Continuous Measurement of Bed Load on Goodwin Creek using Impact Plates

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Introduction

Accurate quantitative determinations of the rate of bed load transport in a stream or river are difficult to obtain. Physical samplers are difficult to deploy during bed load transporting events which often occur during thunderstorms or at night. Collecting enough bed load samples to ensure that they are representative of the range of expected flows is challenging due to the number of samples required laterally and at each point in the cross section to prevent skewed measurements caused by large spatial and temporal variations in transport rate. Prediction equations for bed load generally have a limited range of conditions over which they are applicable. Use of predictive equations for conditions that vary from the flow and sediment conditions from which they were developed often leads to large errors in the predicted rates. However, the rate and timing of bed load movement in channels are important for determining the total sediment load and net erosion from upstream of a channel reach. Excessive erosion or deposition of bed material in a reach may cause instability of the channel banks, damage crop lands, endanger infrastructure, and have negative impacts on the aquatic habitat (biota) in the water column and on the bed. Also, information on the rate of transport of the bed load is necessary for designing effective and stable channel restorations. Clearly, it is desirable and necessary in many instances to have accurate knowledge of the rate of bed load transport for a given stream or river.

In this study, impact plates were used to measure bed load at a field location on the Goodwin Creek Experimental Watershed. This technique has allowed bed load rates to be measured continuously during entire transport events without the gaps associated with manually deployed bed load samplers. The method also allows a much more comprehensive data set, which encompasses all flow events during the deployment period. This study is ongoing with new data being collected during each bed load transport event on the Goodwin Creek Experimental Watershed.

Methods

Watershed Description

The Goodwin Creek Experimental Watershed (GCEW) is in Panola County, MS. The region is characterized by erodible soils, mean annual rainfall of 1400 mm, and mean channel slopes of 0.004. The GCEW is located just east of the Mississippi River alluvial floodplain within the bluff hills physiographic sub-province and drains an area of 2132 ha in the north central part of the state of Mississippi (Figure 1). The soils of the watershed are predominantly silty and highly

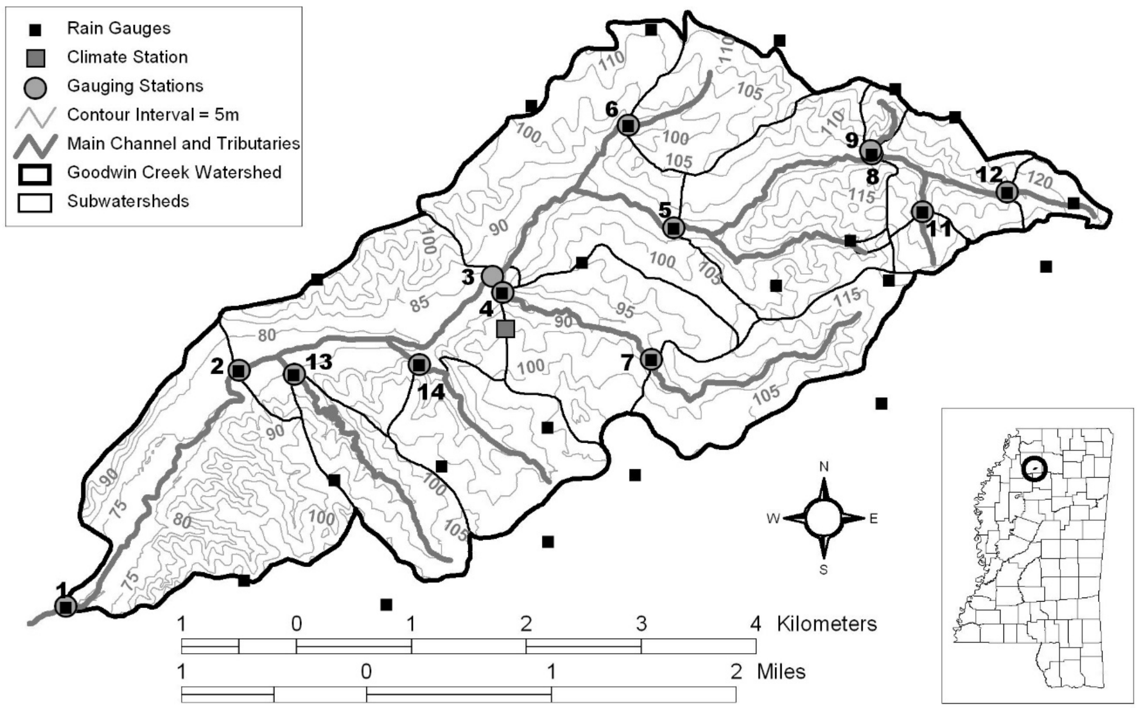

Figure 1. Map of GCEW with elevation contours, gauging station locations and rain gauge locations.

erodible when surface cover is removed. Unlike in the past, most of the cultivation is currently along the larger streams of the watershed. Channels in much of the watershed are deeply incised and oversized for their drainage area. Concentrations of suspended sediments of thousands of milligrams per liter occur regularly during larger runoff events, which usually occur in winter and spring months of the year. Environmental concerns for the watershed consist of water quality and aquatic habitats impacted by unstable channels and high sediment concentrations during runoff events (Shields et al., 1994). Aquatic invertebrates have been shown to be impacted by the high suspended-sediment concentrations which persist for significant durations during runoff events (Kuhnle et al., 2001).

The land use of the watershed was approximately evenly split among cultivated, forest, and pasture/idle uses in 1980 when the watershed was first instrumented. Runoff data collection started in 1981 when 14 supercritical flow structures were designed and installed by the Vicksburg District of the US Army Corps of Engineers to serve as combination grade control and measurement platforms for discharge determinations and sediment sample collection during runoff events. The reinforced concrete supercritical flow structures have a longitudinal slope of 0.04 and maintain supercritical flows over the range of expected flows in the watershed. This prevents deposition of sediment on the structures and assures a stable platform for flow measurements and the collection of sediment transport samples (Willis et al., 1986). Historical bed-load samples were collected from the upstream part of the structure (Figure 2) using a modified Helley-Smith sampler (Bowie and Sansom, 1986; Willis et al., 1986; Kuhnle et al., 1989, 1996; Kuhnle, 1992). The drainage area upstream of station 2 is 1790 hectares. During 1984 – 1988 more than 500 bed load samples from 24 runoff events, covering a wide range of discharges, were collected by a three-person team with a boom-mounted sampler on the upstream footbridge of the structure at station 2. Each sample was dried, weighed, and sieved to obtain a size

Figure 2. (Top) Upstream footbridge and sampling rig at station 3 of GCEW. (Bottom) Closeup of modified Helley-Smith sampler on sampling rig at station 3. The sampling equipment at structure 3 is very similar to that at station 2.

distribution. The data show a steady pattern of coarsening with increasing flows until the size distribution of the bed material is nearly reached (Figure 3).

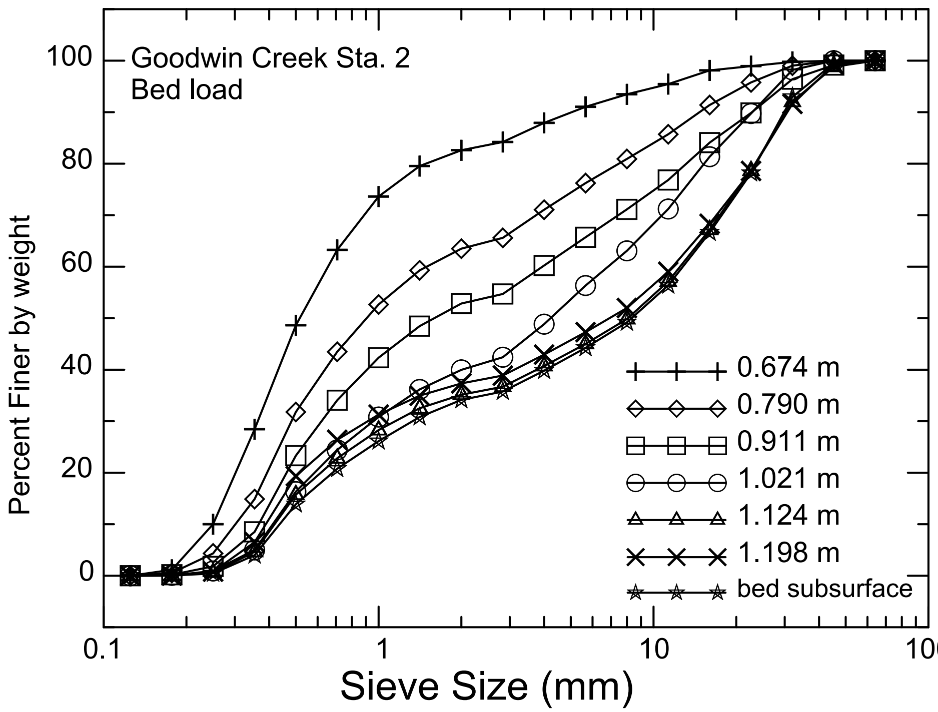

Figure 3. Mean grain size distributions of bed load from samples collected during 1984-1988 at structure 2, GCEW.

Surrogate Bed-Load Measurements

During the Fall of 2021, two impact plates were installed just upstream of the supercritical flow structure at station 2 of GCEW (Figure 4). The impact plates were based on the same design as those used at a similar study in the Elwha River (Hilldale et al., 2015), and have also been previously used in flume studies at the National Sedimentation Laboratory (Kuhnle et al., 2017, 2021). The stainless steel impact plates are 0.35 by 0.50 by 0.016 m, with the largest dimension in the cross-stream direction. The plates were installed at bed elevation just upstream of the supercritical flow structure at station 2. Mounted to the underside of each impact plate using threads tapped into the plate is a CMCP-1100 accelerometer (STI Vibration Monitoring, League City, Texas). As bed material in transport contacts the plates, the deformation of the plate induces a voltage in the accelerometers that is recorded by a Zoom F8n MultiTrack Field Recorder at 48 kHz with 16-bit resolution. The Zoom Field Recorder is housed in the instrument house at station 2. The data is stored on SD cards with a maximum file size of 512 Mb. The unit is left on continuously with data only retained during bed load transporting events.

Figure 4. Impact plates with bed-load trap sampler in position just downstream of one of the plates. Photo taken at base flow.

Calibration of Impact Plates

The installation was designed for the impact plates to be calibrated using physical bed-load samplers deployed immediately downstream of the plates. A modified version of the bed-load trap sampler (Figure 4), similar to one designed by Bunte et al. (2004), was constructed for each of the impact plates to collect simultaneous physical and electronic data during selected runoff events. The bed-load samplers (0.25 x 0.50 m opening) are the same length as the impact plates in the cross-stream direction and are deployed directly downstream of the plates to trap essentially all the grains that are transported over the plates during a sampling interval. Matching of the largest peaks recorded by the plates with the masses of the largest grains collected during the sampling time will be the basis for calibration. Identifying the recorded signal that corresponds to the excursion of one grain moving across a plate utilized Hilbert transforms of the data to identify the maximum voltage of signal packets (Kuhnle et al., 2017).

Physical samples and impact data were collected simultaneously during the 25 May, 2022 runoff event, where 7 physical samples of the bed load were collected on the rising side of the hydrograph until the mounting arm of the sampler malfunctioned. A large amount of organic material was in motion near the bed at the time the samples were collected. The physical bed-load samples collected during this runoff event were not sufficient to establish a calibration for converting impact data to bed load. As an alternative, a provisional calibration equation was developed using historical bed-load data collected using modified Helley-Smith samplers during the 1984-1988 period. First, a relation was found between the mean $D99$ (99th percentile of the grain size, D, in mm) of the bed load and the flow rate when the bed-load samples were collected. This was combined with a relation between $V99$ (99th percentile of the peak voltage, V, in mV) over an interval and the flow rate for all runoff events with impact plate data. This resulted in a relation between peak voltage, flow rate, and particle diameter that could be used to find the mass of particles transported over the plates:

$$D = 6.568V - 1.376;\ 1.75 < V \leq 9.15 \quad (1)$$

$$D = 58.7;\ V > 9.15 \quad (2)$$

$$M = 0.00154\ D^{2.994} \quad (3)$$

where M is the mass (g) of the sediment grain. The main assumption required for using this calibration is that the relation between the sizes of bed load in transport for a given flow range has not changed since the historic samples were collected. The veracity of this assumption will be tested as further physical bed-load samples are compared to impact-plate data. This provisional calibration of the impact plates should not be taken as final as the relation between peak voltage and grain size of the impacting grains will change as more physical bed load samples are collected and analyzed.

Results

From December, 2021 to December, 2022, bed-load impact data was collected from 27 runoff events (Table 1). Four of the runoff events had peak flow depths greater than 1-m, with most events occurring during the winter and spring months.

Table 1. Dates of runoff events with bed-load impact data at structure 2 of the GCEW.

Date of peak flow	Peak flow depth at measurement location in structure 2 (m)	Total rainfall for runoff event (mm)
12-06-2021	0.36	22.1
12-17-2021	1.56	59.7
01-16-2022	0.43	25.9
01-19-2022	0.70	19.3
02-03-2022	1.09	40.1
02-21-2022	0.78	30.5
02-24-2022	0.31	14.0
02-27-2022	0.80	34.5
03-07/2022	0.59	22.6
03-09-2022	0.35	11.7
03-15-2022	0.55	26.4
03-18-2022	0.84	24.1
03-22-2022	1.20	47.8
03-30-2022	1.15	36.6

04-05-2022	0.53	21.3
04-13-2022	0.36	46.7
04-17-2022	0.68	25.6
05-01-2022	0.42	23.9
05-06-2022	0.38	31.0
05-13-2022	0.54	28.2
05-25-2022	0.78	26.7
07-30-2022	0.92	68.1
08-17-2022	0.55	66.8
08-21-2022	0.42	24.9
10-29-2022	0.44	51.8
11-29-2022	0.85	62.2
12-05-2022	0.48	37.3

Bed-load transport data covering the entire runoff event for nearly all runoff events during the year has never been available on the GCEW. Having this type of data allows, for example, comparisons to be made between runoff events of similar magnitude during different seasons. Having bed load data throughout the year is much more accurate than using a relation between flow strength and transport rate to predict the rates for a given runoff event. The potential for error in using mean relations rather than measurements can be demonstrated by comparing the bed-load transport rates for individual runoff events of similar magnitude.

Bed-load data from two runoff events with similar magnitudes of peak flow are shown in Figures 5 and 6. Despite having nearly the same peak depths, peak rates of bed-load transport differ between the paired events by approximately an order of magnitude. Likely much of this variability can be explained by conditions in the channel upstream of the impact plates and by the rainfall driving the events. Analyses are in progress to document the range of bed-load transport rates and explain their causes.

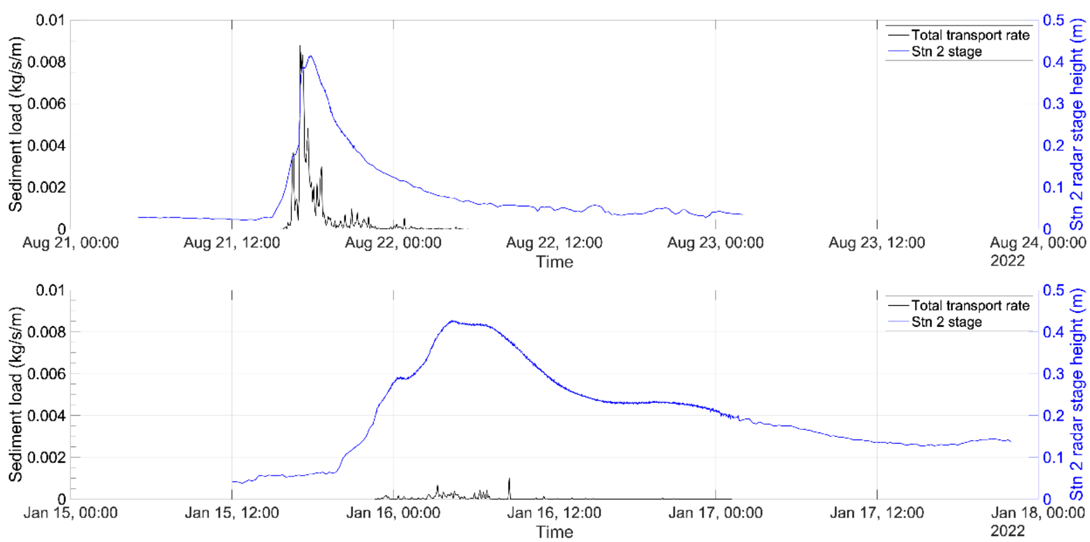

Figure 5. Stage and bed-load transport rate from January 16, 2022, and August 21,2022 runoff events. Peak flow depth at the measurement station was 0.43 and 0.42 m for the January 16 and August 21 events, respectively.

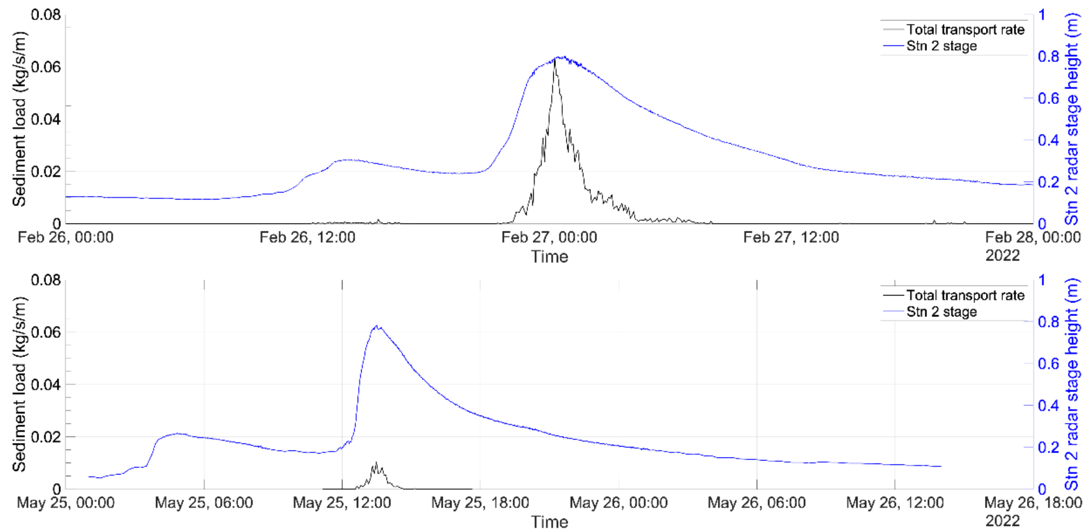

Figure 6. Stage and bed-load transport rate from May 25, 2022, and February 27,2022 runoff events. Peak flow depth at the measurement station was 0.78 and 0.80 m for the May 25 and February 27 events, respectively.

Conclusions

Two accelerometer-equipped impact plates began collecting bed-load transport data in December of 2021 from the Goodwin Creek Experimental Watershed. The impact plates were provisionally calibrated using data from physical samples collected during the late 1980s at structure 2 of the GCEW. As of December, 2022, bed-load data has been collected from more than 25 runoff events. Collecting bed-load data automatically has for the first time provided transport information from nearly all the runoff events over the past year. This wealth of data has demonstrated the large degree of variability of bed-load transport rates for events of similar peak flows. The main cause of variability between flows of lower magnitudes may be related to changes in the local topography and grain size of the bed material just upstream of the structure. For larger runoff events, local upstream bed topography and local grain size variations are likely not the main cause of variations measured between runoff events. The causes of these variabilities are currently being investigated.

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