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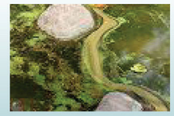

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Feature Story:
Water-powered Milling and Its Legacy as a Source of Suspended Sediment to the Susquehanna River and Chesapeake Bay

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Recent research by Walter and Merritts (2008) and Walter et al (2007) explains a well-known enigma from studies of sediment loads in mid-Atlantic streams for the Chesapeake Bay Watershed: Piedmont streams contribute unusually high modern suspended sediment loads to the Chesapeake Bay, despite their low relief and low, long-term (i.e., geologic) erosion rates (Gellis et al, 2009). The commonly held view since the 1930s has been that modern agriculture is the primary source of suspended sediment through upland slope wash, rilling, and gullying. Human activities associated with construction also are thought to be a source of sediment to streams. This new research indicates, however, that massive amounts of historic sediment are stored along tens of thousands of kilometers of valley corridors upstream of tens of thousands of milldams that once supplied water power to early American industry. This historic sediment – sometimes dubbed legacy sediment – is remobilized by stream bank erosion once a milldam breaches and a stream incises into the historic reservoir sediment (Walter et al, 2007).

In colonial and post-revolutionary America, low head dams typically one to three meters high were built for hydropower that propelled the Industrial Revolution. Mill acts crafted to promote economic development were passed in every early American colony and most states east of the Mississippi throughout the 18th to mid-19th centuries. Milldam proliferation coincided with dramatic changes in upland land use that accelerated soil erosion from an ancient, deeply weathered landscape. Wedges of sediment with km-long length scales were trapped in the reservoirs of relatively small but plentiful milldams, burying ubiquitous springs, widespread marshes, and other types of wetlands, and perennial streams.

Although milldams were widespread, the Piedmont streams in the Chesapeake Bay Watershed had the right combination of characteristics for becoming the greatest sources of fine-grained, suspended sediment to the Bay. First, many major ports in Colonial and early U.S. history – including Philadelphia, Baltimore, and Wilmington – were located along the Fall Zone, the topographic boundary that separates the Coastal Plain and Piedmont physiographic provinces. As a result, the density of mills was particularly high in the Piedmont region. Second, Piedmont valleys were the ideal size for water-powered mills. The flow of water was sufficient to turn 17th-early 20th century water wheels, yet not too high to pose engineering challenges for building and maintaining dams and mills along valley bottoms. Finally, 18th- to 19th-century land-clearing that increased upland erosion rates 50-400 times greater than long-term geologic rates washed rich, fertile soils from Piedmont hill slopes into the chains of millponds below. These soils typically were silt loams, with equal parts clay, silt, and sand. Gradients along Piedmont streams are gentle, and as a consequence, millponds filled with mud and sand for long distances upstream of milldams.

Base-level lowering from dam breaching causes channel incision and deepening that lead, in turn, to greater flow velocities, bed shear stresses, and stream power. Many incising channels reach pockets of gravel and sand along valley margins, much of it probably periglacial toe-of-slope deposits that date back to the last full glacial conditions of approximately 15,000 to 50,000 years ago. With their high banks and greater power, incised streams are able to transport this gravel as bed load. Bars of gravel build up along incised streams at the inside curves of meander bends, where flow velocities are lower, leading to further erosion along the outside of meander bends. Overbank deposition, which could store some of the eroded fine sediment, is uncommon along deeply incised channels because water rarely goes over bank.

Breaching and removal of obsolete milldams over the last century have caused widespread channel entrenchment, even along un-urbanized, forested stream reaches. This phenomenon is largely decoupled from modern land use. In other words, even without an increase in stormwater runoff, a breached dam can lead to incision, eroded stream banks, and increased loads of suspended sediment in a stream. The clay, silt, and sand trapped in millponds are relatively easily eroded by incised streams. In parts of southeastern Pennsylvania, for example, Merritts et al (2010) estimate that bank erosion of legacy sediments could account for at least 50-80% of suspended sediment loads to downstream waterways.

Sediment production in an incised reservoir is the result of mass movement, freeze-thaw, wetting and drying, and fluvial entrainment from exposed stream banks. All of these erosional processes occur over a period of years to centuries after a milldam breaches. Low stream flow relative to high banks results in constant undercutting, which leads to collapse during wetting-drying events. Near-vertical banks also are prone to freeze-thaw because they are exposed to lower air temperatures during the winter and night time. Channel flow at the base of near-vertical banks can sweep away material shed by collapse or freeze-thaw processes, resetting the bank for future erosion.

One of a dozen milldams on Mountain Creek in Cumberland County, Pennsylvania, provides an example of the impact of a single milldam breach. The left end of a 19th century paper milldam was breached in 1985 in response to concerns about its safety. Since then, the stream has eroded deeply into the mud and sand that had accumulated for nearly two km upstream of the 4-m high dam. Using lidar (light detection and ranging) high-resolution topographic data acquired in 2007, we estimate that nearly 40,000 cubic m of sediment were eroded from this reservoir since 1985. If erosion was constant with time, it would have been removed at a rate of 1,738 m^3 per year. The resultant sediment load from stream bank erosion is approximately 2,000 to 2,400 tons/year from just one of nearly a dozen breached dams along this small stream. Aerial digital orthoimages for this same stream reveal that stream bank edges retreated at an average rate of 0.3 m/yr from 2003-2007. At this breached reservoir, we measured significantly more lateral bank erosion in the late fall and winter (November to April) than in other seasons, and attribute this to freeze-thaw processes, needle ice, and saturated sediment during these seasons.

In sum, wetlands once ubiquitous throughout the Piedmont mid-Atlantic region were transformed – inadvertently – to incised streams with high banks of mud that are capable of eroding and carrying significant loads of suspended sediment (Figure 1). Suspended sediment is a major contributor to degradation of streams and the Chesapeake Bay, but stream bank erosion as a source of this sediment has been largely unrecognized to date. Dam breaching and its effects on suspended sediment loads are perhaps more important than the percent of impervious land cover for sediment loads in modern streams heavily impacted by historic milling. This finding requires us to re-evaluate the common belief that modern land use is the dominant cause of modern sediment loads.

Figure 1. (A) Big Spring Run, a small Piedmont stream in Lancaster County (upstream drainage area ~2.6 km^2), has high eroding banks of silt and clay. Historic millpond sediment in the banks overlies a black hydric (wetland) soil that contains seeds of marsh plants, mostly sedges, and dates to the past few thousand years (Voli et al, 2009). (B) Rare patches of historic valley bottom wetlands not covered by millpond sediment include tussock sedge meadows with low-energy streams, as shown here along Gunpowder Falls, MD, that contain species identical to paleo-seeds found in buried hydric soils beneath millpond sediment elsewhere in the Piedmont region.

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