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Original Research Article

Model analysis of check dam impacts on long-term sediment and water budgets in Southeast Arizona, USA

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ABSTRACT

The objective of this study was to evaluate the effect of check dam infrastructure on soil and water conservation at the catchment scale using the Soil and Water Assessment Tool (SWAT). This paired watershed study includes a watershed treated with over 2000 check dams and a Control watershed which has none, in the West Turkey Creek watershed, Southeast Arizona, USA. SWAT was calibrated for streamflow using discharge documented during the summer of 2013 at the Control site. Model results depict the necessity to eliminate lateral flow from SWAT models of aridland environments, the urgency to standardize geospatial soils data, and the care for which modelers must document altering parameters when presenting findings. Performance was assessed using the percent bias (PBIAS), with values of ±2.34%. The calibrated model was then used to examine the impacts of check dams at the Treated watershed. Approximately 630 tons of sediment is estimated to be stored behind check dams in the Treated watershed over the 3-year simulation, increasing water quality for fish habitat. A minimum precipitation event of 15 mm was necessary to instigate the detachment of soil, sediments, or rock from the study area, which occurred 2% of the time. The resulting watershed model is useful as a predictive framework and decision-support tool to consider long-term impacts of restoration and potential for future restoration.

1. Introduction

Soil erosion by water is one of the most important land degradation processes in aridland environments and is linked to flooding and water-resource management (Poesen and Hooke, 1997). Sediment transport in streams is a major nonpoint source pollutant (NPS) in surface waters that compromises water clarity and health by increasing water temperatures and decreasing dissolved oxygen (Branson et al., 1981; Gray et al., 2000). Sediment can also serve as a transport mechanism for other pollutants. Rockström et al. (2010) argue that investments in catchment-scale management of water and soils is necessary to minimize the risk for climate-related failures and emphasize water harvesting systems to build resilience and address trade-offs between ecosystem services. Studies of rock structures placed in channels document decreased peak flows (Baker et al., 1995; Peterson et al., 1960; Norman et al., 2010a, 2010b, 2015), a reduction in sediment load (Hadley and McQueen, 1961; Hassanli et al., 2008; Polyakov et al., 2014), and increased vegetation (Bombino et al., 2009; DeBano and Heede, 1987; DeBano and Schmidt, 1990; Heede, 1978; Heede and DeBano,

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1984; Hendrickson and Minckley, 1985; Norman et al., 2014).

Kingsford (2000) suggests better models of ecological and hydrological impacts of dam installation for an improved understanding of the interaction between river flows, floodplain ecology, and management practices. Traditional models cannot consider all the watershed-scale erosion and sediment transport processes at once due to knowledge and/or data limitations (De Vente and Poesen, 2005). However, there are many models that have been applied to develop estimates of runoff, erosion, and sediment yield and to mimic how check dams and rock structures might influence those (Martín-Rosales et al., 2007; Remaître et al., 2008; Boix-Fayos et al., 2008; Norman et al., 2010a, 2010b; Garbrecht et al., 2014). In this study, we simulate the hydrologic processes documented in riparian areas treated with check dams using the Soil and Water Assessment Tool (SWAT; Arnold et al., 1998; Neitsch et al., 2009) to extend the hydrologic budget and describe the fate and transport of sediments. In selecting a model to use, our goals were to extrapolate on our limited field data, be sparing with the adjustment of parameters, provide better estimates of the response, and contribute to the scientific understanding of the impacts of check dams in aridlands.

In valleys of these arid and semiarid rangelands, fluvial sediment deposits accumulate on low parts of hillslopes or in the channel and floodplains (Osterkamp, 1999; Coblentz, 2005). Gullies are formed by flowing water eroding soil on a hillside and leads to the destruction of riparian habitat in headwater channels (DeBano and Schmidt, 1990). Material is easily carried along when runoff begins on a hillslope but this declines after the first flush, as new sediment must be detached (Zabaleta et al., 2007). Rates of sediment delivery in aridlands are hard to document due to the ephemeral nature of local streams and large flood-recurrence intervals (Griffiths et al., 2006). The U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS) Southwest Watershed Research Center (SWRC) is monitoring water and soil at two heavily-instrumented locations in the Madrean Sky Islands: the Walnut Gulch Experimental Watershed (WGEW) and the Santa Rita Experimental Range (SRER). WGEW is a 149 km^2 research area, approximately 312 mm of precipitation is measured annually and elevation ranges 730 m (1220–1950 m; Goodrich et al., 2008). Nearing et al. (2007) found that few precipitation events produce sediment yields, ranging 0.07–5.7 t/ha/yr, on watersheds <5 ha and Nichols (2006) reported 0.17–1.1 t/ha/yr on larger (35–159 ha) watersheds. Schreiber and Kincaid (1967) documented runoff to be most dependent on storm size vs. antecedent moisture. The SRER in a 210 km^2 study site where 250–500 mm of precipitation is measured annually and elevation ranges 500 m (900–1400 m; Polyakov et al., 2010). Lane et al. (1997) found rainfall extent and intensity, vegetative, soil cover, and topography influence sediment yield. Polyakov et al. (2010) document approximately 6.4% of rainfall events produce runoff, with the primary driver being the intensity – sediment yield occurs in 26% of runoff events (0.85–6.69 t/ha/yr).

Negative effects of accelerated erosion and sedimentation on water quality have been well-documented in the Madrean Sky Islands (Lopes and Ffolliott, 1992; Marsh, 1968) and in other environments (Gray et al., 2000; Marsh, 1968; Zabaleta et al., 2007). Soil and water conservation experts have developed Best Management Practices (BMPs) to reduce soil loss and improve water quality (Young et al., 2010). Check dams and rock gabions are examples of BMPs that can help to stabilize channels and trap sediment in upstream deposits. These deposits provide a nutrient-rich foundation that helps instigate plant establishment and promotes growth (DeBano and Schmidt, 1990). By trapping sediment, these features also help improve water quality downstream, through attenuation of particles and pollutants (Pettersson, 1998). Griffiths and Walton (1978) suggest 80–100 milligrams of solids per liter (mg/L) is the upper tolerance level for fish.

It is difficult to discern if changes in fluvial-sediment load is the result of changes in management (BMPs, grazing, etc.), climate, or if they are part of natural cycles triggered when a geomorphic threshold is exceeded (Osterkamp, 1999). The objective of this research is to provide a predictive framework to analyze impacts of restoration in a 3-year model iteration which could be projected into the future and to guide the further restoration of ecological processes. The installation of check dams is assessed in the context of demonstrating the benefit of these features for protecting water quality. We hypothesize that the installation of a series of check dams can support storage of organic soils and carbon, improve water quality, and increase local water supplies. Our primary results include annual estimates of runoff, evapotranspiration, soil–water storage, soil erosion, and watershed sediment yield at a paired watershed site.

2. Materials and methods

2.1. Study area

In the mid-western slope of the Chiricahua Mountains, in Southeast Arizona, average annual precipitation is 534 mm, with approximately 70% occurring July through September (Fuller, 2015). A historic stream gage (1919–1925) documented average annual daily flow at West Turkey Creek ~0.24 cubic meters per second (cms), which nearly doubled during the monsoon (US Geological Survey, 2015). This a valuable perennial stream and the largest source of water contributing to both the Willcox Playa and groundwater Basin (Fig. 1), but lowering water levels (Brown and Schumann, 1969; Jacobson et al., 2008) and total dissolved solids impact drinking water (Arizona Department of Water Resources, 2009).

Proprietors at El Coronado Ranch, who lease the West Turkey Creek allotment from the U.S. Forest Service, began installing low-lying rock check dams in 1983 averaging >2.5 check dams per ha. Now, more than 2000 loose-rock structures have been strategically constructed by hand and placed in tributaries flowing into the Turkey Pen sub-watershed (769 ha). The Turkey Pen is approximately 5 km long, with 554-m change in elevation. Sands, silts, and