EFFECTIVE PARTICLE SIZES OF COHESIVE SEDIMENT IN NORTH MISSISSIPPI STREAMS

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Abstract Knowledge of the size of cohesive sediment particles transported in streams is important information for predicting how the sediment and contaminants the sediment may be carrying will be transported by the flow. Cohesive sediments (less than 0.062 mm in diameter) generally are not transported in their primary dispersed particle sizes, but commonly assume larger sizes as aggregates and/or as flocs. Due to a lack of models for predicting effective particle sizes of fine sediments in streams, it is common for researchers and practitioners to assume that the sediment transported in a stream assumes the primary size of the sediment. Information on the effective sizes of fine sediment in streams is available for only a small number of streams. More data on the effective size of cohesive particles in streams is needed to allow more accurate modeling of their transport. In this investigation, measurements of the effective particle size were made using a portable laser particle size analyzer which was deployed in three streams during runoff events. The primary particle sizes were determined from samples of the suspended sediment which were collected in close proximity to and at the same time as the effective particle sizes were measured. The effective particle sizes were found to be coarser than the primary sizes and did not vary in a predictable manner with the stage of the streams during the runoff events. Ratios of the effective mean sediment size to the primary mean sediment size ranged from 6 to 21 for the three streams considered.

INTRODUCTION

Accurate determinations of the sizes of sediments are necessary for the study of sediment transport by flowing water. The grain size along with other physical properties of the sediment, including the composition, density, and shape are needed for determining how the sediment will be transported and how it will interact with materials in the water column such as chemicals and aquatic biota. The most widely accepted method for measuring particles greater than 62 microns in diameter is the use of sequentially sized sieves. For particles finer than 62 microns, pipettes and calculated fall velocities are typically used. Other techniques, based on automated fall-velocity determinations and laser-based measurements are also in use, but have not been standardized and tested and adopted by sedimentationists to the extent that sieve and pipette methods have been.

Measurements of the diameters of sand-sized sediments (62-2000 microns) and coarse silt-sized sediments (30-62 microns) that are transported in a channel have become routine and are repeatable if proper sediment collection and preparation methods are used (Rigby and Wren, 2013); however, the determination of the effective sizes of finer sediments in transport is problematic. As the size of the sediment decreases, properties such as cohesion and interactions with aquatic biota become important (Droppo, 2001) and measurement of size becomes more difficult. The effective particle size distribution (EPSD) of fine (< 62 microns in diameter) suspended sediment in fluvial transport is generally regarded to develop in balance with local conditions (Kranck, 1979), such that samples that are withdrawn from the channel, stored, and resuspended will have a particle size distribution that is not representative of the one present while the particles were in fluvial transport (Phillips and Walling, 1995). Measurements of fine sediment particles in fluvial transport must therefore be measured in situ.

Traditionally, studies of sediment transport by streams have made the assumption that the dispersed sizes of the inorganic material of the fine sediment fraction contain the information that is important for discerning how that sediment will be transported. However, because fine sediments in fluvial transport often consist of composite particles (Droppo, 2001; Walling and Woodward, 2000; Woodward and Walling, 2007) which may be composed of aggregates inherited from when the sediment was eroded (Meyer et al., 1980), or which formed by flocculation in the channel of the stream (Droppo, 2001), dispersed sediment size will not yield useful information on how fine sediment is transported or what it is carrying. Large differences in EPSD of fine sediments have been measured over separate sub-catchments of one basin (Woodward and Walling, 2007). Effective mean particle sizes have been found to be just slightly larger than the primary particle sizes (Williams et al., 2007) to more than two orders of magnitude larger than their constituent mineral grains (Woodward and Walling, 2007). Measurements from a wider variety of physical conditions and stream types are needed to determine the range of EPSD expected for different conditions. Measurements of EPSD and primary size distributions of fine sediments in fluvial transport from three streams northern Mississippi are presented and compared.

FIELD SITES

Samples of the fine suspended sediment in transport during runoff events were collected from three locations, Goodwin Creek, Yocona River, and Little Tallahatchie River, all located in the northern part of the state of Mississippi (Figure 1). The drainage areas upstream from the sample collection points were as follows: 18 km^2 for station 2 of Goodwin Creek, 679 km^2 for the bridge crossing of Mississippi State Highway 7 at the Yocona River, and approximately 3000 km^2 for the bridge crossing of Mississippi State Highway 7 at the Little Tallahatchie River. The samples from Goodwin Creek were collected 65 m upstream of the station 2 gauging station. The Yocona River samples were collected 10 m downstream of the bridge crossing of Mississippi State Highway 7 and south of Oxford. The samples from the Little Tallahatchie River were collected 300 m downstream of the bridge crossing of Mississippi State Highway 7 north of Oxford. Land use was 39 and 60 percent agriculture for the Yocona (Mississippi Department of Environmental Quality, 2003) and Little Tallahatchie Watersheds (Free Flow

Power, 2013), respectively. Recent surveys of land use at Goodwin Creek Watershed indicated that 8 percent of the land was cultivated (Kuhnle et al., 2008).

Figure 1. Map of the three sample locations: 1 – Little Tallahatchie River, 2 – Yocona River, 3 – Goodwin Creek.

Sample Collection

The collection of samples was undertaken as soon as practical after rainfall caused runoff events. Physical samples of sediment and water were collected while wading in water up to 1 m in depth. The samples were collected near the surface using 20 L buckets to ensure that sufficient quantities of sediment were collected to measure dispersed or primary sediment size distributions. After being transported to the laboratory and total weights had been measured, the samples were allowed to settle and the clear water was decanted. The sediment was collected and organic material was removed by treating with hydrogen peroxide. Samples were agitated overnight after the addition of sodium hexametaphosphate. Primary particle size distributions (PPSD) were determined in the laboratory following standard techniques using the pipette method (Brakensiek et al., 1979).

Measurement of Effective Particle Size Distributions

A self-contained portable laser particle size analyzer was used to collect measurements of EPSD of the fine sediments that were concomitant in time with the collection of physical samples. This instrument measures particle diameter using 32 logarithmically spaced size classes from 2.5 to 500 µm (LISST-100X, Type C from Sequoia Scientific). The size distribution of the particles is measured by volume with no assumptions made concerning density or mass. While the previous version of the instrument software only had the option of calculating the equivalent spheres size distribution, version 5.0 of the instrument software has the option to convert the diffraction data to particle diameters using algorithms which were developed using the light scattering properties of natural, random shaped particles (Agrawal et al., 2008). As fine sediment grains generally are not spherical, our experience with the new routines is that they yield more accurate size distributions than previous versions that used the spherical shape assumption. In some of the deployments the turbidity of the water was of a sufficient magnitude that the laser beam could not be pass through the measurement volume of the LISST. In these cases a 90 percent path reduction module was used to allow data to be collected.

The LISST was deployed in a vertical position with the measurement area perpendicular to the direction of the flow. The instrument was positioned near the bank in water depths of 0.6 to 0.9 m on the Yocona and Little Tallahatchie Rivers, and either near the bank or in the center of the channel mounted on a moored floating platform (Figure 2) on Goodwin Creek. The end of the instrument was mounted between 0.15 to 0.3 m below the surface of the flow.

Figure 2. Deployment of the LISST on tethered floating platform in Goodwin Creek during 06/10/2014 runoff event.

Effective size data was collected from five runoff events on Goodwin Creek, one runoff event on the Yocona River and one event on the Little Tallahatchie River (Table 1). Most of the samples were collected during relatively low stages in the channels after the peak flow had passed. Primary particle size data was measured for three of the events on Goodwin Creek and the events from the Yocona and Little Tallahatchie Rivers (Table 1).

Table 1. Dates and locations of sample collection.

date	location	Mean stage during sampling (m)	Relation to peak stage	Range in effective sizes (mm)	Range in primary sizes (mm)	Mean ratio effective to primary size
04/11/2013	Goodwin Creek, upstream of station 2	1.14	during	0.025 – 0.029	--	--
04/19/2013	Goodwin Creek, upstream of station 2	0.25	11 hours past	0.015 – 0.031	--	--
04/04/2014	Goodwin Creek, upstream of station 2	0.31	2.6 hours past	0.012 - 0.017	0.0029 - 0.0034	4.6
06/09/2014	Goodwin Creek, upstream of station 2	0.26	3.4 hours past	0.022 – 0.024	0.0029 - 0.0041	7.7
06/10/2014	Goodwin Creek, upstream of station 2	0.47	15.9 hours past	0.039 – 0.14	0.0062 - 0.0084	16.9
10/03/2014	Yocona River at MS Highway 7	1.01	6.5 hours past	0.039 – 0.045	0.0024 – 0.0027	15.2
10/15/2014	LittleTallahatchie River at MS Highway 7	3.26	7.8 hours past	0.017 – 0.065	0.0038 – 0.0041	10.5

RESULTS

Particle Sizes

The effective particle sizes with time for the sampled runoff events are presented in Figures 3 and 4. Changes in effective mean grain sizes over the periods measured (0.8 – 1.2 hr) on Goodwin Creek were nearly constant or changed gradually for three of the events, while the mean effective sizes during the 04/19/13 and 06/10/14 events increased by factors of 2.1 and 4.4, respectively. Changes in the trends of effective size were also small for the events sampled on the Yocona and Little Tallahatchie Rivers (Figure 4). Mean sizes of primary particles ranged from 0.0024 to 0.0084 mm with ratios of effective to primary sizes ranging from 4.6 to 16.9 (Table 1).

To investigate more fully the observed changes in effective sediment size during the 04/19/14 and the 06/10/14 runoff events on Goodwin Creek, the D_{16} and D_{84} particle sizes (sizes in which 16 and 84 percent of the distribution are finer) were plotted in Figure 3B and 3F. It is apparent for both of these runoff events that the D_{84} of the effective size distribution increased more rapidly than the D_{16} size. This was particularly true in the beginning part of the measured flows. Apparently the initial changes in mean size occurred mostly in the coarser part of the size distribution. This may be related to how flocs are created and destroyed during a runoff event.

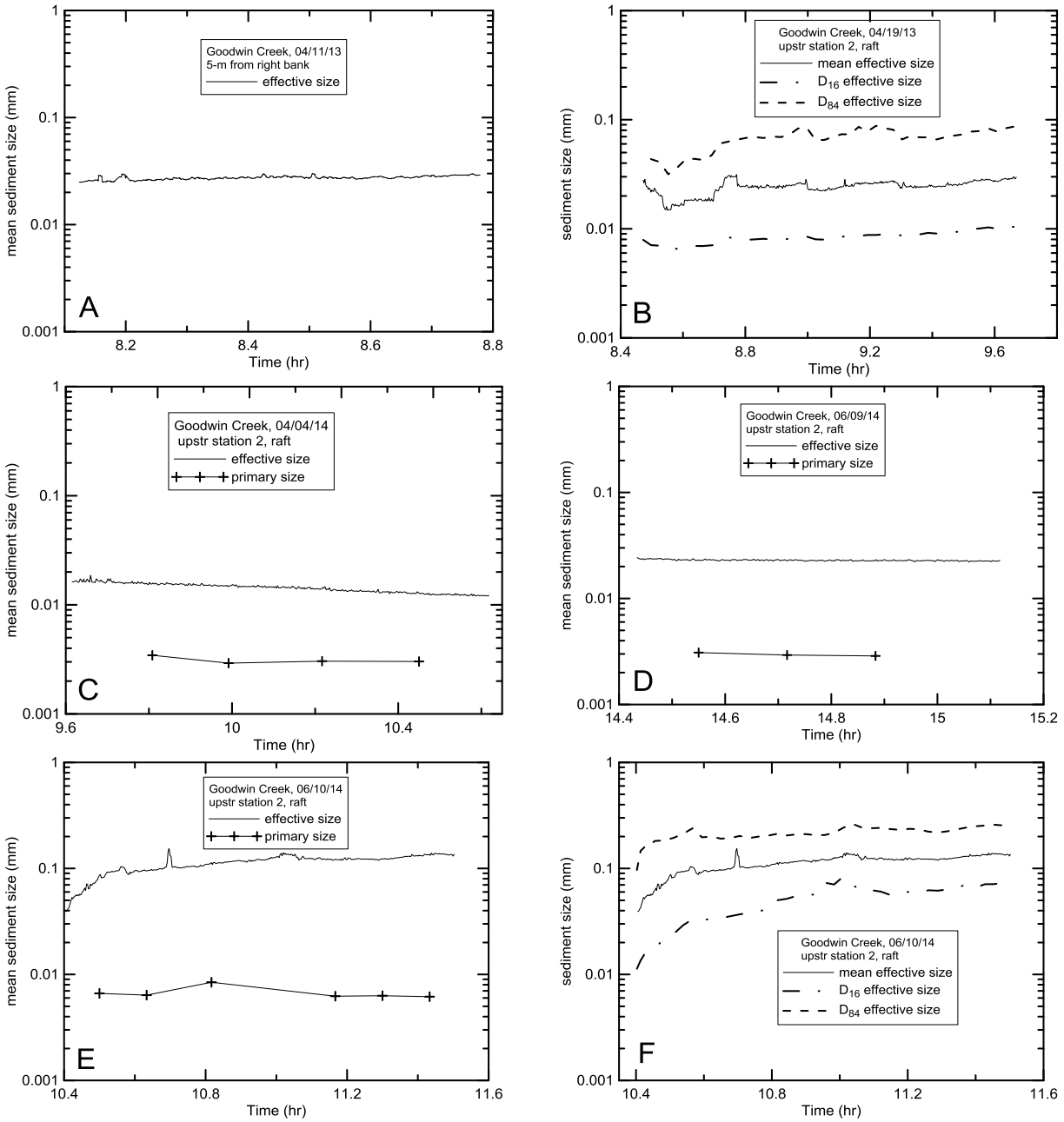

Figure 3. Effective and primary particle sizes measured in the main channel of Goodwin Creek 65 m upstream of gauging station 2.

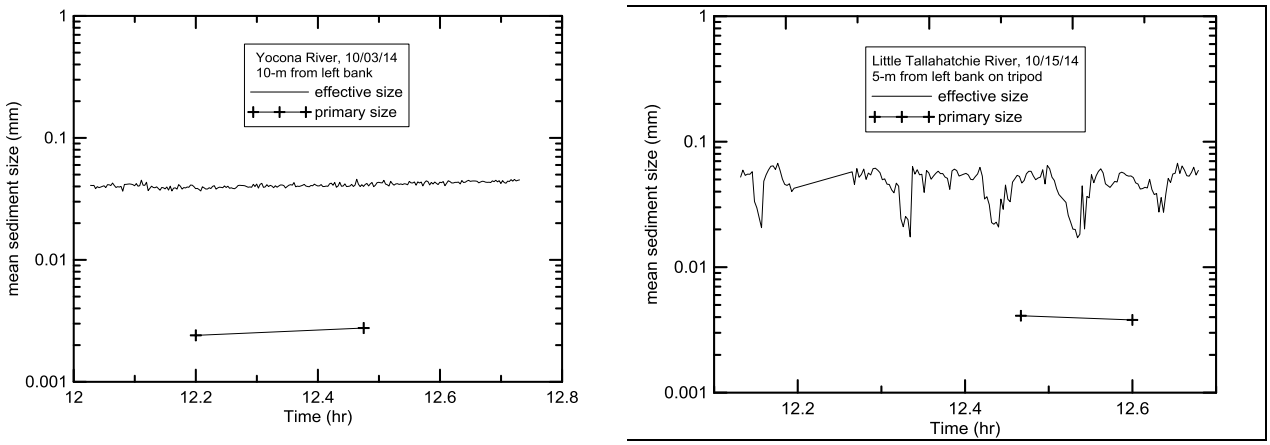

Figure 4. Effective and primary particle sizes measured at the Yocona River and Little Tallahatchie Rivers.

Discussion and Conclusions

The particle size data from this study indicates that the fine sediments of Goodwin Creek, Yocona River, and Little Tallahatchie River are transported as aggregated or flocculated collections of primary particles that range in size from about 5 to 20 times the mean diameter of the dispersed primary particles. Particle size data collected from multiple runoff events on Goodwin Creek have demonstrated that effective sizes may vary by more than an order of magnitude from different runoff events collected at the same site, while the mean sizes of primary particles varied only by about a factor of two. It has also been observed that effective sizes may vary by at least a factor for four over relatively short periods of time with nearly steady conditions of flow in the channel. The reasons for this range in effective sizes are possibly related to changes in the sources of sediment to the channel and how they were eroded and transported. It is clear that the effective particle sizes on the three watersheds were similar even though the drainage areas of the watersheds range over more than two orders of magnitude and channel lengths of the main channel upstream of the measurement sites were 10, 35, and 100 km for the Goodwin Creek, Yocona River, and Little Tallahatchie Rivers, respectively.

Past studies on the provenence of fine sediment conducted at Goodwin Creek have revealed that the dominant sources of sediment changed from surface to bank dominated during the course of a runoff event (Wilson et al., 2008, 2014) and may also vary with season and the characteristics of the rainfall and runoff. The different processes of erosion associated with different sediment source types would likely lead to different effective sediment size signatures in the channel of a stream. Aggregates of fine sediment, for example, may be more plentiful in sediment that was derived from bank erosion than from sediment that originated from upland sources. The intensity of the rainfall event and shape of the hydrograph also would likely affect the size of eroded particles and the evolution of particles as they are transported through the channels of a watershed. The season of the year may also be an important piece of information affecting effective sediment sizes particularly in watersheds with significant percentages of the land surface involved in agriculture activities such as tillage, planting, and cultivation. It has been shown from previous studies that the type and extent of agricultural practices have a direct effect

on the nature of runoff and the production of fine sediment from plots and watersheds (McGregor et al., 1969; Dendy et al., 1979; Kuhnle et al., 1996). This may also be true when biological activity affects particle flocculation (Droppo, 2001).

A related study conducted on the River Exe watershed in southern England (Williams et al., 2007), in which effective sizes were measured with a LISST-100, found that median of the EPSD ranged from about 70 to 200 microns over four runoff events. Two of the events were in the spring of the year and two were in the fall of the year and the durations of the measurements were 2.5 to 16 hours. These median values were about three to four times larger than the values measured in this study. It is not clear to what extent the differences in measured EPSD from the Exe watershed and the ones from this study were due to physical differences of the watersheds or to the effect of sampling differences. Measurements collected over larger portions of several runoff events from different seasons would yield a better picture of the variations present in EPSD on watersheds such as Goodwin Creek.

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