Seven years of sediment measurements at the Arroyo de los Pinos monitoring station

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Abstract

We present a seven-year summary of sediment transport data from the Arroyo de los Pinos sediment monitoring station. The channel, located in central New Mexico, is a direct ephemeral tributary to the Middle Rio Grande, a main stem river system in the American Southwest. These data represent the most comprehensive transport measurements made in an ephemeral watershed anywhere in the U.S., providing evidence of the capabilities of ephemeral channels to efficiently transport sediment. Bedload flux was monitored and sampled using continuously recording Reid-type slot samplers. Suspended sediments were collected using automated pump samplers and depth-integrated manual sampling.

Flows within the Pinos are relatively short-lived and infrequent, 3-5 bedload transporting events occur annually. More than 550 bedload flux measurements and 230 samples of suspended sediment have been recorded since 2016. Instantaneous bedload flux is high compared to global averages – up to 14 kg/s m. Total sediment production for the period 2018-2022 was, on average, 390 t/km^2 yr. Suspended sediment made up a majority - 80% - of this annual yield. However, this value varies considerably depending on water discharge; for the most commonly observed, shallow flows, bedload dominated transport, not suspended sediment. Taken in total, data collected at the Pinos station provide a new context on the frequency and connectivity of flows, the efficiency of sand and gravel mixtures in transport, and the development of new, cost-effective monitoring techniques for sediment transport. These findings can aid river managers throughout the desert Southwest and other drylands in understanding and forecasting sediment dynamics.

Introduction

Ephemeral channels occur worldwide (Messager et al., 2021), but are particularly prevalent in arid environments. Frequently, more than 80% of total river lengths in arid regions may be classified as ephemeral (Goodrich et al., 2018). Despite this ubiquity, their role in sediment transport dynamics and landscape evolution are sometimes overlooked in favor of perennial systems, where access to constructed infrastructure and population centers have led to more frequent transport studies (Milhous, 1973; Leopold & Emmett, 1976; King et al., 2004; Recking, 2010). Large variations in sediment delivery are associated with ephemeral channels because of their highly variable flow regime. In the few sediment transport studies that have been conducted in ephemeral systems, transport rates have been shown to be high when compared to global averages (Powell et al., 1996). The discontinuity of flow in these networks adds additional complexity; with the very short-lived recessions and lack of baseflow, much of the finest grain fractions are often preserved on the channel bed and available for transport during flood periods.

These factors: the general lack of available data, commonality of ephemeral networks (particularly in semi-arid and arid regions), and complexities associated with grain size led to the construction of a sediment monitoring station on the Arroyo de los Pinos in central New Mexico. The original goal of this station was to provide a consistent location to collect the highest quality measurements of sediment transport from an ephemeral channel. Here, we present the first seven years of observation at the Pinos, with the objective of describing the overall state of the system and to provide suggestions for monitoring these systems into the future.

Site Description and Methods

The principal monitoring site was constructed in 2018 (Figure 1); data collected beforehand (years 2016 and 2017) were limited, but included suspended sediment, seismic data, flow depth, and velocity. Data collected from 2018 onward followed consistent methodologies described in detail elsewhere (Stark, 2018; Stark et al., 2021), and are described in brief here. Bedload transport rates were captured using three Reid-type slot samplers (Reid et al., 1980). These instruments measure bedload continuously and directly: sediment falls through a slot in the channel bed and into a buried vault containing a steel box. The width of the slot can be adjusted using sliding plates and cross-channel sediment movement into the slots is limited with wings on either side. Sediment accumulation is recorded using calibrated pressure transducers. Data are processed following a mass-aggregation method (detailed further in Halfi et al., 2020) and reported as flux (kg/[s m]). Suspended sediment data were collected using two different methods. Automated pump samples were collected at two static depths near the right bank and depth-integrated sampling (using a DH-48) was collected across the channel, when depths were wadable. Samples were weighed, dried, and reported as concentrations (mg/L).

Other flow and sediment parameters were also collected. These included water depth (via pressure transducer) at three cross-channel locations, water velocity (using a handheld 1D electromagnetic velocimeter for wadable depths, surface velocity radar and Large-Scale Particle Image Velocimetry for depths too dangerous to wade), channel bed grain size, and drone-based digital elevation models. These data were used to inform observations and analyses described here (e.g., flow depth and velocity were used to develop a site-specific flow rating curve), but are not discussed in detail.

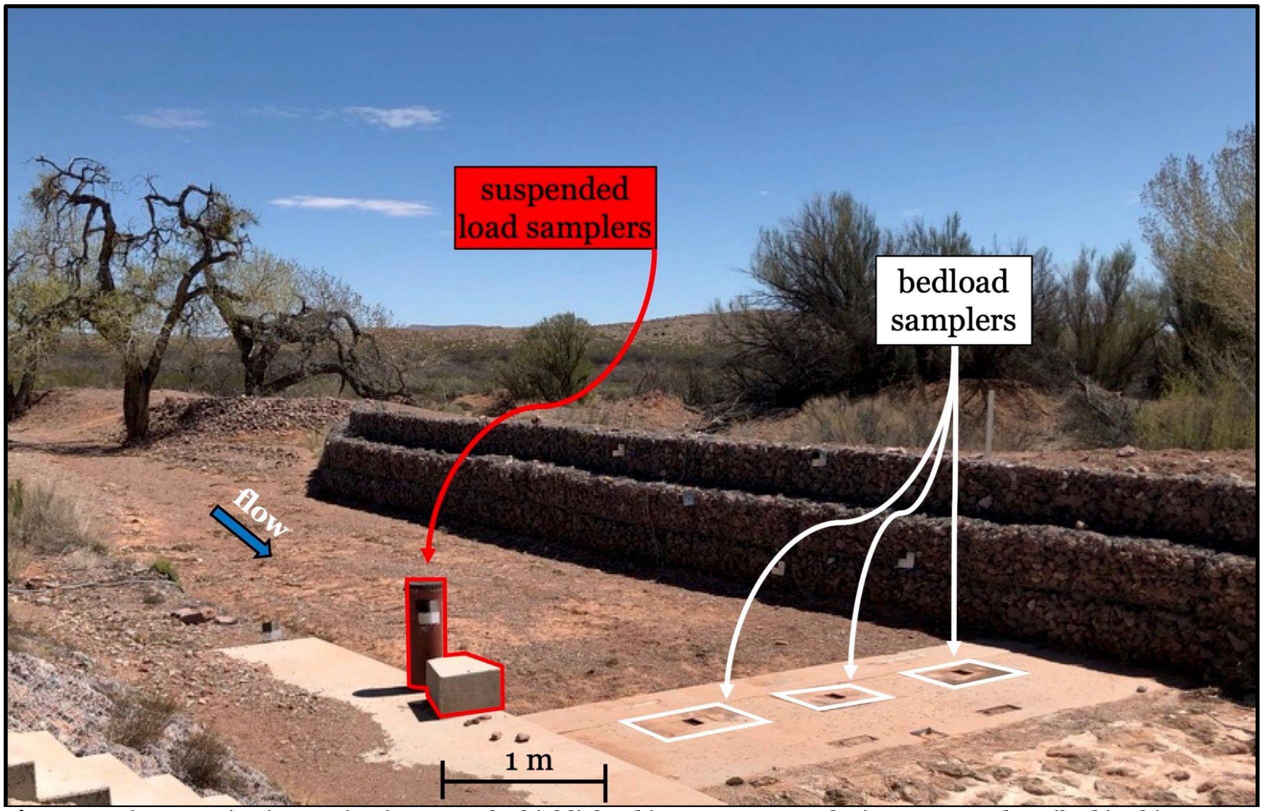

Figure 1: Pinos monitoring station in 2021. The highlighted instruments are the instruments described in this paper.

Discussion and Results

Flow Summaries

Twenty-nine bedload-transporting events were recorded at the monitoring location since 2016 (Table 1 & Figure 2). Personnel were on site during the majority of events and captured a wide range of quantitative and qualitative datasets. Flows rose quickly and achieved peak discharge in less than 0.75 hours, on average. Recessions were much longer; averaging 4.5 hours. Hydrographs were primarily single-peaked (e.g., July 26, 2018) or double-peaked (e.g., July 6, 2021) and were occasionally bore-styled, attaining peak within <5 minutes. We recorded on average 4.1 events/year, totaling an average 16 hours for measurable flow. This represents an actively flowing channel of 0.18% of the year. The majority of flow events occurred during July and August, matching the typical regional summer monsoon season.

Table 1: Summary of flow characteristics of every bedload-transporting event observed at the Pinos monitoring station

Date (YYYY-MM-DD)	maximum shear stress N/m^2	peak water discharge* m^3/s^1	peak channel-average bedload flux kg /(s*m)	max suspended sediment concentration mg/L
2017-07-02	23.1	2.6	--	--
2017-07-09	18.8	1.8	--	6,900
2017-07-13	35.1	5.2	--	--
2017-07-15	69.6	16.5	--	66,400
2017-07-22	36.2	5.5	--	74,700
2017-08-01	16.6	1.5	--	--
2017-09-27	30.8	4.2	--	49,200
2017-10-05	65.0	14.7	--	51,300
2018-07-16	51.8	10.1	--	103,000
2018-07-26	144	74.3	11.3⁺	--
2018-08-09	20.4	1.97	3.8⁺	29,600
2018-08-24	34.8	4.95	10.9⁺	90,100
2018-09-01	13.9	1.03	1.0	18,600
2020-07-23	20.5	1.99	3.8	52,200
2020-07-24	33.3	4.61	--	58,300
2020-09-01	15.5	1.24	2.0	--
2021-07-02	35.1	5.03	7.1⁺	45,800
2021-07-05	118	48.9	11.4⁺	76,700
2021-07-06	76.2	20.5	--	64,700
2021-07-23	95.2	31.6	6.0⁺	79,900
2021-08-12	14.5	1.1	3.2⁺	50,000
2021-08-23	21.8	2.21	4.1⁺	--
2021-08-27	61.2	13.6	8.3⁺	78,300
2021-09-28	12.4	0.85	1.4	--
2022-07-08	22.5	2.3	7.4	--
2022-07-11	17.2	1.5	2.3	--
2022-08-11	83.1	24.2	--	--
2022-08-20	11.3	0.72	2.7	--
2022-10-05	88.1	27.2	11.4⁺	--

* calculated using a site-specific rating curve
+ peak bedload flux measured prior to peak water discharge due to limited sampler capacity

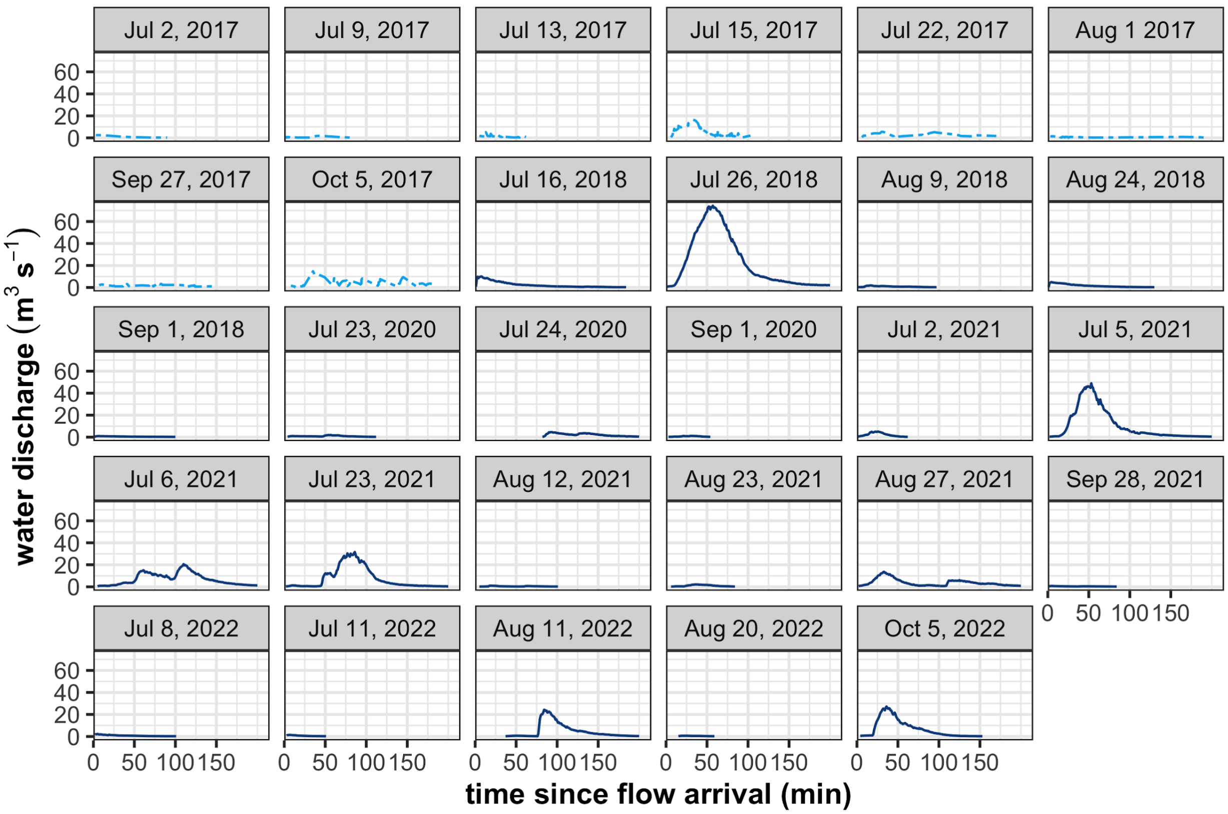

Figure 2: Hydrographs for each monitored flow event. Data collected prior to 2018 are less accurate and denoted with a lighter blue, dashed line.

Sediment Transport Data Analysis

Bedload flux was characteristically high, increasing in a predictable fashion with shear stress (Figure 3). Flux measurements were also consistent between monitoring years, giving confidence to our sampling methodologies and suggesting a channel in a state of relative equilibrium. Due to limits of sampler capacity, the vast majority of bedload data were from small, commonly-occurring flow periods. Because of this, bedload flux during periods after the samplers became full were estimated with a simple linear relation (r^2= 0.73); total sediment yield was estimated using this relationship.

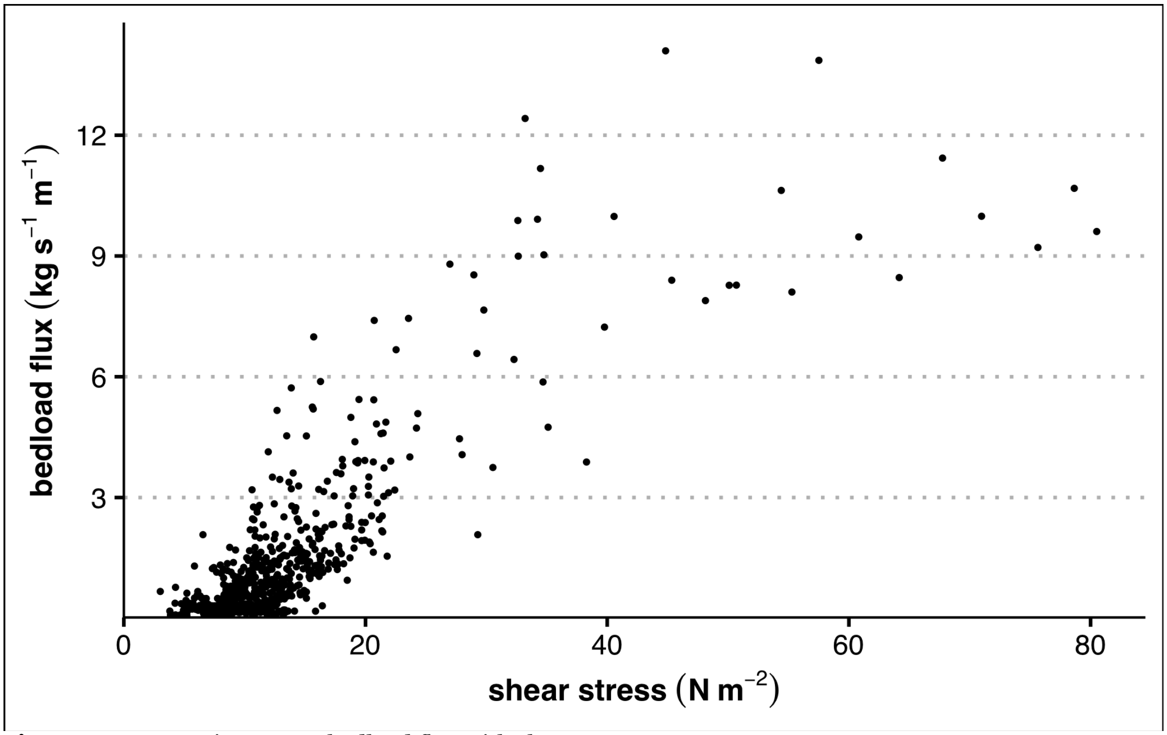

Figure 3: Increase in average bedload flux with shear stress.

SSC was also high; the average concentration was 34,000 mg/L. Sediment concentration increased with water discharge (Figure 4). We observe differences in SSC between rising and falling limbs; SSC prior to peak discharge was 40% higher on average, even when controlling for differences in sampling periods. There were no statistically significant differences in concentration between the depth-integrated and discrete grab samples; however, concentrations tended to be higher in grab samples collected at the lower intake compared to samples collected contemporaneously at a higher intake. If depth-integrated samples were available at higher discharges, we expect them to include higher rates of sand transport. Total sediment yield was estimated using an empirical relationship between SSC and water discharge ($r^2 = 0.58$).

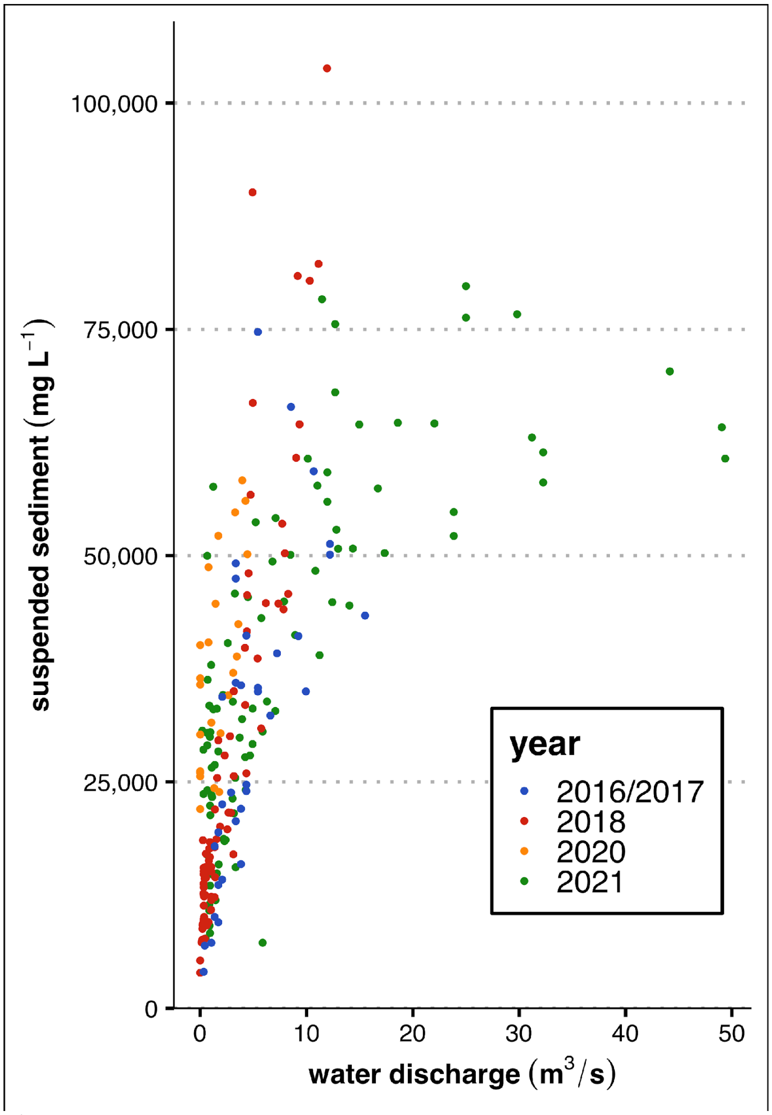

Figure 4: Increase in suspended sediment concentration with water discharge.

Individual event yields and annual sediment yields were estimated for years when the monitoring station was active (2018 – 2022). High sediment yields were observed; the annual average sediment yield was 390 t/km² yr. This average includes 2019, when no bedload transporting events occurred. Years with no flow may be somewhat common, roughly 1-2 every 10 years, given the climate and observations made to date. Twenty percent of the total load is estimated to have been transported as bedload. At the flow event scale, bedload/suspended yield ratio changed dramatically, depending on the size of the flood (Figure 5). These data show a general increase in the share of the total load that is bedload to a value as high as 0.75 (75% of the sediment is transported as bedload), then a general decrease afterwards. This may be interpreted as bedload transport rising quickly up to equal mobility (when all grain sizes represented on the channel bed begin to transport in equal proportions), then reversing slowly as more sand (which is initially transported as bedload) transitions into suspension. This is significant, because the peak in bedload/suspended yield ratio corresponds to the discharge of the commonly recurring flow events. Bedload from the Pinos provides the majority of sediment transported during commonly observed flows to the Middle Rio Grande.

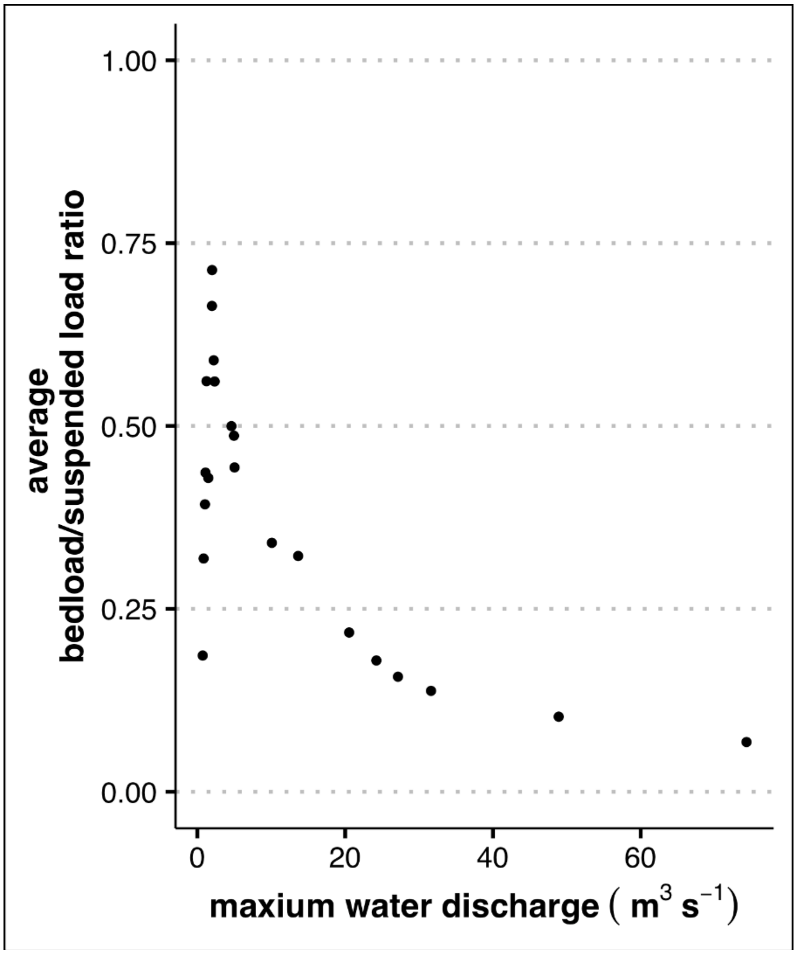

Figure 5: Average bedload/suspended load transport ratio vs. maximum event water discharge. There is a sharp increase in the proportion of material transported as bedload when discharge is low, followed by a gradual decrease in transport ratio as additional material transitions into suspension.

Dataset limitations

While this dataset of sediment transport represents the most thorough and complete dataset from an ephemeral channel, some limitations exist. Reid-type slot samplers are 100% efficient at sampling small grains transported downstream, but sampling of larger grains may be limited due to slot width (Poreh et al., 1970). For the reported range of bedload data in this manuscript, the effect of slot width on bedload flux measurements is minor (Stark et al., 2021), but field observations suggest some large, 100 mm boulders were transported in flows as small as 25 N/m^2 (*pers. comms.* McLaughlin, 2022). The fraction of missed large grains is increasingly important as flow strength increases – based on analysis of collected grain size material, as much as 5% of bedload mass is larger than 30 mm (the size at which the Reid samplers in their current configuration begin to under sample grains) for flows larger than 20 N/m^2. This results in a general underestimate of the bedload fraction of total sediment yield, especially for large flows.

The suspended sediment dataset is generally more complete. Data were collected across a larger range of flow strengths and conditions. However, grab sampling has been shown to underestimate the actual sediment concentration, especially when sands are being transported in suspension (Groten & Johnson, 2018). Grain size data (see Stark et. al., 2021 for a detailed discussion) suggest a large majority of sediment is fine-grained, but that the fraction of sand increases as flow strength increases. No statistically significant differences in grain-size and SSC were observed between our three different measurement types (grab-upper, grab-lower, and depth-integrated), but it may be reasonable to expect that depth-integrated sampling during larger flows would reveal a more stratified flow system.

Conclusions and general dataset observations

Data collected at the Pinos sediment monitoring station adds a crucial, comprehensive dataset in semi-arid landscapes (which comprise more than 25% of the conterminous U.S.). Sediment discharge from this ephemeral channel is high – up to 390 t/km^2 yr. Bedload flux is an important contributing factor; roughly 75% of sediment delivery to the Middle Rio Grande is bedload during the most common flow events. During larger floods, this contribution decreases and bedload contributes roughly 20% of the total sediment load across all observed events. When interrogating the bedload transport data in more detail, we found consistency between flow events. Bedload flux is high, particularly at low flow strengths because of the particular size distribution of the bed material. A majority of the bedload mass was sand-sized at these low flow strengths, which quickly transitioned to gravel-dominated as more sand material was transported in suspension. Suspended sediment data display evidence of a first flush, where concentrations are generally higher at the beginning of events and at the beginning of flow seasons, even when controlling for flow strength.

Large discharge events have lasting downstream effects in systems like this. Vestiges of a large 2018 event can still be seen today at the Arroyo's confluence with the Rio Grande. Deposition of a coarse fan forced the Rio Grande to its adjacent bank. Vegetation established on this fan, and continues to alter the Rio Grande's course. The Arroyo de los Pinos is but one of a multitude of direct tributaries of sand and gravel throughout this region; events like this occur annually. We hope that sediment transport information collected and presented here - and to be further continued into the future at the Arroyo de los Pinos station may better inform river managers of the importance of ephemeral tributaries in sediment delivery downstream. These data can be used to fill an apparent gap of high-quality ephemeral gravel river sediment transport data. These channels produce a significant amount of sediment despite their size and infrequency of flows.

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