some cases a discharge-weighted factor may be applied to achieve a satisfactory relationship.

- Check to see if a high dB correction is needed. This is typically only required if the acoustic instrument is measuring in the range between the logarithm of the gain setting and the acoustic signal strength.
- Calculate silt and clay concentrations and sand concentrations for each frequency. The silt and clay concentrations calculated from the lower frequency instrument is typically used as the final silt and clay concentrations values, if the lower frequency instrument is unavailable the results of the higher frequency instrument are used.

Multi-frequency sand concentrations and sand D_{50} are calculated from the calibrated results from each frequency instrument using the relative unit target strength method (Appendix 8 Topping and Wright, 2016). The calibration of the AquaDopps at the San Acacia site utilized both measured EWI data and collected ISCO® pump data. The suspended sediment concentrations for the silt/clay fractions from the ISCO® samples were used directly, while the suspended sediment concentrations for the sand fraction required a discharge-weighted correction within each ¼ phi sand class. This correction was done to provide an equivalent relationship to the EWI collected samples (Topping, Rubin, et al. 2010). Acoustical data was only reported when discharge was greater than 400 cfs at the San Acacia gage since the acoustic beams are influenced by the water surface at lower discharges. This streamflow minimum is expected to change as channel geometry near the AquaDopps changes.

Collected Data

Between the installation of the AquaDopps at the end of September 2016 (21 September 2016) through the end of the calendar year in 2017, the following information was collected as part of the data collection at the San Acacia gaging station.

- 15-minute discharge information (based on staff gage height)
- 26 site visits (NMSC)
  - Discharge measurements for 24 site visits (velocity, depth, wetted width, wetted area)
  - Suspended sediment (EWI measurements) for 16 site visits
    - 38 suspended sediment concentrations analyzed
    - 18 of the collected samples had an additional gradation analysis performed by GCMRC using laser diffraction.
    - 4 suspended sediment gradations analyzed
    - 39 sand split percentages analyzed
  - Bed material samples for 13 site visits, with 12 bed material gradations collected
  - Six suspended sediment grab samples with three site visits
- 634 point sediment samples (collected using ISCO® pumps)
  - 383 daily samples
  - 153 event samples (11/4/2016, 3/22/2017 through 4/11/2017, 4/13/2017 through 4/22/2017, 5/9/2017 through 5/19/2017, 5/25/2017 through 6/3/2017, 9/30/2017, 10/2-3/2017, 11/11/2017, 11/14/2017, 11/16/2017, and 11/18-19/2017.

- 98 samples collected during site visits (10/7/2016, 11/4/2016, 11/22/2016, 12/5/2016, 1/13/2017, 2/2/2017, 2/22/2017, 3/21/2017, 4/12/2017, 6/19/2017, 7/13/2017, 8/10/2017, 8/31/2017, 9/25/2017, 9/30/2017, and 12/13/2017.
- 382 of the collected samples had an additional gradation analysis performed by GCMRC using laser diffraction.
- 172 of the collected samples only had a sand split gradation done (wet sieve)
- The remaining samples just had a suspended sediment concentration collected

Performance of AquaDopps

During periods of sufficient discharge (generally greater than 400 cfs) the AquaDopp instruments measured sand concentrations, silt and clay concentrations, and sand grain size collected between 21 August 2016 and the end of December 2017 with an accuracy estimation of +/- 10%. The sediment and grain size information obtained from the acoustic instruments is provided along with 95% confidence intervals of the combined field and lab errors (https://www.gcmrc.gov/discharge_qw_sediment/station/URG/08354900). The link also provides the ability to plot and download total suspended-sediment concentration, suspended-silt-and-clay concentration and loads, suspended-sand concentrations and loads, and cumulative sediment loads over time (Porterfield 1972). Data can be plotted as a time series or as duration curves.

The AquaDopps collected data during the time periods listed below and shown graphically in Figure 28. Most of the periods where acoustic data is not available are when the AquaDopps are not covered by water. The one exception is during the end of the 2017 calendar year.

a few hours on 11/5/2016 and 11/6/2016
11/7/2016 – 6/27/2017
most of the day on 6/28/2017
an hour on 8/13/2017 (two nonconterminous events)
a few hours on 8/14-15/2017
less than an hour on 9/27/2017
a couple of hours on 9/28/2017
multiple hours on 9/29-30/2017
10/1/2017 – 10/4/2017
multiple hours on 10/5-6/2017
10/7/2017 – 10/25/2017
multiple hours on 10/26-30/2017
11/1/2017 – 11/7/2017
hours on 11/8/2017
11/9/2017 – 11/25/2017
continuous collection on 11/26/2017 until 20:00

Performance of NCPA Acoustic

Once installed, the NCPA acoustic instrument did collect some data during this period as well, as shown in Figure 29. Acoustic information for the NCPA instrument is available during the following time periods:

a few hours on 8/10/2017 (due to power issues)*
a few hours on 8/14/2017 (due to power issues)*
8/14/2017 - 8/15/2017*
10/30/20107 - 11/02/2017*
11/22/2017 - 11/28/2017*
*-can make a comparison to physical USGS samples and AquaDopp acoustic data.

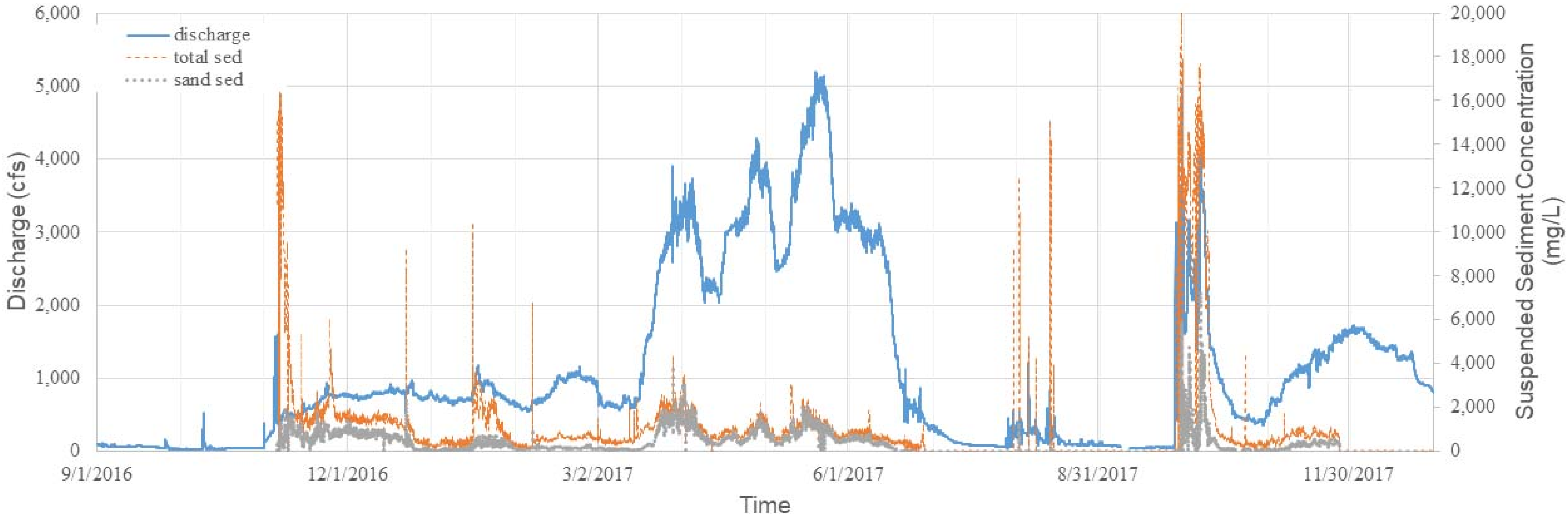


Figure 28. Water and suspended sediment (sand and total) at the San Acacia USGS gage from 1 September 2016 to 31 December 2017. The suspended sediment information was calculated from the post processing of the collected AquaDopp information.

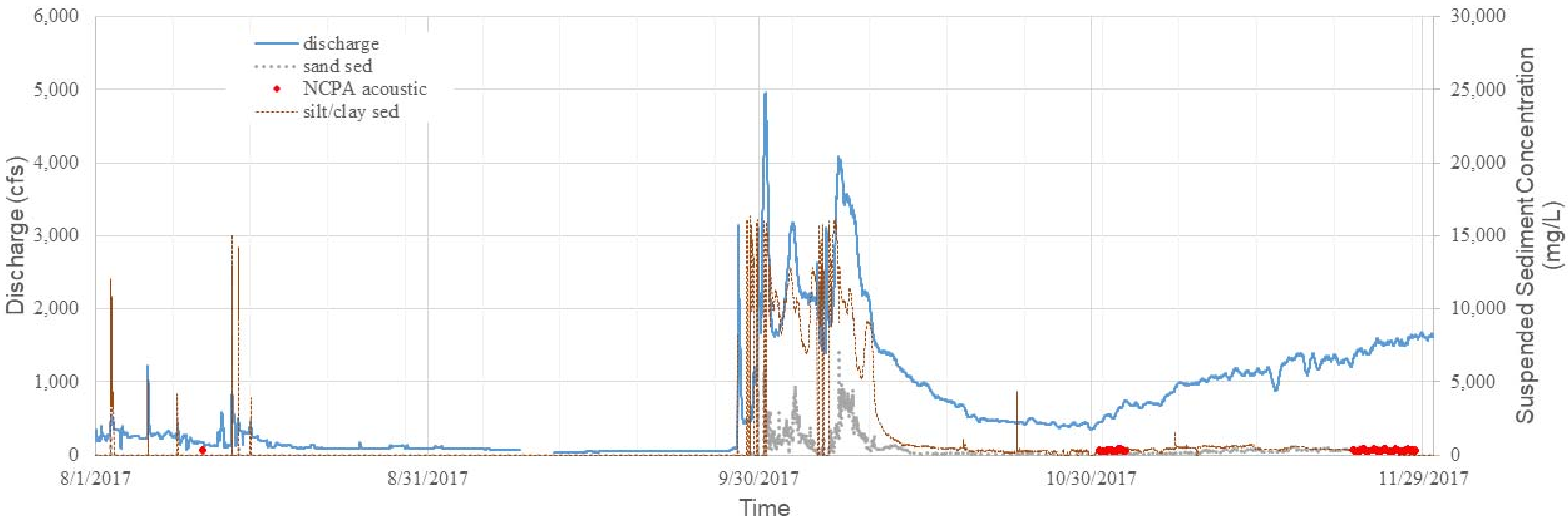


Figure 29. Water and suspended sediment (sand and silt/clay) at the San Acacia USGS gage from 1 September 2016 to 31 December 2017. The suspended sediment (sand and silt/clay) information was calculated from the post processing of the collected AquaDopp information. The NCPA acoustic information was calibrated to the suspended sediment less than 0.0625 mm in size.

Follow up years (January 2018 to July 2019)

The hydrograph as recorded at the San Acacia gaging station for the second and third year is shown in Figure 30. At the beginning of March 2018 the discharge in the Rio Grande was below the median daily flow, based on 45 years of collected discharge data. Discharge on the Rio Grande stayed below the median daily flow until early March 2019. Flows stayed above the median daily flow until the end of July, facilitating data capture during an above-average spring snow pack runoff year.

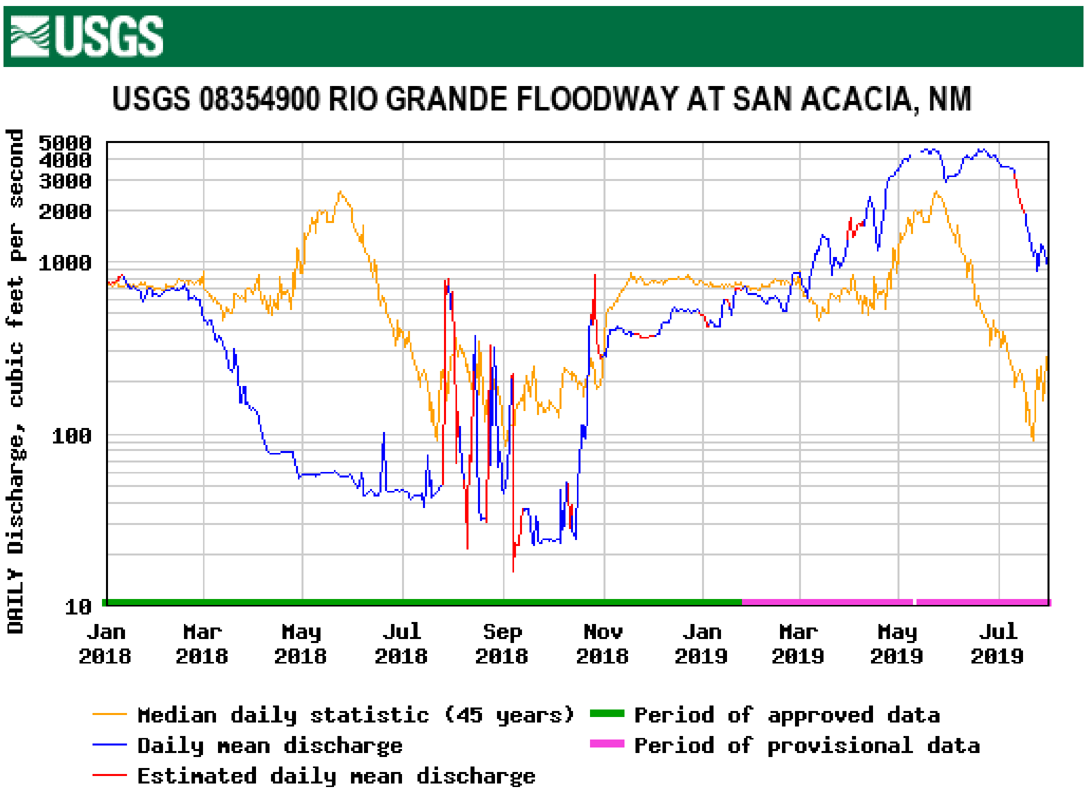


Figure 30. Daily average discharge values at the USGS San Acacia gaging station (# 08354900) between 1 January 2018 and 31 July 2019.

Collected Data

Between the beginning of January 2018 and the end of July 2019, the following information was collected as part of the NMWSC data collection at the San Acacia gaging station.

- 15-minute discharge information (based on staff gage height)
- 25 site visits
  - Discharge measurements for 25 site visits (velocity, depth, wetted width, wetted area)
  - Suspended sediment (EWI measurements) for 11 site visits
    - 48 suspended sediment concentrations analyzed

        - 15 of the collected samples had an additional gradation analysis performed by GCMRC using laser diffraction
        - 16 suspended sediment gradations analyzed
        - 48 sand split percentages analyzed
    - Bed material samples for 10 site visits, with 21 bed material gradations collected
    - Three suspended sediment grab samples with one site visit
- 559 point sediment samples (collected using an ISCO pump sampler)
    - 364 daily samples
    - 129 event samples (3/19/2019, 3/31/2019, 4/12-16/2019, 4/22-24/2019, 4/29/2019 through 5/6/2019, 5/11/2019 through 6/15/2019, and 7/8-17/2019).
    - 66 samples collected during site visits (2/20/2018, 3/15/2018, 4/5/2018, 5/23/2018, 6/14/2018, 7/28/2018, 9/11/2018, 1/30/2019, 3/18/2019, 5/10/2019, and 6/5/2019).
    - 48 of the collected samples had an additional gradation analysis performed by GCMRC using laser diffraction.
    - 555 of the collected samples had a sand split gradation done (wet sieve) and a suspended sediment concentration evaluated.

Performance of AquaDopps

During periods of sufficient discharge (generally greater than 400 cfs) the AquaDopp instruments measured sand concentrations, silt and clay concentrations, and sand grain size collected between 1 January 2018 and 5 June 2019 with an accuracy estimation of +/- 10%. Both the AquaDopps and the NCPA acoustic device were not covered with water for most of the period between March and late October 2018. There were a few rainfall-runoff events during this period of low flows (late July through August), but these were brief hydrologic events. The AquaDopps did pick up a few of these events. No acoustic (and thus sediment) data is available during periods when the acoustics are out of the water. Discharges after November 2018 were large enough to submerge the installed acoustics and allow for continuous monitoring of the data. Data from the AquaDopps is generally available for all periods when the discharge was above the acoustic instruments. There were two exceptions during this period. The first was between November 2018 and January 2019 and the second was after 6 June 2019. The AquaDopps collected data during the following time periods. This is also shown graphically in Figure 36.

a few hours on 1/4/2018
1/5/2018 – 1/21/2018
a few hours on 1/22/2018
a few hours on 1/25/2018
1/26/2018 – 1/27/2018
a few hours intermittently between 1/28/2018 and 1/31/2018
a few hours on 2/3-4/2018
2/5/2018 – 2/19/2018
a few hours on 2/20/2018
a few hours on 7/28-29/2018
an event only minutes on 7/29/2018
a few hours on 7/29-30/2018

hours on 7/31/2018
hours on 7/31 to 8/1 2018
hours on 10/26-27/2018
minutes on 12/27/2018
hours on 1/30/2019
1/31/2019 – 6/5/2019
hours on 6/6/2019

Performance of NCPA Acoustic

The NCPA acoustic instrument did collect data during the following time periods (see Figure Figure 37):

1/25/2018 - 2/5/2018*
2/20/2018 - 2/27/2018*
a few hours on 5/24/2018 (due to power issues)
a few hours on 7/26/2018 (due to power issues)
8/23/2018 - 8/28/2018†
1/21/2019 - 1/29/2019†
1/29/2019 – 2/3/2019*†
4/15/2019 – 4/22/2019*†
*- can make a comparison to physical USGS samples.
† - backscatter data was collected

Due to equipment malfunctions, no physical samples were present from 8/23/28-8/28/18. It should also be noted that the no physical samples were collected during the period from 1/21/19-1/29/19, as the automatic samplers were full and not being serviced due to the government shutdown.

The data set collected from 1/25/2018 – 2/5/2018 is shown in Figure 31. This data set shows some overlap between the AquaDopps and the NCPA acoustic instrument. While there are a few hours missing on 1/29/2018, the NCPA dataset is largely continuous. USGS samples collected at the site suggest a lower adjusted suspended sediment concentration than the estimated values produced using the NCPA acoustic instrument. It is possible that the NCPA acoustic instrument was detecting a different makeup of the suspended concentration than was evaluated for the initial calibration or that the suspended sediment concentrations pulled from the ISCO® pump sampler and estimated at the NCPA acoustic instrument were not the same (non-uniform suspended sediment concentrations).

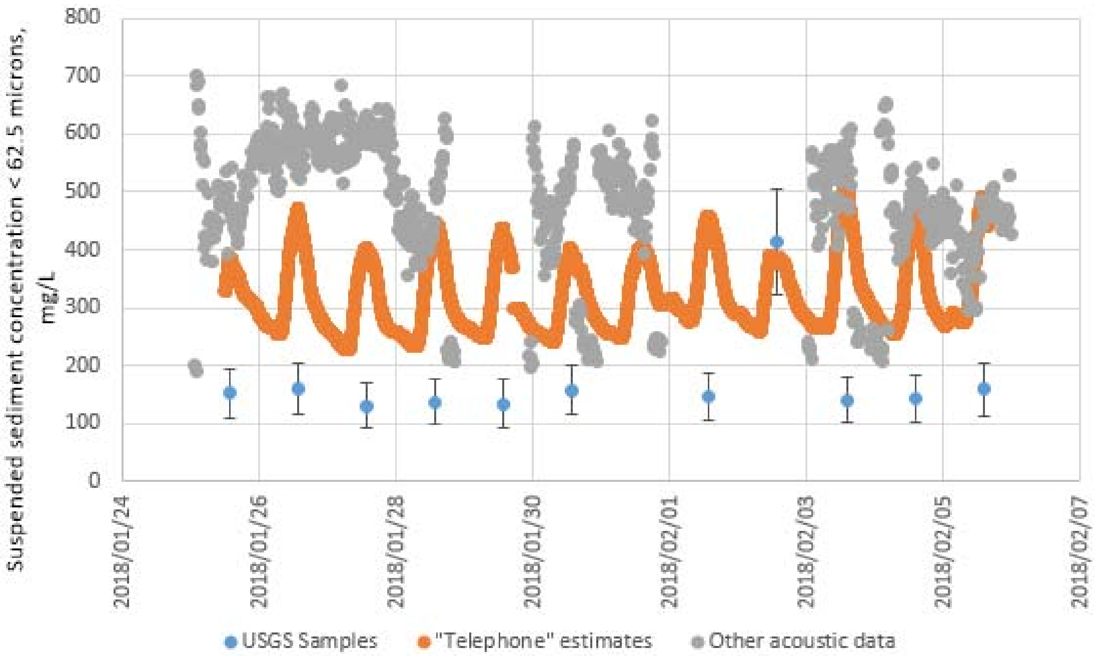


Figure 31. 25 January 2018 through 5 February 2018 measurement of fine suspended sediment concentration from the NCPA acoustic isntrument ("Telephone" estimate) compared to acoustic surrogate estimates of fine suspended sediment concentration for the AquaDopps. Also shown are collected physical samples (ISCO® pump samples at lower suspended sediment concentrations (~ 150 mg/L)).

During the 2/20/2018 – 2/27/2018 NCPA data collection, low flow discharge (529 cfs to 679 cfs) lead to small suspended sediment transport. Figure 32 shows that the NCPA acoustic instrument over estimates the suspended sediment concentration compared to the ISCO® pump samples. The acoustic estimates of suspended sediment concentration from the AquaDopps were not available likely due to the low discharge. It is likely that observed suspended sediment information from the NCPA acoustic data is due to localized sediment movement within the reach of the San Acacia gaging station or fines deposited during the previous monsoon season further upstream.

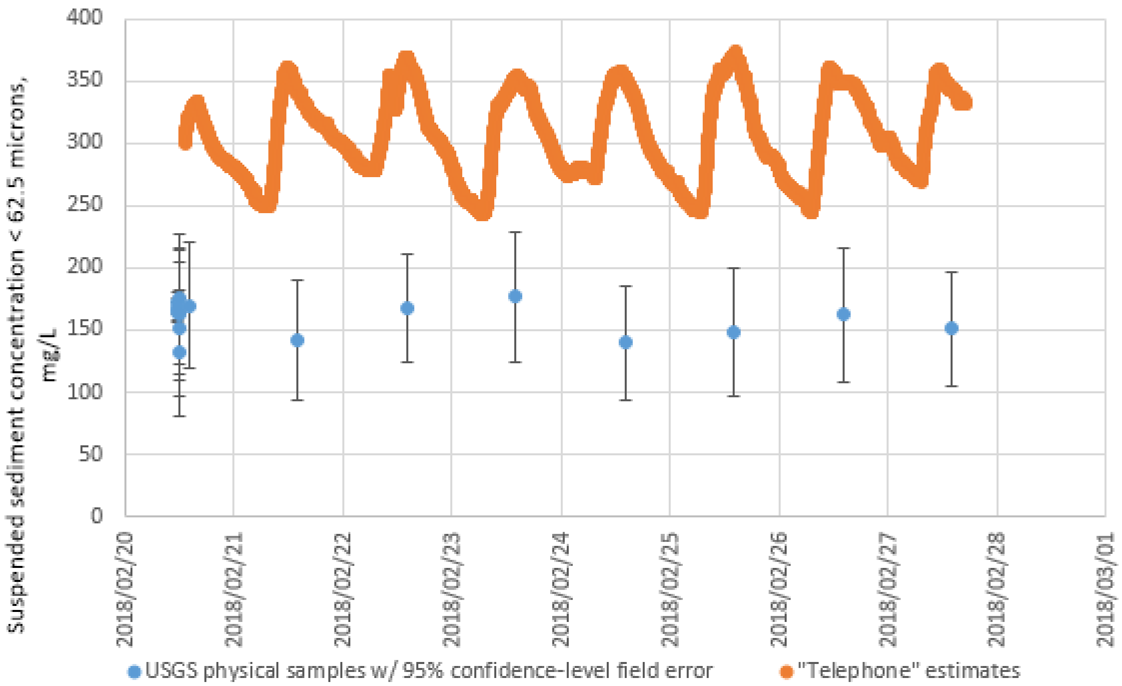


Figure 32. Low discharge suspended sediment transport from 20 February 2018 through 27 February 2018. Measurement of fine suspended sediment concentration from the NCPA acoustic isntrument ("Telephone" estimate) compared to collected physical samples (ISCO® pump samples.

During August 2018, NCPA returned to the San Acacia gauge station site. The purpose of the trip was three fold: optimize power consumption of the float-switch trigger, perform routine maintenance, and install a 10 MHz backscatter transducer to the existing bracket. The prototype bracket was modified to accept an orthogonal transducer (10 MHz) in addition to the original transducer configuration in the laboratory (two 20 MHz transducers). This refined orthogonal position allowed for simultaneous backscatter measurements to be collected with the attenuation measurements.

In short, acoustic attenuation is the measure of energy loss in a medium when sound propagation occurs. A mixed medium containing a greater concentration of particles will yield a greater amount of attenuation and therefore, a lower amount of received signal. Acoustic backscatter is the measurement of a transmitted signal as it is reflected from the particles. In contrast to measuring attenuation, a backscattered signal increases as more particles become present in the beam path.

Using this multi-frequency approach, backscattered signals could be related to grain size while attenuated signals could be related to suspended sediment concentration. As the backscattered signal increases, the distribution of larger grain sizes increases. Software for the calculation (see Figure 33) was written in National Instruments LabVIEW (Version 16.0f5 64-bit) to coordinate this data collection over the two measurement techniques.

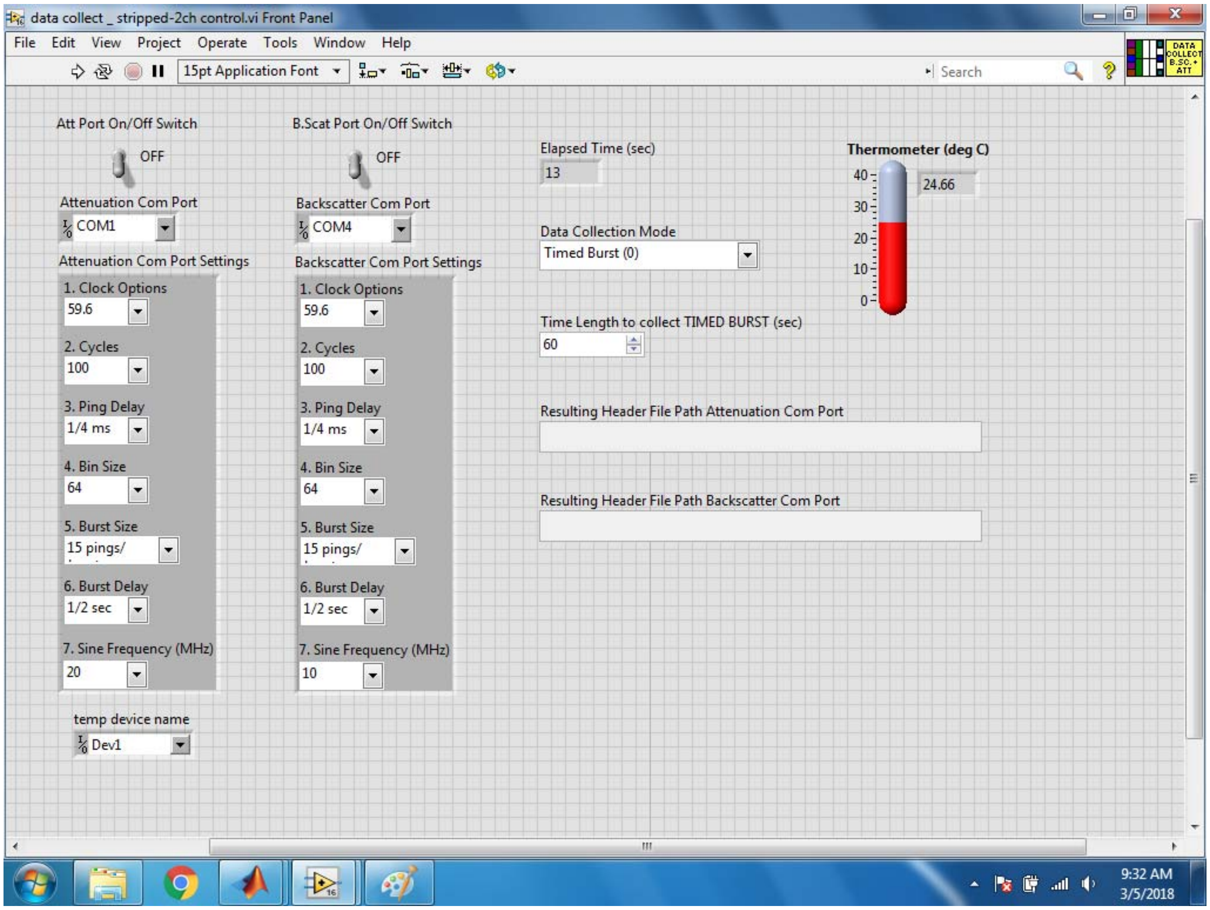
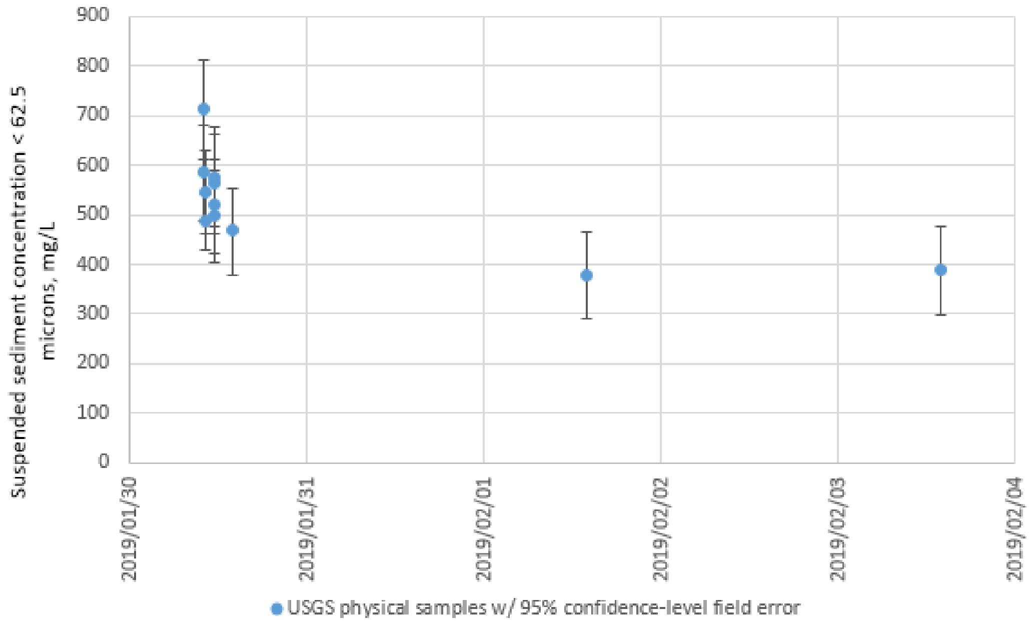


Figure 33. Screenshot of attenuation and backscatter monitoring graphical user interface

Data from two events after this site visit (1/21/2019 – 2/3/2019 and 4/15/2019 – 4/22/2019) predict much higher concentrations than were measured by the physical samples (see Figure 34 and **Error! Reference source not found.**). The inconsistency with the measurement suggests that there is an issue with the NCPA acoustic surrogate correlation. It is possible that the original calibration was based on a specific composition of suspended sediment and over the timeframe the composition has changed. During this timeframe, a discharge of roughly 640 – 660 cfs was recorded with a stage height of over 11.34 ft. indicating that the device was underwater. Potential problems with the NCPA acoustic observations include: the device getting intermittently buried, debris trapped on the apparatus, or potential transducer damage. The bottom figures in Figure 34 and **Error! Reference source not found.** show the collected acoustic backscatter data for these events. The bottom figure in Figure 34 indicates that a larger grain size distribution was initially present followed by a smaller grain size distribution. This relationship is in agreement with the physical samples as shown in the top figure of Figure 34. The intent of the backscatter collection is to differentiate between silt particles and clay particles. This distinction is not part of the NMWSC lab protocol for data collected at this site. Therefore as of this writing, there are no physical sample results for median grain sizes under 0.062 mm (silts and clays) to compare to this acoustic data. However, these events were useful as tests of the hardware and software systems.



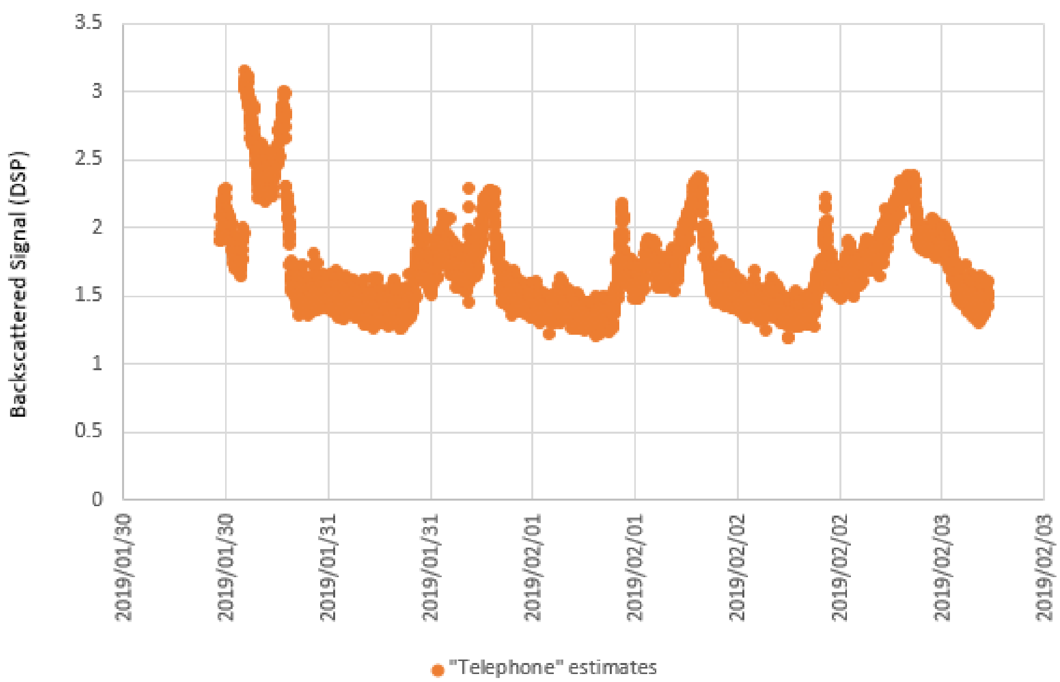
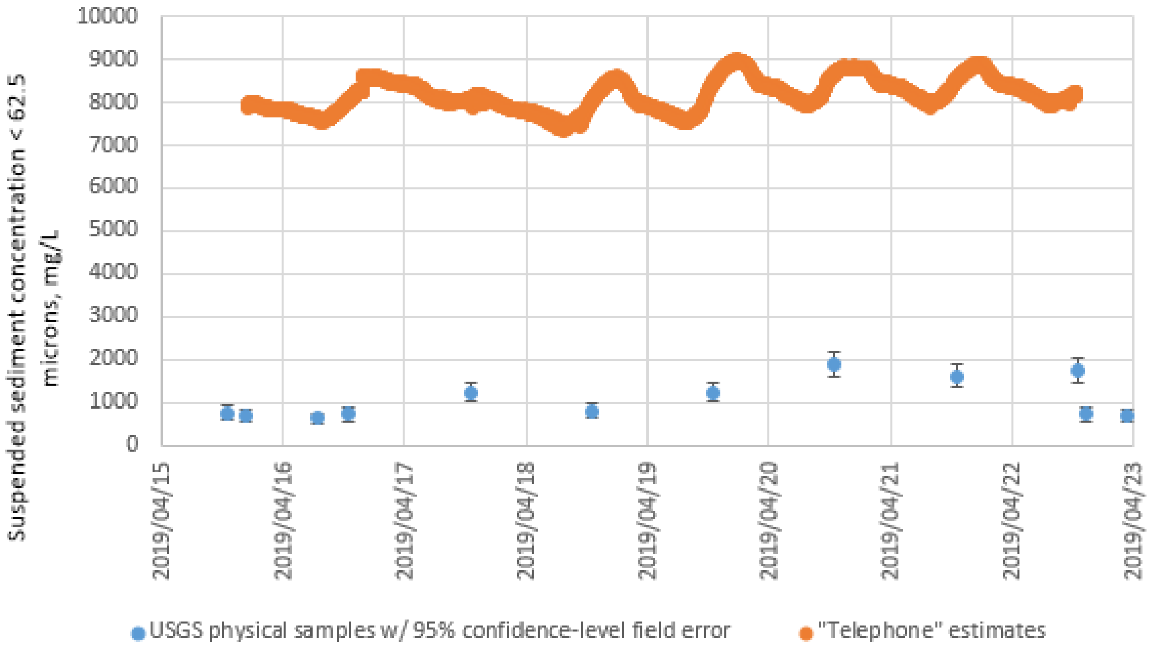


Figure 34. Top: Collected ISCO® pump samples with error bars from Jan 30 – Feb 04, 2019. Bottom: NCPA acoustic backscatter ("telephone" estimate) for the event from Jan 30 – Feb 04, 2019.



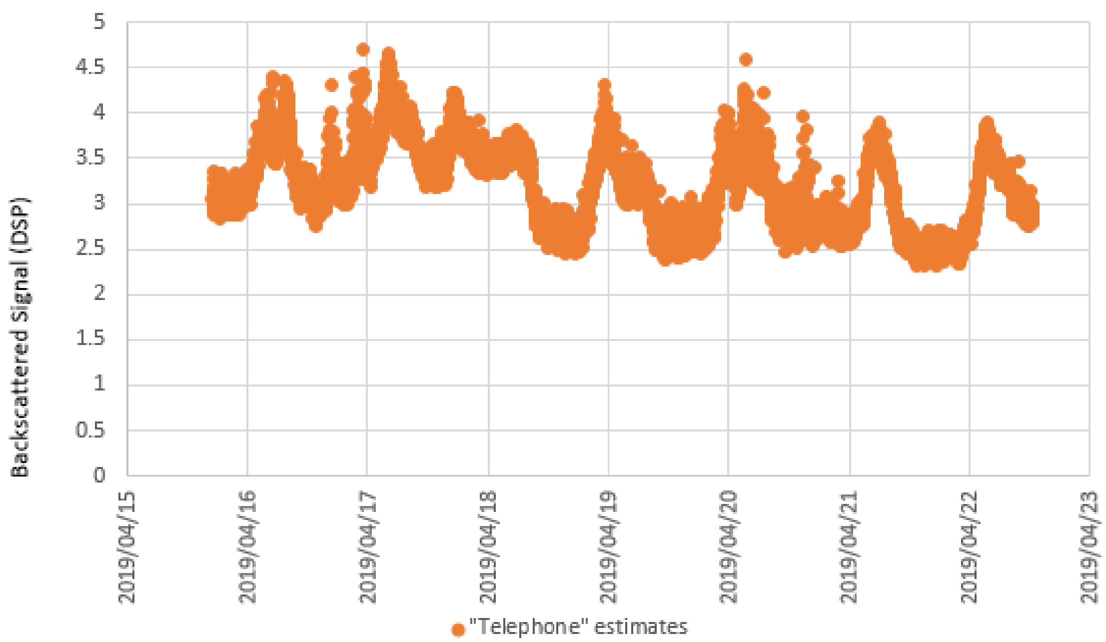


Figure 35. Top: NCPA acoustic attenuation for the event from April 15 – April 22, 2019 shown with collected ISCO® pump samples with error bars. Bottom: NCPA acoustic backscatter for the event from April 15 – April 22, 2019. The NCPA acoustic instrument measurements are listed as “telephone” estimates

While NCPA acoustic data was collected in 2018 and 2019, there were still laptop failures that continued to occasionally occur. The NMWSC personnel also noted that LabView became unresponsive after continuous data collection for days. One potential workaround for this issue was to cause a restart at midnight, forcing an autostart of the program.

The generated files were also quite large and took considerable time to download (field times around 12 hours had been experienced). The computer is also limited in the number of files it can copy to a USB device at once (~ 19,000). One proposed workaround is to periodically move the files from the laptop HDD to the SD card slot until filled. The SD cards can then be swapped out by NMWSC personnel on routine visits to the site. It was also proposed that data can be averaged over a set amount of time and then saved (for instance saving a 15 minute increment average value). This would further reduce the required file storage.

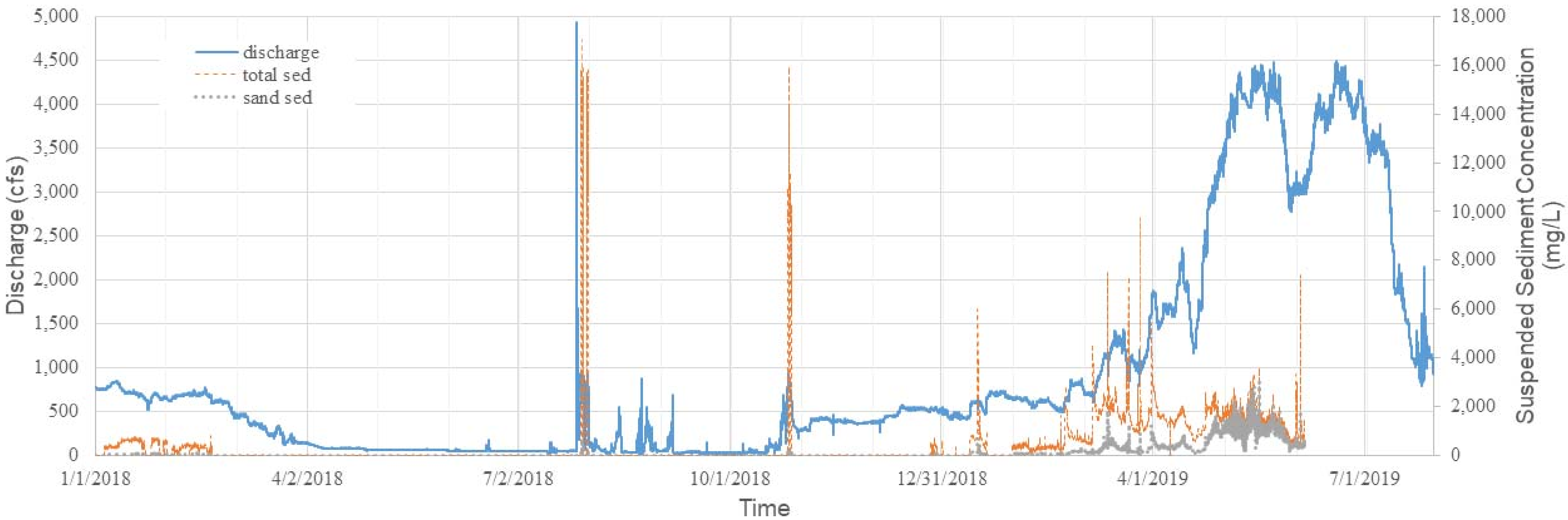


Figure 36. Water and suspended sediment (sand and total) at the San Acacia USGS gage from 1 January 2018 to 31 July 2019. The suspended sediment information was calculated from the post processing of the collected AquaDopp information.

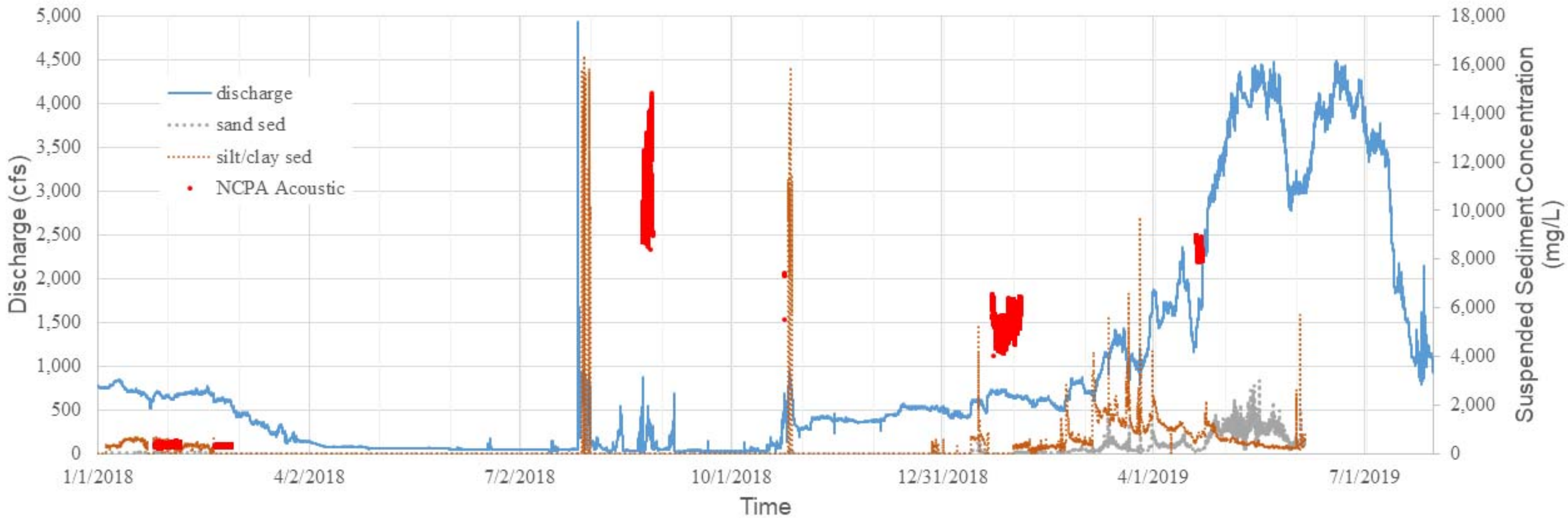


Figure 37. Water and suspended sediment (sand and silt/clay) at the San Acacia USGS gage from 1 January 2018 to 31 July 2019. The suspended sediment (sand and silt/clay) information was calculated from the post processing of the collected AquaDopp information. The NCPA acoustic information was calibrated to the suspended sediment less than 0.0625 mm in size.

Results

Between the fall of 2016 and the end of July 2019, both physical and acoustical data was collected at the San Acacia USGS gage station to evaluate the efficacy of active acoustic technology in a shallow, mobile-bed fluvial system. Results of the observed suspended sediment transport during this time are described in the sections that follow.

Suspended Sediment Concentration

A comparison (Figure 38 and Figure 39) of the collected physical samples (EWI and ISCO pump samples) with the observed discharge at the San Acacia USGS gaging station illustrates that there is a correlation between discharge and the observed suspended sediment concentration. Information from these samples indicate that the highest concentration of sediment is moved during rainfall-runoff events in the late summer/early fall (monsoon events). These events tend to be flashy and can be captured to some extent by the ISCO® pump samplers. The EWI measurements, while providing a more robust analysis of the suspended sediment concentration across the river channel, are not collected frequently enough to ascertain trends between suspended sediment concentration and discharge.

The advantage of using active acoustics is that the temporal resolution of the suspended sediment concentration is improved. A comparison of the total and sand fraction of the suspended sediment concentration measured by the AquaDopps to the recorded discharge and measured suspended sediment concentrations (ISCO® pump samples and EWI) is shown in Figure 40 and Figure 41. The measurements from the AquaDopps correlate well with the measured suspended sediment concentrations, although the magnitude of the higher suspended sediment concentrations from the ISCO® pump samplers (>15,000 mg/L) is often not captured by the AquaDopps [N.B. this is true for data between 2016 and 2017 (Figure 40), but there is a better correlation with data collected in 2018(Figure 41)]. The AquaDopps were configured to provide estimations of suspended sediment concentration every 15 minutes, providing additional temporal resolution of the data provided by the ISCO® pump samples (set to every day or to collect based on changes in the stage). Figure 40 and Figure 41 show that while the suspended sediment concentration trends observed in the collected physical measurements are similar to the acoustically estimated measurements, there are additional discrete events captured by the acoustic instruments that are missed in the physically collected samples. This can be more easily shown when focusing the time frame on more discrete hydrological events. The flows in the MRG were separated into three events for the purpose of this analysis: snow-melt runoff, monsoon events, and base flows. The snow-melt runoff on the MRG typically begins in the spring and can extend into the summer. The monsoon events are associated with intense thunderstorm activities between July and October that are typically large hydrologic peaks, but short duration events. The base flow period typically runs between November and February when irrigation diversions are not occurring on the MRG.

Spring snow-melt runoff

Figure 42 shows the 2017 spring snow-melt runoff. The first observation is that the EWI measurements (only three were captured during this event) by themselves would be inadequate to define the suspended sediment transported through this hydrologic event. The ISCO® pump samples provide a general trend of the suspended sediment concentration changes with discharge but there are localized peaks, observed in the acoustically collected data, that are missed by the ISCO® pump samples. The more frequently collected acoustic data pick up this signal and illustrate that there is more fluctuations in the suspended sediment concentration on the rising and falling limbs of the hydrograph. One of the more interesting capabilities of the dual acoustic frequencies provided by the AquaDopps is the differentiation of suspended sediment concentrations by size fractions. This allows a comparison of the changes in the sand and the finer (<0.0625 mm) size fraction. For the spring 2017 snow-melt runoff it can be observed that the sand fraction becomes a larger percentage of the suspended sediment load on the rising limb of the hydrograph. The finer size fraction (silts and clays) are more dominant early on the rising limb and again on the falling limb of the hydrograph. It is also observed from Figure 42 that the concentration from the ISCO® pump samplers generally underestimates the acoustically measured sand fraction of the suspended sediment concentrations.

The AquaDopps are configured so that they capture a horizontal slice of the river cross section. In this way, the measurement of the AquaDopps is similar to the EWI measurements, to which they are calibrated (along with an adjusted ISCO® pump sample to account for changes in the sediment distribution in the cross section based on EWI measurements). As such these acoustical measurements are felt to be a better temporal representation of the average suspended sand concentration in the cross section and indicate that the unadjusted ISCO® pump samplers at San Acacia are likely underrepresenting the sand fraction of the suspended sediment concentration. Another interesting insight gleaned by the acoustic data is the variation of the suspended sediment peaks with the discharge peaks. In general the suspended sediment concentrations for the 2017 spring snow-melt runoff have a clockwise hysteresis, as shown in Figure 43 and Figure 44. The clockwise hysteresis indicates that in general the suspended sediment concentrations peak before the hydrograph peaks. These two figures show the variation in total and sand suspended sediment concentration, respectively, with discharge. While there is a significant amount of scatter, the larger concentrations tend to occur on the rising limb of the spring snow-melt hydrograph.

The 2019 spring snow-melt runoff (Figure 45) shows similar trends as observed in the 2017 spring snow-melt runoff. The sand starts to move on the rising limb and becomes more predominant during the runoff than the fine fraction. There is also more variability in the suspended sediment concentration during the rising and falling limbs of the hydrograph. The concentrations also show a clockwise hysteresis for both the total and sand suspended sediment concentration, as shown in Figure 46 and Figure 47, respectively.

Late summer/early fall monsoon events

Observations of monsoon events (Figure 48, Figure 49, and Figure 56) also provides some insight into the quantity, type, and timing of suspended sediment concentration changes with discharge. For the monsoon events captured during the time period between late September and early October 2017 (Figure 48), it can be seen that primarily the silt/clay fraction is transported, but for discharge events greater than about 2,000 cfs there is also a percentage of the suspended sediment that is sand. There are large fluctuations of the suspended sediment concentration on the rising limbs (September 30 and October 5).

Between July and October 2018 there were approximately five hydrologic monsoon events captured by the San Acacia gage (see Figure 49). Both the ISCO® pump samplers and the AquaDopps recorded large suspended sediment concentrations (>10,000 mg/L). The material was predominantly particles smaller than 0.0625 mm, as very little sand was assessed to be moving by the acoustic measurements.

The movement of suspended sediment during these events does vary. The October 2017 monsoonal event had a clockwise hysteresis for the total suspended sediment concentration (Figure 50), but a counter-clockwise hysteresis for the sand fraction of the suspended sediment concentration during that same event (Figure 51). A July 2018 monsoonal event showed a counter-clockwise hysteresis for the total suspended sediment concentration (Figure 52) and a slight counter-clockwise hysteresis for the sand suspended sediment concentration (Figure 53). A similar trend in the total and sand suspended sediment concentrations are shown for a monsoon event captured in October 2018 (Figure 54 and Figure 55, respectively). This would indicate that there is some variability as to the timing of the peak suspended sediment concentrations relative to the discharge peaks, with potentially a slight tendency for the peak suspended sediment concentrations to lag the peak discharge, during monsoon generated flows.

The October 2018 monsoon event is shown in Figure 56. No ISCO® pump samples or EWI measurements were collected during this event. There is a minimal amount of sand suspended sediment moving and significantly more variability in the suspended sediment concentration than in the observed hydrology.

For all of these monsoon events, the ISCO® pump samplers, due to the limited temporal resolution, are not able to capture the sediment concentration variability to the same extent as the AquaDopps. While the suspended sediment concentration generally follows the discharge trends, the correlation during the monsoon events is not as well defined as observed during the spring snow-melt runoff.

Base Flows

There is suspended sediment that is moving during the base flow period (see Figure 57) on the MRG (November through February). This is the period of time when there are no diversions on the river and there are typically few storms that add additional discharge. Due to compact agreements there is typically additional water added to the base flows in November and December from stored water volumes to account for water volumes needed to make agreed upon annual water deliveries. While there is some sand moving in suspension, the bulk of the suspended sediment concentration at San Acacia is the fraction finer than 0.0625 mm.

Figure 58 and Figure 59 show a comparison of the total and sand suspended sediment concentrations, respectively, versus discharge. While these are not true hydrologic events with a rising and falling limb, there is some variability in the suspended sediment concentration with discharge. For these events the correlations are provided based on months (January and February). For the total suspended sediment concentration (Figure 58) there is a clockwise hysteresis from January to February as the discharge decreases. This trend is less discernible for the sand suspended sediment concentrations shown in Figure 59.

Summary

The dynamic variability of the mobile-bed at the San Acacia gaging site provided limitations on the data. In order to minimize burial of the instruments, the acoustics were set out in the channel at an elevation above the channel invert. Thus the acoustics are not always able to collect data. The NCPA instrument must be submerged in order to collect data, while the AquaDopps must be submerged and have sufficient transmission length in order to collect data (i.e water must be sufficiently above the instruments such that the acoustic signal travels a certain distance before being reflected by the water surface or the bed). For the latter this means that even though the AquaDopps are submerged, no data may be collected if an insufficient horizontal collection distance is acquired prior to the outgoing acoustic signal reflected by a shallow water covering or a depositional bed form that raises the channel invert. This is a limitation of the use of acoustics on shallow, mobile bed fluvial systems that precludes the data collection to periods above a given discharge. There were also some limitations with the acoustics in collecting the flashy monsoon events, although it is not known if this is due to stage and duration of flow since the AquaDopps collected some flashy events (July and October 2018) but missed three other events in the summer of 2018 and one rainfall-runoff event in late January 2018.

The mean suspended sand concentration during the period from September 2016 through December 2017 was around 200 mg/L, while the max observed was close to 8,000 mg/L (see Figure 60). The mean suspended sand concentration during the period from January 2018 to July 2019 was around 50 mg/L with a maximum around 3,000 mg/L (see Figure 61). It should be noted that the lower value between January 2018 and July 2019 may be a reflection of fewer observations (~17,000 acoustic measurements) than made during the September 2016 to December 2017 period (~27,800 acoustic measurements).

While there is limited data collected by the NCPA acoustics, there are some captured events which allow a comparison between the various acoustics measuring at the site. The NCPA acoustic is capturing data on a 1 minute time scale and is calibrated to the fine (silts and clays) fraction of the suspended sediment. Figures are provided for the following events: brief event in August 2017 (Figure 62), October to early November 2017 (Figure 63), end of November 2017 (Figure 64), January and February 2018 (Figure 65), January and February 2019 (Figure 66), and April 2019 (Figure 67). In general the NCPA acoustic estimates provide a smoother variation of concentration with time than the AquaDopps, with variable suspended sediment concentrations (Figure 62, Figure 64, and Figure 65). Figure 66 and Figure 67 provide significantly larger sediment concentration estimates for the NCPA acoustic than either the physical measurements or the AquaDopp estimates for suspended sediment concentration. This may be due to a change in the suspended sediment gradations compared to the limited calibration period. This would suggest that a larger breadth of measured suspended sediment concentration is needed over a range of hydrologic events (spring snow melt runoff, monsoon events, and base flows) in order to develop a more robust estimate of the suspended sediment concentrations from the acoustic signal. There is some cyclical variation in the NCPA acoustic data as well that is a response to the degradation of the signal strength. This has yet to be corrected, but is something accounted for in the collection of the AquaDopp data.

Suspended Sediment Sizes

One of the benefits of a dual acoustic setup with the AquaDopps is the ability to discern median grain sizes in suspension. Figure 68 plots the median sand grains in suspension along with the discharge and median sand sizes measured from physical samples between 21 September 2016 and 31 December 2017. The median sand size in suspension is also plotted in Figure 69 with the median size of bed material samples (total and sand fraction) analyzed from EWI measurements at San Acacia. Figure 70 presents the median sand grains in suspension along with the discharge and median sand sizes measured from physical samples between 1 January 2018 and 31 July 2019. Figure 71 displays the bed material information along with the collected acoustical median sand sizes in suspension for the period between 1 January 2018 and 31 July 2019.

Acoustical measurements (AquaDopps) of the mean sand suspended sediment size (Figure 68 and Figure 70) indicate a larger scatter during base flow events (November through February), on the rising and falling limbs of the spring snow-melt runoffs, and during monsoon events. During the 2017 spring snow-pack runoff event, the median sand size was around 0.15 mm, with a median size of around 0.14 mm for the period between September 2016 and December 2017 (see Figure 72). The maximum suspended size indicated by the acoustical instruments was around 0.3 mm. A comparison of the suspended sediment sizes with the collected bed material sizes (Figure 69 and Figure 71) shows that the bed is considerably coarser than what is in suspension. The median sand size in the suspended sediment load between January 2018 and July 2019 was 0.13 mm, with a maximum also around 0.3 mm (see Figure 73).

Suspended Sediment Loads

Correlations of suspended sediment concentration with discharge provide relatively poor relationships (see Figure 74 and Figure 75). For information collected at the San Acacia USGS gage for the physically collected data, the suspended sediment concentration spans 3 orders of magnitude for a given discharge. This contributes to the low correlation (range in R^2 is from 0.13 to 0.49) observed with linear regression lines between suspended sediment concentration and observed discharge. This is the typical relationships developed for the purpose of estimating annual suspended sediment discharge or evaluation of sediment transport because discharge is readily known. There are significant fluctuations in the suspended sediment transport though that make this correlation problematic. Parsing the data by season or by the primary type of sediment being transported (sands versus silts/clays) can improve this relationship (Harris and AuBuchon 2016, Klein, et al. 2018) but there is still a variation that cannot be explained solely by the fluctuation of discharge.

Cumulative sediment load curves with time (single mass curves) and with cumulative discharge (double mass curves) provide the ability to assess differences between traditional physical measurements and use of discharge as an approximation of the suspended sediment load and more temporally robust acoustical estimations of the sediment load. The information shown in the single (Figure 76 and Figure 77) and double mass curves (Figure 78 and Figure 79) is based on the best fit linear regression lines from the physically collected data (ISCO® pump samples and EWI measurements) and the acoustically measured (AquaDopp) concentrations. The cumulative load is calculated by using the available 15 minute hydrologic data (cfs) and multiplying by the suspended sediment concentration (mg/L). The units are converted to short tons (multiplied by a factor of 1.87E-6) and then multiplied by a 15 minute time period. The suspended sediment concentration for the physical measurements is based on the best fit linear regression between the physical measurements and discharge as shown in Figure 74 and Figure 75. The acoustic (AquaDopp) suspended sediment concentration is based on the 15 minute data collected from the acoustics. The cumulative mass is displayed on the graphs in terms of million short tons (division by 1.0E-6). It should be noted that where the slope of the single mass curve for the acoustics is flat, there is no available acoustic data and thus no accumulation in the suspended sediment load. The cumulative water mass is calculated by taking the available 15 minute hydrologic data (cfs) and multiplying by 15 minutes. This is then converted to acre-feet (ac-ft) through multiplication of a conversion factor (0.00138).

Single mass curves for the period from 21 September 2016 through 31 December 2017 (Figure 76) and for the period from 1 January 2018 through 31 July 2019 (Figure 77) show that the sand fraction of the suspended sediment load contribute more to the cumulative suspended sediment load during the spring snow-melt runoff and the fines (suspended sediment fraction less than 0.0625 mm) contribute more during the monsoonal events. It is also interesting to note that there is also more or less a constant (straight line) transport of fine suspended sediment during the entire year outside of the monsoon season, which tends to have a markedly steeper slope.

In a comparison of the load from the acoustics and traditional approach, it is seen that the cumulative load from the acoustic estimates is between 0.4 and 0.6 million tons greater than the traditional approach for the 2016-2017 period of measurements. The difference in the acoustic during the 2018-2019 measurement period ranges from 0.1 million tons greater to 1.0 million tons less than the traditional approach. The highest estimated suspended sediment load from the traditional approaches is obtained from the EWI measurements. Because the traditional methods correlate suspended sediment to discharge, the single mass curves increase continuously with time. The acoustic measurements did not always capture a measurement, so there are periods of time when the single mass curves are not continuously increasing. This likely underestimates the actual suspended sediment load, especially in the 2018-2019 time period as the AquaDopps did not collect information after 5 June 2019 during a period when the sand transport was high.

The acoustics provide a better estimation of the continuous suspended sediment load with time when there are measurements. It can also be seen in the single mass curves that the actual suspended sediment load during an event can be greater (steeper slope in acoustics) than estimated by the linear regression with discharge methods.

The double mass curves for the period from 21 September 2016 through 31 December 2017 and from 1 January 2018 through 31 July 2019 are shown in Figure 78 and Figure 79, respectively. The slope of the lines for the double mass curves is a representation of the average suspended sediment concentration. A comparison of the slopes between the acoustic (AquaDopp) estimates and the linear regression on discharge based on the physically collected samples indicates that the linear regressions underestimate the peak concentrations and overestimate the low flow concentrations.

Graphical Results

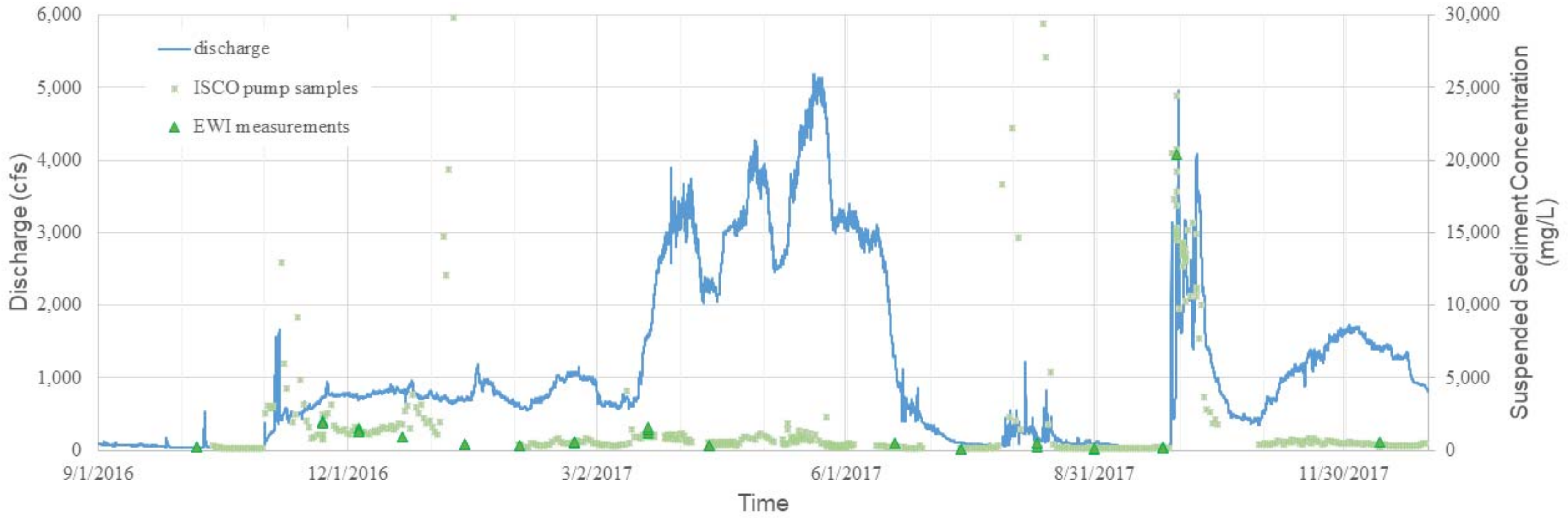


Figure 38. Water and collected suspended sediment (point and cross section average) at the San Acacia USGS gage from 1 September 2016 to 31 December 2017. The collected suspended sediment samples are physical samples with suspended sediment concentrations analyzed by the NMWSC.

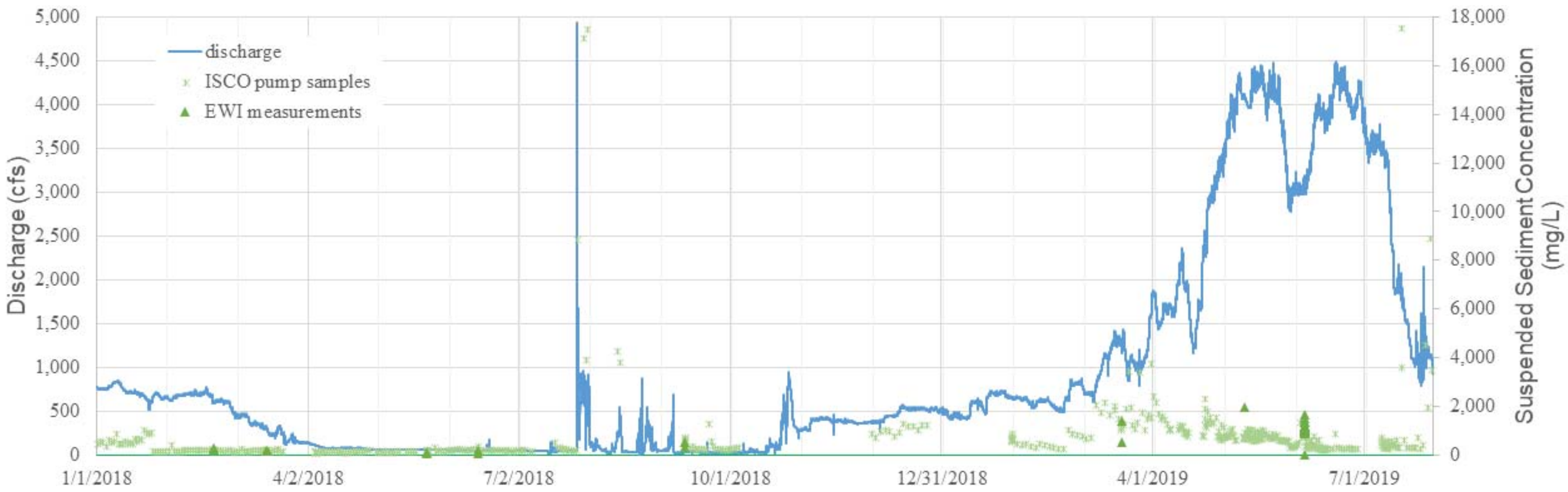


Figure 39. Water and collected suspended sediment (point and cross section average) at the San Acacia USGS gage from 1 January 2018 to 31 July 2019. The collected suspended sediment samples are physical samples with suspended sediment concentrations analyzed by the NMWSC.

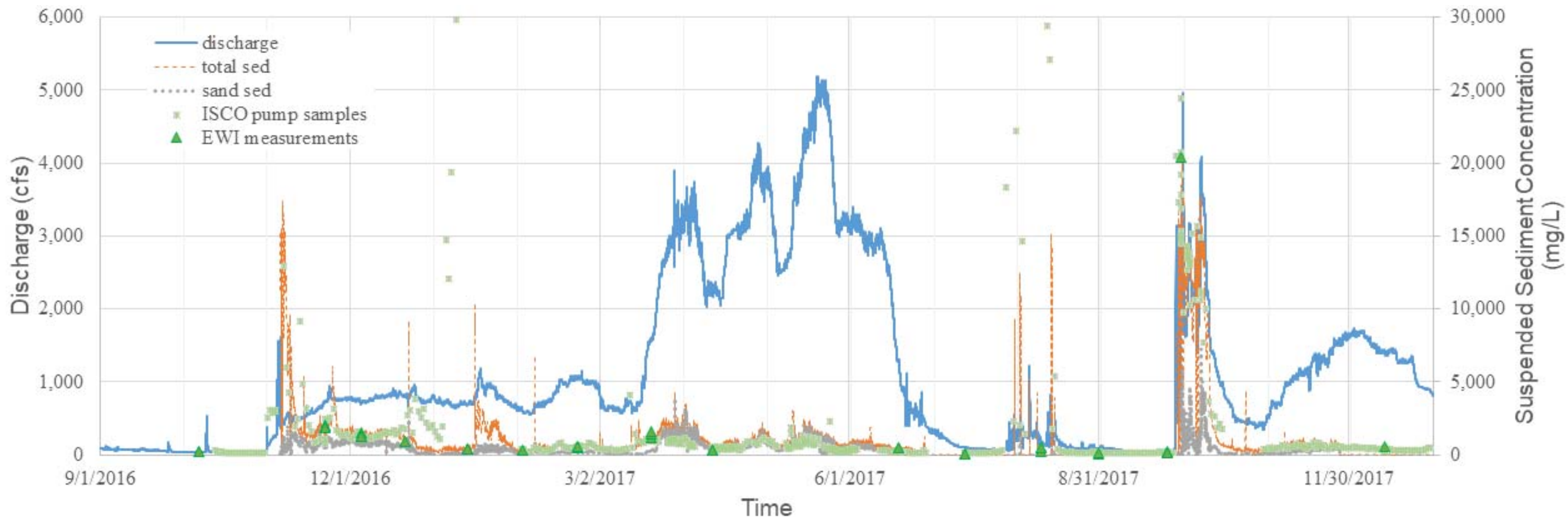


Figure 40. Water and suspended sediment at the San Acacia USGS gage from 1 September 2016 to 31 December 2017. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

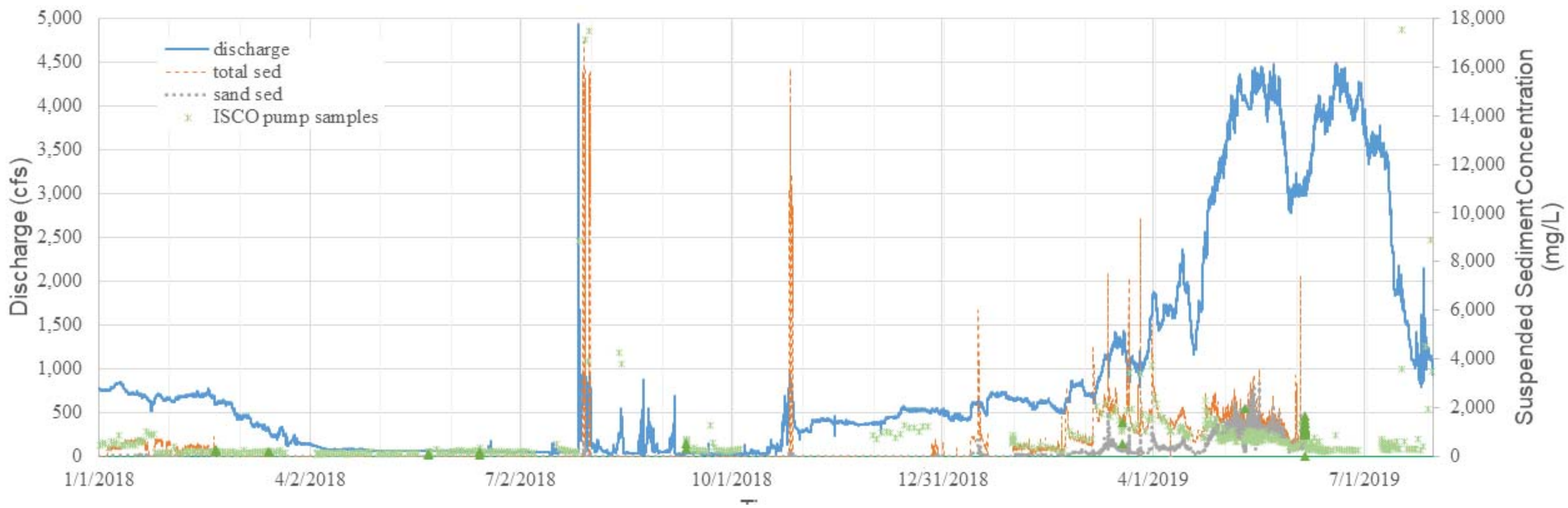


Figure 41. Water and suspended sediment at the San Acacia USGS gage from 1 January 2018 to 31 July 2019. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

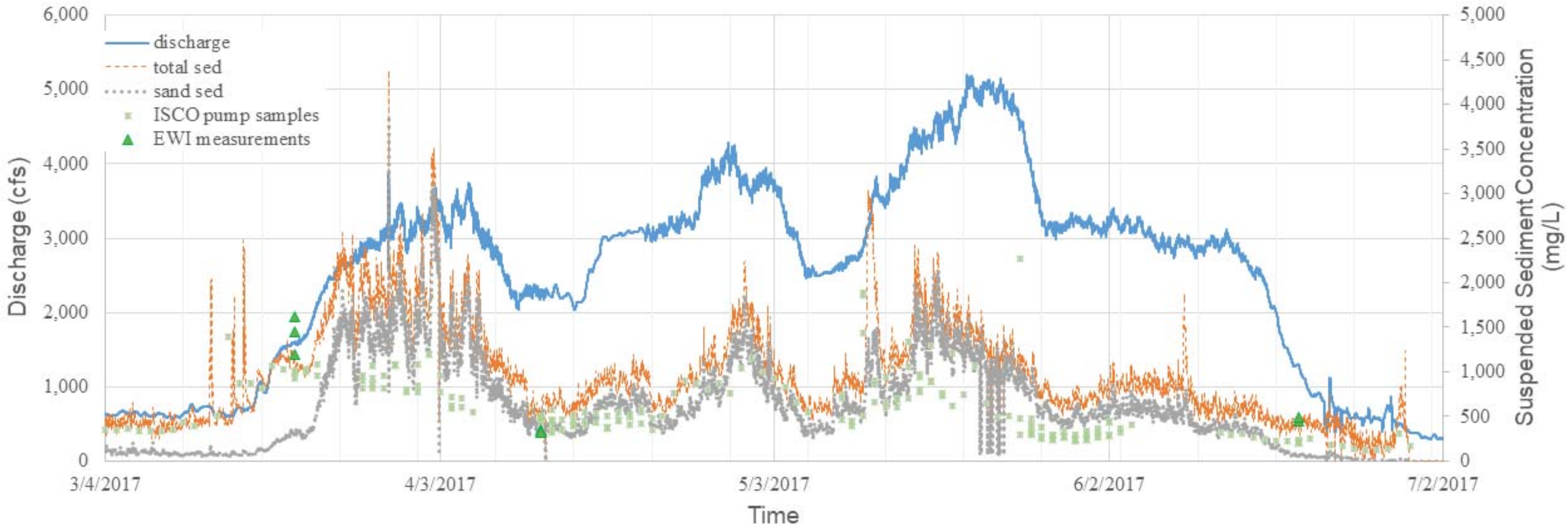


Figure 42. Water and suspended sediment at the San Acacia USGS gage during the spring snow melt runoff of 2017. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

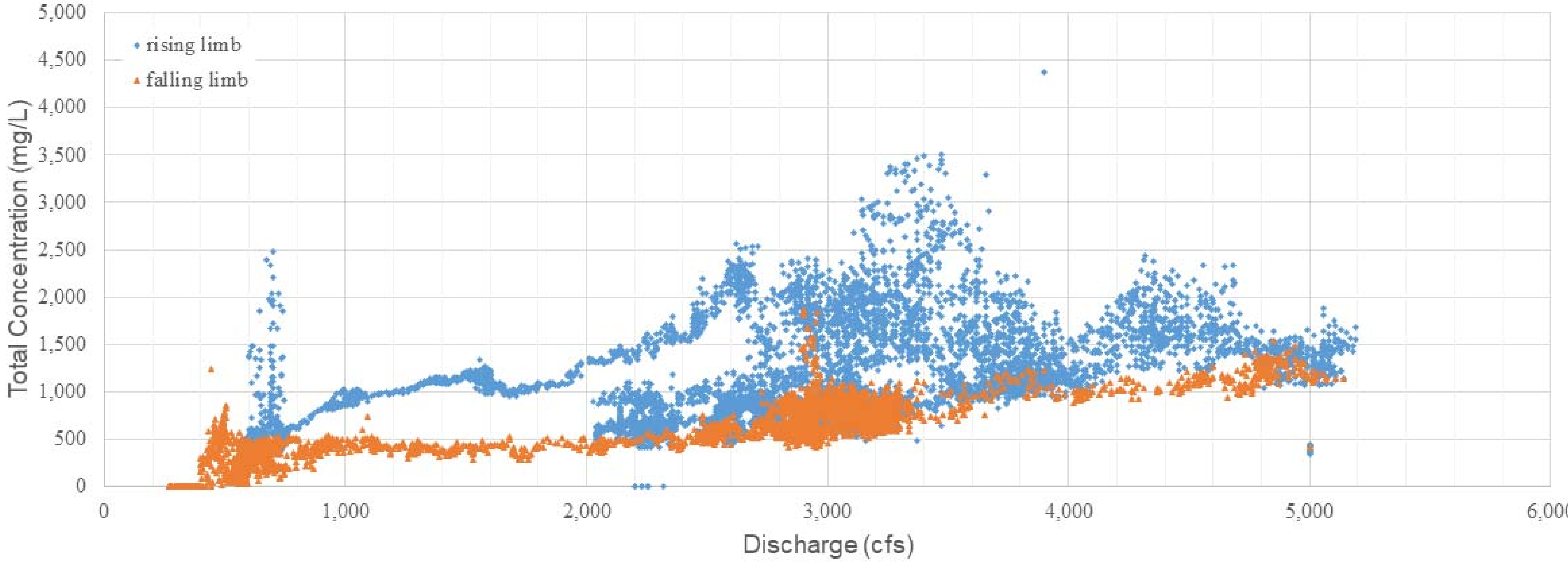


Figure 43. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during the spring snow melt runoff of 2017. The concentration is the total suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 4 March 2017 at 0:00 through 23 May 2017 7:45. The falling limb is defined as the period from 23 May 2017 8:00 through 2 July 2017 23:45.

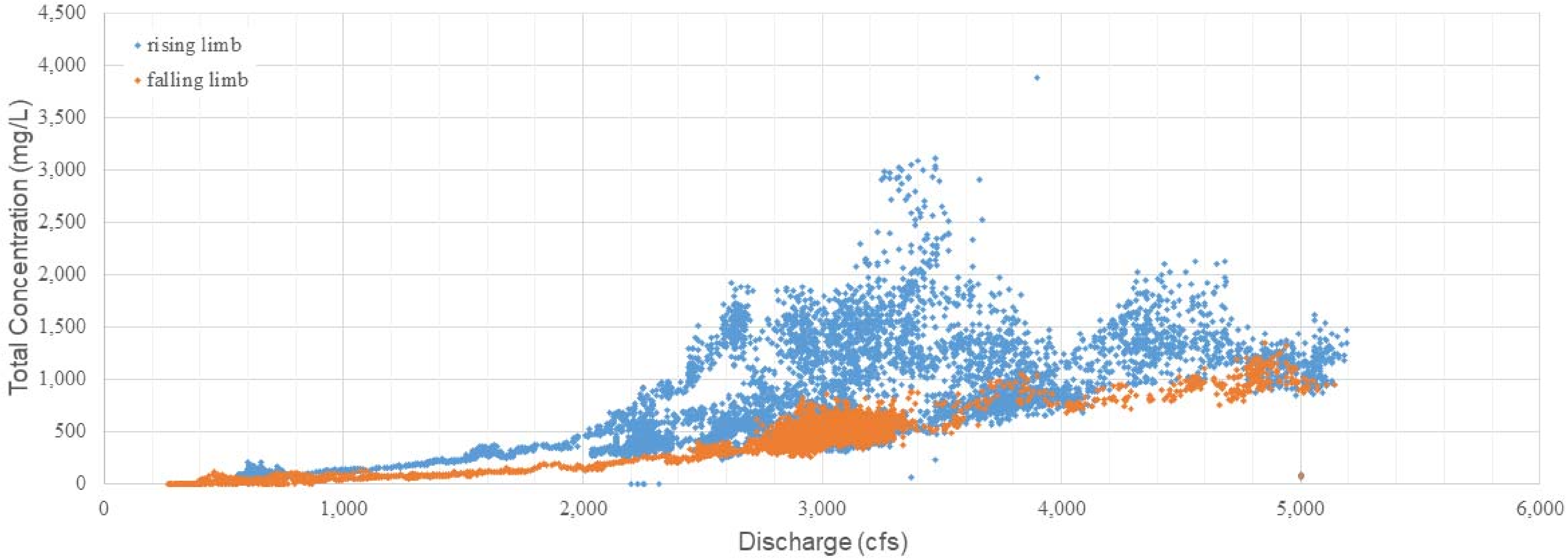


Figure 44. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during the spring snow melt runoff of 2017. The concentration is the sand suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 4 March 2017 at 0:00 through 23 May 2017 7:45. The falling limb is defined as the period from 23 May 2017 8:00 through 2 July 2017 23:45.

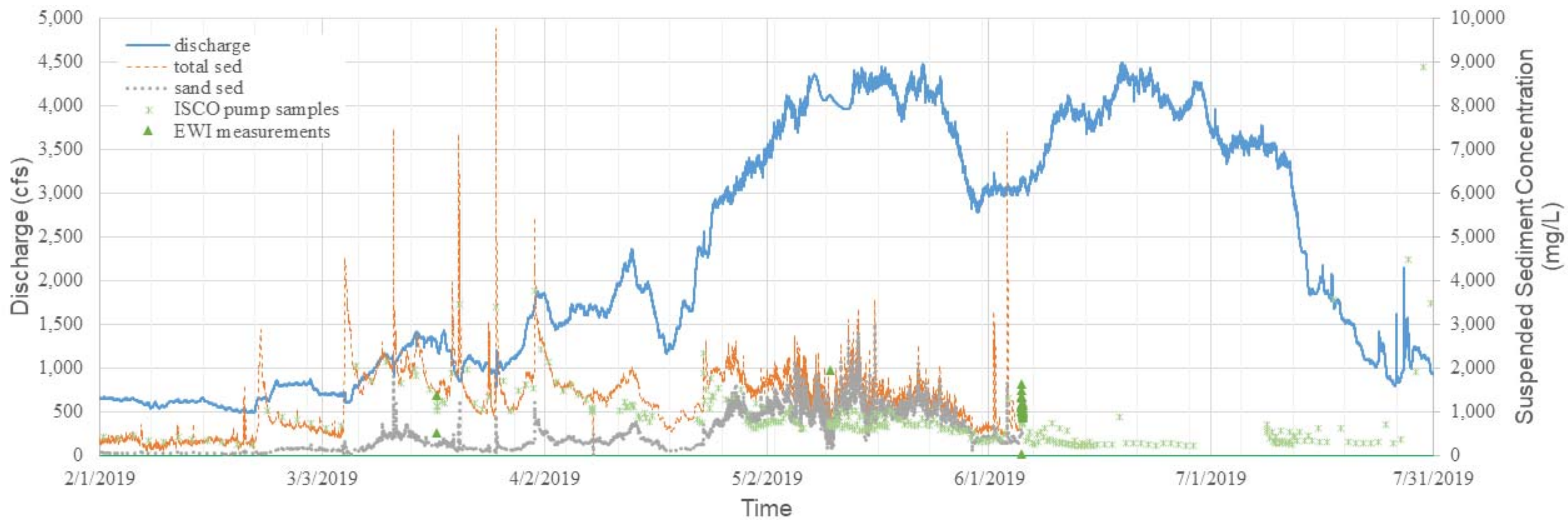


Figure 45. Water and suspended sediment at the San Acacia USGS gage during 2019 spring snow melt runoff. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

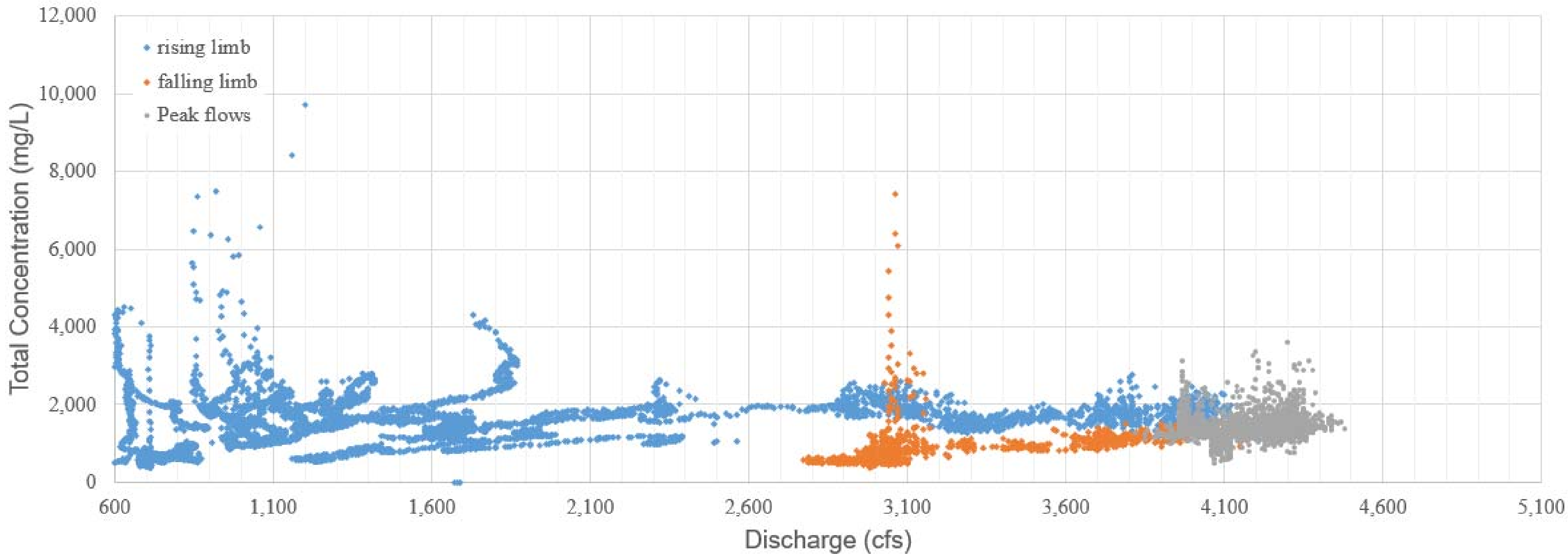


Figure 46. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during the spring snow melt runoff of 2019. The concentration is the total suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 22 February 2019 at 0:00 through 8 May 2019 7:00. The peak flow period is defined as the period from 8 May 2019 7:15 through 25 May 2019 12:30. The falling limb is defined as the period from 25 May 2019 12:45 through 5 June 2019 11:45.

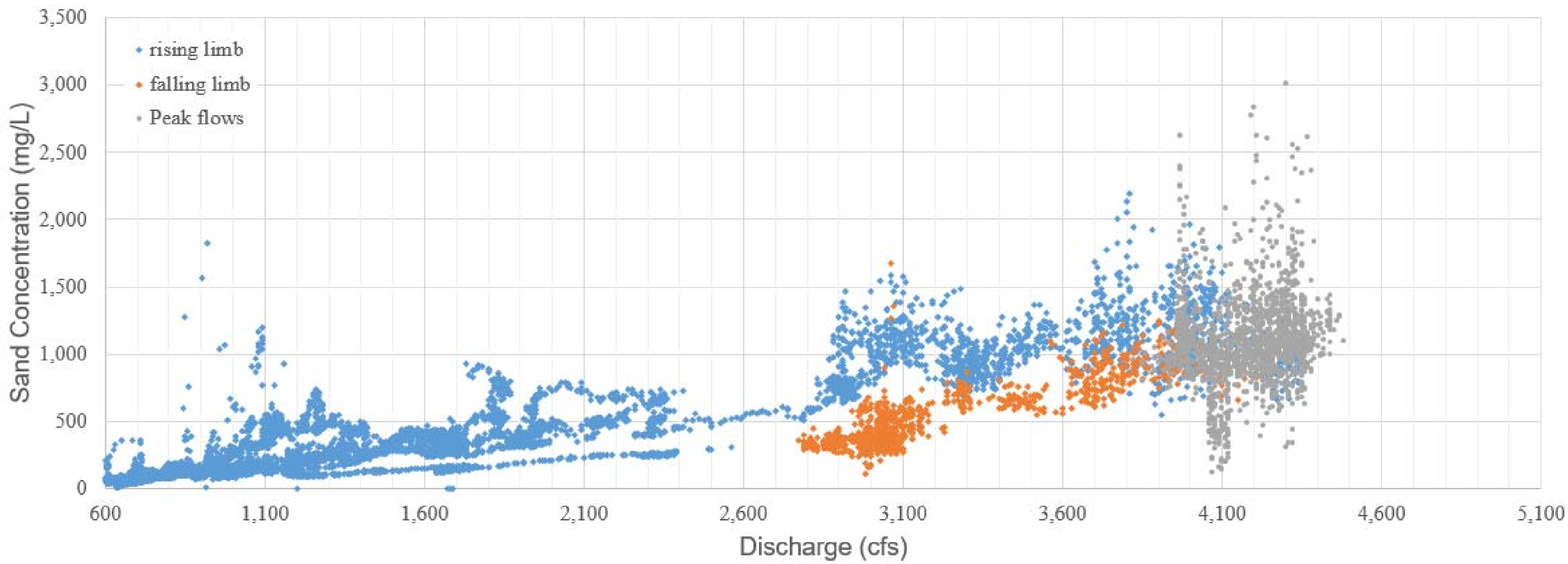


Figure 47. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during the spring snow melt runoff of 2019. The concentration is the sand suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 22 February 2019 at 0:00 through 8 May 2019 7:00. The peak flow period is defined as the period from 8 May 2019 7:15 through 25 May 2019 12:30. The falling limb is defined as the period from 25 May 2019 12:45 through 5 June 2019 11:45.

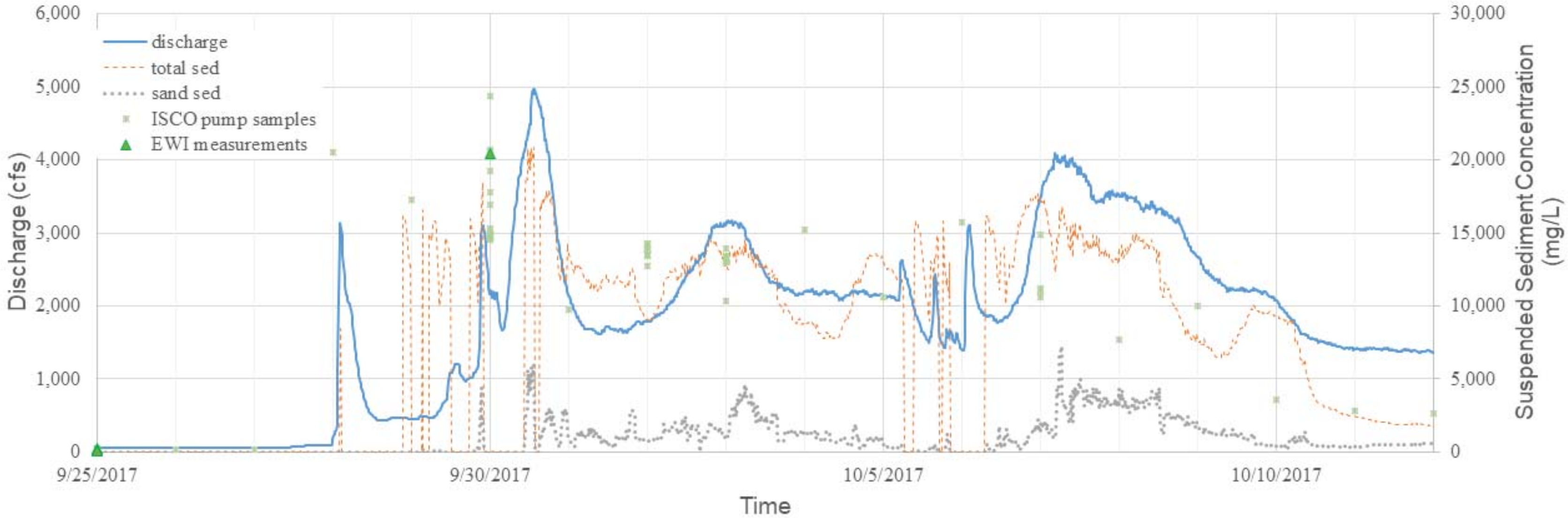


Figure 48. Water and suspended sediment at the San Acacia USGS gage during a September 2017 monsoon event. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

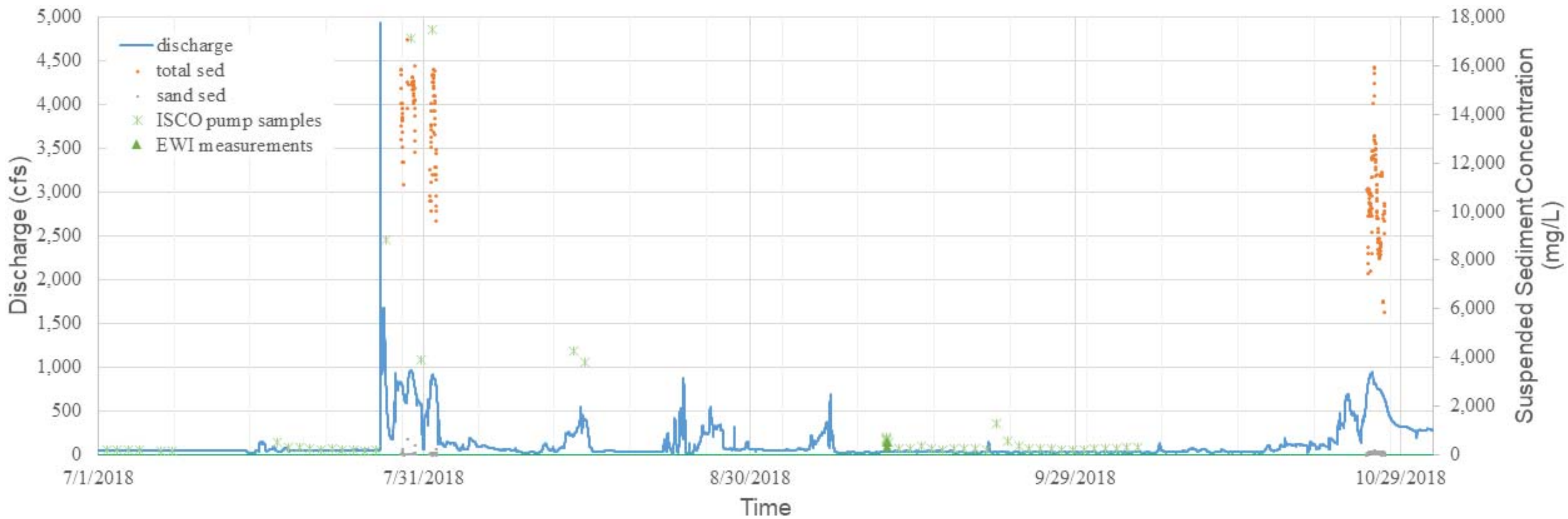


Figure 49. Water and suspended sediment at the San Acacia USGS gage during brief monsoon events of 2018. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

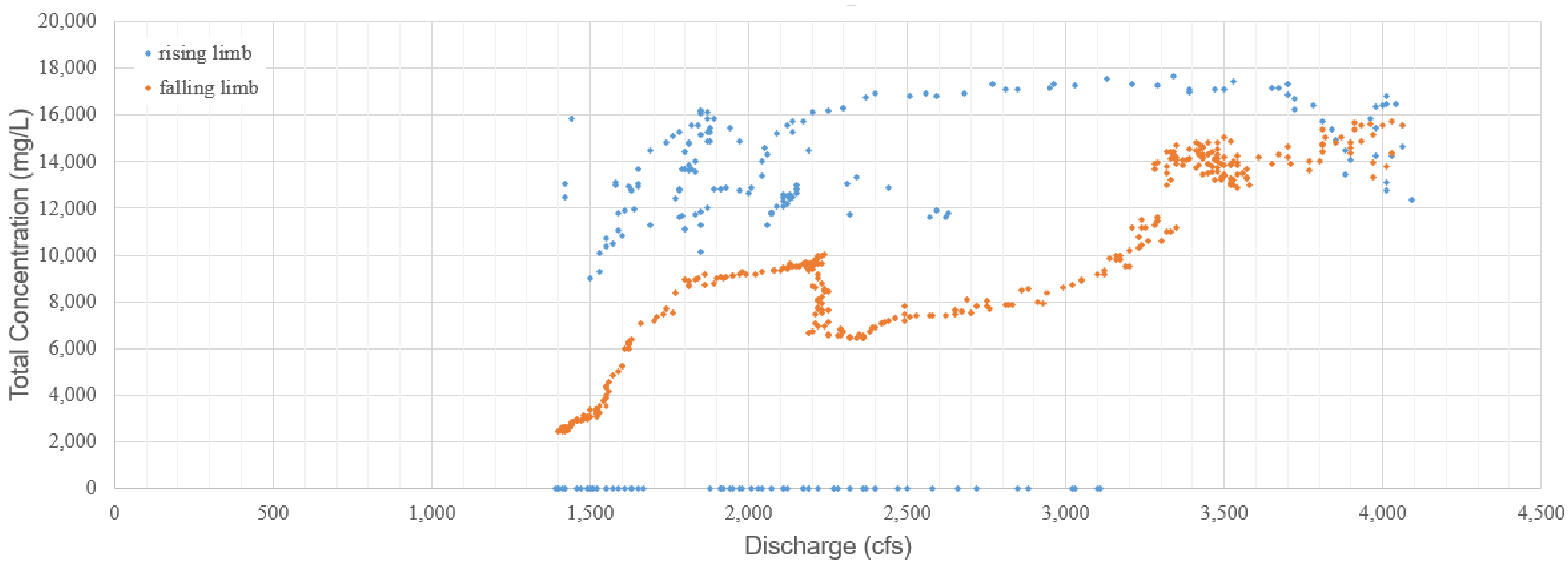


Figure 50. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during the monsoonal events in October 2017. The concentration is the total suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 5 October 2017 at 0:00 through 7 October 2017 7:15. The falling limb is defined as the period from 7 October 2017 7:30 through 10 October 2017 23:45.

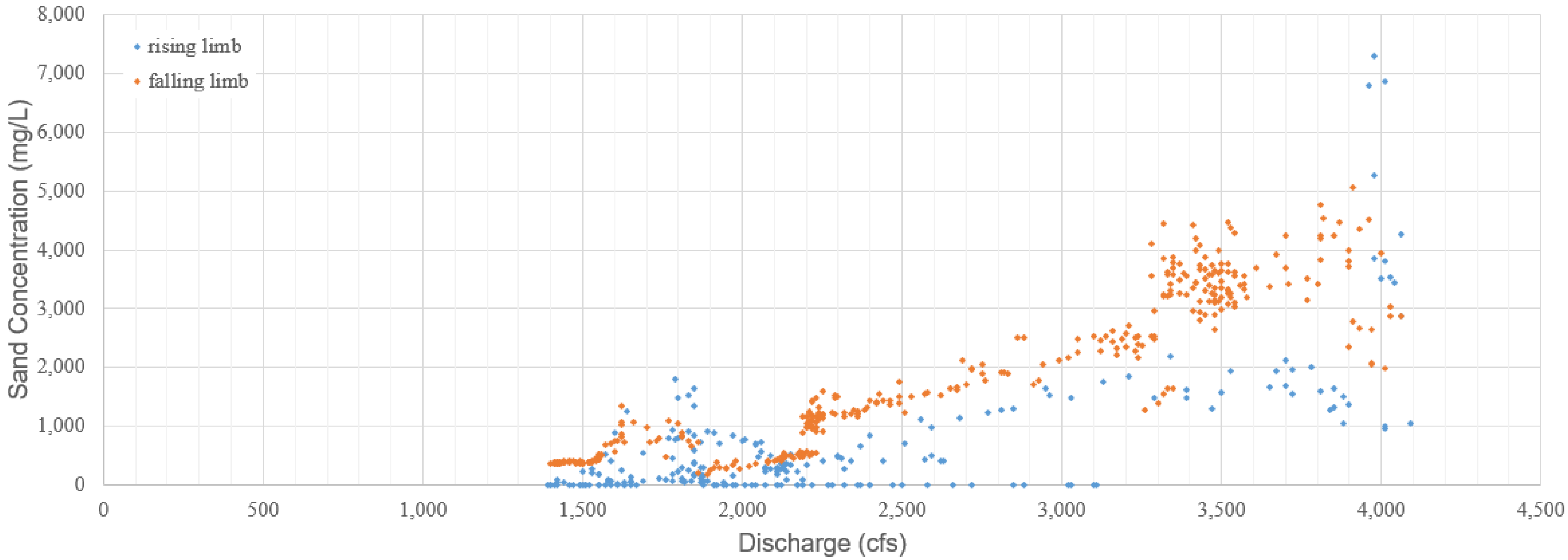


Figure 51. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during the monsoonal events in October 2017. The concentration is the sand suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 5 October 2017 at 0:00 through 7 October 2017 7:15. The falling limb is defined as the period from 7 October 2017 7:30 through 10 October 2017 23:45.

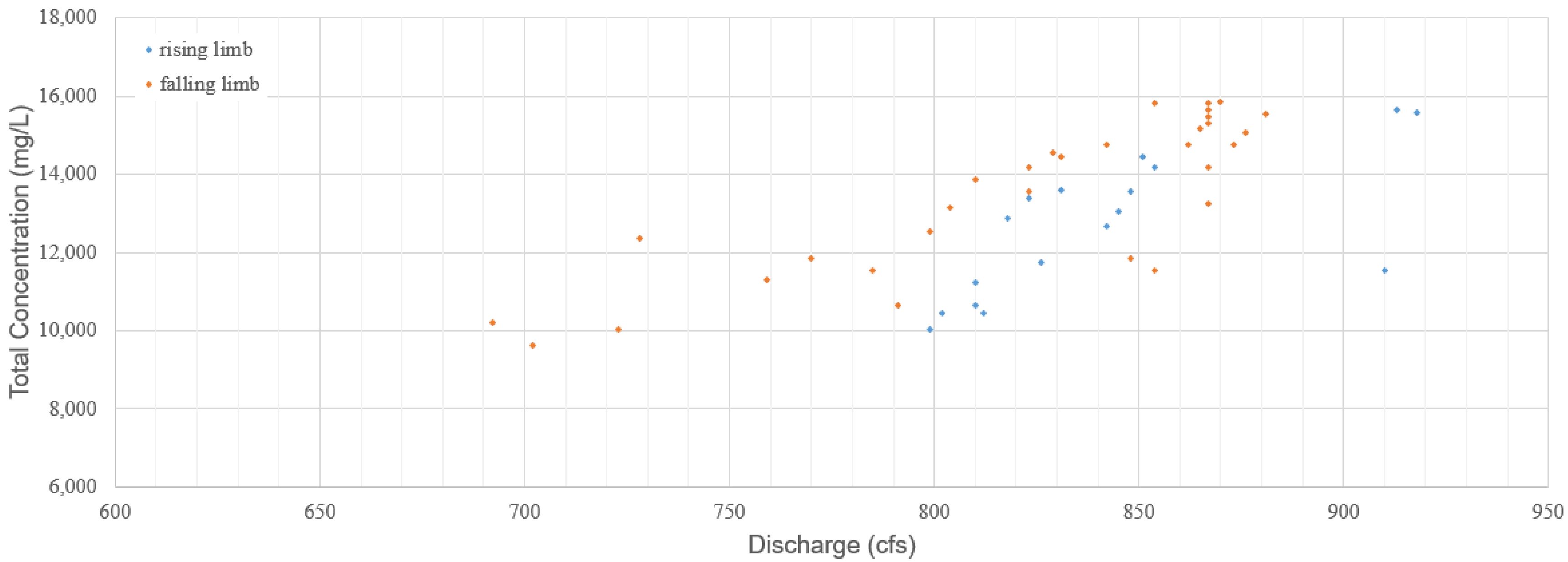


Figure 52. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during a monsoonal event in July 2018. The concentration is the total suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 31 July 2018 at 14:00 through 31 July 2018 18:00. The falling limb is defined as the period from 31 July 2018 20:15 through 1 August 2018 3:45.

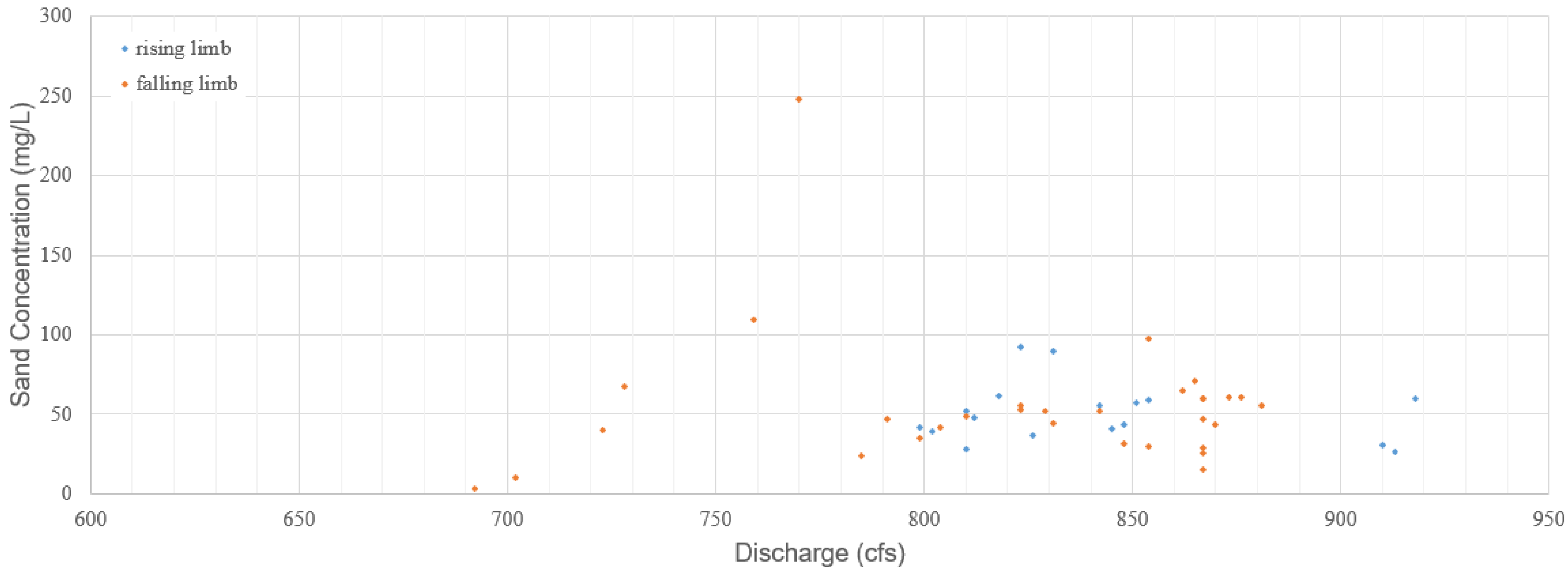


Figure 53. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during a monsoonal event in July 2018. The concentration is the sand suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 31 July 2018 at 14:00 through 31 July 2018 18:00. The falling limb is defined as the period from 31 July 2018 20:15 through 1 August 2018 3:45.

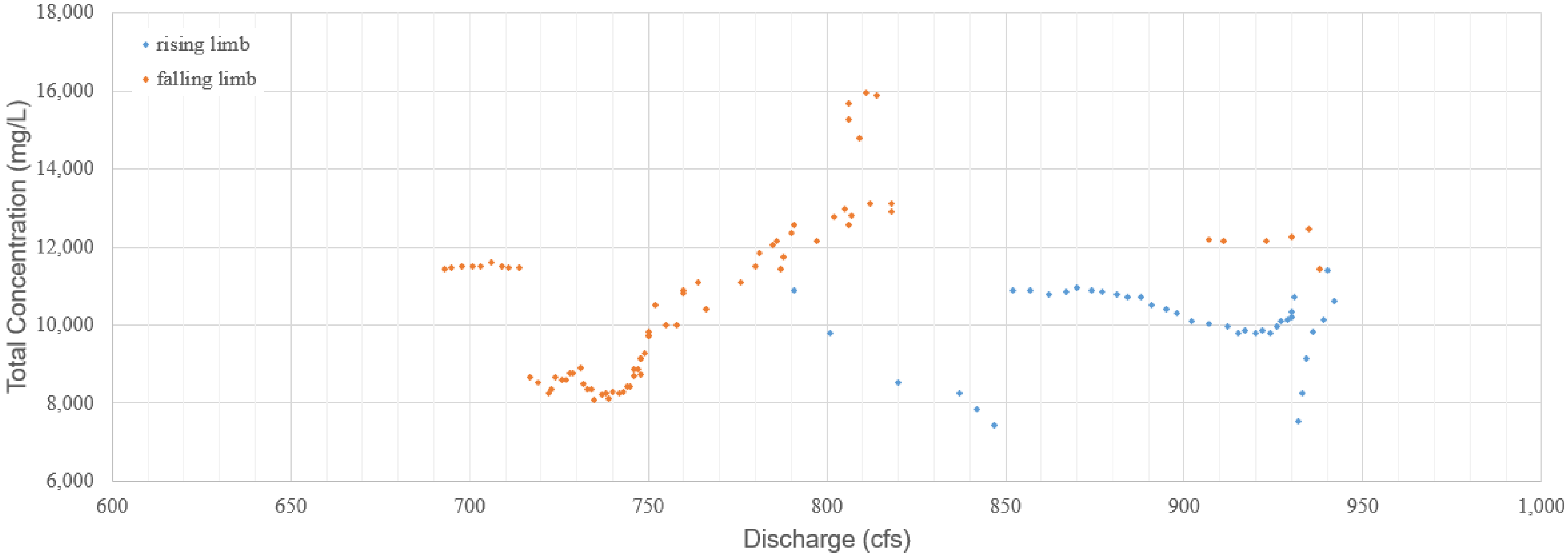


Figure 54. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during a monsoonal event in October 2018. The concentration is the total suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 25 October 2018 at 21:15 through 26 October 2018 7:45. The falling limb is defined as the period from 26 October 2018 8:00 through 27 October 2018 5:45.

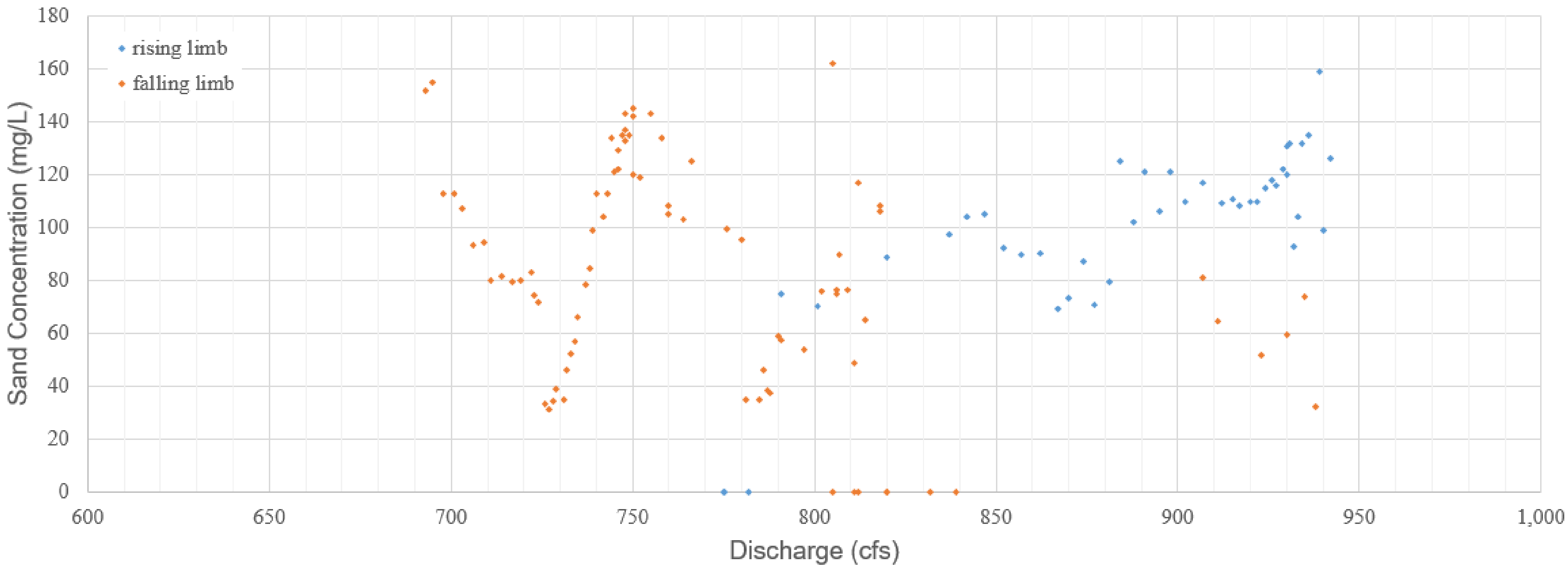


Figure 55. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during a monsoonal event in October 2018. The concentration is the sand suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. The rising limb is defined as the period from 25 October 2018 at 21:15 through 26 October 2018 7:45. The falling limb is defined as the period from 26 October 2018 8:00 through 27 October 2018 5:45.

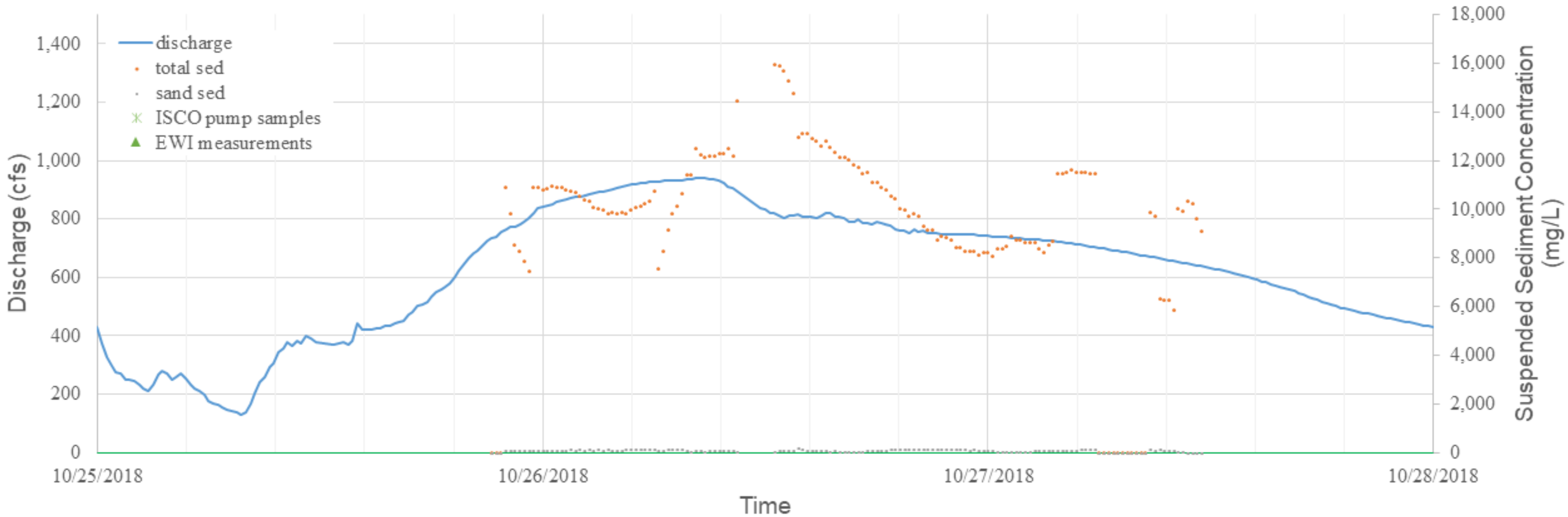


Figure 56. Water and suspended sediment at the San Acacia USGS gage during October 2018 monsoon event. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

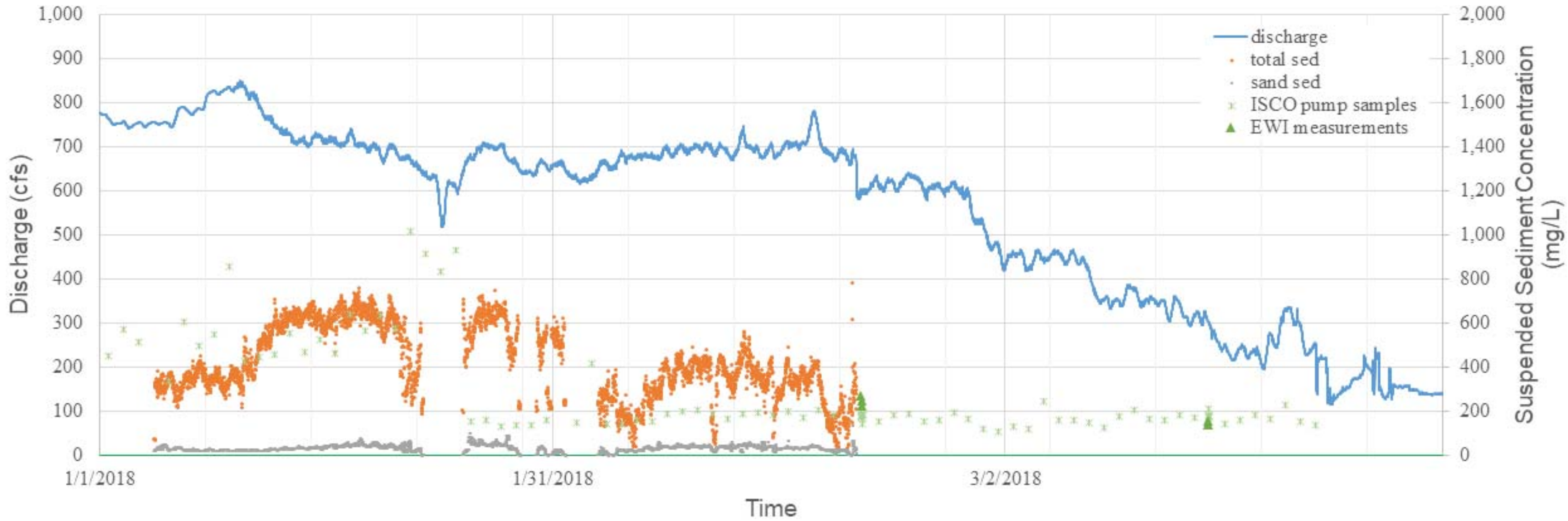


Figure 57. Water and suspended sediment at the San Acacia USGS gage during the early part of 2018. The AquaDopp suspended sediment information is listed as total and sand concentrations. The collected suspended sediment samples (ISCO and EWI) are physical samples with suspended sediment concentrations analyzed by the NMWSC.

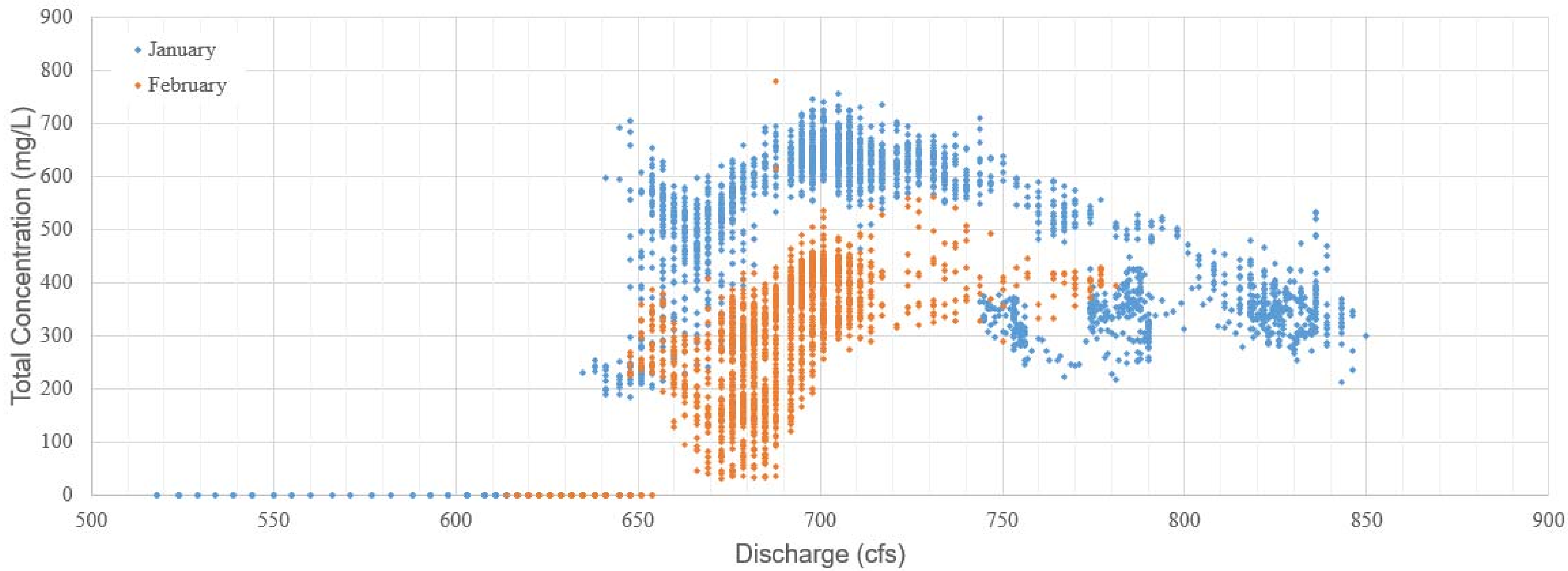


Figure 58. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during 2018 base flow period in 2018. The concentration is the total suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. January is defined as the period from 5 January 2018 at 0:00 through 31 January 2018 23:45. February is defined as the period from 1 February 2018 0:00 through 20 February 2018 3:00.

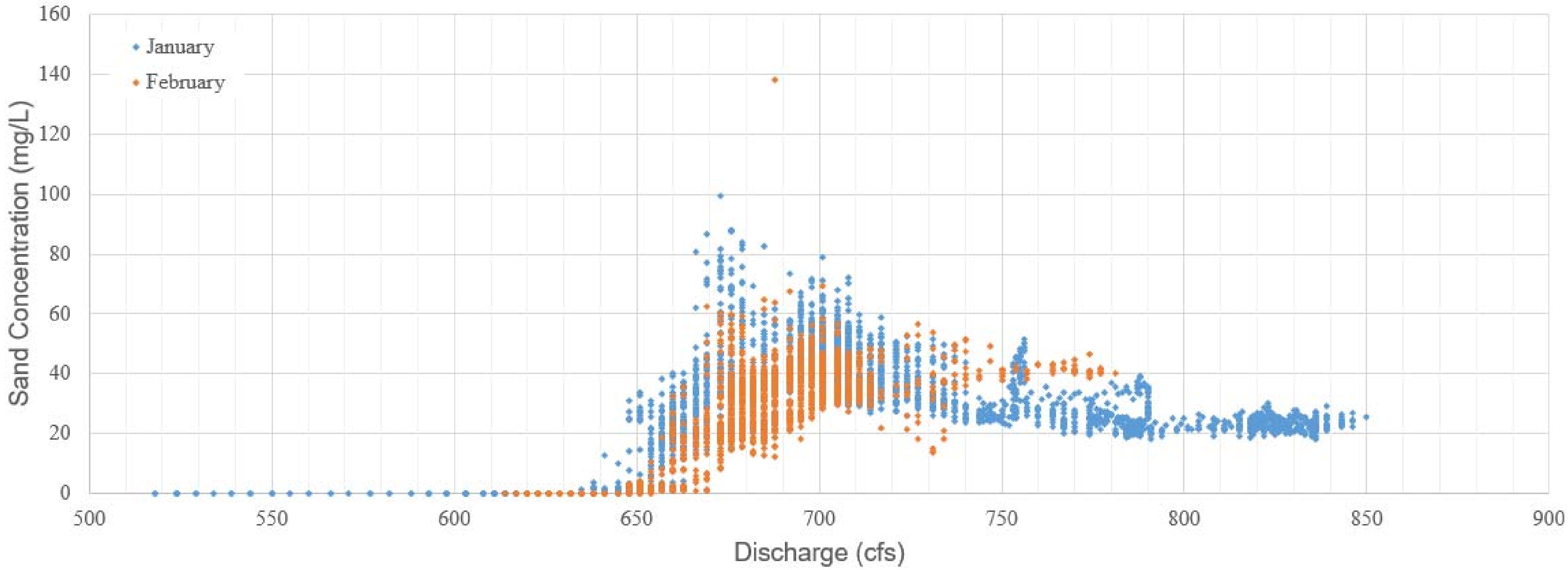

January
February
Sand Concentration (mg/L)
Discharge (cfs)
0
20
40
60
80
100
120
140
160
500
550
600
650
700
750
800
850
900

Figure 59. Relationship between suspended sediment concentration and discharge at the San Acacia USGS gage during 2018 base flow period in 2018. The concentration is the sand suspended sediment concentration estimated from the AquaDopps. The 15 minute discharge and concentration are used for this graph. January is defined as the period from 5 January 2018 at 0:00 through 31 January 2018 23:45. February is defined as the period from 1 February 2018 0:00 through 20 February 2018 3:00.

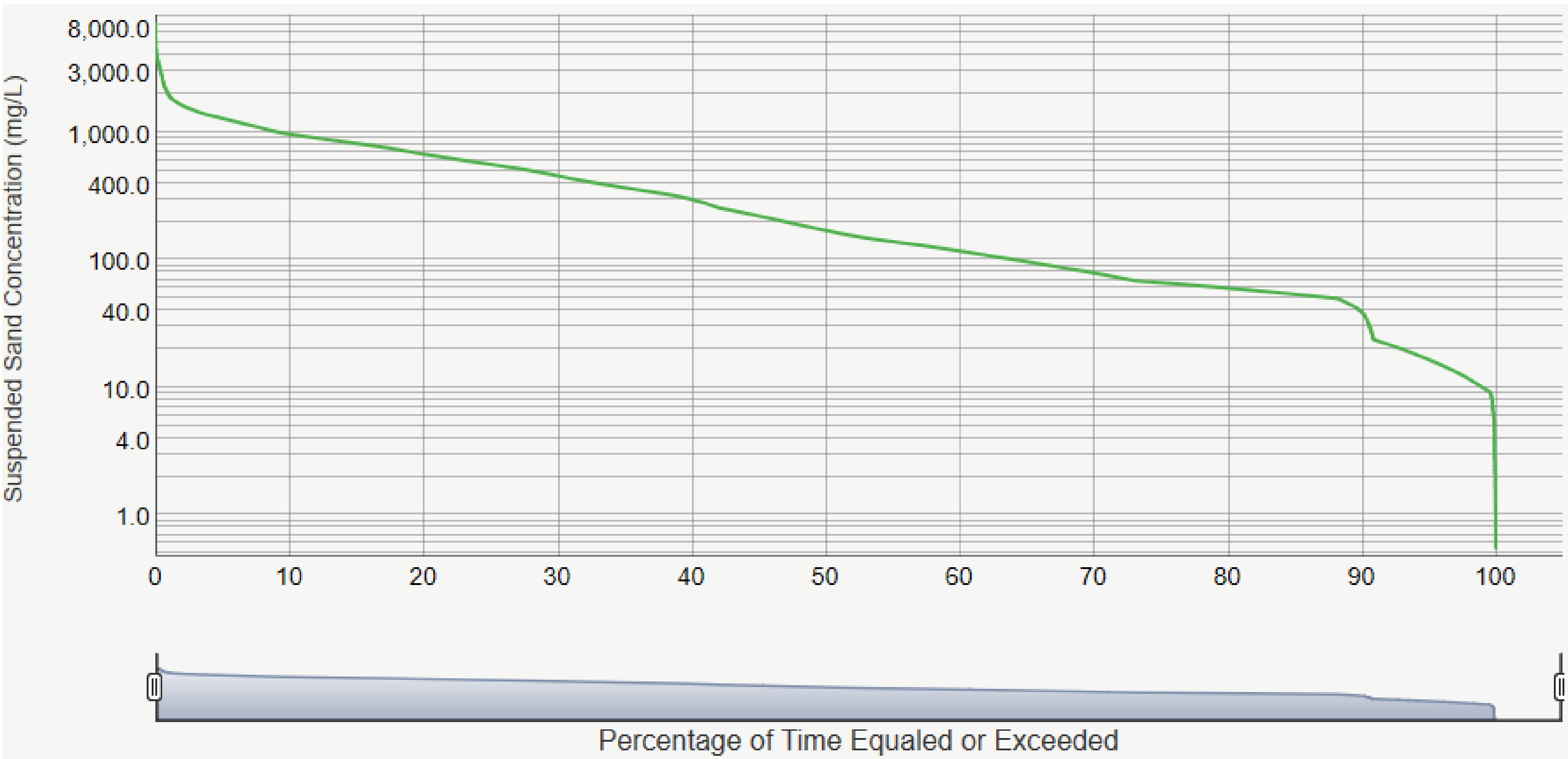


Figure 60. Suspended sand concentration frequency curves for data collected at San Acacia USGS gaging station from 1 September 2016 through 31 December 2017. Data extracted from the GCRMC website.

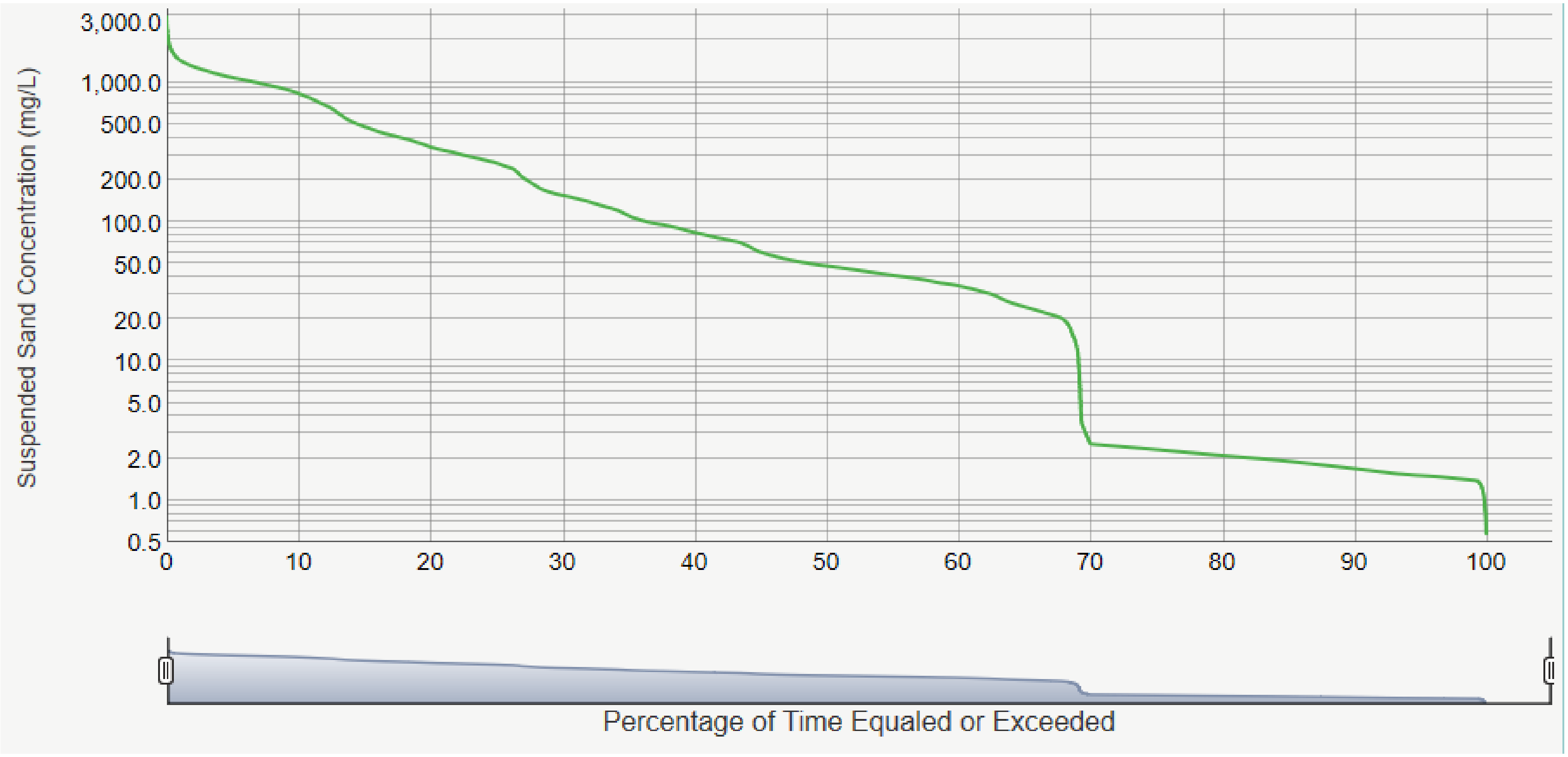


Figure 61. Suspended sand concentration frequency curves for data collected at San Acacia USGS gaging station from 1 January 2018 through 31 July 2019. Data extracted from the GCRMC website.

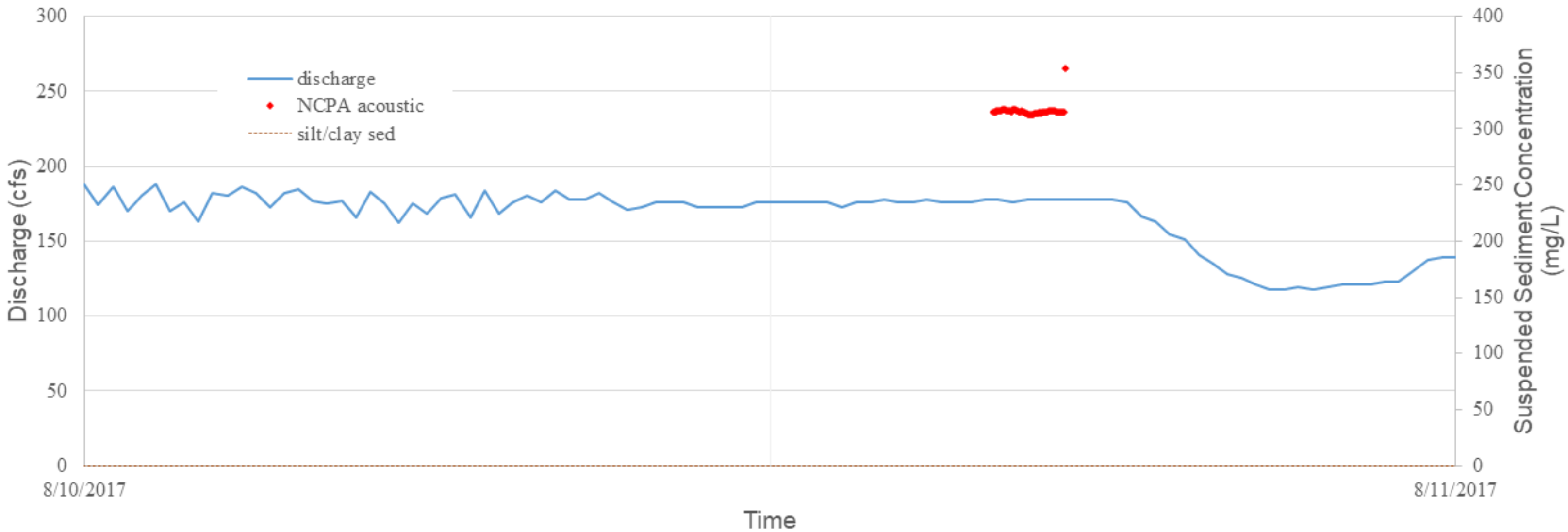


Figure 62. Water and suspended sediment (fraction less than 0.0625 mm in size) at the San Acacia USGS gage around the middle of August 2017. The AquaDopp suspended sediment information is listed as the silt/clay concentrations (15 minute increments). The NCPA acoustic instruments are the calibrated silty/clay fraction concentration (~ 1 minute increments).

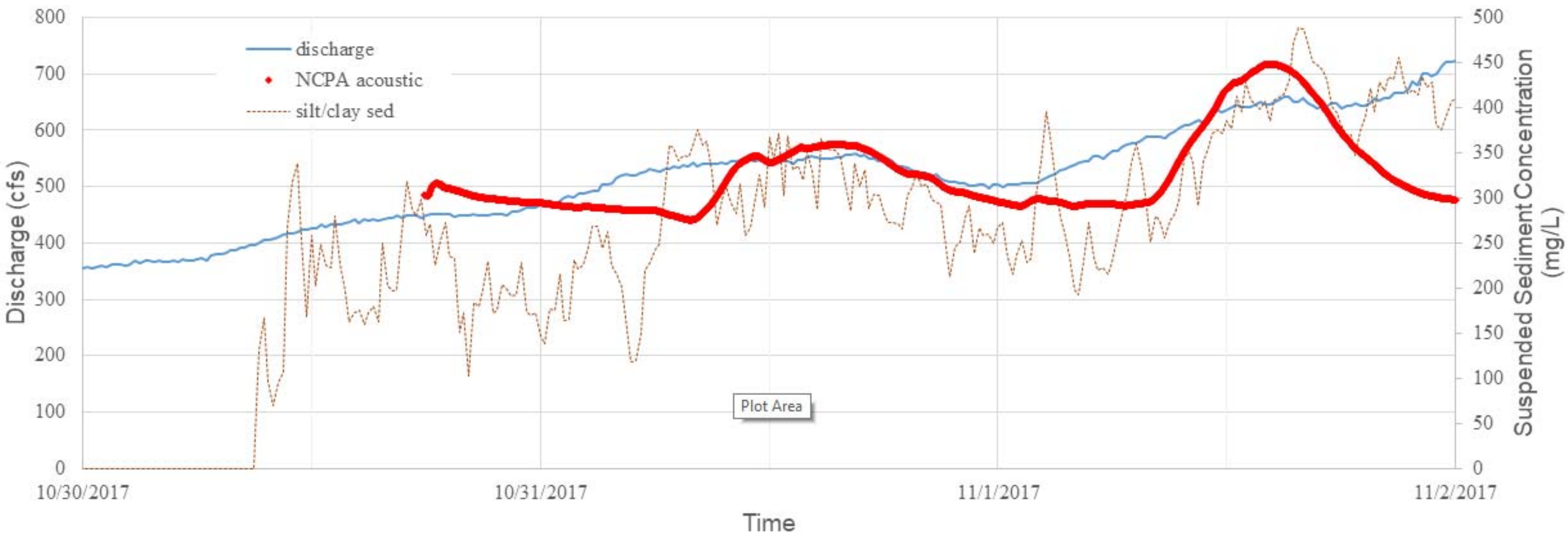


Figure 63. Water and suspended sediment (fraction less than 0.0625 mm in size) at the San Acacia USGS gage from the end of October to early November 2017. The AquaDopp suspended sediment information is listed as the silt/clay concentrations (15 minute increments). The NCPA acoustic instruments are the calibrated silty/clay fraction concentration (~ 1 minute increments).

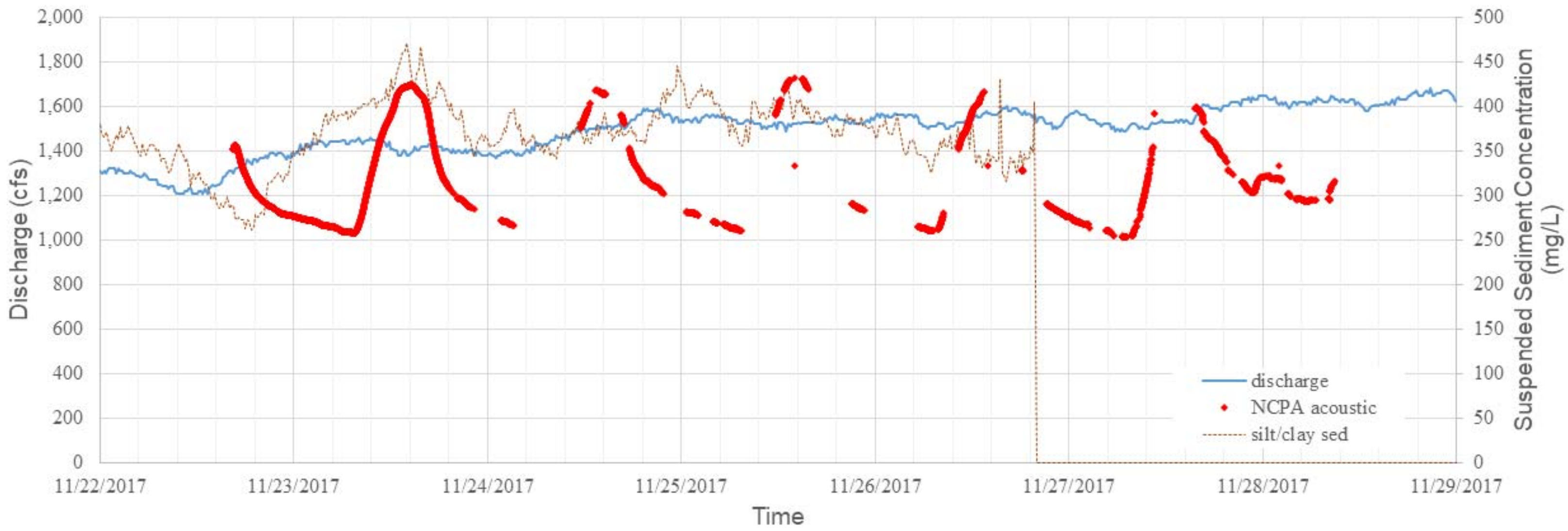


Figure 64. Water and suspended sediment (fraction less than 0.0625 mm in size) at the San Acacia USGS gage around the end of November 2017. The AquaDopp suspended sediment information is listed as the silt/clay concentrations (15 minute increments). The AquaDopps didn't collect any information after the 27 November 2017. The NCPA acoustic instruments are the calibrated silty/clay fraction concentration (~ 1 minute increments).

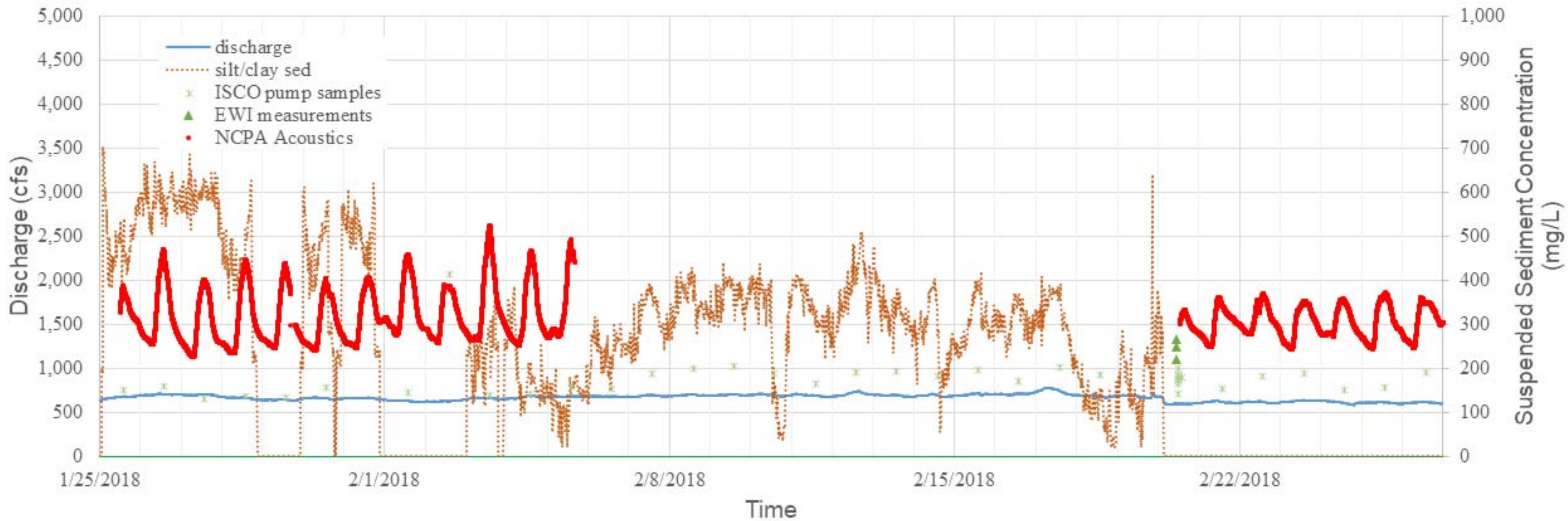


Figure 65. Water and suspended sediment (fraction less than 0.0625 mm in size) at the San Acacia USGS gage from 25 January 2018 through 27 February 2018. The AquaDopp suspended sediment information is listed as the silt/clay concentrations (15 minute increments). The AquaDopps didn't collect any information after the 20 February 2018. The NCPA acoustic instruments are the calibrated silty/clay fraction concentration (~ 1 minute increments). Also shown are physical suspended sediment concentrations (ISCO® pump samples and EWI measurements).

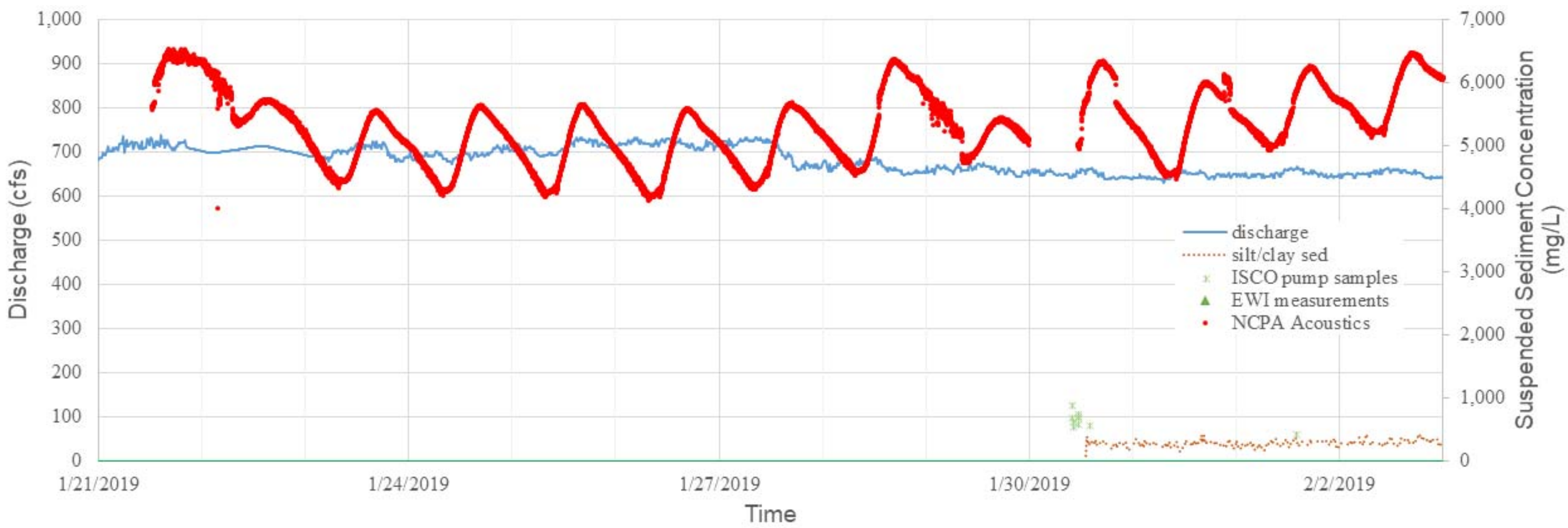


Figure 66. Water and suspended sediment (fraction less than 0.0625 mm in size) at the San Acacia USGS gage from 21 January 2019 through 3 February 2019. The AquaDopp suspended sediment information is listed as the silt/clay concentrations (15 minute increments). The AquaDopps didn't collect information prior to 30 January 2019. The NCPA acoustic instruments are the calibrated silty/clay fraction concentration (~ 1 minute increments). Also shown are physical suspended sediment concentrations (ISCO® pump samples and EWI measurements).

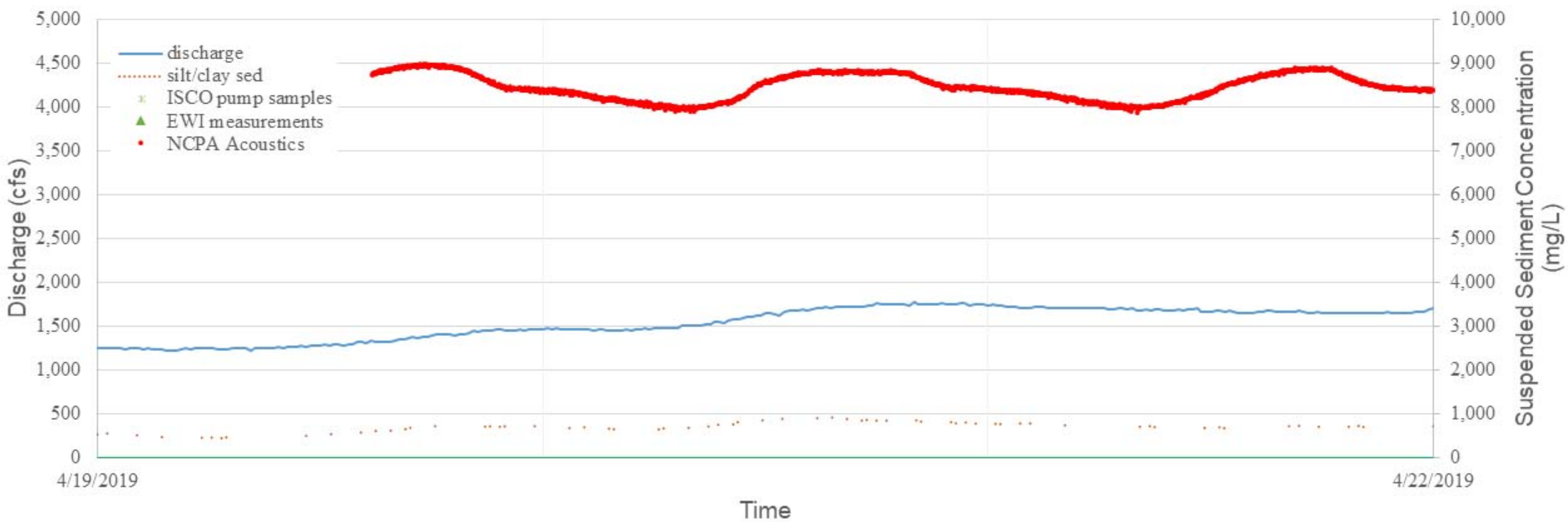


Figure 67. Water and suspended sediment (fraction less than 0.0625 mm in size) at the San Acacia USGS gage from 19 April 2019 through 22 April 2019. The AquaDopp suspended sediment information is listed as the silt/clay concentrations (15 minute increments). The AquaDopps didn't collect information prior to 30 January 2019. The NCPA acoustic instruments are the calibrated silty/clay fraction concentration (~ 1 minute increments). No physical suspended sediment concentrations (ISCO® pump samples and EWI measurements) are available during this period.

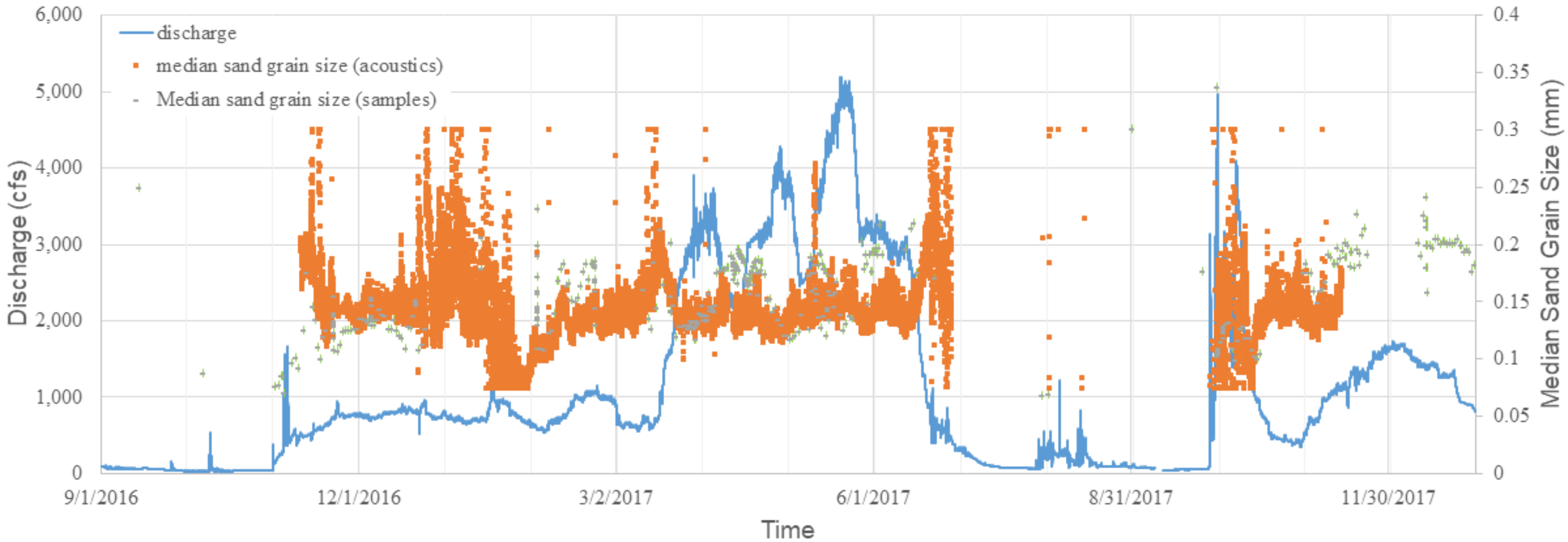


Figure 68. Discharge and median suspended sand grain size at the San Acacia USGS gaging station from 1 September 2016 through 31 December 2017. The AquaDopps were installed around 22 September 2016.

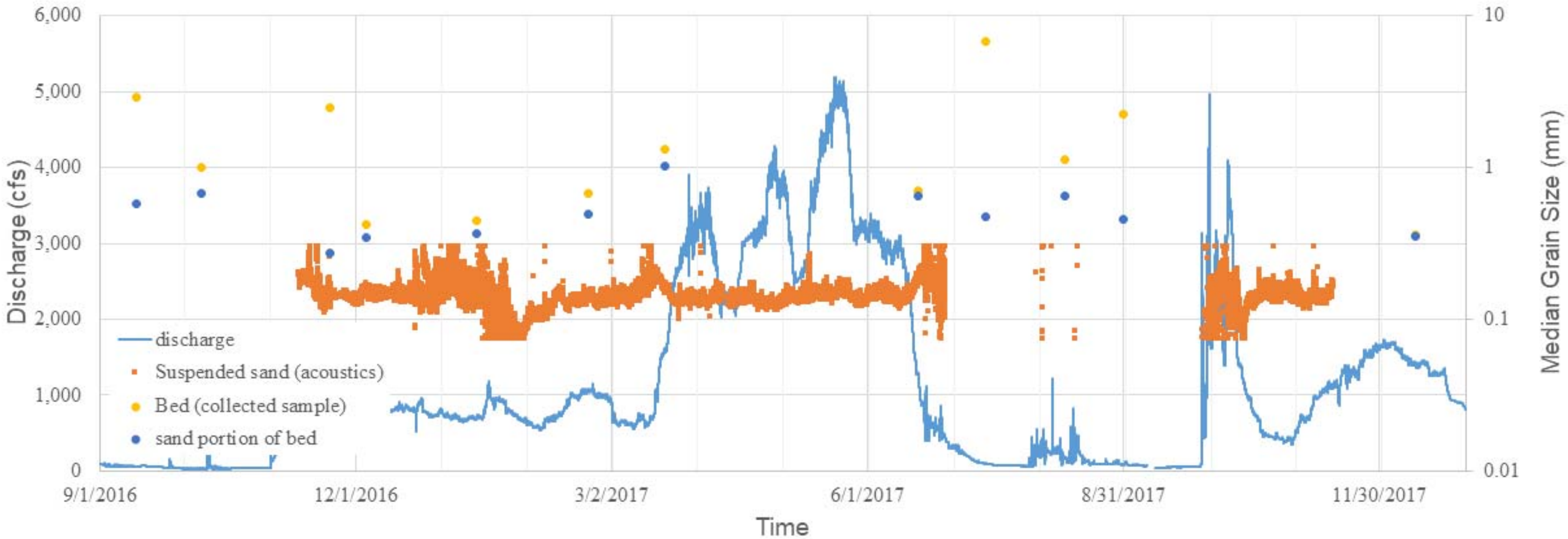


Figure 69. Discharge and median suspended sand grain size along with collected bed material samples at the San Acacia USGS gaging station from 1 September 2016 through 31 December 2017. The AquaDopps were installed around 22 September 2016. The bed material samples are shown by the median for all collected grain sizes (yellow dots) and median of the sand portion of the bed sample (blue dot).

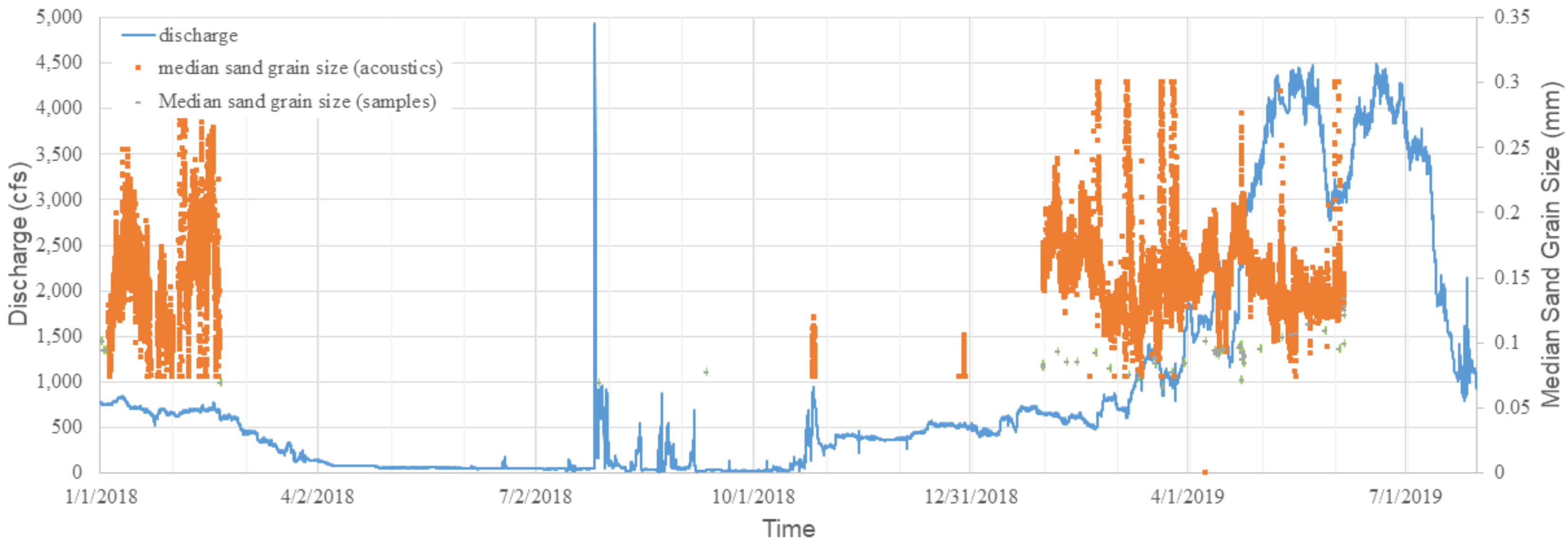


Figure 70. Discharge and median suspended sand grain size at the San Acacia USGS gaging station from 1 January 2018 through 31 July 2019.

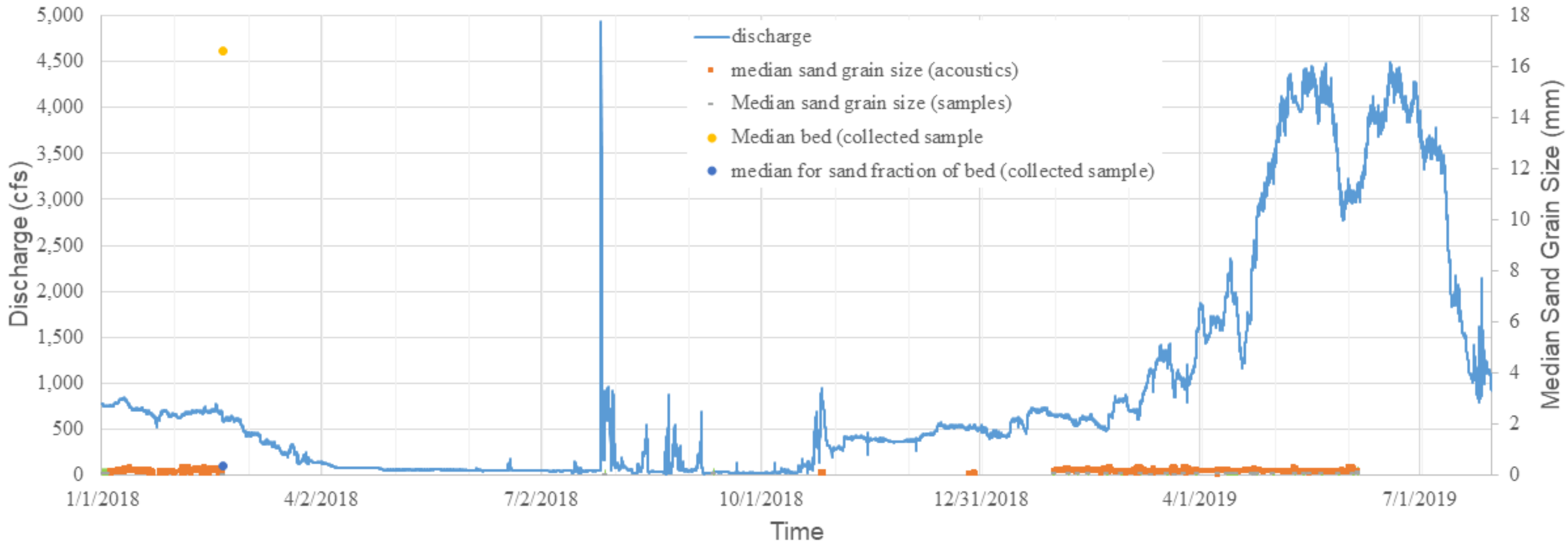


Figure 71. Discharge and median suspended sand grain size along with collected bed material samples at the San Acacia USGS gaging station from 1 January 2018 through 31 July 2019. The bed material samples are shown by the median for all collected grain sizes (yellow dots) and median of the sand portion of the bed sample (blue dot).

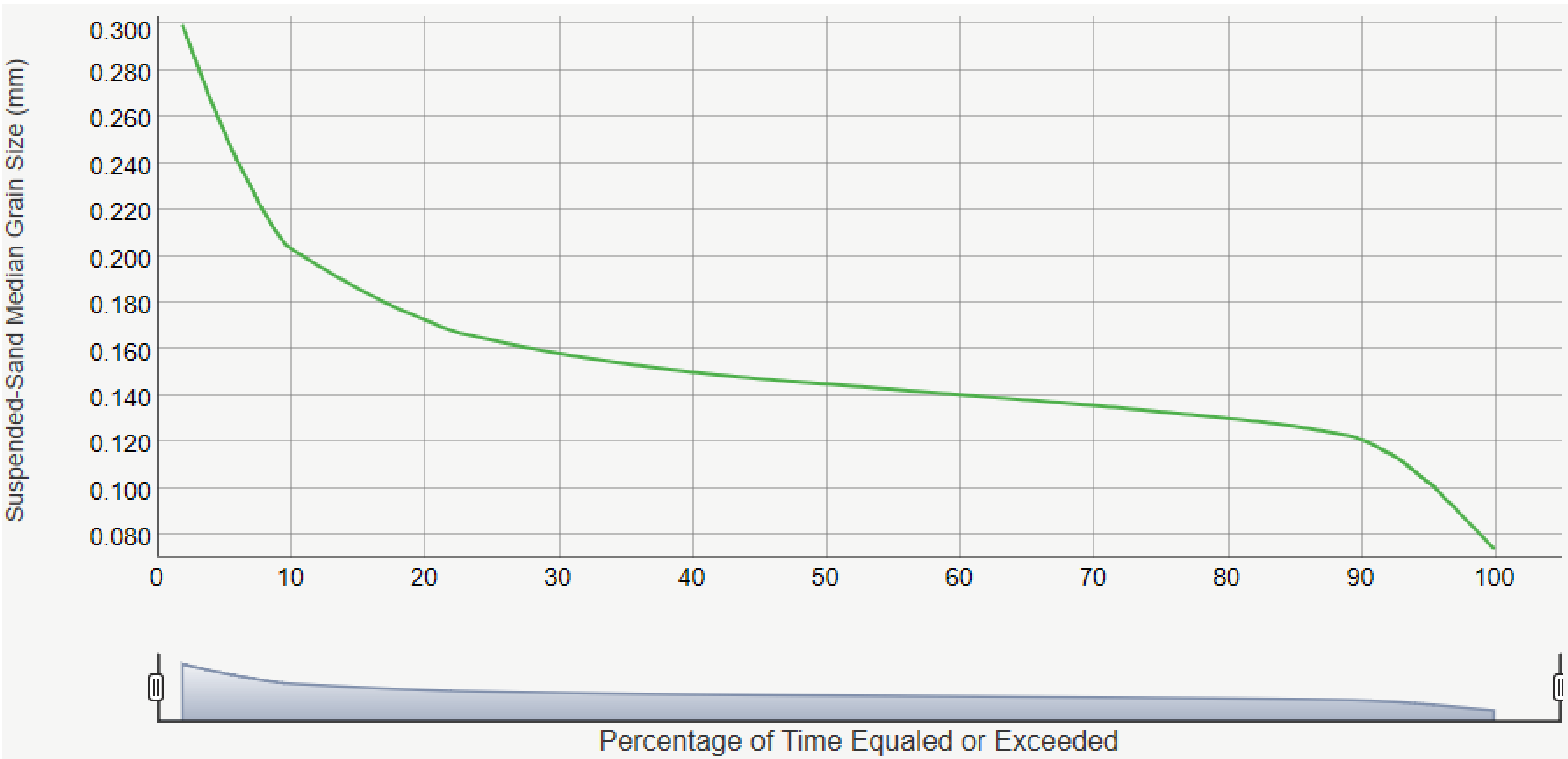


Figure 72. Suspended sand median grain size frequency curves for data collected at San Acacia USGS gaging station from 1 September 2016 through 31 December 2017. Data extracted from the GCRMC website.

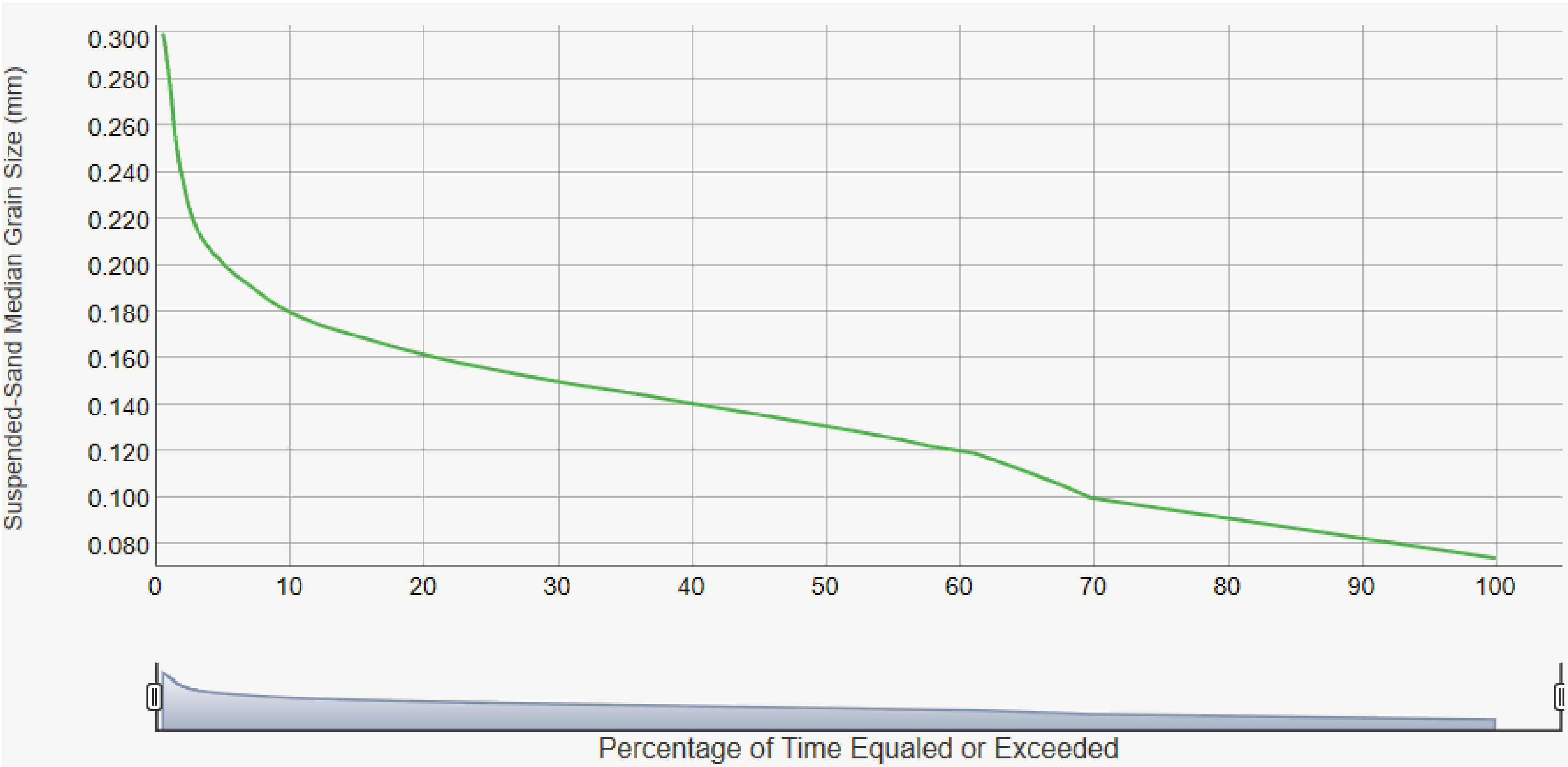


Figure 73. Suspended sand median grain size frequency curves for data collected at San Acacia USGS gaging station from 1 January 2018 through 31 July 2019. Data extracted from the GCRMC website.

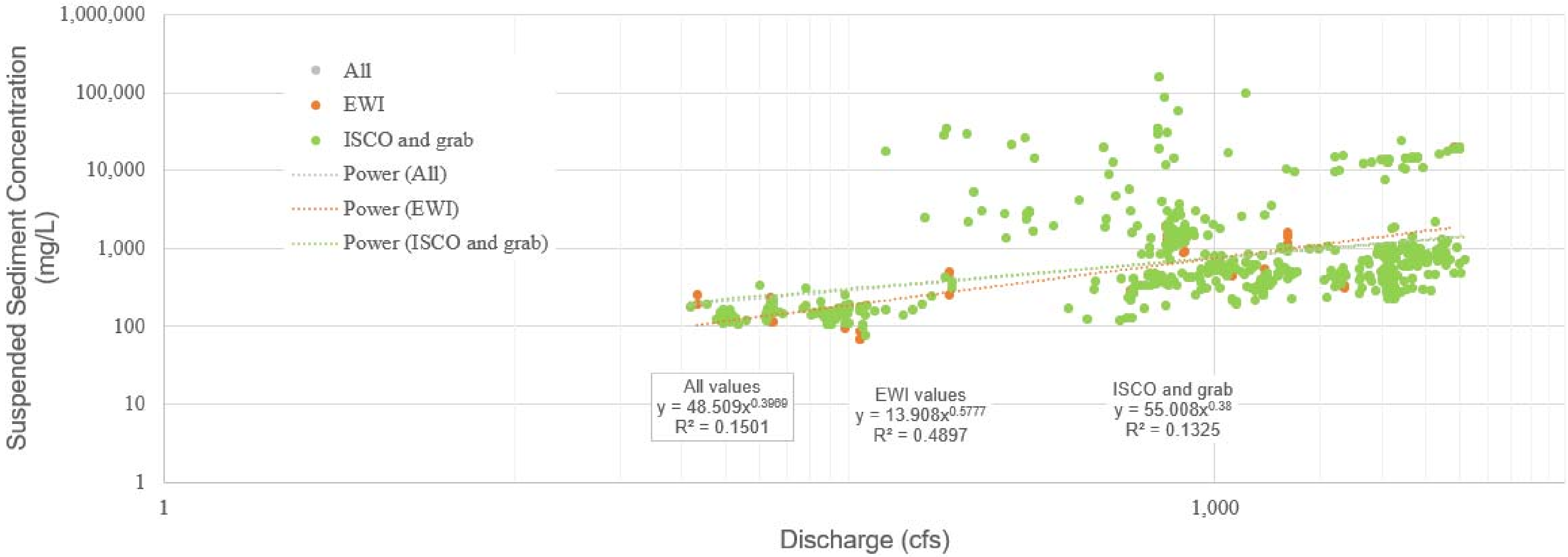


Figure 74. Suspended sediment concentration rating curves from collected physical sample at the USGS San Acacia gage between 22 September 2016 and 31 December 2017. Best fit regression power curves are shown at the bottom of the graph.

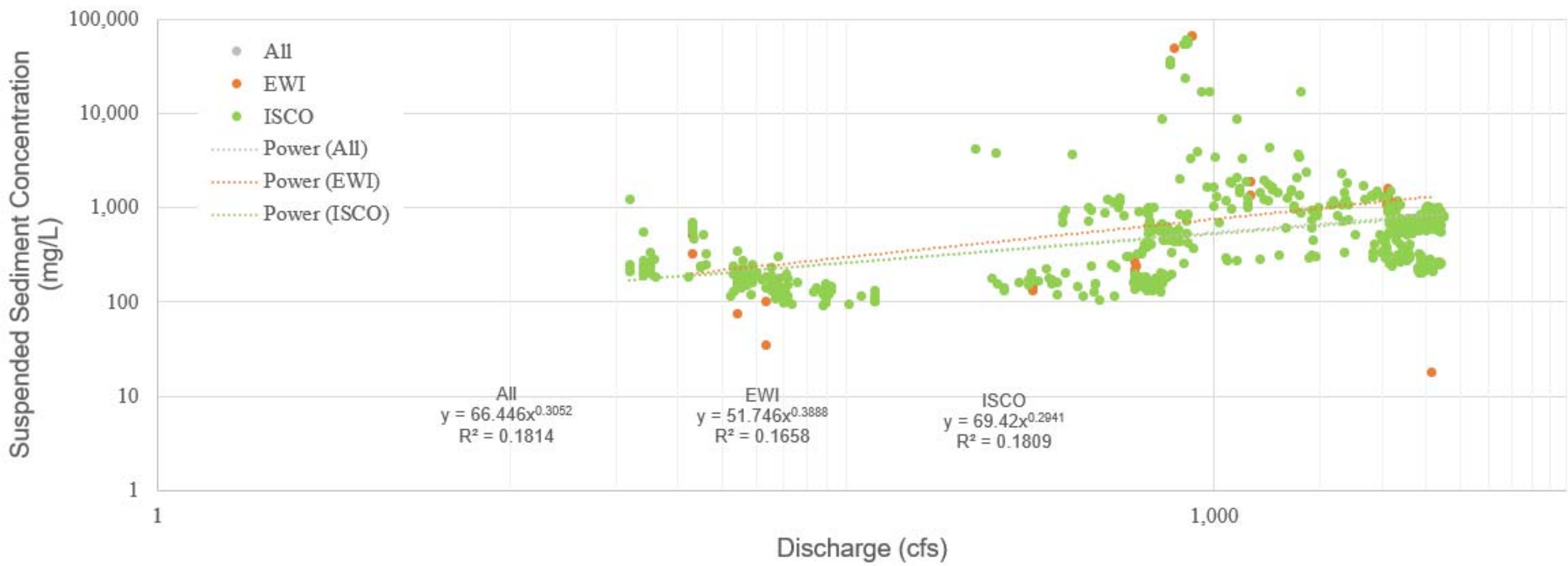


Figure 75. Suspended sediment concentration rating curves from collected physical sample at the USGS San Acacia gage between 1 January 2018 and 31 July 2019. Best fit regression power curves are shown at the bottom of the graph.

Figure 76. Suspended sediment single mass curves between 22 September 2016 and 31 December 2017. Dashed lines are based on best fit power relationships of the suspended sediment concentration and discharge. The acoustic information is based on the calibration of the collected acoustic signal. Cumulative suspended sediment is calculated on 15 minute intervals.

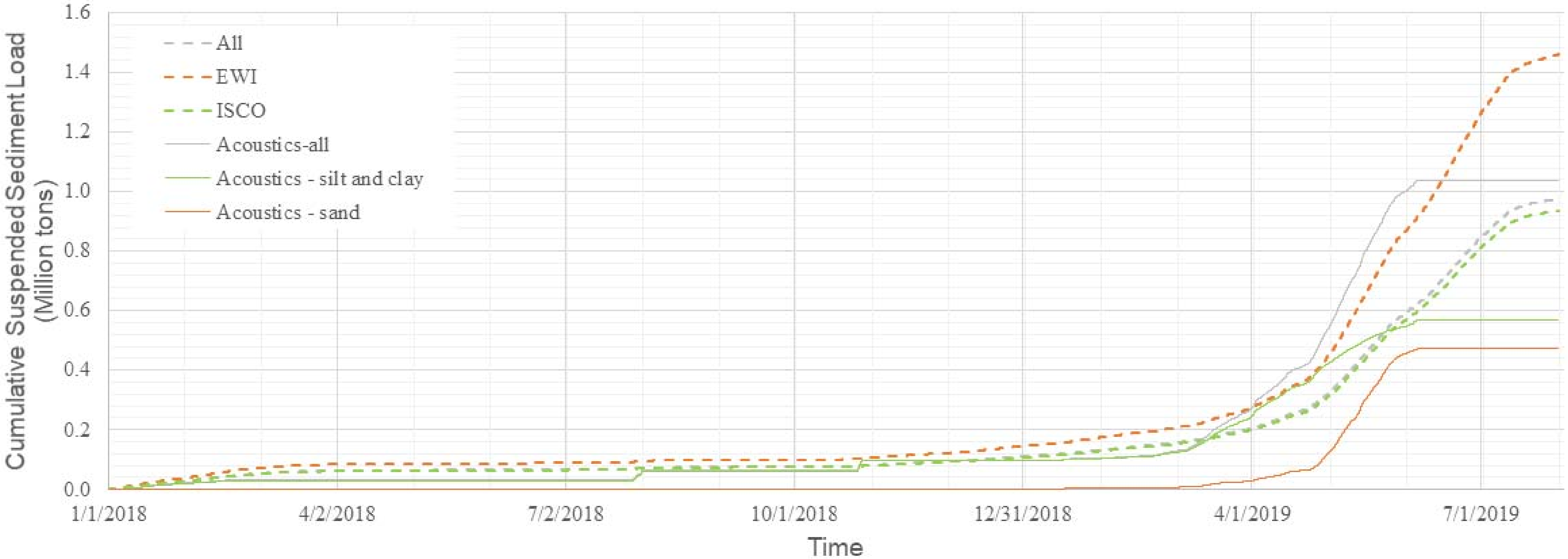


Figure 77. Suspended sediment single mass curves between 1 January 2018 and 31 July 2019. Dashed lines are based on best fit power relationships of the suspended sediment concentration and discharge. The acoustic information is based on the calibration of the collected acoustic signal. Cumulative suspended sediment is calculated on 15 minute intervals.

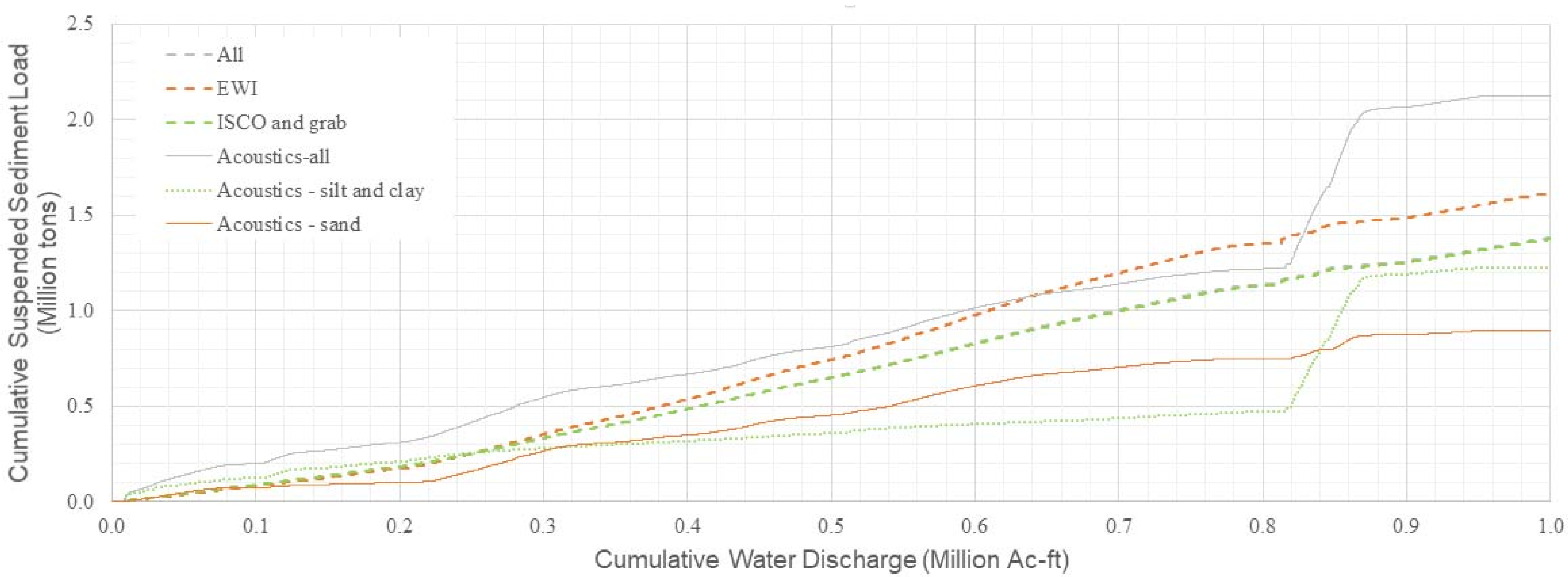


Figure 78. Suspended sediment and discharge double mass curves between 22 September 2016 and 31 December 2017. Dashed lines are based on best fit power relationships of the suspended sediment concentration and discharge. The acoustic information is based on the calibration of the collected acoustic signal. Cumulative suspended sediment is calculated on 15 minute intervals.

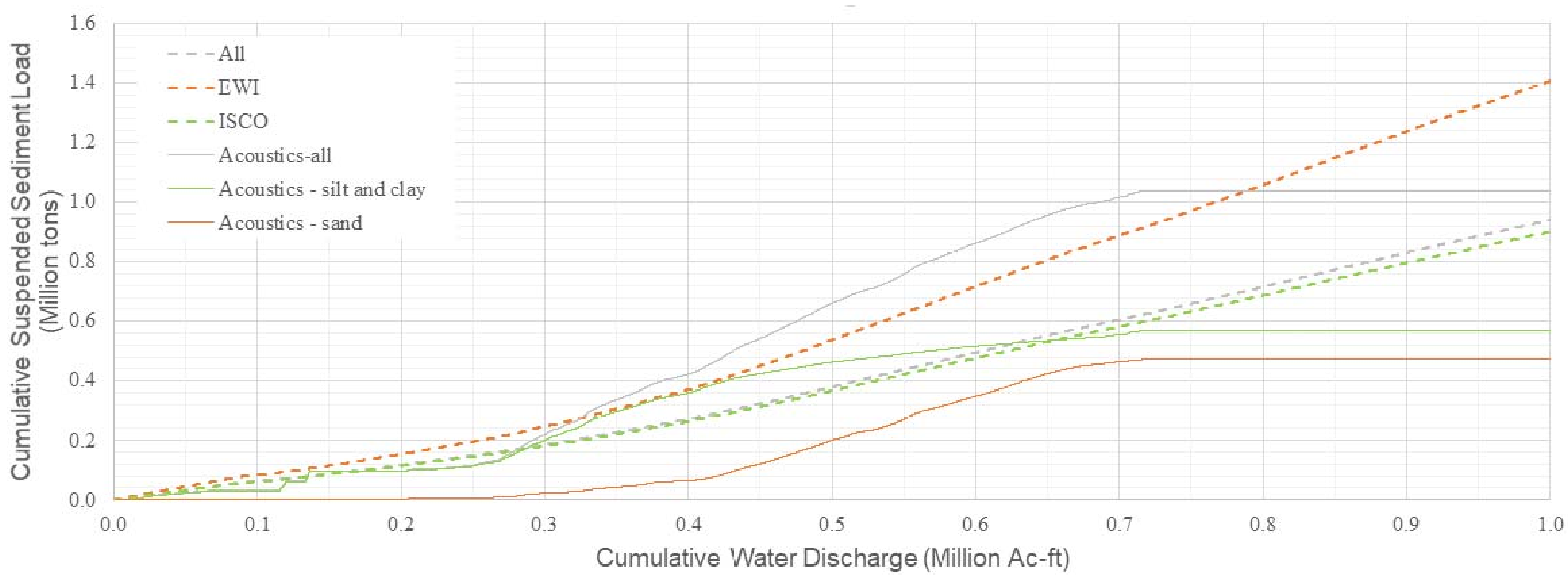


Figure 79. Suspended sediment and discharge double mass curves between 1 January 2018 and 31 July 2019. Dashed lines are based on best fit power relationships of the suspended sediment concentration and discharge. The acoustic information is based on the calibration of the collected acoustic signal. Cumulative suspended sediment is calculated on 15 minute intervals.

Conclusions

Active acoustic measurements have been successfully utilized for suspended sediment measurements on larger fluvial systems where the influences of the bed morphology are not as influential on the suspended sediment concentrations. Testing on shallow, sand bed rivers (10 feet or less) though, has been limited to areas where the local geology provides a sufficient flow depth at various discharge stages. The objective of this research endeavor was to see if current acoustic configurations would work in shallow, sand bed rivers where bed adjustments can occur which may affect acoustic measurements. The research proposed a test site on the MRG near San Acacia, NM and provided options to explore testing on other fluvial systems (such as the San Juan River) if testing at the San Acacia site went well. Two different active acoustic setups were utilized at the San Acacia site. A single frequency acoustic system (20 MHz) for collecting suspended sediment concentrations for fines (suspended sediment < 0.0625 mm) was developed by NCPA for a long term deployment at this site. A dual frequency (1 MHz and 2 MHz manufactured by AquaDopp) was also deployed at the site. These three acoustic instruments were calibrated using physical suspended sediment measurements collected at the existing USGS gaging station at San Acacia (ISCO® pump samples and cross sectional EWI samples).

The first hurdle that needed to be overcome was the actual placement of the acoustics in the water column. The NCPA acoustic instrument collected information from a point location, while the dual AquaDopps are configured to collect information along a horizontal plane through a river cross section. While ideally the instruments would be inundated throughout the year, if the instruments collected floating debris or were buried by the bed sediment load moving through the MRG then data collection would be limited. Expertise from the NMWSC was utilized in the final mounting design, to situate the instruments a certain distance from the right bank (looking downstream) and a set height above observed base flows. While this positioning would not allow data collection during low flow periods, it was felt to be more desirable to be able to continuously collect the suspended sediment information during the larger discharge events, when it is known, anecdotally, that the sediment on the bed is active.

The AquaDopps were installed in April 2016 and operated more or less continuously until the conclusion of this research in July 2019. The NCPA acoustic instrument was installed in July 2017 and operated intermittently through July 2019. Both instruments were found to be good estimators of the suspended sediment concentrations, providing a more temporally robust dataset than would have been collected with only the physical measurements.

From the collected suspended sediment measurements, a better understanding of the timing, magnitude, and duration of the suspended sediment on the MRG at San Acacia, NM was developed. From the collected acoustic information it was observed that more sand sized particles are moved during the spring snow-melt runoff than at other time periods. From the collected acoustic information, there appears to be a continuous discharge threshold of around 1,500 cfs to mobilize the sand particles. Fine particles tend to dominate during the rest of the year and are also dominant on the rising and falling limb of the spring snow-melt runoff. Suspended sediment concentrations tend to peak before the discharge peak (clockwise hysteresis) on the two spring snow melt runoffs observed between 2016 and 2019. Monsoon flows showed more variability with discharge of the suspended sediment measurements. Both clockwise (sediment peak before the discharge peak) and counterclockwise hysteresis (sediment peak after the discharge peak) were observed in the collected monsoon event data. Collected base flow information suggested higher suspended sediment concentrations in January than February.

Acoustical measurements (AquaDopps) also provided median sand suspended sediment size information, revealing a larger scatter during base flow events (November through February), on the rising and falling limbs of the spring snow-melt runoffs, and during monsoon events. During the two spring snow-pack runoff events observed during this research period, the median sand size was around 0.15 mm. Because of the differentiation of particle size, the AquaDopps also provided the ability to assess sediment load contributions. The sand fraction of the suspended sediment load contribute more to the cumulative suspended sediment load during the spring snow-melt runoff and the fines (suspended sediment fraction less than 0.0625 mm) contribute more during the monsoonal events. A more or less constant (straight line) transport of fine suspended sediment was also observed during the entire year outside of the monsoon season, which tends to have a markedly steeper slope.

In this regard the acoustic instruments, especially the AquaDopps, installed at the San Acacia site indicate that the developed acoustic technology on larger river systems is applicable on shallow, mobile bed systems like the MRG. The collected data was not always continuous though, often a result of the mounting decision. Large time periods exist when there is minimal flow in the river and the acoustics were above the water surface elevation and thus no information could be collected. This is a limitation of the use of acoustics on shallow, mobile bed fluvial systems that precludes the data collection to periods above a given discharge. Even when the AquaDopps are submerged, no data may be collected if an insufficient horizontal collection distance is acquired prior to the outgoing acoustic signal reflected by a shallow water covering or a depositional bed form that raises the channel invert. This may be one of the reasons the AquaDopps didn't collect data during hydrologic events that had a water surface elevation that was known to have submerged the instruments. While there were some limitations with the AquaDopps in the collection of longer duration discharges (most notably the 2019 spring snow-melt runoff), the flashy, short duration monsoon events were also problematic. Only a fraction of the monsoon events were captured, and those that were captured by the AquaDopps often underrepresented the suspended sediment concentration observed from the collected physical measurements.

The NCPA acoustic instrument only collected data from 13 events between 2017 and 2019. Power issues and file storage protocols were the primary reasons that additional data was not collected. In many cases, the collected NCPA acoustic data could be compared to physical samples and often to the AquaDopps. Estimated suspended sediment concentration from the NCPA acoustic instrument correlated well with the trends of the physical samples, though often over-estimated the suspended sediment concentrations. Different gradations of sediment in suspension passing by the instrument than what was present during the calibration process may be responsible for this over-estimation. Other possible reasons for this include: the system getting buried, debris collecting on the apparatus, and system malfunctions due to intermittent power. Due to issues experienced with the NCPA acoustic instrument, efforts were focused on improving the design rather than on deployment to another fluvial system.

When acoustic systems were functioning, the active acoustics provided a good estimator of the in-situ suspended sediment concentrations. The additional temporal resolution provided the ability to better understand the transport of suspended sediment on the MRG at San Acacia. In fact, utilization of the suspended sediment measurements from the acoustics indicates that traditional methods of estimating the suspended sediment from discharge measurements may under predict the cumulative suspended sediment load and the sediment concentrations during larger flow events, while over predicting the suspended sediment moved during low flow periods. This provides additional insight into the timing of sediment movement that is important in the creation of transitory sediment features, like low elevation bars, where the RGSM have been found (Dudley and Platania 1997, Mortensen, et al. 2019).

There are still limitations to the utilization of active acoustics, such as the need for physical measurements to calibrate the systems over a range of hydrologic events, as the suspended sediment makeup is variable. Multiple frequency deployments were observed to be beneficial on the MRG in tracking median sand size particles. A similar observation of the median fines would also be beneficial and was something NCPA was developing on their acoustic instrument. Data storage and power supply are critical issues when deploying the active acoustics. The AquaDopps were chosen because of their internal power regulation which closely regulates the outgoing power signal, an issue that was observed to be problematic with the NCPA acoustical instrument. Both active acoustics at the San Acacia site required the installation of additional solar panels to provide adequate power. Additional shade was also added to avoid overheating of the electronic equipment collating the collected acoustical data. Man-hours were also required to clear debris off the acoustic mount and to download the data.

Recommendations for Next Steps

In the long term, more continuous acoustic data sets and accompanying physical samples will provide an understanding of the sediment transport in the river better than the discrete information currently acquired. This research encompassed a 2.5 year monitoring effort, for which both spring snow-melt runoffs and monsoon events were observed. More events measured at the San Acacia site will enhance the predictive capabilities of the active acoustics by providing a larger dataset as well as greater suspended sediment concentration ranges for which to calibrate the instruments. Moreover, deployments at other sites on the MRG will provide additional insight into the movement of suspended sediment within the system. And deployments on other fluvial systems, such as the San Juan River or the Platte River, would provide more robust data collection methods, better mounting configurations, and potentially more general sediment active acoustic models.

Issues still needing to be resolved for the NCPA acoustic data collection to provide more continuous data sets primarily involve file download time and overall data acquisition stability. Researchers at USGS tried compressing the data files into an archive while at the site, and the download time was estimated at 12 hours. The data collection computer can only copy ~19,000 files at a time to a hard drive via USB. Moving forward, a possible solution would be to automatically move files from the laptop HDD to the SD card slot until filled. This would allow researchers to quickly remove data and not wait at the site. Additionally, the computer at the site is occasionally becoming unresponsive after continuous data collection for multiple days. A workaround for this issue might be to force a restart and auto-launch of the program at midnight. All of these need to be investigated, programmed, and tested in the field.

Fluctuations in power have created shortened data sets as well as potential weakened acoustic signals. Power regulation must be optimized to insure proper charging during data collection. A possible solution would be to connect a relay switch to allow for charging batteries via solar panel only when the float switch is not activated. Another solution may include solar charging of batteries when a minimum voltage threshold is met. Other power saving measures can be gained by acquiring less data (i.e. 5 minute pauses between data sets).

Currently the NCPA acoustic instrument is set to measure only fines (particles less than 0.0625 mm). It is possible that the NCPA acoustic system could be modified to measure suspended sand-sized particle concentrations. This could be accomplished by adding an orthogonal transducer in the down-facing position. The down-facing position of the transducer is critical to prevent cross-talk between transducers operating at other frequencies. This transducer would operate at a lower frequency (i.e. 1 MHz) and could measure the backscattered signals from the larger silt and sand sized grains. Using these three frequency approach, the calibrated acoustic surrogate device would allow researchers to measure clay, silt, and sand grains in the same water column.

For the AquaDopps, additional exploration of why data was not collected when the instruments were covered with water may help to develop more robust data processing steps. Exploration of the infrequent monsoon data collections and the observed under representation of the monsoonal suspended sediment concentrations would also be useful. It may be that there is an upper bound on the suspended sediment concentrations that can be measured from the AquaDopps.

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Data Sets that Support the Final Report

Data used to evaluate the active acoustics is provided at this shared drive folder:

Information on the shared drive is primarily compiled USGS and NCPA acoustic, discharge, and suspended sediment data for two time periods: September 2016 – December 2017 and January 2018 – July 2019. These are provided in an Excel spreadsheet and are about 56 MB each.

AquaDopp information can also be downloaded from this website: https://www.gcmrc.gov/discharge_qw_sediment/station/URG/08354900

Discharge and physical measurements are available from the NMWSC at this website: https://waterdata.usgs.gov/nm/nwis/uv?site_no=08354900

The USGS primary point of contact information is provided on the respective websites. Ari Posner would be the primary contact person for the data provided on the shared drive.