Sediment Yield from Semiarid Watersheds

M. H. Nichols, K. G. Renard

Abstract

Stock tanks on the United States Department of Agriculture – Agricultural Research Service Walnut Gulch Experimental Watershed were instrumented in the mid-1960s with the goal of quantifying sediment yield from small rangelands watersheds. Periodic topographic surveys of stock tanks at the outlet of four watersheds ranging in size from 35 to 92 ha are used to compute sediment yield. Unit sediment yield from the four watersheds studied ranged from 0.4 to 2.8 m^3/ha/yr. Computed sediment accumulation is used in conjunction with observed precipitation and runoff data to relate the variability in sediment yield to the variability in climate. These data will be useful to land managers, decision makers, and scientists concerned with semiarid rangeland sediment yield.

Keywords: sediment yield, semiarid, rangeland, watershed

Introduction

Soil movement is of considerable interest to rangeland managers. Healthy ecosystems in properly functioning watersheds depend on maintaining soil onsite. Vegetation loss is often accompanied by erosion and transport of eroded sediment. In addition to productivity loss on uplands, eroded soil can have significant impacts on downstream water quality, and sediment deposition can reduce reservoir storage capacity.

Soil loss and movement in watershed uplands is difficult to measure, and may go unnoticed until it is a severe problem. Deposition is often easier to identify and measure. Water supply reservoirs, or stock water tanks, are found throughout the rangelands in the southwestern United States. These reservoirs collect sediment as well as runoff water, and can be monitored to assess sediment yield. Within the Walnut Gulch Experimental Watershed (Renard and Stone 1982, Renard et al. 1993), stock tanks behind earthen dams provide sites for sediment accumulation measurement. The objectives of this paper are to briefly describe the sediment measurement methods and to present a summary of sediment yield from four stock tank watersheds.

Study Site and Methods

The Walnut Gulch Experimental Watershed (WGEW) is located in the transition zone between the Sonoran and Chihuahuan Deserts in southeastern Arizona. Twenty-two stock tanks on the watershed collect surface runoff that is used to water livestock. Twelve of the stock tanks have been instrumented to evaluate the interactions and effects of various soil and vegetation complexes on local runoff, water yield, and sediment production (Figure 1). Sharp-crested weirs are located in the spillways of four of the stock tanks. These four sites provided data for this paper.

Figure 4. Stage gage for measuring water level at stock Tank 223 on the Walnut Gulch Experimental Watershed.

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The watersheds above the four stock tanks range in size from 35 ha to 92 ha and are underlain by a coarse-grained Quaternary and Tertiary alluvium shed from the Dragoon Mountains (Gilluly 1956). Vegetation, soil, and geology of each watershed were summarized from GIS layers developed at the Southwest Watershed Research Center (Table 1). Historically, the primary land use on the WGEW has been cattle grazing. The complex interactions between vegetative cover, underlying geology, and land use result in variation in sediment yield among small watersheds (Lane et al. 1997).

Table 1. Characteristics of selected stock tank watersheds.

Stock Tank Number	2002 Tank Volume (m^3)	Dominant Soil Type	Dominant Vegetation Type
208	7700	McAllister-Stronghold complex	Black Grama, Curly Mesquite
215	7200	Tombstone very gravelly fine sandy loam	Whitethorn Acacia, Creosote Bush, Tarbush
216	6600	Stronghold-Bernardino complex	Black Grama, Curly Mesquite
223	2900	LuckyHills-McNeal Complex	Whitethorn Acacia, Creosote Bush, Tarbush

Sediment accumulation and measurement

Sediment yield is the amount of eroded material that moves from a source to a downstream control point, such as a reservoir, per unit time (Chow 1964). The fate of eroded material within a watershed is influenced by hydrologic, topographic, vegetative and groundcover characteristics. Eroded particles may be transported to the watershed outlet, or they may be deposited and stored within the watershed. Stock tanks trap sediment at an outlet point, where topographic measurements of the dry stock tank surface can be taken to quantify sediment yield.

Periodic topographic surveys of the stock tanks on the WGEW are conducted to quantify the amount of sediment transported off the watershed above the stock tank and to compute reductions in tank storage capacity. As part of a nationwide sedimentation survey, methods for measuring the volume of sediment in small reservoirs were established in 1935 by USDA Soil Conservation Service (SCS) personnel (Eakin 1939, Brakensiek et al. 1979). Although surveying equipment has evolved, the general procedures remain unchanged and are currently in use by the Natural Resources Conservation Service (NRCS) and other federal agencies (SCS 1983).

Topographic surveys of dry tank surfaces consist of measuring the location and elevation of a sufficient number of points within the tank to map the surface shape. Tank surfaces are surveyed up to spillway elevation, or up to a level inclusive of the highest water level achieved during the period between surveys.

During the 1950s and early 1960s, a plane table was used to conduct surveys at Walnut Gulch. A level and stadia rod replaced the plane table in the 1970s and since 1993, a Sokkia Set 3CII Total Station has been used to characterize tank surface topography. Data are stored electronically and Surfer (Golden Software 1994) is used to generate stage-volume curves and contour plots and to compute volumes.

For each tank, the volume at sequential elevations is computed and plotted against the elevation to produce a stage-volume curve (Figure 2). The total tank capacity is the volume computed at the level of the spillway. Throughout the summer thunderstorm season, runoff transports sediment into the tank. As the tank fills with sediment the stage-volume relationship changes and a new survey is required to update the plot. Changes in volume between successive surveys can be attributed to the influx of sediment during the runoff season. Tank capacity is maintained by periodic sediment removal. Surveys before and after cleanouts are used to account for the material removed.

Following plane table and stadia surveys, collected data were plotted by hand, and a planimeter was used to compute the area enclosed by a contour. Tank volumes were calculated by computing volumes between successive contours and summing over the range of elevations. Recently, each of the hand-plotted maps was digitized, and elevations were adjusted using vertical control benchmarks to establish a common coordinate systems and datums for each of the four tanks. Surfer was used to re-generate contour plots and to re-compute volumes. Thus for each tank, a common datum, electronic data format, and computational method were used to quantify sediment accumulation. The calculated amount of sediment accumulated is reported as a volume in units of cubic meters. Units of m^3/ha provide information on the sediment yield relative to the watershed area.

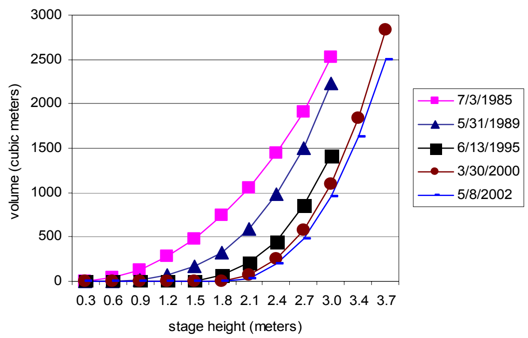

Figure 5. Tank 63.223 stage-volume curves generated for five different years.

Precipitation and runoff

Runoff-generating precipitation in southeastern Arizona is generally the result of high intensity, short duration airmass thunderstorms during the months of July, August, and September (Osborn 1983). Approximately 2/3 of the total annual precipitation on the WGEW occurs during the summer "monsoon" season (Nichols et al. 2002). Precipitation is recorded at 100 raingages distributed across the entire 150 km^2 watershed (Figure 3). Specific raingages associated with runoff within each tank watershed were determined based on Theissen weighted area coverages.

Each stock tank is instrumented to monitor water level. A vertical culvert pipe with slots at the bottom for water access acts as a stilling well. An instrument box on top of the stilling well pipe contains a water level recorder, which is connected to a pulley and a float that rests on the water surface. Analog recorders (Brakensiek et al. 1979) on the tanks were converted to electronic potentiometer systems in 1999.

Recorded water levels are used to calculate runoff. The relationship between water level and tank volume changes as sediment is deposited (Figure 2). Outflow over the spillway is monitored with sharp crested weirs. Spill volumes are computed using standard weir formulae (Brakensiek et al. 1979). In the absence of a spill, water depth is converted to volume based on the stage-volume relationship computed from topographic survey data.

Results

Overall average annual sediment yield from the four watersheds ranged from 36 to 142 m^3/year (Table 2). The total sediment yield for the period of record at each tank ranged from 1060 m^3 to 5670 m^3, although the period of record ranges from 29.0 years to 45.6 years.

Annual sediment yield values provide a general basis of comparison between watersheds. Sediment yield is influenced by hydrologic, geomorphic, and watershed characteristics. Sediment yield is directly related to runoff (Figure 4). During drought years when no runoff-producing precipitation events occur, sediment yield is zero. In contrast, high velocity flows associated with high intensity precipitation events can transport and deposit large sediment amounts. At tank 223, sediment yield ranged from a low of 1.2 m^3/ha/yr during the 1965 - 1975 time period and a high of 6.0 m^3/ha/year during the 2000 – 2001 period (Table 3). **However, caution must be exercised in comparing rates computed over differing time interval lengths. As the length of time between surveys increases, computed annual sediment yield rates can mask the variability.**

The annual variability in sediment yield is a reflection of the variability in precipitation and runoff. Theissen weights were assigned to raingages to determine the spatial contribution of measured precipitation over each watershed. Precipitation recorded at gage 23 contributes to runoff in stock tank 23. Figure 5 is a graph of annual rainfall at gage 23 for the time period 1953 – 1996 and illustrates the typical variability in precipitation on the WGEW. In general, the unit rate of sediment yield decreases as drainage area increases. Branson et al. (1981) presented a graph illustrating the relationship between sediment yield and drainage area based on the work of several researchers. The decrease in sediment yield can be explained in part by increases in deposition and sediment storage within the channel network with increasing watershed size. In addition, precipitation in semiarid areas like the WGEW is usually not spatially uniform over the basin. As watershed area increases, relative spatial coverage of precipitation decreases. Sediment yields from the four watersheds presented in this paper are plotted on the same graph (Figure 6). The relationship is consistent with the previously reported studies.

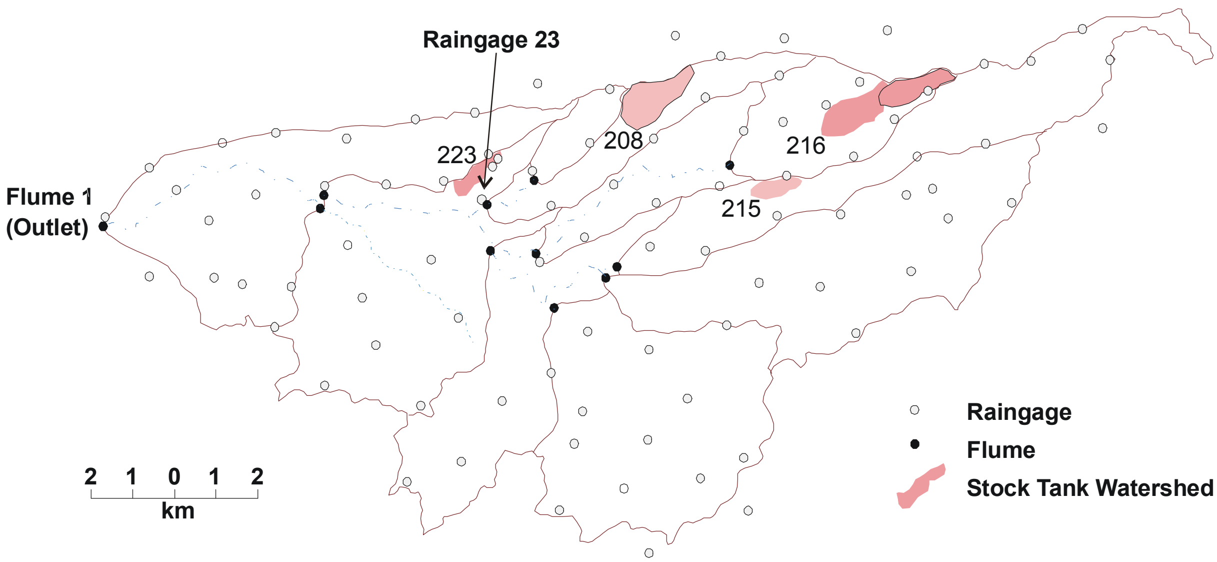

Figure 3. Walnut Gulch Experimental Watershed stock tank location map.

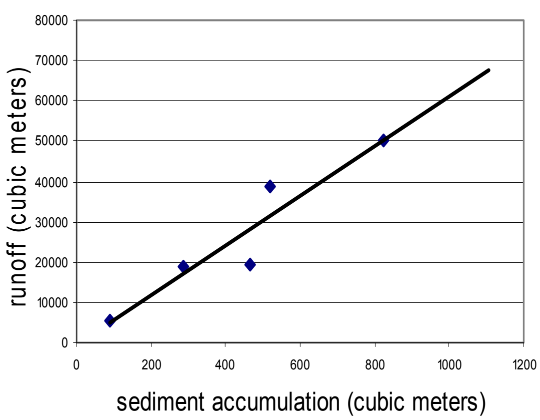

Figure 4. Relationship between runoff and sediment accumulation in Tank 63.223. R2 = 0.90.

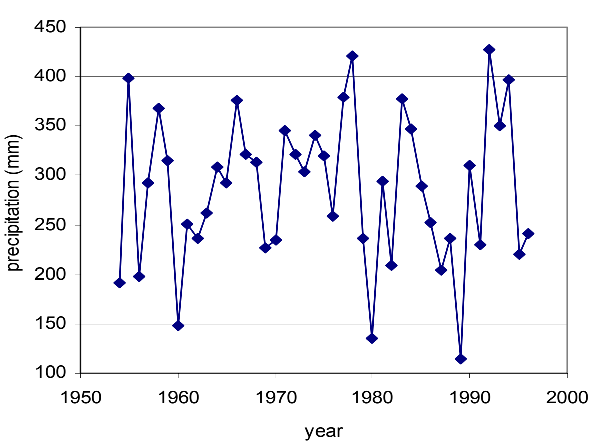

Figure 5. Annual precipitation at rainage 23.

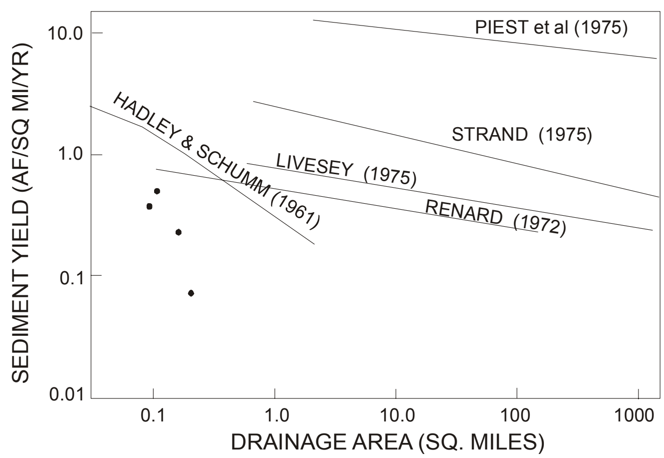

Figure 6. The relationship between sediment yield and watershed area including 4 WGEW stock tank watersheds (Branson et al. 1981, Figure 6-24).

Conclusions

Sediment yield from semiarid watershed is highly variable because precipitation and runoff are highly variable. One of the objectives of long-term sediment accumulation monitoring is to evaluate trends in sediment yield in relation to land management. However, conditions of stable sediment yield from which to compare are atypical. The variability suggests that average annual sediment yield rates may not provide sufficient information to interpret causes and effects of upland land management.

Table 2. Summary of sediment accumulation.

Stock Tank Number	Drainage area (ha)	Period of Record	Year of Record	Volume of Accumulated Sediment (m^3)	Sediment Yield (m^3/yr)	Unit Sediment Yield (m^3/ha/yr)
208	92.2	1973 - 1984	29.0	1057	36	0.4
215	35.2	1966 - 1984	35.9	2936	82	2.3
216	84.2	1962 - 1996	39.9	5667	142	1.7
223	43.8	1956 – 2002	45.6	5658	124	2.8

Table 3 Summary of Sediment yield in Stock Tank 223.

Survey Date 1	Survey Date 2	Fractional Years	Sediment Yield (m^3)	Annual Sediment Yield (m^3/ha/yr)
10/11/1956	6/27/1963	6.712	1672	5.7
6/27/1963	6/7/1965	1.948	464	5.4
6/7/1965	6/4/1975	9.997	518	1.2
6/4/1975	4/30/1985	9.912	1106	2.5
4/30/1985	7/3/1985	CLEANOUT		
7/3/1985	5/31/1989	3.912	286	1.7
5/31/1989	6/13/1995	6.038	823	3.1
6/13/1995	11/11/1996	1.416	89	1.4
11/11/1996	3/30/2000	3.384	267	1.8
3/30/2000	5/8/2001	1.107	290	6.0
5/8/2001	5/8/2002	1.000	144	3.3

Continued monitoring of sediment yield is necessary to obtain long-term records sufficient to incorporate variability when assessing trends. Sediment yield data play a key role in simulation model calibration and validation. Additional work to further quantify the spatial variability of sediment yields will indicate the watersheds where sediment production is the highest, and can be used to identify those areas where remediation efforts will have the greatest impact on reducing erosion.

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