Colonial Mill Ponds of Lancaster County Pennsylvania as a Major Source of Sediment Pollution to the Susquehanna River and Chesapeake Bay

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INTRODUCTION

The timing and ultimate source of sediment erosion in Lancaster County has far-reaching implications beyond local interests in farmland conservation. The Conestoga watershed is an environmental hotspot, yielding by far more sediment pollution to the Susquehanna River per acre of land than any other part of the Susquehanna River watershed (c.f., Reuter et al., this volume; Gellis, this volume). Sediment is the greatest stream pollutant in the United States, and it is especially devastating to the Chesapeake Bay as a contributor to algal blooms, low oxygen levels, and habitat degradation.

Until the 1930s, much of the sediment in Lancaster County streams came directly from farm slopes, as greater than 70% of the County was farmland and farmers had not yet begun to practice conservation techniques such as contour plowing and crop rotation. Since that time, however, many Lancaster County farmers have worked with county, state, and federal agencies to mitigate soil erosion. Still, the amount of sediment pollution from Lancaster County to the Susquehanna has remained high. The critical question is why – why fifty years after the implementation of conservation farming practices is Lancaster County still one of the most significant contributors of sediment to the Susquehanna River and the Chesapeake Bay. Our research is aimed at understanding the cause of this paradox, which in turn will help direct policy decisions regarding regional land use planning and conservation practices.

Our study, which is still in a developmental stage, stems from fieldwork conducted between June 2002 and September 2003 in which we discovered that large quantities of sediment are stored in stream corridors of Lancaster County. We suspect that the bulk of this confined sediment post-dates, and is the direct result of, the onset of deforestation for the agricultural exploitation of Lancaster County's rich limestone soil during Colonial times.

The goal of our study is to acquire detailed knowledge of these sedimentary deposits and an understanding of what stream ecologies were like prior to colonization. We are in the second year of a long-term investigation to determine the extent and geometry of the sediment stored in the stream corridors, the type and volume of sediment, when and how it got there, the extent to which it is being eroded now, and its impact on pollution to the Susquehanna-Chesapeake watersheds.

BACKGROUND

Little is known about the physical geography of Lancaster County prior to Colonial settlement. Most historians envision the region to have been completely forested, but some accounts by early settlers marveled at the large tracts of open grasslands they witnessed on their arrival to the region (Harold Weaver, pers. comm.). There is no doubt, however, that in the early 1700s Lancaster County was still very much a frontier, and that the German and Swiss pioneers to this region quickly transformed the natural landscape into a productive agricultural center.

Today, Lancaster County is the agricultural leader, in terms of the value of farm products sold or traded, of all non-irrigated counties in the nation (Pennsylvania State Archives 2003). The county is well known for its quaint Pennsylvania Dutch farms, its gently rolling pastures, and the numerous covered bridges that still span the county's small streams This bucolic setting possesses some of the richest agricultural land in the world, from which a prosperous farming industry had sprung by the early 1700s. By 1750, Lancaster County had become a major grain-producing region for the American Colonies, even exporting large quantities of grain abroad (Lemon, 2002).

Its rich carbonate soil, moist, temperate climate, subdued topography and numerous springs and small streams combine to make Lancaster County an ideal agricultural region. As land was cleared and farms became productive, grain production increased and the demand for milling increased in kind. Here again, low relief and plentiful small streams of the County produced an ideal setting for the construction of water-powered grist mills.

Water-powered mills require dams and ponds to store water, which provide a reliable, constant hydrostatic head throughout the seasons for moving the waterwheel and gears that turn the mill stone. Between 1700 and 1900, over 300 grist mills were built on Lancaster County streams (Landis, 1964) (Fig. 1). The majority of these were constructed between 1730 and 1850, and many remained in operation until the mid 1900s, Over the same period, more than 200 saw mills, fulling mills, boring mills and other water-powered mills also were constructed. The number of all mills totals over 450 (Landis, 1964; Barton, 1998), roughly two thirds of which were on streams in the northern half of the county, north of the Martic Line. The Martic Line is a Paleozoic shear zone that separates the subdued limestone terrain of northern Lancaster County (dominantly Conestoga Limestone) from the more deeply incised stream valleys in the south (dominantly Wissahickon Schist).

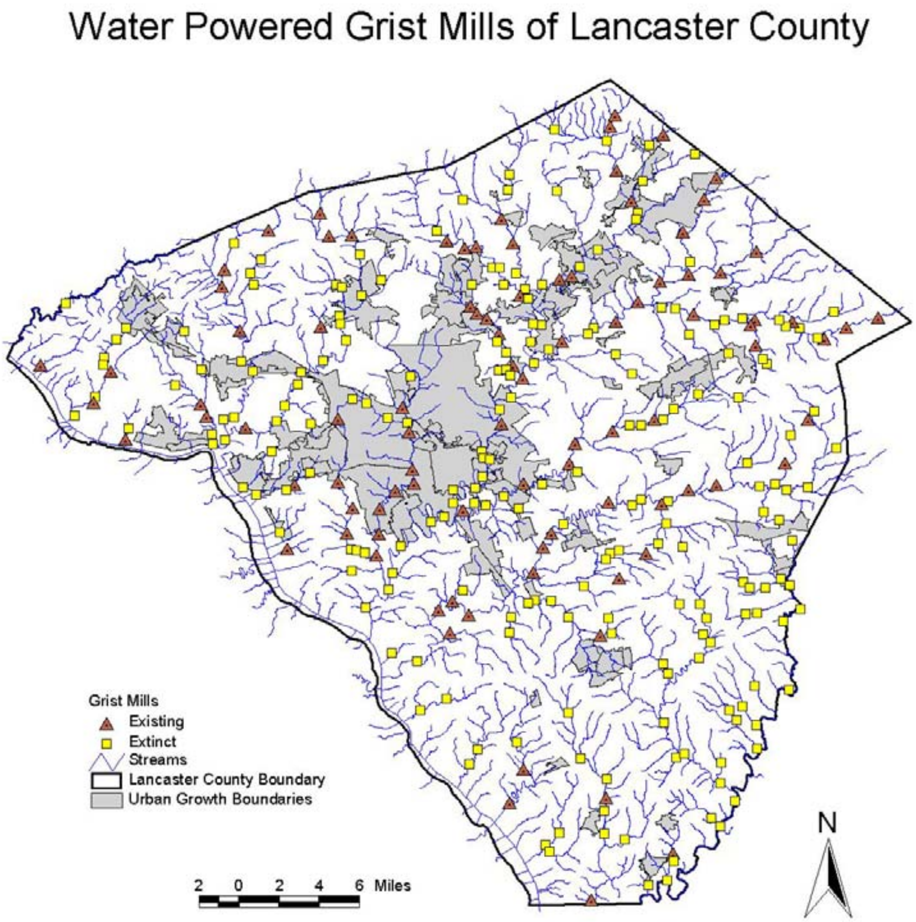

Figure 1 Location of existing and extinct grist mills in Lancaster County, from Lord, 1996. Urban growth areas are shaded gray.

A GIS analysis of Lancaster County streams shows that, on average, there was roughly one mill dam every 2.8 km of stream length. This is a conservative estimate, as the analysis groups all streams in the County and does not consider differences between mill/stream densities north and south of the Martic Line. Still, this large density of mills (Fig. 1) means that streams throughout the County were trapping sediment since the early 1700s. A key question is what did these streams look like prior to Colonial settlement?

HYPOTHESIS

Our hypothesis is that the stream corridors changed considerably, and that most of the sediment currently held in stream corridors in Lancaster County is the result human changes to the landscape since that time, particularly: (1) the clearing of land for agriculture and logging for paper production and fuel for forges, kilns, and iron furnaces; and (2) the construction of numerous mill dams throughout Lancaster County. This initial phase of land clearing induced rapid erosion of topsoil, which was trapped by mill dams and stored within the confines of the stream corridors.

Our working model is that there were more mill dams per unit stream length in Lancaster County than in any neighboring county or state, and that mill ponds became the principle storage basins for soil eroded from Lancaster County's hill slopes during initial phases of land clearing and cultivation. It has been only since the mid-twentieth century – as the grist mills of Lancaster County gradually went out of production and disintegrated by human or natural causes – that massive amounts of sediment stored in these mill basins began to wash down stream to the Susquehanna River and Chesapeake Bay.

THE LITTLE CONESTOGA CREEK WATERSHED

The Little Conestoga Creek flows through a part of Lancaster County -- west of the city of Lancaster -- that is experiencing rapid land-use change from primarily agricultural and rural lands to new suburban development and urban sprawl (Fig. 1). Since the 1950s , excessive runoff of water from the proliferation of parking lots, suburban lawns, driveways, and buildings has increased the rate and magnitude of flooding in the Little Conestoga Creek, which in turn accelerated channel-bank incision and erosion. Erosion of channel banks, which consist largely of loose sediment deposited during previous centuries of land clearing and erosion from farm slopes, has contributed large amounts of sediment to water in the Little Conestoga stream channel. This mixture of sediment and water drains into the Conestoga River, which in turn empties into the Susquehanna River, and ultimately into the Chesapeake Bay.

During times of high floodwaters, the Little Conestoga Creek and Conestoga River turn a deep chocolate brown from their excessive sediment loads. During such floods, the rich soil of Lancaster County is carried to the Susquehanna River. But which soil? The common view is that the streams are carrying modern topsoil eroded from farmers fields and/or from major land development sites. Although these sources are certainly contributors to the sediment flux (Moss and Kochel, 1978), we suspect that the main source of sediment now is the soil already trapped in the streams.

We began considering this hypothesis in the summer of 2002 when Merritts began a project with F&M student Lauren Manion to document the extent of channel-bank erosion along the Little Conestoga Creek. At that time, the goal was simply to test the hypothesis that sediment in the Little Conestoga is derived largely from the stream corridor. Sediment in stream corridors might have accumulated during the past few centuries as a result of land clearing, farming, and other post-colonial activities, but the mechanism for storing this sediment remained a mystery.

COLONIAL MILL DAMS AND MILL PONDS

In the summer of 2002, Lauren Manion and several F&M student field assistants discovered a number of sites along the Little Conestoga stream channel where unusually large amounts of sediment are stored. These sediments are finely layered silts and clays, with alternating shades of red-brown and gray-blue. Such sediments are characteristic of those deposited in small lakes or ponds. In places, the sediment forms walls up to 5 m high above the stream channel bottom (Fig. 2).

Figure 2 Left -- Bedded and laminated fine-grained sediments deposited in the Denlinger Mill pond. Tape in image on left is approximately 5 m long. Right – close up view of laminated silty-clays from the Denlinger Mill Pond. Images from Lauren Manion. Franklin and Marshall College UndergraduateThesis, 2002.

A second F&M student, Christina Arlt, conducted historical research to determine the history of mill dam activities along the Little Conestoga. Her work revealed that at least 300 dams existed in Lancaster County by 1830, with as many as 10 on the West Branch of the Little Conestoga alone (Lancaster County Historical Society). The West Branch of the Little Conestoga is only about 10 km long, so that on average there was one mill pond every 1 km, a figure that graphically illustrates the profound impact mill dams might have had on altering stream dynamics. Our more recent historical study reveals that over 450 mill dams existed on Lancaster County streams (Barton Collection, Lancaster County Historical Society).

Early historic documents allude to the environmental impact these dams had on the Conestoga watershed. As early as the mid-1700s native spawning fish disappeared soon after the streams were lined with dams: “A petition of 1763, by settlers along the Conestoga, complains of its dams, as destroying the former fishery of shad, salmon and rock fish, which were before in abundance, and the tributary streams had plenty of trout, --- all now gone” (Watson’s Annals of Philadelphia, 1857). Nevertheless, mills were vital to colonial economies, lending considerable substance to Lancaster’s claim as the “breadbasket of the Revolution”.

When a mill dam is abandoned and parts of the dam structure are removed, the stream begins to cut through the stack of sediments that once filled the millpond reservoir (Doyle et al., 2003). Such incisions reveal the finely layered sediment that accumulated during the life of the dam and pond. Many of the 450+ mills in Lancaster County are now extinct, and the mill pond sediments are being exhumed by stream incision. In the summer and early fall of 2003, we conducted additional fieldwork and historical research, and began to realize that the volume of sediment stored in these mill pond basins is immense.

At Denlinger’s Mill, the first mill dam site recognized by our group --roughly 5 km southwest of Millersville -- we observed a thick sediment package (Fig. 2) to merge downstream with hand-cut blocks of locally quarried rock, which we interpreted to be the remnants of a man-made dam structure. This interpretation was verified by discussion with local residents who informed us of the history of the gristmill that once occupied this site. We have subsequently obtained copies of historical documents and survey maps dated to the early 1800s (Fig. 3) that describe the operation and location of the mill structures.

Figure 3 Portion of original survey map (ca. 1818) of properties around Denlinger mill. The Little Conestoga Creek is shown running left to right in middle of frame. The West Branch of the Little Conestoga enters the Little Conestoga from the top right, with the Denlinger Mill dam shown at the confluence, and the mill race running from the dam on the right to the mill on the left.

At the base of the mill pond sediment stack we observed tree stumps in growth position and a pristine 5 cm thick layer of carbonized organic debris consisting mainly of leaf matter, which we interpret to be remnants the forest floor and the riverine wetlands that predate colonial settlement (Fig. 4). The current residents of the Denlinger Mill site have documented 4+ m of lateral stream bank erosion of the mill pond sediment stack in the last 25 years.

Figure 4 Stream bank at Denlinger Mill pond section showing dark organic layer at base of ca. 5 m thick section of silty clay. Tree stump in growth positon is visible on the left extending upward from the dark organic layer.

Erosion Rate Calculations from Reservoir Trapping of Sediment at Denlinger's Mill Pond, West Branch Little Conestoga Creek

The amount of sediment trapped behind a dam can be used to estimate the rate of erosion, or denudation, of the contributing watershed area. Denlinger's mill dam was located at the approximate mouth of the West Branch of Little Conestoga Creek and trapped sediment in a pond that extended at least 800 m upstream in the 1700 and 1800s. The drainage basin area upstream of this location is about 31 km^2.

We do not know how much sediment was trapped by the pond (i.e., the trapping efficiency). Instead, we assume that the sediment deposited behind the mill dam is merely a minimum value. In addition, at least one episode of scour carved a wide channel into the pond sediment. The channel then filled again as the reservoir continued to aggrade. The rate of filling of the reservoir was not likely to be continuous and it is possible that the reservoir filled with sediment long before the dam was destroyed in 1902.

The volume of sediment trapped as a prism-shaped wedge behind the dam is about 20,250-40,500 m^3 (range of values represents minimum and maximum estimates). Assuming that sediment has a density of 2000 kg/m^3, and rock a density of 2700 kg/m^3, the amount of lowering of the landscape upstream of the dam would have been about 5-10 mm/Kyr over a period of 100+ years. This is a minimum value of valley denudation because at least 9 other mill ponds existed upstream of Denlingers Mill by the 19th century. Furthermore, the reservoir is not likely to have had a 100% trapping efficiency for the life of the dam. A minimum estimate of 5-10 mm/Kyr is consistent with low values of erosion rates for streams in the Susquehanna River watershed (Figure 1). The modern erosion rates shown in Figure 5 are based on suspended sediment loads at USGS gage stations (see Reuter et al, this volume).

If we assume that the sum of all upstream dams held at least 2-4 times as much sediment as Denlingers mill pond, then rates of erosion are consistent with those for other streams in the Conestoga River watershed that transport as much as 17-24 mm/Kyr (same as 17-24 m/My) as suspended load.

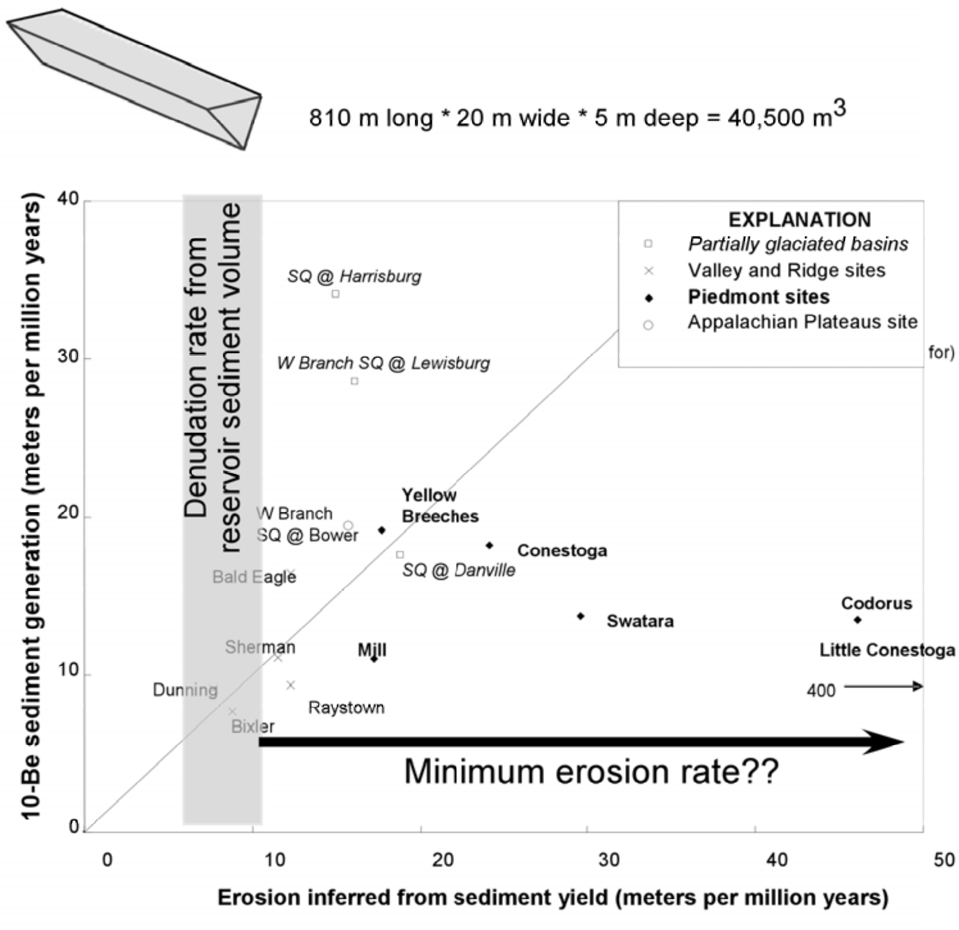

Figure 5. Comparison of erosion rate estimates from 10-Be, suspended sediment, and reservoir trapping. (Figure from Reuter et al, this volume.)

PROPOSED RESEARCH METHODS

Our immediate goal is to determine the amount of sediment stored behind now-abandoned milldams along the Little Conestoga Creek, the rate at which the sediment was deposited during Colonial times, and the rate at which it now is being eroded. We will use the following procedures to achieve these goals:

1. An inventory, or sediment budget, of the volume of loose sediment stored in now-abandoned mill ponds along the western and main branches of the Little Conestoga Creek.
2. Determine the timing of deposition of the mill pond sediments through historical research.
3. Determine the age of the deposits using one or more geochronological methods to directly date the sediments and/or the organic debris buried by the sediments. Such methods include, but are not limited to the radiocarbon (C-14), lead-210 and the cesium-137 methods.
4. We also will use pollen, wood and leaves to reconstruct the landscape conditions before and after land-clearing and mill construction.
5. Acquire and analyze cores of sediment that penetrate the entire stack of millpond sediments at Denlinger's Mill.

CONCLUSIONS

We suspect that sediment pollution from Lancaster County is extensive and extreme, not necessarily because of increased water runoff, but rather because stream channels are now cutting through unusually thick, soft sediments that accumulated behind abundant mill dams. Standard efforts to minimize such erosion, for example, by tree plantings or rip-rap will be futile because the sediments are too thick and the stream banks too steep to have any meaningful effect. New conservation mechanisms might need to be developed that take these new observations into account.

The main goal of our study is to acquire a better understanding of the significance of these newly discovered sedimentary deposits along the Little Conestoga Creek, Lancaster County. This is an effort to elucidate and understand the timing, cause and effect of sediment influx by the Conestoga watershed to the Susquehanna River. This study also concerns the transformation of the Conestoga watershed from primarily agricultural to suburban land use. It is thus an opportunity to construct better environmental policies for protecting watersheds from the Conestoga to the Chesapeake.

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