Geomorphology 235 (2015) 88–105

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Sediment contributions from floodplains and legacy sediments to Piedmont streams of Baltimore County, Maryland

Mitchell Donovan [a,*], Andrew Miller [a], Matthew Baker [a], Allen Gellis [b]

[a] University of Maryland-Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA
[b] U.S. Geological Survey, 5522 Research Park Drive, Baltimore, MD 21228, USA

ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form 19 January 2015
Accepted 23 January 2015
Available online 3 February 2015

Keywords:
Fluvial
Change detection
Bank erosion
Legacy sediment
Floodplain

ABSTRACT

Disparity between watershed erosion rates and downstream sediment delivery has remained an important theme in geomorphology for many decades, with the role of floodplains in sediment storage as a common focus. In the Piedmont Province of the eastern USA, upland deforestation and agricultural land use following European settlement led to accumulation of thick packages of overbank sediment in valley bottoms, commonly referred to as legacy deposits. Previous authors have argued that legacy deposits represent a potentially important source of modern sediment loads following remobilization by lateral migration and progressive channel widening. This paper seeks to quantify (1) rates of sediment remobilization from Baltimore County floodplains by channel migration and bank erosion, (2) proportions of streambank sediment derived from legacy deposits, and (3) potential contribution of net streambank erosion and legacy sediments to downstream sediment yield within the Mid-Atlantic Piedmont.

We calculated measurable gross erosion and deposition rates within the fluvial corridor along 40 valley segments from 18 watersheds with drainage areas between 0.18 and 155 km^2 in Baltimore County, Maryland. We compared stream channel and floodplain morphology from lidar-based digital elevation data collected in 2005 with channel positions recorded on 1:2400 scale topographic maps from 1959–1961 in order to quantify 44–46 years of channel change. Sediment bulk density and particle size distributions were characterized from streambank and channel deposit samples and used for volume to mass conversions and for comparison with other sediment sources.

Average annual lateral migration rates ranged from 0.04 to 0.19 m/y, which represented an annual migration of 2.5% (0.9–4.4%) channel width across all study segments, suggesting that channel dimensions may be used as reasonable predictors of bank erosion rates. Gross bank erosion rates varied from 43 to 310 Mg/km/y (median = 114) and were positively correlated with drainage area. Measured deposition within channels accounted for an average of 46% (28–75%) of gross erosion, with deposition increasingly important in larger drainages. Legacy sediments accounted for 6–90% of bank erosion at individual study segments, represented about 60% of bank height at most exposures, and accounted for 57% (±16%) of the measured gross erosion. Extrapolated results indicated that first- and second-order streams accounted for 62% (±38%) of total streambank erosion from 1005 km^2 of northern Baltimore County. After accounting for estimated redeposition, extrapolated net streambank sediment yields (72 Mg/km^2/y) constituted 70% of estimated average Piedmont watershed yields (104 Mg/km^2/y). The results suggest that streambank sediments are a relatively large source of sediment from Piedmont tributaries to the Chesapeake Bay.

1. Introduction

The relation between erosion, storage, and delivery of sediments across a watershed has been an active topic in fluvial morphology throughout the last century (Gilbert, 1917; Mackin, 1937; Trimble, 1983; Phillips, 1991), often examined using a sediment budget (Reid and Dunne, 2005). Despite numerous efforts to connect sources and delivery of sediment (Wolman, 1977; Walling, 1983; Trimble and Crosson, 2000; Knox, 2006), challenges arise from spatial and temporal complexity of sediment sources, transport processes, anthropogenic impacts, and the magnitude and frequency of precipitation events (Harvey, 2002; Orwin et al., 2010). The dominant source(s) of sediment can vary throughout watersheds and over short time scales (Rhoades et al., 2009; Gellis and Brakebill, 2012) as the result of widespread land use change (Wolman and Schick, 1967; Jacobson and Coleman, 1986) and agricultural practices (Gellis et al., 2009).

Observations of high sediment yield throughout the Piedmont of the eastern U.S. have motivated investigations of sediment sources.

* Corresponding author.
E-mail addresses: mdonovan@umbc.edu (M. Donovan), miller@umbc.edu (A. Miller), mbaker@umbc.edu (M. Baker), agellis@usgs.gov (A. Gellis).

http://dx.doi.org/10.1016/j.geomorph.2015.01.025
0169-555X/

Although total streambank erosion has been cited as accounting for 50 to 80% of sediment yields in some Piedmont watersheds (Trimble, 1997; Shilling, 2009; Merritts et al., 2010; Gellis and Noe, 2013), similar contributions have been measured from agricultural and forested upland sources in other watersheds (Phillips, 1991; Gellis et al., 2009; Smith et al., 2011). One factor affecting these varied results is uncertainty in the methods and scales of comparison between watershed measurements. Short-term and reach-scale measurements of bank erosion are subject to high spatial and temporal variability (Wolman and Gerson, 1978; Hooke, 1980; Lawler et al., 1999; Reid and Dunne, 2005; Belmont, 2011), producing considerable uncertainty when generalized to address regional or long-term patterns (Wolman and Leopold, 1957; Smith, 2011). In order to obtain a spatially and temporally representative data set of bank erosion rates, measurements should encompass multiple decades and extend throughout the surficial channel network.

Researchers have long observed the process of laterally migrating lowland channels eroding through historical valley-spanning deposits that resulted from upland land use activities following European settlement (Happ et al., 1940; Costa, 1975; Jacobson and Coleman, 1986; Phillips, 1991; Jackson et al., 2005; Wegmann et al., 2012). Such historical deposits, collectively referred to as legacy sediments (Fig. 1), may be an ongoing dominant source of sediment in watersheds caused by increased runoff and reduced upland sediment supply subsequent to historical peaks of agricultural land use (Colosimo and Wilcock, 2007). Despite evidence that floodplains (Church and Slaymaker, 1989; Allmendinger et al., 2007; Voli et al., 2013) and legacy sediments (Walter et al., 2007; Hupp et al., 2013) are large components of the total sediment load delivered from streams, mobilized sediment may not exit Piedmont watersheds for 6 to 10 millennia (Pizzuto, 2001; Jackson et al., 2005; Pizzuto et al., 2014).

In order to better understand the role of streambank and legacy sediments, our research seeks to quantify (i) rates of sediment remobilization from Baltimore County floodplains by channel migration and bank erosion, (i) proportions of streambank sediment derived from legacy deposits, and (iii) potential contribution of net streambank erosion and legacy sediments to downstream sediment yields within the Mid-Atlantic Piedmont. This research has implications for river-restoration policies, water quality regulations, land use, ecosystem, and flood-risk management (Reid and Dunne, 2005; James, 2013). Evaluating remobilization rates of sediment stored along Piedmont floodplains may help us understand its importance as a source of sediment and help guide sediment reduction policies required to meet current total maximum daily load (TMDL) thresholds set by the EPA (Langland and Cronin, 2003). The TMDLs are calculations of the maximum amount of a particular pollutant that can enter a water body and still meet safe water quality standards as defined in the Clean Water Act.

2. Regional setting/segment descriptions

2.1. Regional setting

We studied portions of 40 Piedmont streams across Baltimore County, Maryland (Fig. 2) within watersheds that are dominantly forested and agricultural land. These watersheds are located mostly outside of the zone of urban and suburban growth surrounding Baltimore City, which corresponds closely with the Urban–Rural Demarcation Line (URDL). The majority of northern Baltimore County is underlain by schist, while central and eastern portions are dominantly underlain by gneiss, quartzite, and marble, eventually transitioning to gravel and sand in the Coastal Plain physiographic province. Some of our segments along Western Run flow through broad valleys underlain by Cockeysville marble, which is relatively soluble and potentially correlated with broad alluvial valleys.

Prior to the 1800s, a relatively stable Piedmont landscape allowed for the formation of thick upland soil profiles that were rapidly truncated in response to forest clearing for agricultural purposes throughout the period of Euro-American colonization (Costa, 1975; Costa and Cleaves, 1984; Jacobson and Coleman, 1986). This disturbance is still evident in legacy sediments deposited across footslopes and pre-settlement floodplains during the peak of agricultural land use in the mid to late nineteenth century (Jacobson and Coleman, 1986). Walter and Merritts (2008) proposed that mill dams were also necessary to explain the extent of legacy sediments across the region. The relative importance of mill dams was investigated as a part of the project and will be addressed in a companion paper. In time, decreased agricultural activities and improving land use management reduced sediment supply from upland areas, as reflected in 75% reductions of annual sediment yields to reservoirs (Wolman and Schick, 1967) and channel incision (Jacobson and Coleman, 1986) in Baltimore County.

2.2. Study segment descriptions

Twenty-five Piedmont streams were originally selected as representative portions of the Baltimore County stream network, with drainage areas from 0.18 to 155 km^2 at their downstream ends. Each stream included multiple contiguous study segments (our unit of observation) ranging from 0.34 to 4.73 km in length. This scale of observation

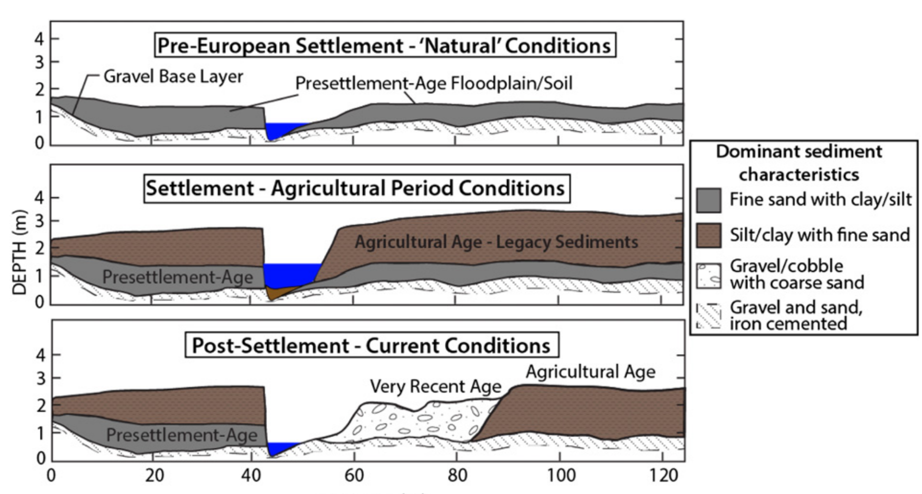

Fig. 1. The evolution of Piedmont alluvial valley conditions. The shifting state of a typical Piedmont stream is illustrated for the pre-colonial period (top), settlement period (middle), and current conditions (bottom) as described in Jacobson and Coleman (1986).