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SEDIMENT RESEARCH AND MONITORING AT THE USDA-ARS WALNUT GULCH EXPERIMENTAL WATERSHED

M. H. Nichols[1] and K. G. Renard[1]

[1]USDA-ARS Southwest Watershed Research Center, 2000 E. Allen Rd., Tucson, Arizona 85719 (mnichols@tucson.ars.ag.gov, krenard@tucson.ars.ag.gov)

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ABSTRACT

The USDA-ARS Walnut Gulch Experimental Watershed (WGEW) has served as an outdoor laboratory for the study of semiarid hydrology, erosion and sedimentation since the 1950s. Hydraulic structures along the large watershed channels, a dense raingage network, and intensively monitored watersheds have yielded a unique database for analyzing and interpreting rainfall, runoff, and erosion processes on semiarid lands. However, there is great potential to expand research into sedimentation, geomorphic process, and sediment transport at the WGEW. An overview of runoff flumes, sediment sampling, and current sediment research is presented to encourage scientific collaboration at the WGEW.

INTRODUCTION

In the early 1950s the Walnut Gulch watershed, surrounding the town of Tombstone in southeastern Arizona, was selected by the USDA-ARS as a site to study the downstream impacts of upland watershed-management practices. Water yield was a critical concern because prior appropriation water laws were in effect throughout much of the western US and upland soil-conservation practices had the potential to minimize erosion and alter the distribution of surface water.

Water continues to be a significant concern in the southwestern US, and sediment is the primary non-point source pollutant. Sediment data for watershed-level planning as well as for regulatory compliance are often incomplete, inadequate, or unavailable. However, advancing the scientific understanding of erosion, sediment transport, deposition, and relations between climate, land use, and sediment yield requires long-term, high-quality monitoring.

This paper presents an overview of the runoff and sediment-monitoring network on the Walnut Gulch Experimental Watershed and describes the potential to expand collaborative efforts to conduct basic and applied research.

HISTORIC PERSPECTIVE

The Walnut Gulch Experimental Watershed (WGEW) comprising 150 km^2 was one of several selected for instrumentation using several criteria with primary focus on the physical attributes of the watershed while incorporating the social impacts of the proposed research (Renard et al., 1993). The selected watersheds were to range in size from 65 to 200 km^2 (25 to 75 mi^2) and were to include a secondary tributary to a main channel that furnished irrigation water. The watersheds were to in areas receiving 250 – 400 mm (10 – 16 in) of precipitation annually, were to contain no closed basins, were to have little or no water loss to deep percolation, and were to be in a sediment-yielding areas. Research efforts required that the sites be accessible during stormy weather and contain sufficient bedrock in the channel upon which to build gaging stations.

The WGEW (http://www.tucson.ars.ag.gov) is in the semiarid transition zone between the Sonoran and Chihuahuan Deserts. The main Walnut Gulch channel drains to the west into the San Pedro River near Charleston, Arizona. The San Pedro River, which heads in Sonora, Mexico and flows north into Arizona, is generally ephemeral with a perennial section associated with bedrock near the surface. Flow events in response to thunderstorm rainfall dominate the runoff regime. Average annual precipitation on the WGEW ranges from 300 mm at the lower end (1275 m) of the watershed to 340 mm at the upper end (1585 m). Precipitation during July, August, and September accounts for approximately 2/3 of the annual total (Osborn, 1983; Nichols et al., 2002).

Initial instrumentation efforts were directed toward collecting flood data. During 1953, five large trapezoidal critical-depth runoff-measuring flumes were constructed and a raingage network was established. By July 1, 1954, the hydraulic sections of five flumes with design capacities ranging from 40 to 200 cms (1500 to 8000 cfs) were completed (Table 1).

A sequence of significant storms over the WGEW started runoff that began in late July, 1954, and continued with generally not more than 24-hour interruption until late August. By the end of the season only one flume remained intact and operational. The original flumes installed in 1954 overtopped in the first year of operation and the structures failed because they were hydrologically undersized, hydraulically inadequate, and structurally insufficient to withstand the loads involved. These failures pointed out the need for improved data to quantify the hydrology and hydraulics associated with runoff in thunderstorm-dominated regions. Subsequent research led to publications quantifying and characterizing precipitation and runoff in semiarid regions (Osborn, 1983; Renard et al., 1993; Lane, 1983), as well as the development of runoff and sediment-measurement equipment designed to accommodate the unique runoff conditions and heavy sediment loads typical of the southwestern US (Renard at al., 1986).

DEVELOPMENT OF SEMIARID MONITORING EQUIPMENT

Following the initial structural failures at Walnut Gulch, a project was begun with personnel of the ARS Hydraulic Structures Laboratory in Stillwater, OK (Gwinn, 1964; Gwinn, 1970) to develop a new supercritical-flow measuring flume. Based on the early field experiences and scale model work, supercritical flume designs evolved (Smith et al., 1981) to measure the flow in "flashy" ephemeral streams. Significant advances were made in developing measuring structures for high-velocity sediment-laden flows (Brakensiek et al., 1979).

SUPERCRITICAL-FLOW FLUMES

From 1964 through 1967, eleven Walnut Gulch supercritical runoff-measuring flumes (Figure 1) were constructed along the main stem of Walnut Gulch and major tributaries (Figure 2). Sediment sampling programs were initiated following flume construction. Suspended sediment samples were collected at Flumes 1 and 6 using a DH48 and/or P61 samplers from 1970 – 1980 during storm events when personnel were available. The large-flume sediment-sampling program was halted in the early 1980's due to safety concerns, as well as personnel and budget limitations.

In 1967, a project was initiated to quantify bedload transported through the concrete supercritical flow flumes in the large channels (Libby, 1968). A sampler was installed at Flume 6 that traversed a track on the downstream side of a runoff-measuring flume. The sampler held a stack of sieves that retained sediment while allowing water to pass. This sediment-collection effort suffered from clogging as well as from damage during high-velocity flows.

In 1973, a concrete footbridge was installed across Flume 6 at the location of the measurement section (Figure 1). The bridge currently provides access and a site for mounting instrumentation and sensors. Runoff in the main Walnut Gulch channel consists of an average of 11 events per year since 1957 (range of 1 to 22 events per year) at Flume 1 and 12 events per year since 1962 at Flume 6 (range of 2 – 28 events per year).

SANTA RITA CRITICAL DEPTH FLUMES AND TRAVERSING SLOT SAMPLERS

Small watersheds presented a challenge to researchers trying to couple runoff and sediment measurements. Instrumentation developed for perennial streams failed largely because of heavy sediment loads. V-notch weirs and Venturi flumes quickly filled with sediment (Smith et al., 1981). Based on the success of the Walnut Gulch supercritical flumes in the large channels, a small supercritical flume was designed and named the Santa Rita Critical Depth Flume (Figure 3.). The Santa Rita Critical Depth Flume is widely used to measure runoff rates generally less than 2.8 cms (100 cfs).

The traversing slot sampler was designed in response to limitations of alternative sampling methods (Renard et al., 1986). 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. Water and particles smaller than the 13 mm (0.5 in) slot are directed into sample bottles. The samples are dried and weighed to quantify concentration of fine sediment. Particles larger than the slot width pass through the flume and are not collected (Figure 3).

Santa Rita Critical Depth Flumes and traversing slot samplers are currently operating in the Lucky Hills intensive study area within the WGEW (Figure 2). Sediment-concentration data are collected at three sampling sites during approximately four to six runoff events each monsoon season.

Table 1. Summary of Large Flume Construction on the WGEW

Flume	Year built	Discharge Area		Capacity		Start of Runoff Record	Notes*
		mi^2	km^2	ft^3/s	m^3/s		
1	1954	57.66	149.3	8000	227	4/8/1954	Original Supercritical Flume
1	1964	57.66	149.3	22,500	637	4/1/1964	Walnut Gulch Supercritical Flume
2	1953	43.91	113.7	8000	227	9/16/1953	
2	1959	43.91	113.7	18500	524	1959	Walnut Gulch Supercritical Flume
3	1954	3.47	9.0	3000	85	6/1/1954	
3	1958	3.47	9.0	6000	170	6/1/1958	Walnut Gulch Supercritical Flume
4	1954	0.88	2.3	2000	57	7/13/1954	
4	1969	0.88	2.3	1500	42	1969	Walnut Gulch Supercritical Flume
5	1954	8.61	22.3	1200	34	7/12/1954	Original Supercritical Flume, decommissioned in 1973
6	1962	36.72	95.1	15000	425	7/4/1962	Walnut Gulch Supercritical Flume Footbridge added 1973
7	1966	5.22	13.5	8000	227	1966	Walnut Gulch Supercritical Flume
8	1963	5.98	15.5	8000	227	8/31/1963	Walnut Gulch Supercritical Flume
9	1967	9.11	23.6	9500	269	5/26/1967	Walnut Gulch Supercritical Flume
10	1967	6.42	16.6	8000	227	6/13/1967	Walnut Gulch Supercritical Flume
11	1963	3.18	8.2	6000	170	3/1/1963	Walnut Gulch Supercritical Flume
15	1965	9.24	23.9	1200	34	6/15/1965	Walnut Gulch Supercritical Flume

* Flume details can be found in Smith et al., 1981; Gwinn ,1964; Gwinn, 1970.

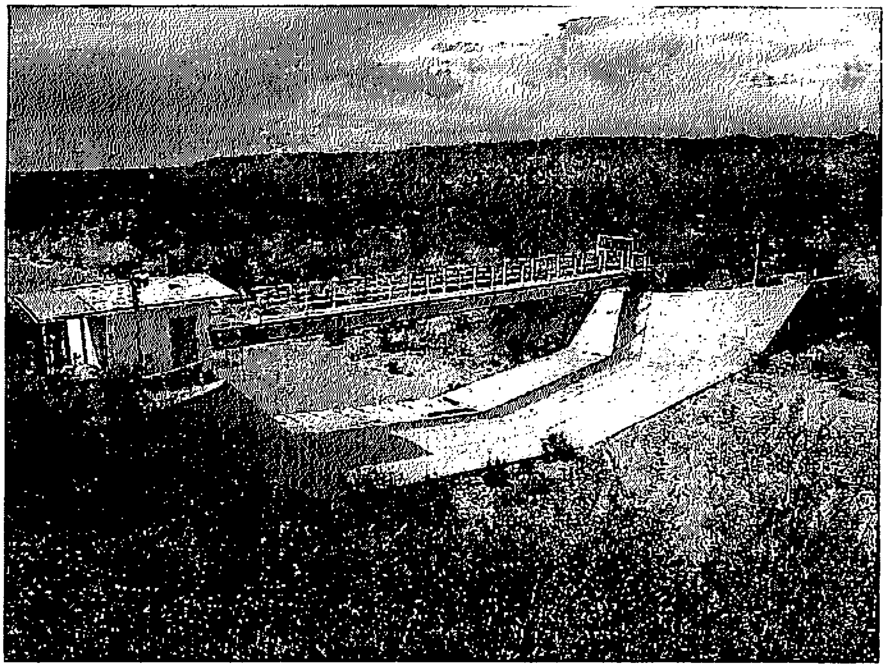

Figure 1. Photograph of Walnut Gulch Supercritical-Flow Flume 6

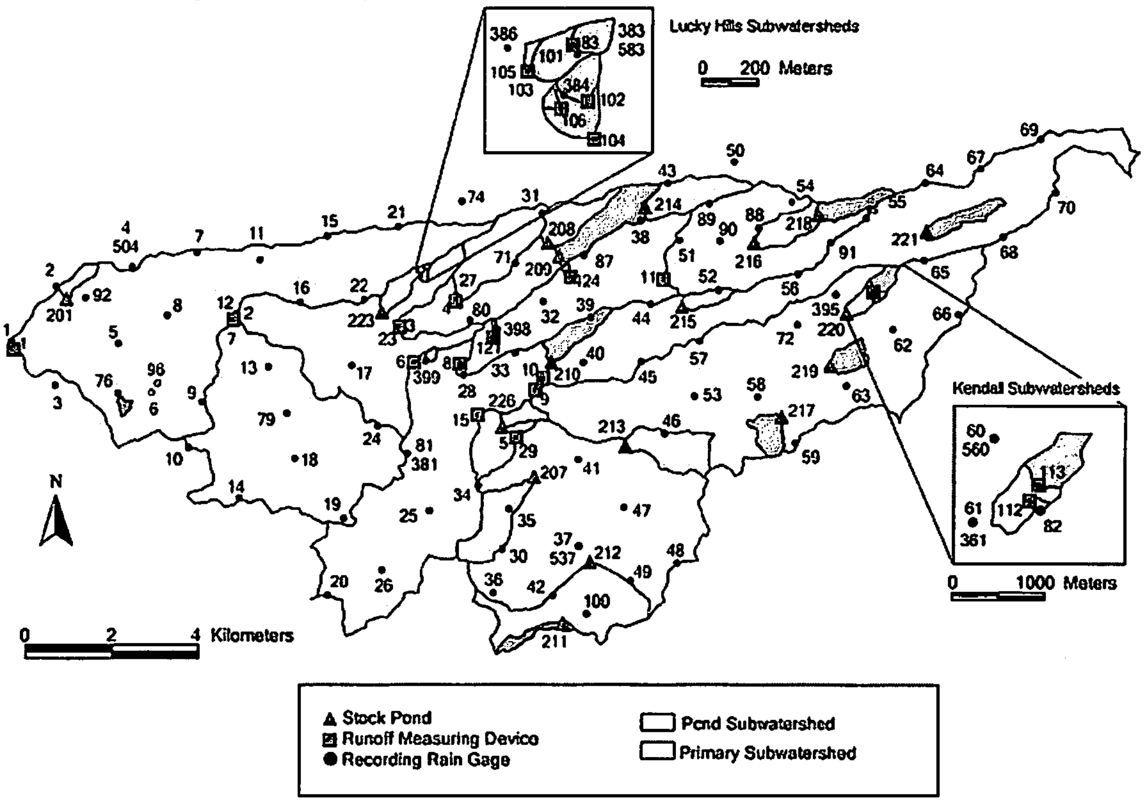

Figure 2. Map showing USDA-ARS Walnut Gulch Experimental Watershed instrumentation

Figure 3. Photograph of a Santa Rita Critical Depth Flume and Traversing Slot Sediment Sampler

CURRENT RESEARCH

Currently, sediment is monitored within the Lucky Hills Subwatersheds and at a second intensive monitoring site designated the Kendall Subwatersheds (Figure 2). As a complement to the collection of sediment smaller than the 13 mm (0.5 in) width of the traversing slot sampler, pit traps have been installed at two of the Lucky Hills stations to quantify coarse particle transport. These data sets provide critical information for calibrating and validating simulation models.

A field experiment to monitor the displacement of coarse particles was initiated in 2002. Individual particles are being tracked with a radio-frequency identification system to quantify particle displacement during individual flow events (Nichols, 2002). The radio-frequency identification system offers the potential to collect data efficiently for developing sediment-transport equations and improving mathematical models to simulate sediment transport under natural runoff conditions.

Sediment yield within the WGEW is monitored through successive topographic surveys of 12 stock ponds. A database has been developed containing periodic sediment accumulations coupled with measured runoff since the early 1960s. Sediment yield from rangeland hillslopes is under investigation using Cesium-137 concentrations, as well as through rainfall simulator experiments (Simanton et al., 1986). The rainfall simulator currently is being used to study rainfall/runoff/infiltration/sediment movement at the plot scale on uplands.

RESULTS AND DISCUSSION

There is an urgent need for improved sediment-transport algorithms, watershed scale sediment transport and yield models, sediment budgets for semiarid watersheds, and interpretations of sediment sources and sinks, all of which require data collection. The Walnut Gulch Experimental Watershed serves as an outdoor laboratory supporting multidisciplinary research with emphasis on hydrology, erosion and sedimentation. The monitoring infrastructure on the watershed is underutilized with respect to the potential to conduct research and interpret sediment-transport processes in ephemeral stream channels. The distributed network of runoff measuring flumes offers a unique opportunity to conduct spatially distributed sediment transport and yield research. In addition, the monitoring infrastructure is maintained and accessible, with significant potential to test new measurement equipment. The ongoing support of ARS and the onsite support of field staff in Tombstone are major benefits of implementing field research and monitoring projects at the WGEW.

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