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Research paper

Predicting bed load transport of sand and gravel on Goodwin Creek

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Abstract

Bed load transport rates are difficult to predict in channels with bed material composed of sand and gravel mixtures. The transport of bed load was measured on Goodwin Creek, and in a laboratory flume channel with a similar bed material size distribution. The range of bed load transport rates measured in the laboratory channel were similar to those measured in the channel of Goodwin Creek; however, the shear stresses calculated on Goodwin Creek were three times greater than in the laboratory channel for similar bed load transport rates. Much of this difference in shear stress was removed by applying the drag partitioning technique of Einstein, although significant differences between the two sets of data remain. Predictions of bed load transport rates using three previously published transport relations were good for most flows for the laboratory data. For the Goodwin Creek bed load data, predicted transport rates were close to measured ones for low flows but diverged by an order of magnitude or more for high shear stresses. Improved methods of shear stress partitioning are needed to improve the performance of bed load transport relations on streams of this type.
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Keywords: Bed load; Grain shear stress; Sand; Gravel

1. Introduction

Experimental watersheds have been operated by the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) for many years. The goals of these watersheds are to understand the movement of water, sediment, nutrients, and other chemicals through the watershed and to determine the impact of the activities involved with agriculture on the movement of these substances through the watershed. Perhaps the most difficult part of determining the sediment load in streams is the determination of an accurate rate for the load moving in contact with the bed. The bed load is generally a small fraction of the total sediment load of streams but serves as an important control on the stability of the channel boundaries and the lands adjacent to the channels. Accurate prediction of the movement of bed material in agricultural watersheds remains elusive, yet knowledge of the rate of bed material transport is critical to determining accurate total sediment load and for predicting the stability of channel banks, which have been shown to be major sources of sediment in many watersheds (e. g. Grissinger et al., 1991; Kuhnle et al., 1996; Wilson et al., 2008).

Goodwin Creek experimental watershed (GCEW) drains an area of 21.3 km^2 (Fig. 1) in Panola County, Mississippi, and has been operated by personnel from the USDA-ARS, National Sedimentation Laboratory since 1981. The watershed is located in the bluff-hills region of the Yazoo River basin just east of the Mississippi River alluvial flood plain. Elevation ranges from 71 to 128 m above sea level, and the average slope of the main channel is 0.004. Supercritical flow flumes, which provide a stable platform for measuring flow rates and sampling sediment during runoff events, have been positioned at 14 subbasins (Fig. 1) (Alonso and Binger, 2000). The bed material of the main channel is predominantly composed of sand in the upstream portions of the watershed (median diameter of 0.5 mm), has increasing amounts of gravel in the middle portion (median diameter of 7 mm), and has progressively less gravel (median diameter of 1 mm) in the downstream part of the watershed (Kuhnle, 1996). The fraction of

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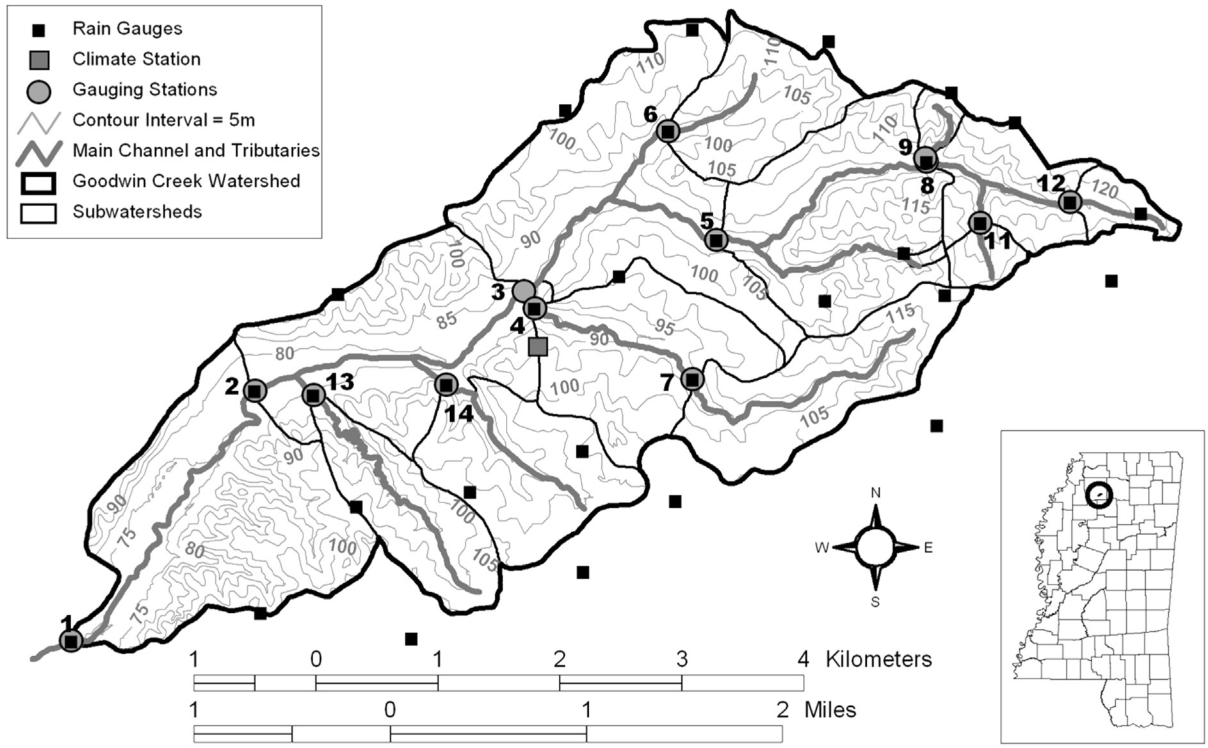

Fig. 1. Map of Goodwin Creek experimental watershed.

sand in the bed of a channel has been shown to have a major effect on the transport rate of the sand-gravel mixture (Iseya and Ikeda, 1987; Curran and Wilcock, 2005).

During the past several years, there have been a number of studies focusing on the challenges of measuring and calculating the transport of bed load on streams with bed material consisting of sand and gravel (McLean et al., 1999; Kleinhans and Ten Brinke, 2001; Habersack and Laronne, 2002; Bunte et al., 2004; Claude et al., 2012). These studies have made progress on the measurement of long-term changes in bed load (McLean et al., 1999), on characterizing error in bed load measurements (Kleinhans and Ten Brinke, 2001), and on the methodology for collecting representative data sets of bed load (Bunte et al., 2004; Habersack and Laronne, 2002; Claude et al., 2012). Streams in which the bed material has well defined modes in the sand and gravel sizes often have a range of flows in which sand is the dominant size of the bed load. As flow strength increases the bed load generally becomes progressively coarser as the gravel size fractions become entrained (e.g. Kuhnle, 1992; Recking, 2010). The sand and gravel modes in the bed material can cause the sampler to over-sample at lower flows due to the scouring of sand from the bed near the sampler intake (Potyondy et al., 2010). The sand and gravel modes also make accurate predictions of the bed load rate difficult because more than one grain size is necessary to characterize the bed (Claude et al., 2012). Research has been conducted by several workers to improve bed load transport rate predictions for streams with sand and gravel in the bed material without having to individually calculate the transport rate of multiple size fractions (e.g. Kuhnle, 1992; Wilcock, 1998; Recking, 2010). Success in this endeavor has been mixed.

One of the key goals for the GCEW has been to measure and predict total sediment load from the channels of the watershed. Rates of bed load transport have been one of the most difficult of the sediment fractions to measure and predict accurately. The purpose of this study was to collect bed load data under controlled conditions in a laboratory flume to improve our understanding of the problems with the prediction of sand and gravel transport in streams of the GCEW. This series of experiments, while designed to model conditions specific to Goodwin Creek, will also provide information on how to predict transport rates on other streams with sand and gravel bed material.

2. Field data

The samples considered here were collected at station 2 (Fig. 1), which drains 17.9 km^2 of the watershed. The channel at station 2 is 25 m wide and 3 m deep, and the bed material surface and subsurface layers have median grain diameters (D_{50}) of 11.7 and 8.3 mm, respectively (Kuhnle, 1992). Mean slope of the channel bed upstream from station 2 is 0.003. Samples of the bed load were collected within a concrete "V"-shape flume with a 4% longitudinal slope, which causes local supercritical flow and prevents sediment deposition on the structure. The V-section of the flume is compound with 5:1 side slopes for 4.7 m each side of the center and 2:1 slopes thereafter. Samples of bed load were collected from a footbridge over the upstream edge of the supercritical flow flume