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Sediment source identification in a semiarid watershed at soil mapping unit scales

F.E. Rhoton [a], W.E. Emmerich [b], M.A. Nearing [b], D.S. McChesney [a,*], J.C. Ritchie [c]

[a] USDA-ARS National Sedimentation Laboratory, Oxford, MS 38655, USA
[b] USDA-ARS Southwest Watershed Research Center, Tucson, AZ 85719, USA
[c] USDA-ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD 20705, USA

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ABSTRACT

Selective erosion and transport of silt and clay particles from watershed soil surfaces leads to enrichment of suspended sediments by size fractions that are the most effective scavengers of chemical pollutants. Thus, preferential transport of highly reactive size fractions represents a major problem relative to sediment/chemical transport in watersheds, and offsite water quality. The objective of this research was to develop an approach to identify sediment sources at a soil mapping unit scale for the purpose of designing site specific best management practices which affect greater reductions in runoff and erosion losses. Surface soil samples were collected along transects from each of the major 25 mapping units in six subwatersheds of the Walnut Gulch Experimental Watershed. Suspended sediments were collected from supercritical flumes at the mouth of each subwatershed. Laboratory analyses included basic soil/sediment physical and chemical properties, radioisotopes, and stable carbon isotopes, all by standard methods. Aggregation index (AI) values [100 · (1 − water dispersible clay / total clay)] were taken as an indicator of relative soil erodibility. Potential sediment yield index (PSYI) values were calculated by multiplying percent relative area for individual soil mapping units times (100 − AI). Particle size results indicated that suspended sediments were enriched in clay, relative to the watershed soils, by an average of 1.28. Clay enrichment ratios (ER) were significantly ($P \leq 0.01$) and positively correlated with AI, an indication that these two parameters can be equated with erodibility and sediment yield. The PSYI values for the six subwatersheds ranged from 68.0 to 81.7. The stable carbon isotope data for the suspended sediments gave a C3 (shrubs) to C4 plant (grasses) ratio that ranged from 1.06 to 2.25, indicating greater erosion from the more highly erodible, shrub-dominated subwatersheds which also coincided with the highest PSYI values. Correlation coefficients determined individually for PSYI versus clay ER, C3/C4 plant ratios, and multivariate mixing model results were: 0.962 ($P \leq 0.01$), 0.905 ($P \leq 0.01$), and 0.816 ($P \leq 0.05$), respectively. These statistically significant relationships support the accuracy of a potential sediment yield index approach for identifying suspended sediment sources at soil mapping unit scales.

1. Introduction

Estimates of annual, worldwide soil erosion losses published over the past few decades (Brown and Wolf, 1984; Pimentel, 2000; Pimentel et al., 1995; Boardman, 1998; Trimble and Crosson, 2000) vary in some cases by an order of magnitude, however, it is safe to state that the losses, in terms of tonnage and dollar costs, are in the tens of billions. Regardless of the validity of these soil erosion loss estimates, more efficiently designed best management practices (BMP) are needed at relatively small scales to reduce runoff and sediment loads to acceptable levels. This can be accomplished by detailed, comprehensive landscape analysis using soil geomorphology and pedology approaches to characterize soil erodibility from the standpoint of its role in the identification of sediment sources at a range of scales.

In terms of sediment transport and its role in environmental degradation, silt and clay fractions in suspended sediment largely control water quality problems that create impaired waters, both physically by contributing to excessively high turbidity, and chemically through the transport of adsorbed contaminants such as mercury, arsenic, lead, and phosphorus. Enrichment of silt and clay fractions in the suspended sediment (Rhoton et al., 2007) increases with transport distance from the source materials as the coarser, denser fractions are deposited (Slattery and Burt, 1997). Nutrients and heavy metal contaminants are concentrated orders of magnitude above normal soil and water concentrations by this process (Ongley, 1982; Rhoton and Bennett, 2009), because most of the cation exchange capacity is associated with the clay fractions (<2 μm) that are preferentially eroded and transported (Rhoton et al., 1979; Walling and Moorehead, 1989). Further, silt and clay fractions of suspended sediments are enriched in organic carbon relative to the

* Corresponding author. Tel.: +1 662 232 2938; fax: +1 662 232 2988.
E-mail address: dan.mcchesney@ars.usda.gov (D.S. McChesney).

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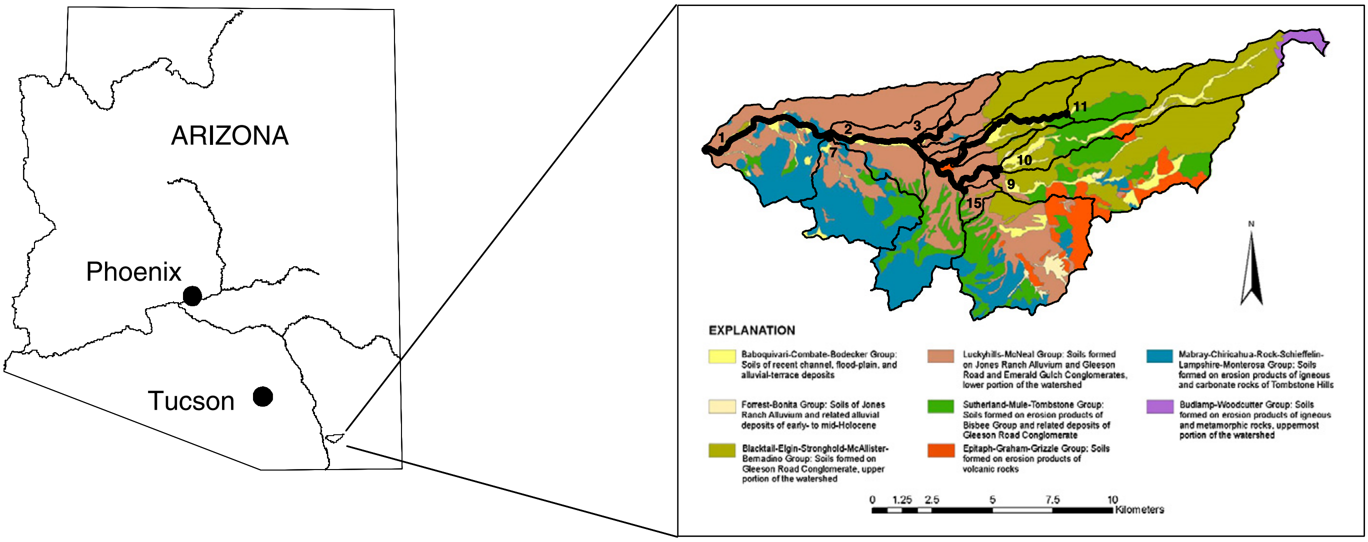

Fig. 1. Map of Walnut Gulch Experimental Watershed, Arizona, showing soil and parent material distributions by subwatershed.

source soils in the watershed (Rhoton et al., 2008). Thus, the eventual deposition of suspended sediments results in organic carbon and nutrient enrichments in reservoir bottom sediments (Avnimelech and McHenry, 1984).

Numerous studies conducted over the past few decades (Caitcheon, 1998; Dearing et al., 1986; Oldfield et al., 1979; Peart and Walling, 1988; Rhoton et al., 2008; Slattery et al., 1995; Walling, 2005; Walling and Woodward, 1992) have addressed the issue of sediment source identification at watershed scales. Within this context, the two primary approaches employed for sediment source identification are direct monitoring and fingerprinting. Direct monitoring uses methods such as erosion pins, runoff troughs, sediment samplers, and grab samples to estimate relative contributions of individual sources to overall sediment loads in a watershed (Sutherland and Bryan, 1989). Sediment fingerprinting relies on companion suspended sediment, streambank, and watershed soil properties, and is the only approach that can be used at large watershed scales to distinguish between sediment source types within or between individual storm events (Slattery et al., 1995).

Recent sediment fingerprinting research introduced a soil geomorphology and pedology component to account for variability in soil properties as a function of surface morphometry factors (Rhoton et al., 2008). Data from this work were used in a multivariate mixing model to estimate individual subwatershed (10^3 ha) contributions to sediment loads transported from the watershed, irrespective of streambank and channel sources. Model results showed that the greatest amount of sediment originated in the subwatersheds with the lowest soil aggregation index (highest erodibility), and the highest clay enrichment ratios (ER) in the suspended sediment. Thus, clay ER in suspended sediment was an accurate indicator of sediment sources at scales smaller than watersheds, with sediment yields increasing

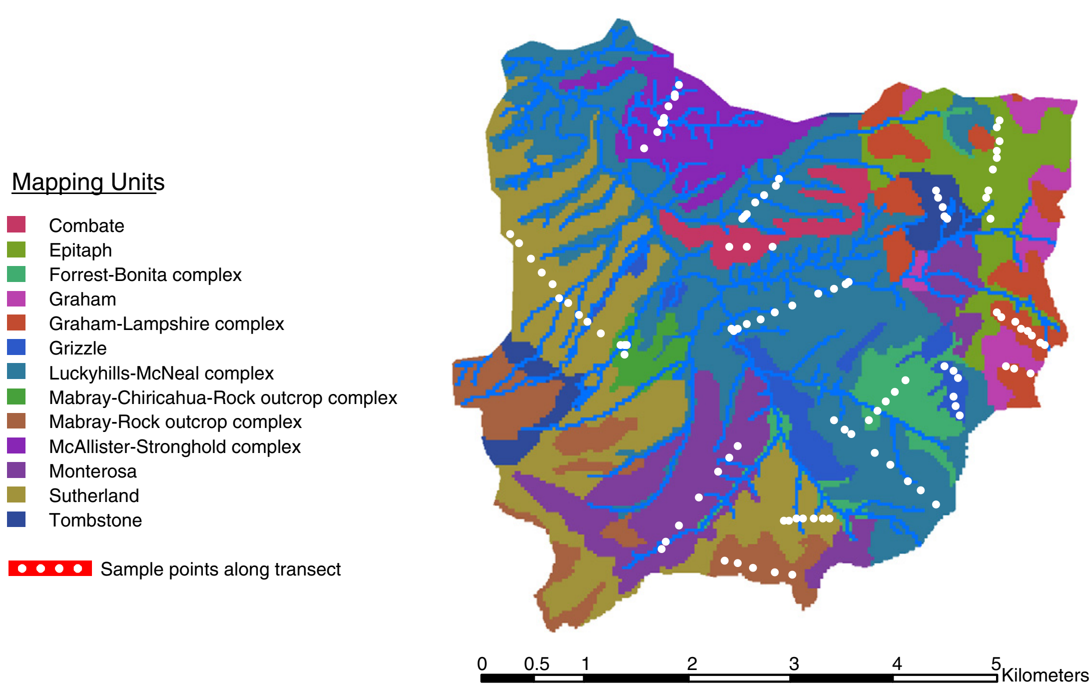

Fig. 2. Watershed soil sampling approach based on relative area of soil mapping units, illustrating sample collection points along individual transects in subwatershed 15.