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CHARACTERISTICS OF TRANSPORTED SEDIMENT FROM SMALL SEMIARID WATERSHEDS DURING THUNDERSTORM GENERATED RUNOFF

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ABSTRACT

Vast areas of rangeland in the semiarid southwestern US are characterized by ephemeral channels that transport sediment during occasional flows. Reducing the amount of sediment in surface water runoff can improve water quality and minimize the impact of upland activities on downstream water users. Because measuring transported sediment in natural channels during highly variable flow conditions is difficult and expensive, total load measurements are relatively rare. There is a need for data, and subsequent interpretation, describing the characteristics of sediment transported in suspension and as bedload in semiarid rangeland regions, for improving prediction technologies and assessing regulatory compliance. Runoff and sediment data are collected at the outlet of a 4.53 ha upland watershed on the USDA-ARS Walnut Gulch Experimental Watershed in southeastern Arizona. A critical depth runoff-measuring flume and depth-integrated traversing slot sampler collects runoff and sediment during flow events. Although the traversing slot collects a depth-integrated sample, computed concentration values do not represent sediment particles greater than the 13 mm slot width. During the 2002 runoff season, a tank was installed at the outfall of the flume to trap coarse sediment. Total load was characterized by coupling sampled sediment < 4 mm collected with the traversing slot and sediment > 4 mm trapped in the tank for three runoff events. Sediment particles larger than 4 mm make up as much as 15% of the total sediment load transported during the measured events.

KEYWORDS. Bedload, Sediment Transport, Semiarid, Ephemeral Channel

INTRODUCTION

Sediment has been identified as a primary pollutant in the United States. Individual states are establishing Total Maximum Daily Load (TMDL) allocations to ensure that surface water quality standards are met as part of the Clean Water Act (US EPA, 1999). The establishment of TMDLs in the southwestern US is complicated because much of the surface runoff is ephemeral and transports sediment in channels only during occasional flows. Because flows are ephemeral, the relationship between sediment delivery from a watershed and the characteristics of transported sediment during individual flows is complex. In addition to conveying sediment, many rills and channels store sediment, which may be subsequently transported in response to temporally variable runoff events. Low discharge flows may deposit transported sediment within the channel network as transmission losses reduce the flow rate and volume, while high discharge flows may transport sediment to perennial receiving waters.

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Many rangelands are subject to accelerated erosion. Soil lost on uplands often becomes a non-point source pollutant as it moves into the channel system with overland flow. Reducing the amount of sediment in surface water runoff can improve water quality and minimize the impact of upland activities on downstream water users. However, evaluating the impact of upland activities requires baseline information for comparison. There is a need for data, and subsequent interpretation, describing the characteristics of transported sediment in semiarid rangeland regions, for improving prediction technologies and assessing regulatory compliance.

A great deal of uncertainty is associated with quantifying sediment loads in semiarid watersheds (Simanton et al. 1993). How much sediment is transported during runoff events? In the semiarid southwest, short durations and high intensity thunderstorms result in rapidly rising runoff hydrographs. Highly variable flow creates difficult conditions for measuring sediment transported in normally dry channels. As a result, measurements and data sets containing coupled hydrograph and total load transported during individual flow events in natural channels are rare.

TMDLs are likely to be site specific, especially where long-term monitoring data are available. Attempts to quantify total load have yielded site specific information with a broad range of results. Although there is no generally applicable technique for quantifying sediment transport in ephemeral, alluvial channels, transported sediment can be quantified through sampling, sediment rating curves, or trapping material during flow events (Vanoni 1975). However, sediment sampling and collection is difficult. Although samples collected during flows can be used to quantify suspended load (Edwards and Glysson, 1999, Renard et al., 1976), quantifying the total amount of material transported is more difficult and is often of questionable accuracy. Pit traps have been installed in the channel bed to collect the total load (Reid et al. 1980, Kuhnle 1992, Wilcock et al., 1996). There are a few examples of data collection on larger channels (Leopold and Emmett, 1976, Emmett 1980). In the absence of long-term monitoring data, analytical tools, such as simulation models, can be used to compute sediment yields. However, algorithm development, calibration, and validation require measured data.

Sediment in ephemeral channels in the southwestern US can range in size from very fine silt and clays to large cobbles and boulders, and may be transported as suspended load or as bedload. Finer material is derived from eroded upland soils that are transported to the channel system through overland flow where it mixes with particles derived from bank sloughing, the eroding channel bed, and sediment deposited during previous flows. The material that travels in suspension includes silt and clay size particles that are of particular concern for water quality because they transport organics and contribute to turbidity. Suspended solids contribute to turbidity, and the size of particles in suspension generally increases as flow velocity increases. The bedload contribution to the total load of sediment transported varies with water discharge.

Research is being conducted to characterize and quantify the total sediment transported during short duration flows with rapidly rising and falling hydrographs that occur during the summer "monsoon" season in southeastern Arizona. In contrast to perennial streams, the total daily flow in normally dry channels may be the result of single, short duration flow. This paper presents initial results of efforts to characterize the total sediment load from individual runoff events by collecting coarse particles in a trap and coupling these data with fine particle samples collected with a traversing slot sediment sampler at the outfall of a critical depth runoff measuring flume.

METHODS

Study Site

The 150 sq. km. USDA-ARS Walnut Gulch Experimental Watershed (WGEW) (Renard et al., 1993) is located in southeastern Arizona (http://www.tucson.ars.ag.gov). The watershed is located in the semiarid transition zone between the Sonoran and Chihuahuan deserts. The main Walnut Gulch channel, which is dry most of the time, drains to the west into the San Pedro River. The San Pedro River flows north into Arizona from Sonora, Mexico and is generally ephemeral with a perennial section in association with bedrock near the surface. Flow events in response to thunderstorm rainfall dominate the surface runoff regime. Average annual precipitation on the WGEW ranges from 303 mm at the lower end (1275 m) of the watershed to 339 mm at the upper end (1585 m). Precipitation during July, August and September accounts for approximately 2/3 of the annual total (Nichols et al. 2000).

Within the WGEW, the Lucky Hills study area is intensively instrumented to monitor rainfall, runoff, and sediment movement. The research reported herein was conducted in the subwatersheds designated LH102 (1.46 ha), LH104 (4.4 ha), and LH106 (0.36 ha). The actively eroding watershed is underlain by alluvial material deposited during historic erosion events. The channels above the flume at LH104 are filled with noncohesive sediment particles that range in size from silts and clays to cobbles. Locally, a conglomerate layer underlies the channel and acts as a base level control until it is eroded. Most runoff events occur in response to locally intense summer thunderstorms with occasional winter runoff from long duration, lower intensity frontal storms. Sediment supply is generally unlimited in the channel, and runoff events generally carry high sediment loads.

Instrumentation and data collection

The LH104 watershed is instrumented to measure precipitation, runoff, and sediment movement. Precipitation is measured at a raingage located near the upper end of the subwatershed. Runoff and suspended sediment samples are collected at the outlet of LH104 with a Santa Rita Critical Depth flume (Smith et al., 1982) and a traversing slot sediment sampler (Renard et al., 1976)) (Figure 1). The traversing slot sampler was designed in response to limitations of alternative sampling methods. When flow depth is greater than 0.06 m the traversing slot travels across the outlet of the flume and diverts depth-integrated samples to evenly spaced, stationary slots below the flume exit. The water and sediment mix is directed into sample bottles. The samples are dried and weighed to quantify concentration of sediment less than the 13 mm width of the slot. Particles larger than 13 mm pass through the flume while depth integrated samples of particles smaller than width of the slot are collected.

Operation of the Santa Rita Critical Depth Flume at LH104 requires a free overfall that has created a plunge pool on the down channel end of the flume. The plunge pool was further excavated and a 375 gallon tank was installed to catch and retain sediment transported through the flume. The tank was perforated with 3/16 inch drain holes. Following runoff events, sediment was shoveled into bulk bags and transported to the field station. Sediment was transferred to drying boxes and was air-dried under the hot ambient conditions. Dried sediment was sieved and weighed to measure transported sediment across a range of particle size classes.

Total sediment for each event was computed by integrating the sediment concentration curve computed for particles up to 4 mm and adding the total weight of the sediment >4 mm retained in the sediment trap. The traversing slot sampler was used to quantify the finer fraction of transported material and the sediment trap was used to quantify the coarse material transported. The use of 4 mm as the upper particle size limit from which to compute sediment concentrations was based on a particle size analysis of sediment collected in the sediment tank in comparison with sediment collected by the traversing slot.

Figure 1. Santa Rita Critical Depth Flume and traversing slot sediment sampler.

RESULTS

There were seven runoff events at LH104 during the 2002 "monsoon" season. Two events overtopped the tank with sufficient velocity to transport coarse material down channel. Runoff events ranged in volume from 0.5 to 274 m^3 with peak runoff rates of 0.002 cms and 0.47 cms respectively (Table 1). The traversing slot was halted by a coarse particle during one of the events which limited collected data to one sample that was insufficient to quantify transported sediment. A total of three events yielded sufficient data by both sampling methods to quantify the total transported load.

The tank collected and retained sediment during three flow events, but the tank was too small to accommodate larger flows. No particles greater that 13 mm were sampled by the traversing slot, although particles greater than 13 mm were transported during each event. The sediment trap retained amounts of sediment larger than 16 mm in all 3 flows, and retained sediment particles as large as 145 mm.

The amount of coarse material transported is less than that of suspended material, but, for the 7/26/2003 event, the coarse material (>4 mm) totaled 163 of 1108 kg, or 15% of the transported sediment (Table 2). While it is possible for particles approaching 13 mm to fit through the slot, particles larger than 8 mm appear to be underrepresented in the samples. In each of the three flows analyzed, the fraction of sampled material representing the >8 mm size class in the bottle samples consisted of at most one particle per sample. Most samples (8 of 11 samples) had no particles larger than 8 mm diameter. However, during the 7/26/2002 event, 84 kg of sediment >8 mm were retained in the sediment trap, the 8/30/2002 event retained 61 kg of sediment >8 mm, and the 9/8/2002 event retained 29 kg of sediment >8 mm.

Table 1. Characteristics of seven runoff events during the 2002 monsoon season at the Lucky Hills 104 watershed on the Walnut Gulch Experimental Watershed

Date	Runoff Volume (m^3)	Peak Runoff Rate (cms)	Duration	Comments
7/19/2002	16	0.03	22m 30s	Only 1 bottle sample collected
7/26/2002	90	0.14	35m 30s	Adequate samples
8/4/2002	274	0.47	40m 30s	No total load data
8/30/2002	39	0.14	19m 15s	Slot sampler stuck in flow, analysis based on 3 samples
9/8/2002	20	0.05	20m 30s	Adequate samples
9/9/2002	0.5	0.002		No total load data
9/11/2002	94	0.27	26m 30s	No total load data

Table 2. Summary of sediment collected in a pit trap (tank) and sampled via a traversing slot sampler at the Lucky Hills 104 watershed on the Walnut Gulch Experimental Watershed

Date	# Traversing Slot Samples	Total Sediment[1] (kg)	Traversing Slot kg < 4mm (% of total)	Tank kg > 4 mm (% of total)	Tank kg > 8 mm (% of total)	Tank kg > 16 mm (% of total)
7/26/2002	6	1108	945 (85%)	163 (15%)	84 (7.6%)	35 (3.2%)
8/30/2002	3	908	804 (89%)	104 (11%)	61 (6.6%)	32 (3.5%)
9/8/2002	2	524	460 (88%)	64 (12%)	29 (5.4%)	8 (1.6%)

[1] total sediment = traversing slot <4 mm + sediment trap > 4mm

CONCLUSION

Total load data collected on the WGEW indicates that coarse material transport is underestimated by sampling with the traversing slot sampler. Sediment larger than 13 mm is not sampled, and it appears that particles larger than 8 mm are underrepresented through sampling. Additional data collection is required to fully characterize transported sediment across a range of flow sizes. Sediment traps have been installed at two additional locations on the WGEW to understand the relationships between total sediment load and watershed characteristics.

Establishing TMDL allocations for sediment, or surrogates that indicate changes in sediment transport, requires baseline data to quantify sediment transport during natural runoff events. Measured total load values are rare, particularly in semiarid regions where highly variable runoff conditions make data collection difficult. Continued research to quantify the total load transported across a range of discharges will provide critical data for understanding sediment transport in semiarid watersheds, developing analytical tools, and establishing TMDLs.

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