Geomorphology 180–181 (2013) 137–145

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

A sediment budget for a small semiarid watershed in southeastern Arizona, USA

M.H. Nichols *, M.A. Nearing, V.O. Polyakov, J.J. Stone

Southwest Watershed Research Center, USDA-ARS, 2000 E. Allen Rd., Tucson, AZ 85719, United States

ARTICLE INFO

Article history:
Received 17 November 2011
Received in revised form 31 May 2012
Accepted 3 October 2012
Available online 22 October 2012

Keywords:
Sediment budget
Erosion
Sediment redistribution
Rangeland
Sediment yield

ABSTRACT

A sediment budget was developed for a 43.7 ha and a nested 3.7 ha semiarid, shrub dominated watershed based on hydrologic, geomorphic, erosion, and sediment data collected from 1963 through 2006 on the USDA-ARS Walnut Gulch Experimental Watershed in the southwestern US. Sediment budgets based on such extensive and intensive field campaigns over several decades are rare. The sediment budget was balanced with a high degree of confidence because the study watershed is controlled by an earth dam at the outlet. Although the channel network is well developed and incising in the steeper reaches of the watershed, hillslopes are the dominant source of sediment, contributing 85% of the overall total sediment yield. Erosion and sediment redistribution were driven by highly variable rainfall and runoff during July, August, and September. Sediment transfers are influenced by channel abstractions and the presence of the outlet dam, which created conditions for deposition in the pond approach reach. Although earth dams are ubiquitous throughout the southwestern US, and they can provide a measure of outlet sediment yield, these outlet measurements may be insufficient to interpret temporal and spatial variability in watershed sediment dynamics. Identification of dominant processes and sediment sources is critical for determining management actions that will improve rangeland conditions.

Published by Elsevier B.V.

1. Introduction

Semiarid areas are among the highest sediment producing regions in the world (Graf, 1988, p. 138). Sediment production is often quantified based on watershed outlet measurements or model simulations, and is usually expressed in units of volume or mass per time, typically on an annual basis (Chow, 1964). Such values provide an integrated measure of surficial and fluvial erosion, transport, and deposition processes and thus are of limited value for inferring internal watershed processes. In semiarid regions, the origin and fate of mobilized sediment are only imprecisely related to watershed sediment yield because of the complexity of highly variable rainfall and flash flooding response (Goodrich et al., 1997) and internal watershed sediment storage dynamics. In fact, sediment storage can exceed watershed export (Trimble, 1999; Nearing et al., 2007). Depending on the temporal dynamics of hydrologic inputs and responses, sediment delivered to the watershed outlet may include recently deposited bed material, and the amount of this material may actually exceed the amount of sediment expected to be produced by hillslope erosion and channel scour (Clapp et al., 2000). The sediment budget concept seeks to account for internal watershed processes (Dietrich and Dunne, 1978; Reid and Dunne, 1996); however, data sufficient to develop simple sediment budgets is generally lacking (Graf, 1983). As a result, with few exceptions (Leopold et al., 1966; Schick, 1977; Schick and Lekach, 1993; Bartley et al., 2007) very few sediment budgets have been developed for arid and semiarid watersheds.

Bartley et al. (2007) presented a sediment budget for a semiarid watershed in Australia based on measured erosion from hillslopes, gullies and streambank erosion, bank erosion, channel bed erosion and storage, and fine sediment export at the watershed outlet collected during a 6-year study period. As pointed out by the authors, the study was conducted during a period of drought. In semiarid regions long term records are required to characterize precipitation and flash flood dynamics that drive sediment transfers. These records are required to provide context for extreme events and to understand the lag time between cause and effect (Moran et al., 2008). Because data collection is difficult in semiarid regions, coupled hydrologic and sediment measurements over long time periods are limited in number. In contrast, sediment budgets developed for longer time periods (Graf, 1983; Trimble, 1999) are usually based on limited measured data and a general lack of information on land use/cover conditions that can affect interpretations of long-term averages.

Data collected over four decades on the USDA-ARS Walnut Gulch Experimental Watershed (WGEW), near Tombstone, Arizona, offer the rare opportunity to develop a sediment budget using data collected at high spatial resolution during a multi-decadal, temporally bounded period of concurrent measurement and known land use and condition history. Since the 1960s intensively instrumented subwatersheds within the WGEW have supported plot scale erosion research (Simanton et al., 1986; Polyakov et al., 2010), field experiments to characterize runoff and sediment processes within "unit

* Corresponding author. Tel.: +1 520 670 6481; fax: +1 520 670 5550.
E-mail address: mary.nichols@ars.usda.gov (M.H. Nichols).

0169-555X/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.geomorph.2012.10.002

source" watersheds (Kincaid et al., 1966), and long term studies to quantify channel evolution (Osborn and Simanton, 1986, 1989) and watershed sediment yields (Nichols, 2006; Nearing et al., 2007). The primary use of these long-term datasets has been to support simulation model development and testing. Recently, several studies have been conducted to quantify erosion and sedimentation processes. These include rare earth element and ^{137}Cs tracer studies to understand soil redistribution on watershed uplands (Nearing et al., 2005; Ritchie et al., 2009), channel scour (Powell et al., 2005) and sediment transport dynamics (Yuill and Nichols, 2010; Yuill et al., 2010).

This study quantifies a multi-decadal sediment budget, accounting for sources, sinks, and re-distribution pathways, within a semiarid rangeland watershed based on research and data collection for the 44 year period from 1963 to 2006. Because the sediment budget is developed from data collected as part of the USDA instrumented watershed network, portions of the budget are developed from previously reported results. Long term precipitation, runoff, and sediment data providing spatially and temporally distributed measurements, coupled with results and interpretations from shorter term process based studies, are incorporated. We present a sediment budget including hillslope erosion and deposition, channel erosion and storage, and outlet sediment yield. The multi-decadal analysis incorporates event and seasonal variability in precipitation and runoff.

2. Study site

The study site is a 43.7 ha (108 acre), actively eroding, semiarid rangeland watershed (watershed 223) within the USDA-ARS Walnut Gulch Experimental Watershed in southeastern Arizona (Fig. 1). The relatively sparse vegetation on watershed 223 is dominated by shrubs including acacia, [*Acacia constricta* Benth.], tarbush [*Flourensia cernua* DC], and creosote [*Larrea divaricata* Cav.]. A sparse understory of grasses and forbs is also found (Weltz et al., 1994). During the rainy season canopy cover is approximately 25% with only minor amounts of litter on the ground. Although historically grazed, the upper end of watershed 223 has been fenced to exclude grazing since 1963, and the lower end was not grazed during the period of study. Because the watershed has been a research site during the entire period of data collection, the scientific staff has firsthand knowledge of general watershed conditions which have not changed over the last 40 years (Ken Renard, personal communication).

Elevations range from 1375 m at the top of the watershed to 1336 m at the watershed outlet. Soils on the watershed hillslopes are primarily gravely sandy loams with approximately 39% gravel, 32% sand, 16% silt, and 13% clay, and a high fraction (46%) of fragmented rocks (USDA, 2003). Rock covers approximately two thirds of the soil surface. Soils in watershed 223 are classified as Lucky Hills–McNeal — very deep, well drained nearly level to strongly sloping, gravelly moderately coarse and moderately fine textured soils on fan terraces. The classifications for the Lucky Hills soils are coarse-loamy, mixed, thermic Ustic Haplocalcids, and the McNeal soils are fine-loamy, mixed, thermic Ustic Calciargids. The gravelly loam layer covers coarse textured calcareous soils that show little soil profile development (USDA, 2003).

Watershed 223 is a headwater watershed drained by a high density, ephemeral channel network superimposed on weakly consolidated Quaternary alluvial material shed from the Dragoon Mountains. The gully density has been reported as 13.29 km km^{-2} (Nichols, 2006). First order channels are strongly coupled to, and receive water and sediment from, rilled and scoured hillslopes. Channels are single thread and relatively steep with average channel slope ranging from 0.8% in the main channel to 9.2% in the first order channels (Table 1). Channels are narrow with bed sediment generally 'very poorly sorted' (Folk and Ward, 1957) with a median grain size (D_{50}) ranging from 1.02 to 2.91 mm. At the lower end of the watershed, hillslopes and channels are less strongly coupled and sediment is stored within a small, poorly developed, discontinuous flood plain and within the main channel. In general, the watershed is underlain by a conglomerate layer of gravels and pebbles locally cemented by caliché (carbonate material formed in soil in semiarid regions). This layer is relatively impervious and provides a local base level control.

Mean annual rainfall recorded on watershed 223 is approximately 292 mm. Approximately two thirds of the rainfall occurs during the July–September (and occasionally October) monsoon season (Goodrich et al., 2008). The streams in watershed 223 are ephemeral, and only contain water for a few hours out of the year. Thus runoff only occurs in distinct storm-generated events that last on the order of minutes to a few (usually less than two) hours. Runoff produced during monsoon season storms causes almost all of the water driven erosion and sediment redistribution on the watershed (Nearing et al., 2007; Nichols et al., 2008). Runoff from watershed 223 is controlled by an earthfill dam, 6 m high and 45 m long, across the main channel. The seasonal pond contained by the dam serves as a watershed outlet runoff and sediment measurement site.

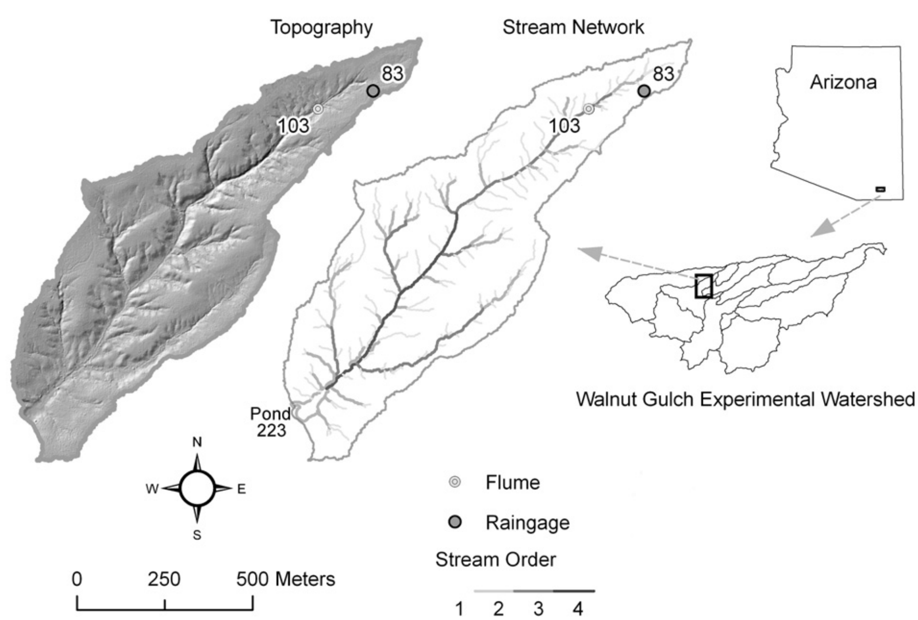

Fig. 1. Location map of the Walnut Gulch Experimental Watershed showing the measurement sites.