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Sediment yield in a semiarid basin: sampling equipment impacts

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Abstract Sediment yields from two small semiarid subbasins within the Walnut Gulch Watershed in southeastern Arizona, USA, are estimated using three types of sediment sampling equipment. Because efficiency of sampling equipment affects these estimates, measured sediment yields from each subbasin were compared by sampling method and then to estimates using the Revised Universal Soil Loss Equation (RUSLE). Sediment yield versus storm runoff volume were related for each sampling method and results showed that as sampling equipment became more efficient, regression line slope increased indicating an increase in subbasin sediment yield. The magnitude of difference between RUSLE estimates and measured sediment yields changed with sampling method.

INTRODUCTION

Sediment-yield estimates and erosion prediction models depend on experimental data collected from field and small drainage basin areas. Fluvial sediment samplers range from those that measure suspended loads to those that measure time-integrated total loads. Sediment-yield measurements are not only affected by the portion of flow being measured but also the sampling action and technique. Results using one sampler may not be comparable to those using another, even though each sampler collects from the same part of the water column. Because of vertical and horizontal spatial variability of sediment concentration within the stream flow, samplers approach the spatial concentration problem with different techniques. Sampler efficiency can have a major impact on the accuracy of the sediment-yield estimates and the subsequent validity of erosion model estimates.

This study determined whether sediment yields changed with sampling equipment and how changes modified erosion model estimates. The study was conducted in subbasins of the 150 km^2 Walnut Gulch Experimental Watershed in southeastern Arizona, USA (31°43′N, 110°41′W) (Fig. 1). The watershed is representative of semiarid brush and grass rangeland of the southwestern USA and is transitional between the Chihuahuan and Sonoran Deserts. Annual precipitation averages about 300

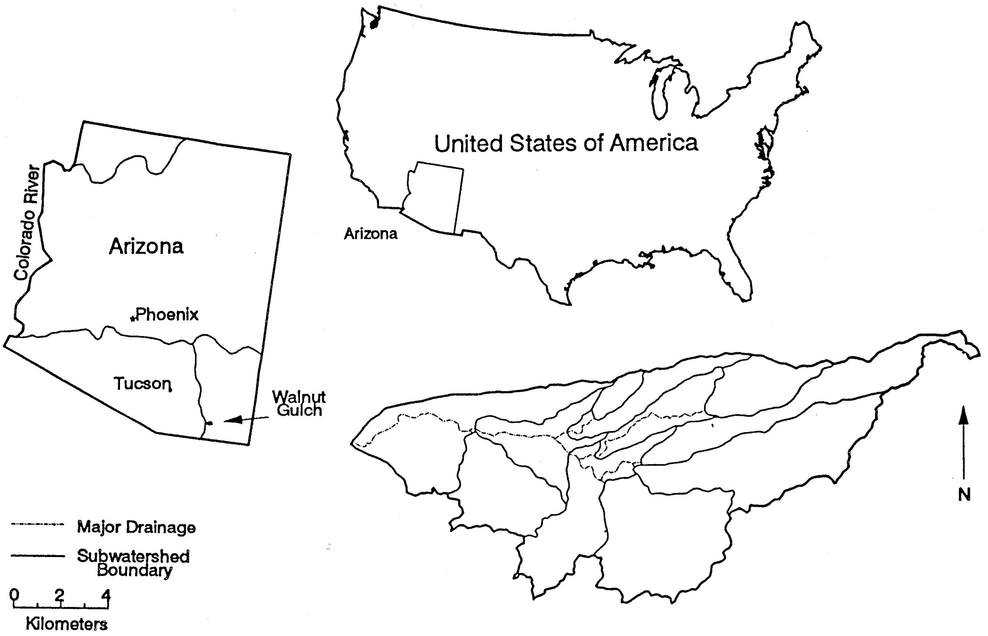

Fig. 1 Location map of the Walnut Gulch Experimental Watershed, Arizona, United States of America.

mm: 70% occurs as thunderstorms from July to mid-September. Runoff during this season accounts for 99% of the annual total.

Runoff and sediment-yield data from adjacent subbasins, Lucky Hills 3 (LH3)(3.68 ha) and Lucky Hills 4 (LH4)(4.53 ha), were used in this study. The subbasins have similar vegetation and topography, but different channel characteristics and parent material of the soils. The main channel of LH3 is deeply incised, relatively straight, and actively eroding; LH4 has a meandering channel with gently sloping banks. This channel difference could be a function of soil type in which the channel has formed. The LH3 channel was formed in a fine textured, relatively rock-free soil whereas the LH4 channel formed in a soil similar to that of both subbasins. Sediment yields from LH3 are about 3 times greater than from LH4, the difference being a greater amount of channel erosion in LH3 (Osborn & Simanton, 1989). Livestock have been excluded from both subbasins since 1962 but little change in vegetation type and density and surface ground cover has been measured. Shrubs less than 1 m high and with a canopy area of about 35% dominate the subbasins. Vegetation consists of creosote bush (*Larrea tridentata*), white-thorn (*Acacia constricta*), tarbush (*Flourensia cernua*), snakeweed (*Gutierrezia Sarothrae*), and burroweed (*Aplopappus tenuisectus*).

Pedogenesis has resulted in medium-depth (1.2 m), well-drained, calcareous loams. Calcretes are common at depths of 0.5 to 2 m. The uppermost 10 cm of the soil profile contains up to 60% gravel but underlying parts of the profile usually contain less than 40% gravel (Gelderman, 1970). Surface rock fragment cover (erosion pavement) ranges from negligible on shallow slopes to over 70% on the very steep slopes (Simanton *et al.*, in press).

INSTRUMENTATION

Event runoff and sediment-yield data were collected from 1973 through 1989. During the period 1973 to 1977 broad-crested V-notch weirs were used for runoff measurement. Suspended sediment passing over the weir was measured with an automatic pump sampler (Allen *et al.*, 1976) equipped with a depth-integrating sampling tube. Bed load was measured after each runoff event as trapped sediment in the stilling basins behind the weirs. The weir stilling basins were large enough that all bed load was trapped. The weirs were replaced in 1977 at LH3 and in 1978 at LH4 with supercritical flow flumes (Smith *et al.*, 1981) equipped with total-load automatic traversing slot samplers (Renard *et al.*, 1986).

Three methods were used to measure sediment yields: (a) depth integrated pump sampler (DIP), (b) DIP plus the bedload trapped sediment behind the weir (DIPT), and

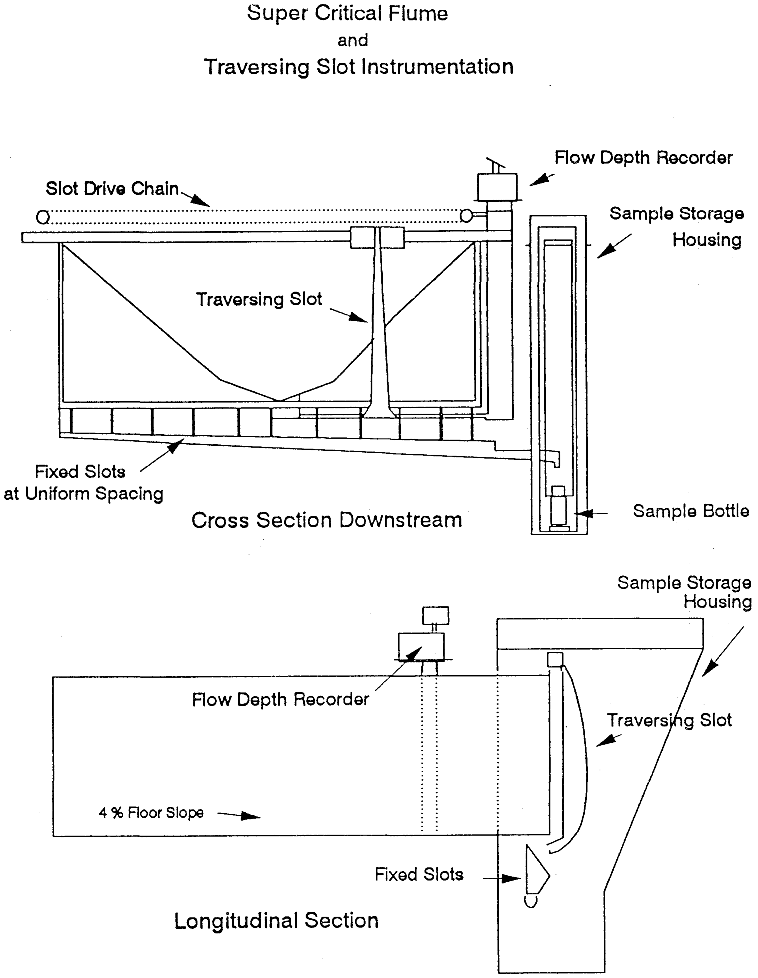

Fig. 2 Schematic of the traversing-slot sediment sampler and associated instrumentation.

(c) total-load traversing slot sampler (TS). The DIP method takes periodic sediment samples, throughout the hydrograph, that consist of fine suspended sediment from the water column at the intake tube. Thus, concentrations may not be representative of the entire flow width. It is assumed that the sample is vertically integrated because the bottom-pivoting sampling tube in the flow profile samples from equally spaced holes in the tube. The DIPT and DIP methods are similar except that the DIPT method includes coarse sediment, trapped behind the weir, that was measured and removed after each runoff event. The trapped sediment weight was added to the DIP sediment to give a total load for the event. The TS method uses a supercritical flume with a traversing slot sediment sampling device that diverts a water-sediment mixture at the flume discharge into fixed slots (Fig. 2). The water-sediment mixture then flows into sample bottles within the sample storage housing. The traversing slot was assumed to provide a horizontally and vertically-integrated, total-load sediment sample. Temporal changes in sediment concentration were quantified by periodic sampling throughout each hydrograph.

DATA ANALYSIS AND RESULTS

Direct comparison of sediment yields by the DIP and DIPT methods were made, but neither method can be compared directly with the TS method because its equipment replaced the V-notch weirs. Comparisons of DIP and DIPT to TS were made by relating storm runoff volume to sediment yield. Total sediment yields, in kilograms per hectare (kg/ha), for selected storms were regressed with storm runoff volume (depth over the subbasin area), in millimeters (mm), to determine differences in sediment yield among the sampling methods. In the regression analysis, the regression was forced through the origin and produced the equations given in Table 1. The coefficients of the equations (sediment yield (kg/ha) per unit of runoff volume (mm)) for the two subbasins indicate that sediment yields increased when the sampling method changed from DIP to DIPT. Changing from the DIPT to the TS method did not affect sediment-yield measurements at LH3 (Fig. 3(a)) but the sediment yields at LH4 showed an increase (Fig. 3(b)). However, by eliminating one point (runoff = 14.5 mm and sediment = 626 kg/ha) in the DIPT regression analysis for LH4, the regression

Table 1 Regression equation and coefficient of determination (R^2) for the storm sediment yield (kg/ha) *vs.* storm runoff volume (mm) relations of the Lucky Hills subbasins.

	Lucky Hills 3	(LH3)			Lucky Hills 4		(LH3)
Method	Equation	R^2	N	Method	Equation	R^2	N
DIP	Y= 83.1 X	0.91	20	DIP	Y= 29.0 X	0.88	20
DIPT	Y= 187.8 X	0.95	20	DIPT	Y= 59.5 X	0.73	20
				DIPT(w/o)	Y= 79.5 X	0.73	19
TS	Y= 193.1 X	0.88	30	TS	Y= 80.1 X	0.86	13

Y= Sediment yield (kg/ha), X= Runoff Volume (mm)
DIP = Depth integrated pump sampler
DIPT = Depth integrated pump sampler plus trapped sediment
DIPT(w/o) = DIPT without one data point (x= 14.5, y= 626)
TS = Traversing slot sampler

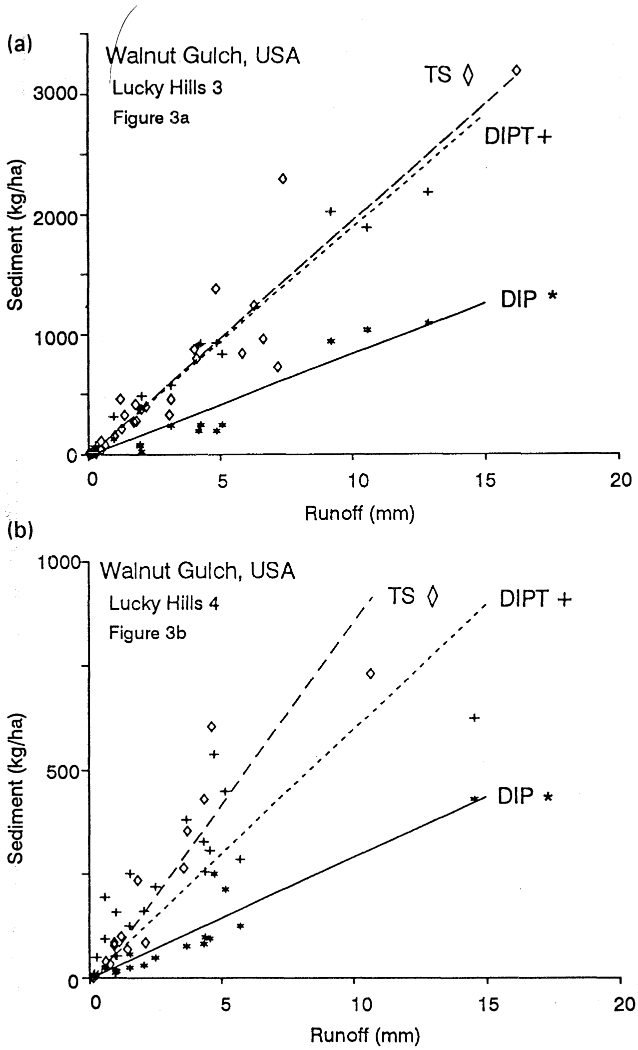

Fig. 3 (a) Runoff volume *vs.* sediment yield of three sampling methods on the Lucky Hills 3 subbasin. (b) Runoff volume *vs.* sediment yield of three sampling methods on the Lucky Hills 4 subbasin.

coefficient became 79.5 (Table 1) which would plot very similar to the TS regression line. Student's t-tests of mean sediment yield showed that measured sediment yields were significantly ($P < 0.05$) greater when measured with the DIPT and TS methods than with the DIP for both subbasins; sediment yields were not significantly ($P < 0.05$) different between the DIPT and TS methods for either subbasins. Runoff volumes during the periods of different sampling methods were not significantly ($P < 0.05$) different for either subbasin. Annual sediment yields (kg/ha/yr) from both subbasins were compared to estimates of soil loss using the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1991). For this study it was assumed that soil loss equals sediment yield and that each subbasin had a sediment delivery ratio of 1.0. Comparisons of the RUSLE estimates to measured sediment yields showed differences

Table 2 Measured annual *vs.* RUSLE estimated soil losses (kg/ha/yr) and the difference (measured-estimated) from Lucky Hills 3 subbasin. (Measured data from Osborn & Simanton, 1989.)

Lucky Hills 3 (LH3)

Year	Method	Measured	Estimated (kg/ha/yr)	Difference
1973	DIP	1330	680	650
1974	DIP	880	850	30
1975	DIP	1260	1960	-700
1976	DIP	1020	310	710
			Mean difference	170
1973	DIPT	2780	680	2100
1974	DIPT	4860	850	4010
1975	DIPT	8590	1960	6630
1976	DIPT	2420	310	2110
			Mean difference	3710
1977	TS	6810	870	5940
1978	TS	2000	480	1520
1979	TS	470	270	200
1980	TS	560	290	270
			Mean difference	1980

DIP = Depth integrated pump sampler
DIPT = Depth integrated pump sampler plus trapped sediment
TS = Traversing slot sampler

Table 3 Measured annual vs. RUSLE estimated soil losses (kg/ha/yr) and the difference (measured-estimated) from Lucky Hills 4 subbasin. (Measured data from Osborn & Simanton, 1989.)

Lucky Hills 4 (LH4)

Year	Method	Measured	Estimated (kg/ha/yr)	Difference
1973	DIP	460	630	-170
1974	DIP	390	770	-380
1975	DIP	1980	1840	140
1976	DIP	270	290	-20
1977	DIP	370	820	-450
			Mean difference	-180
1973	DIPT	780	630	150
1974	DIPT	1680	770	910
1975	DIPT	3180	1840	1340
1976	DIPT	700	290	410
1977	DIPT	2980	820	2160
			Mean difference	990
1978	TS	180	440	-260
1979	TS	0	240	-240
1980	TS	220	270	-50
			Mean difference	-180

DIP = Depth integrated pump sampler
DIPT = Depth integrated pump sampler plus trapped sediment
TS = Traversing slot sampler

that varied considerably in magnitude (Tables 2 and 3). For both subbasins, RUSLE estimates were similar to sediment yields measured by the DIP method (because of low degrees of freedom, Student's t-test were not attempted). Greater differences occurred when RUSLE estimates were compared with the total-load measurements of sediment yields. Years of greater than normal water and sediment discharge measurements showed larger differences with RUSLE estimates than did years with lower than normal measured water and sediment discharges. A possible explanation is that much of the coarse sediment does not reach the basin outlet during low-volume runoff events, and that the assumption of unity for the sediment-delivery ratio is inappropriate. A delivery ratio greater than unity may be appropriate for these subbasins because of the relatively large amount of gully erosion observed in LH3.

In all field studies the design should ensure, as practically and economically as possible, that complete measurement of data is made; ie. suspended and bed load both need to be sampled to get accurate information about the sediment yield of the Lucky Hills subbasins. Limitations of sampling techniques should be recognized and deficiencies be included in interpretations of results.

REFERENCES

Allen, P. B., Welch, N. H., Rhoades, E. D., Edens, C. D. & Miller, G. E. (1976) The Modified Chickasha Sediment Sampler. *USDA, ARS ARS-S-***107**.

Gelderman, F. W. (1970) Soil Survey, Walnut Gulch Experimental Watershed, Arizona. *Special Report, USDA-SCS.*

Osborn, H. B. & Simanton, J. R. (1989) Gullies and Sediment Yield. *Rangelands*, **11**:51-56.

Renard, K. G., Simanton, J. R. & Fancher, C. E. (1986) Small watershed automatic water quality sampler. *Proc. 4th Fed. Interagency Sedimentation Conference, Las Vegas, Nevada, March 1986,* Vol. **1**, pp. 1.51-1.58.

Renard, K. G., Foster, G. R., Weesies, G. A. & Porter, J. P. (1991) RUSLE Revised universal soil loss equation. *Journal of Soil and Water Conservation* **46**:30-33.

Simanton, J. R., Renard, K. G., Christiansen, C. M. & Lane, L. J. Spatial distribution of surface rock fragments along catenas in semiarid Arizona and Nevada, USA. *Catena Supplement No.* **25**, in press.

Smith, R. E., Chery, D. L., Jr, Renard, K. G. & Gwinn, W. R. (1981) Supercritical flow flumes for measuring sediment-laden flow. *USDA Agriculture Technical Bulletin No. 1655.*