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Erodibility of Cohesive Streambeds in the Yalobusha River System

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EXECUTIVE SUMMARY

The general objective of this study was to provide the U.S. Army Corps of Engineers, Vicksburg District with erodibility, erosion rates, and knickpoint migration rates for the cohesive streambeds of the Yalobusha River system. Specifically, the USDA-ARS National Sedimentation Laboratory was charged with:

1. Determining bed-material characteristics, incipient-motion criteria, and erosion rates of the clay beds in reaches targeted by the Corps of Engineers (CoE) for grade control and knickpoint areas previously identified by 1997 CoE surveys and the ARS in Simon (1998);
2. Determining the spatial distribution of the erodibility, incipient-motion criteria, and erosion rates of the clay beds;
3. Developing predictive technology for rates of erosion and knickpoint migration for the clay beds; and
4. Identifying and prioritizing clay-bed reaches in most need of erosion control;

Erosion of streambed materials in the Yalobusha River system is controlled by the nature of the two dominant geologic formations: Naheola and Porters Creek Clay. These are expressed in terms of two parameters: critical shear stress and an erodibility coefficient. Maps of the distribution of these parameters throughout the Yalobusha River system are provided in the body of the report. In general, Porters Creek Clay is extremely resistant to erosion by hydraulic stresses, requiring shear stresses in the hundreds of Pa to initiate downcutting. Given the range of representative flow depths and bed slopes, shear stresses of this magnitude probably do not occur on a frequent basis. This resistance to hydraulic erosion apparently also plays an important role in limiting knickpoint migration in two key ways. Firstly, the potential for geotechnical failure is reduced because of a lack of downcutting needed to produce a knickpoint face of sufficient height to create instability; and secondly, secondary scour, caused by pressure reduction and flow acceleration close to the brink, is reduced. Erosion of streambeds cut into the Naheola formation, however, can occur over a range of commonly occurring shear stresses. These differences lead to stark contrasts in knickpoint migration rates between the two formations, notwithstanding that the geotechnical shear strength of Naheola beds are greater than those composed of the Porters Creek Clay.

Tables are provided that classify erosion resistance (in Pascals) and erodibility (in cm^3/N-s) for every study site. For every site, an estimate of the amount of erosion that would occur for one-day storms at a range of shear stresses is provided as a guide. In addition, shear stress-exceedance series for the intensively monitored sites, and associated erosion estimates have also been provided. These have been compared to the erosion observed in surveys and a hydraulic analysis has been performed to account for discrepancies.

That migration of some knickpoints or knickzones, particularly those cut into the Porters Creek Clay formation, has been severely limited is directly related to the hydraulic resistance of these clay beds. More than 30 years after the completion of the most recent channel dredging on the Yalobusha River main stem (1967), the major erosion zone is still just upstream of the upstream terminus of the channel work (river kilometer 27.8). With maximum critical shear stress values reaching more than 400 Pa, erosion of knickpoints cut into the Porters Creek Clay formation is marginal.

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INTRODUCTION AND BACKGROUND

Thousands of kilometers of cohesive-bed stream channels in the Midwestern United States are incised and eroding at accelerated rates due to human disturbances imposed near the turn of the 20th century (Simon and Rinaldi, 2000). The Yalobusha River of north-central Mississippi (upstream of Grenada Lake) is one of these systems and poses particular concerns to river managers because of downstream flooding problems in the vicinity of Calhoun City. The U.S. Army Corps of Engineers (CoE), Vicksburg District is charged with alleviating the downstream flooding problems resulting from a massive debris dam (see Simon, 1998) while protecting middle and upper reaches from further streambed and streambank erosion. Before the CoE can consider removing the debris dam or re-routing downstream flows, they are protecting reaches upstream from this zone by constructing grade-control and other structures. Prediction of future channel responses and the effects of potential mitigation measures are difficult, however, because of an incomplete knowledge of erodibility and erosion mechanisms in cohesive streams.

The detachment and erosion of cohesive (silt- and clay-sized) material by gravity and/or flowing water is controlled by a variety of physical, electrical, and chemical forces. Identification of all of these forces and the role they play in determining detachment, incipient motion, and erodibility of cohesive materials is incomplete and, at least, still poorly understood. The behavior of cohesive materials in flowing water is important in estimating erosion and sedimentation in a variety of types of waterways, and in the associated transport of adsorbed constituents. Sub-aerial behavior of cohesive materials is important in determining soil detachment and erosion from channels, upland areas (by overland flow or raindrop impact), and with regards to mass movements on hillslopes and channel banks.

Assessing erosion resistance of cohesive materials by flowing water is complex due to the difficulties in characterizing the strength of the electro-chemical bonds that define the resistance of cohesive materials. The many studies that have been conducted on erodibility of cohesive materials have observed that numerous soil properties influence erosion resistance including antecedent moisture, clay mineralogy and proportion, density, soil structure, organic content, as well as pore and water chemistry (Grissinger, 1982). Furthermore, field evidence indicates that cohesive streambeds erode by a variety of mechanisms including particle-by-particle detachment, geotechnical failure of knickpoint faces, and possibly, by upward-directed seepage forces. Studies of streambank stability in cohesive materials have led to recognition of the importance of positive and negative pore-water pressures in accurate numerical analysis of mass-wasting processes and channel widening (Casagli *et al.*, 1997; Simon and Curini, 1998; Rinaldi and Casagli, 1999; Simon *et al.*, 1999). Negative pore-water pressures increase the shear strength of unsaturated, cohesive materials by providing tension between particles. These studies led to the idea that positive and negative pore-water pressures may play an important role in the entrainment and erosion of cohesive streambed particles or aggregates (Simon and Collison, 2001).

The need for evaluation of cohesive streambed erodibility in the incised channels of the Midwestern United States led to initial field testing of the hydraulic stresses required to erode cohesive streambeds (critical-shear stresses; Hanson and Simon, 2001). As part of this effort, a number of sites in the Yalobusha River system were tested during the spring of 1998. The preliminary results from several streams in the Yalobusha River basin along with the location and size of major knickzones were reported to the CoE in Simon (1998) and showed that some of