Legacy Sediments: A Brief History

Most people blame current agricultural practices, sewerage treatment facilities, and development – strip malls, residential subdivisions, and paved roads and parking lots – for polluted waterways and unstable streams, but a greater portion of the problem, especially in the Chesapeake Bay region, goes back to the agricultural period of the 18th through the early 20th centuries, when erosion from large-scale forest clearing and poor farming practices dumped millions of tons of soil into our local streams, valleys, and floodplains. Hundreds of mills and dams along Pennsylvania waterways caused water to slow down behind them and deposit additional tons of sediments. (See Figure 1.) These sediments, deposited throughout our stream and river valleys within the past two centuries, are what we call "Legacy Sediments."

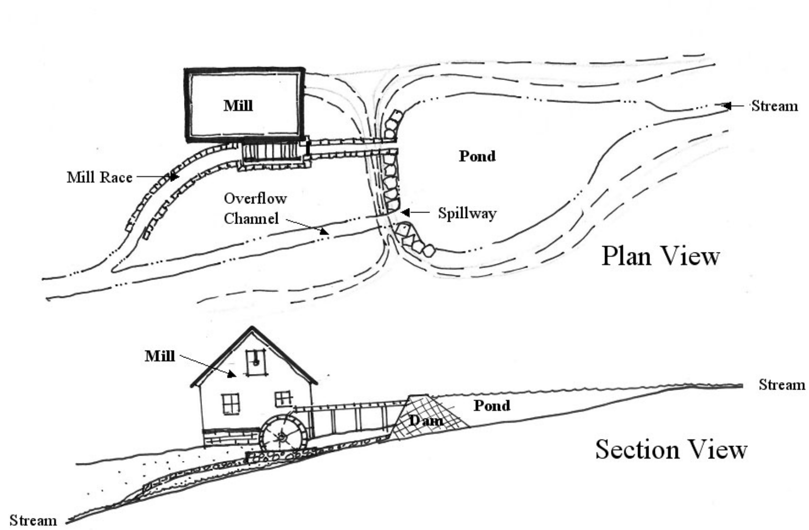

Figure 1. Mill and Dam Construction. Plan and section views make it easy to see how water slowed and ponded behind dams and allowed sediments to build up behind the dams.

Legacy sediments alter the geomorphology – *the processes by which landforms are formed and the materials of which they consist* – and the hydrology – *the cyclic movement of water over and under landforms* – of the valley bottom, producing an array of problems for the streams themselves and for the communities through which they flow. Such problems include increased sediment and unwanted nutrients in the water, bank erosion, debris jams, habitat instability and loss, and flash floods, all of which are common in the small streams of watersheds such as the Susquehanna, Schuylkill, Delaware, and other basins in the Piedmont Province. Many of these problems first surfaced after the onset of urbanization.

By the mid 20th century, conservation farming practices slowed or stopped sedimentation in many streams in these watersheds. Urbanization began in the 1950s, reaching a peak in the 1970s and 1980s, before stormwater management policies were implemented. Stormwater runoff increased dramatically with urbanization, according to models developed by the Lancaster County Office of Engineering and others. Before urbanization, stream channels had been building up – rising in elevation, or "aggrading" – on top of deposited sediments for several centuries. But then, with large-scale sedimentation and erosion halted, these channels began cutting down through the accumulated sediments ("degrading"), commensurate with the flow forces of increased runoff and the removal or crumbling of old dams. Stream channels today are still cutting rapidly through thick stacks of legacy sediments, exposing peats, sands, and gravels of the submerged, pre-settlement valley floors. (See Figure 2.)

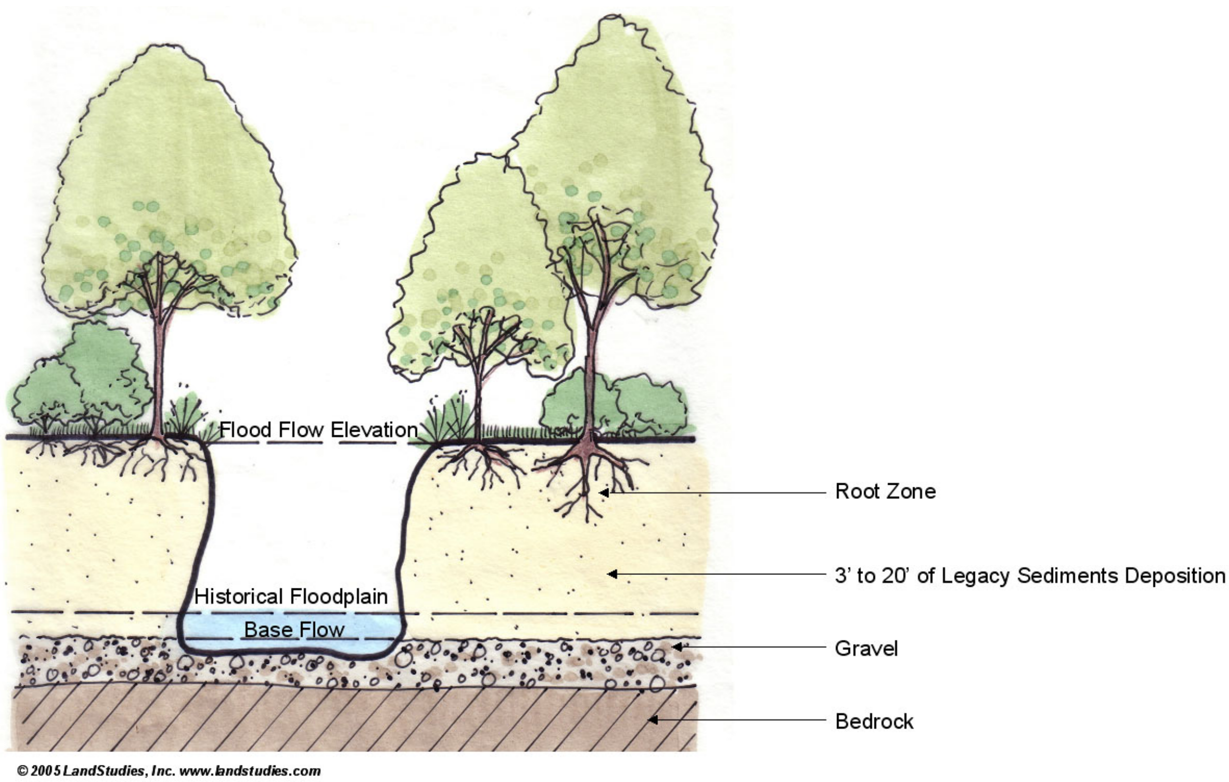

Figure 2. Existing Conditions.

Stream channels are eroding or have eroded down through sediments that collected behind mill dams, leaving their alluvial floodplains high above the current base flow water elevation, and disconnecting riparian root systems from groundwater flows. The processes of frequent floodplain inundation, relieving in-channel stresses; groundwater infiltration through porous floodplain material; and nitrogen removal from groundwater through root systems and bacterial processes are lost under these conditions that are prevalent today throughout the Northeastern United States.

When the channel eventually cuts down to its historical, pre-settlement floor, the gravels at that elevation erode easily, allowing the stream to begin undercutting the banks of the slightly more cohesive, finer grained legacy sediments. In Lancaster County, Pa., bank collapse and erosion now occur along at least 80 percent of the 644 miles (1036 km) of stream channels in the Conestoga watershed. We estimate that 10 percent of the sediment stored along valley floors since 1710 has been removed by channel incision and widening that closely resembles arroyo-cutting in the arid southwest (lateral bank erosion rates of >0.5 m/yr measured at multiple sites). The large volume of sediment trapped in the valley bottoms for several centuries has become a major source of suspended sediment load in local streams and in their downstream receiving water bodies during the past 35 years, and will remain so unless substantial remediation efforts are made. This same phenomenon of channel incision, channel bank erosion, and bank collapse is occurring throughout the Piedmont region of Pennsylvania and Maryland, and beyond.

The deleterious impacts of legacy sediments on stream systems and their receiving waters are numerous and seriously affect groundwater recharge, flooding, water quality, aquatic environments, and native vegetation. Pre-historic floodplain areas that are naturally intended to store water are now filled with legacy sediments. Streambeds that are perched above their historical gravel levels interrupt the natural interplay between stream flow and groundwater recharge. Clays and sediments built up between the gravels and current, historically formed bank tops (often misnamed "floodplains") prevent flows in the channel or on the surfaces of the legacy sediments from entering into the aquifer. Flow is directed, instead, into the channel and its downstream receiving waters.

The sediments now filling former groundwater recharge areas contribute to many of our current flooding problems. Individuals and entire communities grapple with frequent nuisance flooding, and often worse, because 1) less water is able to enter the aquifer as groundwater recharge, and instead is added to stream flow, and 2) legacy sediments have now filled the former floodplains, which used to serve as a storage area for water. As a result, many millions of acre-feet of storage space for groundwater have been filled and lost in watersheds.

Gravels that once served as channel beds still convey groundwater. Because modern streams are perched above the gravels upon which they once flowed, the streams no longer receive the flow of cold groundwater they once did, but rely mostly on warm runoff. The groundwater still flows along the gravels below the existing streambed. A stream that is detached from its historical gravels and base flow has impaired aquatic resources.

Old floodplains hold pre-settlement, 17^{th} century seed-beds, which can re-germinate under the proper conditions. Today's stream and floodplain degradation and erosion remove the historical seedbed and replace suitable, usually native, floodplain and riparian buffer vegetation with opportunistic, often invasive and unwanted species. This same erosive process removes or destroys historical and archeological evidence that also resides in the historical floodplain.

Floodplains and stream banks that typically should be 15 to 24 inches (0.3 to 0.6 m) high are, because of legacy sediments, three to 20 feet (1 to 6 m) higher than the historical floodplain. The result is bank erosion during all storm events and long-term effects on fish and other aquatic life due to increased turbidity that persists from beginning to end of precipitation events.

The legacy sediments stored along streams and abnormally high stream banks contain massive amounts of phosphorus, which is released during channel erosion. Additionally, artificially high banks separate plant root zones from the nitrogen in groundwater. Thus, instead of nitrogen being taken up by plants, groundwater flowing through the sediments transports the nitrates, along with phosphates, into streams. Bacterial processes also assist in denitrification and nitrate reduction, but elevated floodplains seldom experience the saturated conditions that facilitate this process.

The Realities of Stream and Floodplain Restoration

Many stream "restoration" efforts in the Piedmont region show limited success because the effects of legacy sediments are not considered. In order to restore a stream, we must first understand what the stream looked like before settlement and land-clearing. (See Figure 3.)

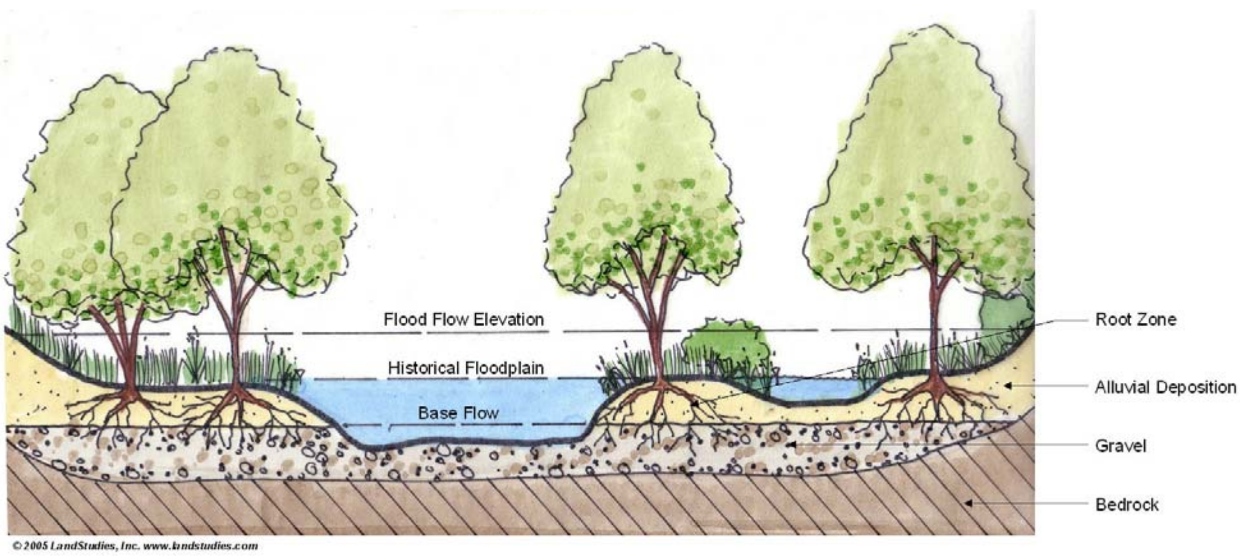

Figure 3. Pre-Settlement and Restored Conditions.
Stable, pre-settlement stream and floodplain systems were characterized by: a low, porous floodplain in close contact with surface water in the stream channel, allowing for frequent inundation of the floodplain during high flows; riparian vegetation with roots zones in contact with ground water that enabled groundwater denitrification through root uptake and bacterial processes; and a channel bed composed of cobble and gravel, which helped protect the underlying bedrock from erosive flow forces.

Most streams will never be restored to their pre-settlement state, but we argue that any remediation effort must "connect" a stream to it's pre-settlement valley floor, otherwise the stream will remain out of equilibrium, and will continue to incise downward and erode laterally. In essence, the banks of most streams in the Piedmont, as they exist today, were determined not by what is required to carry prevailing loads of water and sediment, but rather by the heights of hundreds of centuries-old mill dams that were built to utilize water power throughout the region. In other words, the current channel geometries (bank height and channel width) are merely historical artifacts, and are of little value in estimates of true, stable channel size.

Post-settlement, historical land-use impacts on watersheds must be taken into account in any stream restoration effort. In the Pennsylvania Piedmont, most streams are perched above their historical bed elevations, and restoration of various reaches of the watershed must be completed in a specific order if the restoration is to be effective. For example, if a downstream reach is perched above the historical bed elevation, the reach immediately upstream should not be restored until the downstream reach is corrected to its historical base elevation. It is fundamentally necessary, then, to identify which reaches have streambeds that are too high and which are at the historical bed elevation. Other typical problems include existing dams or culverts and utility crossings that prevent streams from reaching their historical bed elevations. Stream restoration is difficult to complete with long-term stability if the stream is perched above its historical elevation, regardless of efforts to stabilize stream banks. Another important factor in implementing long-term restoration is to restore stream systems that are producing and transporting large bed material that should not be transported. The restored reaches are only going to be able to transport the natural bed load and not the large material carried under degraded conditions.

Our belief is that flooding and bank erosion will not be exacerbated because of urbanization or development along streams restored in this manner, because we predict that floodplains that have been reconnected to their historical levels will be capable of handling increased flows. Water quality and pollutant loads may require stormwater management prior to entering the stream system.

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