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Stream Restoration

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The Institute provides a forum to conduct interdisciplinary research, applied scholarly analysis, public service and educational outreach on environmental and sustainable development issues at the local, state, national and international levels.

KIESD is comprised of eight thematic program centers: Environmental Education, Environmental Science, Land Use and Environmental Responsibility, Sustainable Urban Neighborhoods, Pollution Prevention, Environmental and Occupational Health Sciences, Environmental Policy and Management, and Environmental Engineering.

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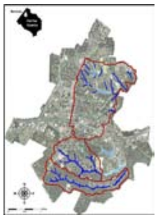

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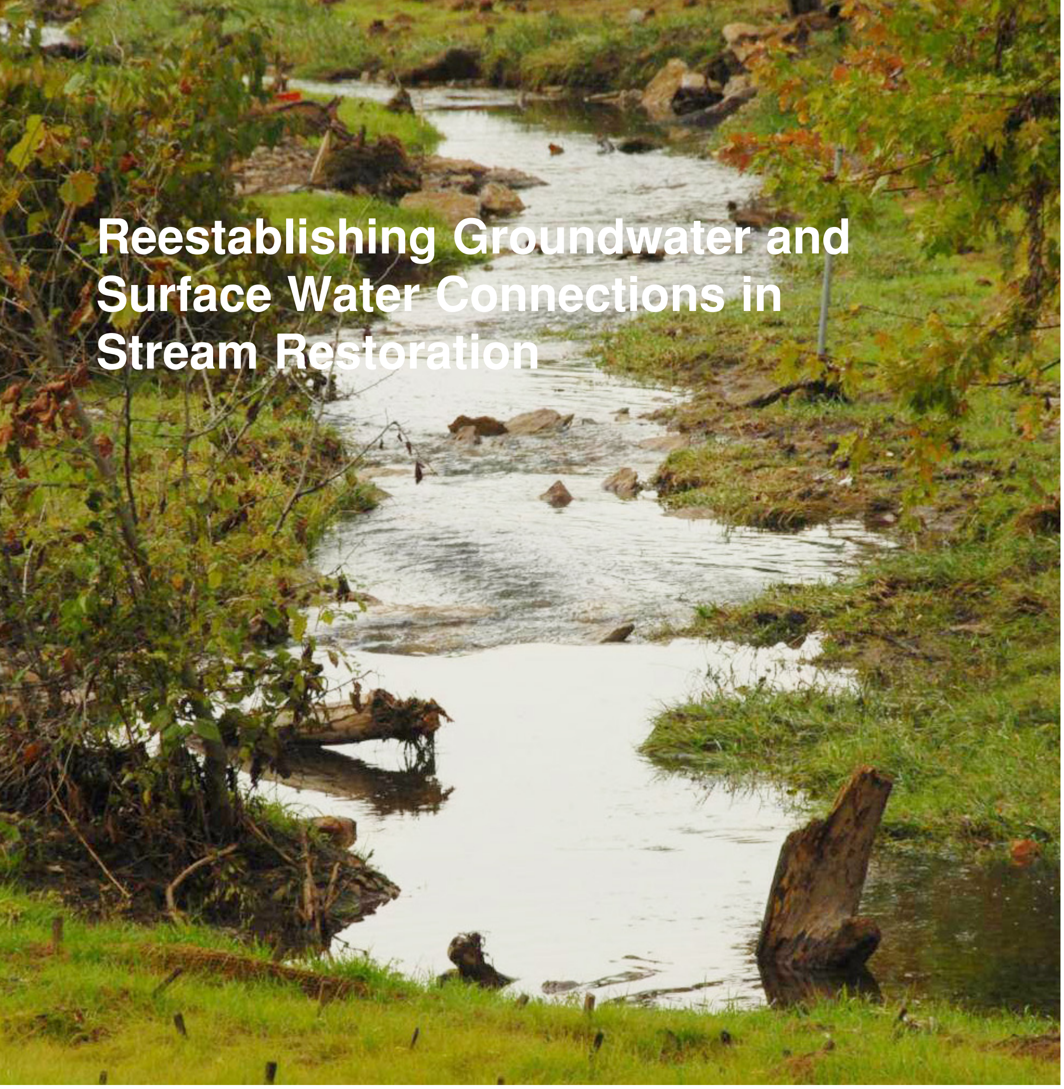
Cover:
Before and after views of the Mill Creek restoration project.



Reestablishing Groundwater and Surface Water Connections in Stream Restoration

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Introduction

One of the most significant effects human activities have had on streams in the eastern US has been the burying of valley bottoms in sediment. In Kentucky, as elsewhere, 19th-century clearing, burning, farming, and grazing of hillsides led to soil erosion and the accumulation of those fine sediments on valley bottoms (Trimble 1974, 1981; Costa 1975; Magilligan 1985; Jacobson and Coleman 1986; Knox 1987). In some valleys, layers of this post-settlement alluvium (Happ et al. 1940) eventually filled the ponds upstream of thousands of dams built to power mills, transport logs, or create fish ponds or farm ponds (Parola et al. 2007; Walter and Merritts 2008). At stream restoration sites in Kentucky, some valley bottoms have been found to have filled with enough post-settlement alluvium to increase their elevations by as much as 3 meters above pre-settlement levels (Figures 1 and 2).

This alluviation, combined with relocation and straightening of stream channels, radically altered stream and wetland systems. Valleys that previously would have stored water and organic material in gravels and sands became filled with sediments that were more cohesive and less permeable and conveyed flow more efficiently downstream. When channels on these deposits were straightened, dredged and cleared of large woody debris for navigation and flood control, and dams were abandoned and breached, the processes that maintained the channel bed and banks were altered. Streams that would have carried minor amounts of gravel or fine sediment (Walter and Merritts 2008) prior to settlement began eroding post-settlement alluvium from their beds and banks, releasing the recently accumulated silt and sand as well as older, underlying alluvial gravel. This incision and widening (Schumm 1999) through the post-settlement alluvium increased the amount of sediment transported and stored in the channel by increasing channel bank heights and reducing the frequency and duration of floodplain inundation. Silt and sand from eroding banks and tributaries was stored predominantly within the channels, as bank heights limited its transfer to floodplains. As bank heights increased, so did the ability of flows to erode the channels, many of which incised all the way to bedrock. The increased bank heights also increased the distance from the roots of floodplain vegetation to the groundwater aquifer.

The increased supply of sediment, the reduced frequency of floodplain inundation, and the extensive exposure of bedrock in channel beds all contributed to degradation of both riparian and aquatic ecosystems (Bravard et al. 1999). Vegetation growing on top of the post-settlement alluvium deposits typically has rooting depths that are insufficient to prevent bank erosion. This condition may result in significant fine sediments and nutrients loads being transported to downstream water bodies such as wetlands, reservoirs or estuaries. The supply of fine sediments from high, unvegetated banks and the reduction of overbank flooding and associated fine sediment deposition may contribute to the high

Figure 1. Fine-grained sediment deposits upstream of historic dams. Mike Croasdaile is standing on the pre-settlement floodplain identifiable from exposed saw-cut stumps in the bank. Measurement rod length is approximately 2 meters.

Figure 2. Brown historic fine-grained sediment overlays historic wetland sediment in the banks of Cane Creek, a tributary of the Red River. William Vesely is standing on the historic wetland floodplain. Measurement rod length is approximately 2 meters.

suspended sediment concentrations that constitute a major water quality problem in many US streams. Bedrock exposed in the stream bed provides limited habitat diversity, and woody debris that would normally enhance deposition of gravel and cobble and the formation of bed forms has been removed, resulting in a subdued riffle-pool sequence and reduced support for aquatic communities (Shields et al. 1994).

Loss of Aquifer-Dependent Hydrologic Functions

Streams on post-settlement alluvium deposits have lost the primary hydrologic functions that support stream, wetland, and riparian system interactions. Much of the degradation of stream and floodplain biota can be related to the disconnection of channels from their groundwater aquifers as a result of alluviation and channel manipulation (Bravard et al. 1999). The pre-settlement floodplains beneath the post-settlement alluvium are commonly composed of a relatively thin layer of organic rich peat or silty clay on top of a gravel layer over bedrock. The water table, controlled by the stream water surface, is often close to the bedrock layer. The bedrock can be of much lower permeability than the overlying alluvium and can act as an aquitard. The variation in its surface elevation across the valley affects the thickness of the aquifer: the aquifer thickness is greatest where the bedrock elevation is lowest. In many valleys, the bedrock tends to be higher along the valley hillsides and lower in the lowest elevation regions of the valley bottom. Stream reaches that were straightened were typically moved away from the center of the valley bottom and aligned adjacent to the valley wall, where the bedrock was higher. This relocation and the deposition of alluvium in the valley bottoms perched the channels above the gravel aquifer, impeding interaction between the channel and the aquifer.

Where the stream is perched on bedrock or clay, the low hydraulic conductivity of the bedrock or clay severely restricts the transfer of groundwater flow, so the hyporheic zone (Kasahara and Hill 2007; Kasahara and Wondzell 2003) is limited to flow through whatever gravel or sand deposits overlay the bedrock or clay. If surface flow in the channel is sufficient to maintain flow over each riffle during low-flow periods, then it will maintain groundwater levels at or above the riffle crest elevation. When surface flow is insufficient to maintain flow over riffles, however, then other factors, such as the conductivity of the valley aquifer, begin to control the elevation of the water table. Thus, the separation of the channel and aquifer can have particularly adverse effects under extreme low-flow conditions, when the water table in the valley drops below the perched streambed, and flow in the channel is restricted to groundwater from the hillside and upstream channel flow and may actually drain into the valley aquifer. As a result of the reduced availability of flow, streams become dry in the summer except in isolated pools that are deep enough to penetrate into the aquifer. The limitation of the transfer of flows between the aquifer and the channel also results in higher water temperatures in the summer and potential freezing in the winter.

The lowered water table and increased bank heights contribute to loss of riparian vegetation (Reilly and Johnson 1982), which may result in a reduction in species diversity as less tolerant species suffer extensive mortality (Miller et al. 1995). Alluviation rendered significant areas of the valley bottom inhospitable for hydrophytic vegetation and wetland perpetuation because groundwater levels are too far below the surface to support wetland hydrology. Zones most intensely affected by this lowered groundwater level are those directly abutting incised stream channels, which only provide surface water to the riparian area during the brief, infrequent periods when extensive overbank flooding occurs. Wetlands that do occur on post-settlement allu-

vium deposits generally form in topographic depressions or in seeps from hillsides and are not hydrologically connected to the stream or the lower gravel aquifer. They depend on the presence of low-permeability soil layers to retain water near the surface.

Where channels were not relocated to the valley wall, they may still receive groundwater flow, but where they incise to bedrock, the thickness of the aquifer may be limited, and the low frequency of floodplain inundation limits groundwater recharge. Under drought conditions, the channel may dry as the water table drops.

Restoration of Hydrologic Functions

Some of these conditions are coincidentally addressed by common stream restoration strategies whose primary objective tends to be stabilization of the stream channel without extensive reconstruction of the valley bottom (Copeland et al. 2001; Soar and Thorne 2001; NRCS 2007). While these approaches focus primarily on constructing a sinuous channel with riffles and pools and a higher bed elevation, this type of channel reconfiguration can also restore some hydrologic functions. At a minimum, raising the channel bed elevation is effective in reducing bank heights, thereby increasing the frequency, duration, depth, and extent of floodplain inundation. Lowered bank heights and increased channel sinuosity also will attenuate flood flows to downstream reaches. The extent to which other hydrologic functions may be restored by this type of approach, however, depends not only on the channel design but also on existing valley conditions such as the depth and permeability of post-settlement alluvial deposits.

Sites where surface and groundwater hydrology are most easily improved without extensive disturbance of the valley bottom are those where valley bottom soils are shallow (less than 0.5 meters) and underlain by gravel and cobble that compose a highly conductive aquifer. These conditions may be conducive to increasing surface water retention, groundwater storage, frequency of flow exchange between the channel and the aquifer, and base flow duration. Where these favorable conditions exist, raising the channel bed elevation may raise the water table boundary condition, thereby increasing the potential for groundwater storage. Reconnection of the entire channel bed with the pre-settlement aquifer establishes an extensive hyporheic zone from the channel through the floodplain. This enhances recharge of the aquifer through the entire streambed and allows constant exchange of flow and transported nutrients between the channel surface water, the aquifer, and floodplain wetlands. Excavation of deep pools will increase the exchange of in-channel surface water and groundwater. Pools will be more likely to remain at least partially filled during periods of low flow and may provide critical refugia during drought, and increased frequency and duration of groundwater supply to the channels will moderate in-channel surface water temperature extremes during summer and winter. Channel planform design can influence the interaction of the channel water and the groundwater in the pre-settlement aquifer. Design of single or multiple channels that traverse back and forth across the floodplain provide greater interaction of the channel with the floodplain and the hyporheic zone than a channel that is straight or occupies a small width of the floodplain.

Diverse surface hydrologic conditions can be created by manipulating the topography to support the functions of diverse wetland areas, including backwater channels, abandoned oxbow channels, and bottomland hardwood swamps. Floodplain depressions can be constructed with minimal disturbance to the valley bottom, and sections of the existing channel can be blocked to create a series of floodplain ponds. A diverse mosaic of dry, moist, and shallow-water areas where soils are saturated to variable depths for different durations and frequencies will support a greater diversity of flora and fauna. Variable floodplain topography and constructed ponds increase both floodplain storage of surface water and subsurface storage of water. The ponds release water gradually into the surrounding soil, which should raise the elevation of the water table and increase the duration of base flow in the channel, especially during low-flow periods. Each of these changes is also likely to increase seasonal depth and duration of soil saturation and, where bank heights are less than 0.5 meters above the low-flow water surface elevation, allow the lower portion of the riparian vegetation roots to extend into the aquifer, which will support native vegetative growth, increase sediment retention, increase nutrient retention and processing, and protect the channel banks and the floodplain from erosive flows.

Each of these hydrologic functions depends on hydraulic connectivity of a permeable hyporheic zone with the valley groundwater aquifer. Therefore, at sites where valley bottom soils are cohesive, impermeable, and/or deep, restoration efforts that seek to restore valley aquifer-dependent hydrologic functions will require that both the channel and the floodplain be re-constructed. This is particularly likely in areas where post-settlement alluvium has deposited in ponds upstream of dams. Dam deposits are typically composed of at least two layers of fine-grained sediment: a lower clay-rich layer and upper laminated silt or silty sand layer (Oberholtzer and Parola 2008). The clay-rich layer is believed to have been formed from the separation of fine sediments entering the pond prior to its substantial infilling. As the pond filled, flow velocities would have increased, and the laminated layer of silts would have deposited over the clays. The characteristics of these fine-grained sediment layers vary with many factors including the length and depth of the pond. At many locations, a loose layer of fine sediments is present on top of the laminated silts. The clay-rich layer forms an aquitard over the pre-settlement floodplain. This aquitard separates an upper perched aquifer in the silt or silty sand layer nearer the current valley surface from the aquifer formed by the pre-settlement gravel layer. Bedrock underlying the gravel often acts as an aquitard that limits the lower elevation of the valley aquifer.

At these types of sites, the restoration of hydrologic functions may be accomplished by excavation of the post-settlement alluvium. That excavation may not always be feasible, however, especially where culverts, rock protection for bridges, dams,

Figure 3. Approximately 1 meter of sandy fine sediment deposited over the valley bottom was excavated to expose pre-settlement gravel. Logs were placed over gravel and were at least partially buried to provide grade control across the valley bottom and to provide habitat wherever they were exposed by stream flow.

Figure 4. Slabcamp Creek restored valley bottom and channel reestablished on pre-settlement gravels. Photo taken approximately one year after construction.

backwater sediment deposits, or other controls cause local base levels to be elevated above the pre-settlement gravel layers. When downstream base level constraints or excavation costs limit the depth of floodplain excavation and thus preclude the reconnection of the entire stream channel and floodplain with the gravel aquifer, hydrologic functions nevertheless may be restored by changing not just the surface hydrology but also the groundwater hydrology of the site. In these cases, two essential factors in restoring aquifer-dependent hydrologic functions are the construction of subsurface groundwater dams and the creation of an extensive hyporheic zone. A layer of coarse gravel and/or cobble constructed to provide grade control can serve as a hyporheic zone for the channel. While other factors such as high or low sediment loads will also influence the potential for hydraulic connectivity of the channel with the groundwater, the combination of the constructed coarse layer and the groundwater dams can provide hydrologic conditions that are functionally equivalent to those at sites where the channel and pre-settlement gravel aquifer intersect.

These design approaches have been implemented in restorations completed by the University of Louisville Stream Institute, including Slabcamp Creek, Mill Branch, and Mill Creek.

Slabcamp Creek (Excavation to Pre-settlement Gravels)

One objective of the Slabcamp Creek restoration in the Daniel Boone National Forest was to increase the duration of flow in the sections of channel that typically dried out during summer months because the channel was perched on a deposit of fine, sandy sediment. Test pits revealed that approximately 1 meter of sand overlaid gravel deposits that varied in thickness from less than a few centimeters to about 1.5 meters. The fine-grained sediment that buried the valley had been eroded from the steep hillsides, transported by steep tributaries (3-8% slopes), and deposited in the valley bottom. To increase the period of flow during the summer and fall dry periods, the channel was re-established on the underlying gravel. To accomplish this, all of the fine-grained material was removed from a width of approximately 40-60 feet in the central area of the valley to expose the underlying gravel (Figure 3). Trees removed during the excavation were placed over the gravel, and about 0.2 meters of topsoil was pushed back over the wood and gravel to reestablish a low floodplain. The channel was formed by leaving the gravel exposed. The channel banks, bed features, and habitat (Figure 4) were allowed to form through scour and deposition around completely buried and partially exposed woody debris.

Mill Branch (Groundwater Dams)

Soil profiling using both pit and trenching methods revealed 2 to 3 meters of sandy silt over most of the valley bottom at Mill Branch in Knox County, Kentucky. This stream, which is one of less than 30 headwater streams containing the federally-listed threatened blackside dace, dried during each summer except for a few pools (Figure 5). Full excavation of the fine sediment to reestablish the stream in the gravel and cobble aquifer would have been cost-prohibitive and was not possible because the gravel aquifer was lower in elevation than the base flow elevation of the much larger Stinking Creek with which Mill Branch confluences at the downstream end of the restoration.

The objectives of increasing the period of flow during the summer and fall dry periods and creation of adjacent wetland habitat were met through a combination of lowering the elevation of the channel and a portion of the valley bottom and by raising the groundwater controls. The floodplain was lowered by excavation of approximately 0.6 to 1.5 meters of fine sediment for a width across the valley that varied from 15 to 20 meters.

Figure 5. One of two pools in the pre-restoration Mill Branch channel that provided refuge for the threatened blackside dace during the summer and fall drought of 2008.

Figure 6. Construction of cross-valley groundwater dam at Mill Branch. Gray, organic-rich gravel and wetland soils were removed and placed on the surface. Brown, clayey silt was placed and compacted in a trench to form the groundwater dam.

Figure 7. Mill Branch channel and valley bottom two years after completion of restoration construction.

Pools were excavated to a depth of approximately 1 meter below the excavated floodplain. Groundwater dams were constructed (Figure 6) across the valley in two locations to (1) interrupt and block the pre-settlement gravel aquifer, (2) force the groundwater flow to exfiltrate in the excavated region of the restored valley bottom, and (3) maintain water in pools during low-flow periods. Because silty, sandy sediment extended from the lower gravel aquifer up to the restored channel pools, the groundwater was hydrologically connected to the pools after the groundwater dams were installed. When pools were being excavated, water partially filled the pools. Since the completion of the restoration in 2008, the stream has flowed continuously (Figure 7), even through a major drought in summer 2009.

Mill Creek (Hyporheic Aquifer)

To increase the capacity for interaction of a channel and groundwater flow, a “hyporheic” aquifer was created at Mill Creek, a small urban stream in Lexington, Kentucky. The combination of a constructed high-conductivity, organics-rich aquifer and groundwater dams was used to enhance groundwater and surface water interaction and to increase the potential for removal and processing of nutrients from urban runoff. Fine-grained sediments were removed, and the valley floor was covered for a width of approximately 10 meters with a mixture of locally-quarried limestone cobble and wood chips. Groundwater dams (Figure 8) were then used to enhance groundwater interaction in the channel by forcing flow from the aquifer into each pool and from the channel into the aquifer at each riffle. Although the enhanced hyporheic aquifer is highly engineered, it is not visible from the surface (Figure 9).

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Art Parola is a professor of civil and environmental engineering at the University of Louisville and director of the Stream Institute. He received his PhD from Penn State University in 1990. His research, teaching, and consulting activities have been focused on applied hydraulics, including bridge scour, stream morphology, and stream restoration. As director of the Stream Institute, he is responsible for leading a diverse team of researchers focused on improvement of stream morphological assessment techniques, stream restoration design, and stream crossing design for aquatic organism passage.

Figure 8. Small groundwater dam constructed at riffle.

Figure 9. Mill Creek restored channel.

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The Stream Institute, University of Louisville's Stream and Wetland Restoration Program

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The Stream Institute is a pioneering applied research program in the University of Louisville Department of Civil and Environmental Engineering. The faculty, staff, graduate, and undergraduate students who form the Stream Institute have a passion for restoring streams and wetlands across Kentucky.

The Stream Institute team (Clayton Mastin, Jeong Park, Dr. Michael Croasdaile, Dr. Art Parola, William Vesely, Chandra Hansen, and Dr. Raja Nagisetty) are currently designing and restoring stream and wetland projects while instructing training sessions, graduate and undergraduate classes, and assisting other natural resource managers who are also involved with restoration.

Looking Back

A little bit of history is fundamental to understanding the role of the Stream Institute program. "I can't believe it," is the reaction most people have after learning that a majority of creeks in Kentucky were moved from their original locations. Driving along the interstate it is evident how creeks bordering fields are straight and flow along the base of the hill. These creeks were moved years ago to improve lands for agriculture.

Kentucky's valleys looked decidedly different in the 1700s than they do today. The stream side or riparian areas were forested with large trees adapted to growing in wet soils such as swamp white oak and pin oak, along with alder, buttonbush, and willow shrubs. Wetlands were common on the floodplain, and these habitats were teaming with beaver and waterfowl. There were different types of wetlands that included shallow marshes, wet meadows, and vernal pools that dried by late summer.

Creeks flowed near the center of the valleys like snakes, winding from side to side as they followed the low and flattest ground or the branched in to several small streams. Bends and small islands were common, with cut-off sections of stream forming small linear ponds and wetlands. The flow of the creek was frequently interrupted by beaver dams and wetlands. The banks on the creeks were low, where floodwaters regularly flowed over them and spread out over the floodplain after a storm.

There were many compelling reasons why people moved creeks,1 but the primary reason being so that they could grow crops in the wet ground. Corn, barley, oats, soybeans, and wheat do not survive in saturated soils, and the same crops wash away in floods. Farmers realized many benefits of moving creeks along the base of a hill including soils would dry sooner; the frequency of floods would be reduced, the field would be larger and easier to farm, and a deep outlet would be available for installing buried drain lines.

When creeks were moved, they were also straightened. The waters in the straightened creeks flowed faster, eroding a much deeper and wider channel, allowing them to carry even more water during heavy rains just like a ditch. An unfortunate consequence to stream channels washing deeper was that steam banks would cut vertically, become unstable, eventually collapsing and washing downstream. The shear stresses on vertical creek banks under flood conditions become so powerful that large trees will fall into the creek and wash downstream or block the channel. Moved creeks evolve into large ditches that move both surface water and groundwater out of a valley while draining adjacent lands.

It's rare to find a creek in Kentucky that has not been moved to create fields for farming. The natural meandering of small streams over areas that were level enough to farm would have saturated the soil, so that could not be farmed. Horses, mules, and oxen would become hopelessly mired in the mud unless creeks were moved and channeled to drain the soil. Clayton Mastin, University of Louisville graduate student, found that over 70 percent of perennial streams with drainage areas of 13 square miles or less within the Appalachian Highlands Region had been modified in the past.2

The numerous moved creeks provide poor habitat for fish and wildlife. They contain few pools, and the pools that are present are shallow. The gravels that are essential to fish spawning and invertebrate survival have been washed downstream. There are scant logs, root masses, branches, and leaves where animals can feed and hide.

Times changed

The Clean Water Act of 1977 required that unavoidable impacts to streams and wetlands that involved filling and dredging activities such as mining, urban development, and road construction be mitigated by restoring habitats on land areas that would be protected. This law started the business of building wetlands and streams to replace those being lost.

For years, much of the required stream and wetland mitigation in Kentucky took place on small tracts of private land in projects often supervised by those impacting the habitats. To help improve the program the U.S. Army Corps of Engineers entered into an agreement with the Commonwealth of Kentucky to provide developers with an option for required mitigation. Those who planned on impacting streams and wetlands could now pay into a fund, managed by the Kentucky Department of Fish and Wildlife Resources (KDFWR), who would then complete the mitigation work. By pooling the funds from a number of permitted activities, the KDFWR would be able to complete larger stream and wetland projects that would provide greater benefits to fish and wildlife.

In July 2000, the Kentucky Legislature passed KRS 150.255,3 which established The Kentucky Wetland and Stream Mitigation Fund. The KDFWR Stream and Wetland Restoration Program manages this fund to provide a consistent and successful approach to fulfill mitigation requirements associated with Section 404 and 401 requirements of the U.S. Army Corps of Engineers and the Kentucky Division of Water.4 The Stream Institute is working in partnership with the KDFWR to complete a number of projects under this program.

Training

A primary mission of the Stream Institute is offering education to those who are involved with wetland and stream restoration, helping them to be successful while improving techniques for restoring these ecosystems. The Stream Institute initiated the Natural Channel Design Working Group in 2000 in partnership with Margi Swisher Jones of the Kentucky Division of Water, providing a forum for the exchange of ideas between Federal, State, and local government agencies. The Group meets bimonthly to participate in training sessions or to examine stream and wetland projects around Kentucky.

Dr. Parola (hand outstretched) instructs a group from the Kentucky Department Natural Resources at Dix River.

The Stream Institute has partnered with the Center for Wetlands and Stream Restoration for four years to instruct the Wetland Restoration Institute on the Daniel Boone National Forest in Bath County, Kentucky. This intense, 60-hour session engages participants from across the Nation in the design, monitoring, and actual construction of wetlands from start to finish. Course evaluations consistently show that participants grade the training with an overall score of 98 percent. The Stream Institute offered a new three-session class beginning in April 2011, titled Assessment and Sediment-Based Design of Stream Restorations Short Course. This training iswas funded by an EPA grant through Kentucky Division of Water.

Innovative Techniques

The Stream Institute changes historically modified creeks so that they will once again flow across their valleys after a heavy rain. This reduces the erosion caused by floodwaters being confined to straightened streams with steep banks, where the water velocity is so powerful that large trees and boulders are washed downstream. Lowering the height of the stream banks and placing gradual slopes on them will cause floodwaters to spread across the valley. The floodwaters fan out and become shallow and slow so that they no longer cause erosion in a restored valley.

The Stream Institute is pioneering ways to reconnect the surface water in streams with groundwater for restoration. Recognizing that channeled and moved creeks are often perched above the water table; actions are being taken to join surface waters with groundwater. This is accomplished by excavating a new floodplain for the creek and by constructing groundwater dams. Once accomplished, water remains in the creek for longer periods, which is of considerable benefit to fish and other aquatic organisms. A bonus to restoring the elevation of the water table is that wetlands can be established by simply creating shallow excavations that expose the groundwater.

“It is crucial to practice adaptive management,” says Art Parola when talking about implementing stream and wetland projects. The engineers who design the projects also work in the field with contractors to complete the projects. This is not always common practice in the restoration field, where design engineers often do not visit the sitehave limited time at the site during construction. “Expect things to change once you start digging,” says Parola. The adaptive management strategy appears to be working. Torrential rains swept across Kentucky in the spring of 2010. A review of projects designed by the Stream Institute following the severe storms revealed little or no damage. They had been built to survive the much larger flood events.

The Stream Institute is striving to use “green” construction practices. Instead of hauling in massive boulders from quarries at enormous expense to build artificial-looking structures , they are figuring out ways to rearrange existing soil, rock, and wood to return riffles and pools to streams. They are also recycling trees fallen in ice storms and using them in floodplains that are being restored. The actions are improving habitat for fish and wildlife, and sequestering carbon.

A basic step that is being incorporated into the stream and wetland projects is the saving and reusing of topsoil. A topsoil layer is being placed over restoration projects like a blanket. The seeds that are present in the topsoil are quick to germinate and grow. In many situations aquatic sedges and rushes, not observed prior to restoration, begin growing near the restored streams and wetlands, indicating that their seeds had remained dormant in the soil and responded when conditions were favorable for their growth.

The Stream Institute has identified how vital it is to loosen soils that are compacted during construction. Heavy equipment will compact soils, even if only one pass is made over a site. The compacted soils are quick to erode, and slow to grow grasses, shrubs, or trees. Soils are routinely loosened on construction sites. The excavator turns over and loosens soils when finishing restoration, much like one works backwards when washing the floor. The loosened soils will absorb storm water and are less likely to erode. Trees, shrubs, and wildflowers are quick to geminate and grow on the aerated ground.

“There is no such thing as too much wood” says Tom Biebighauser. Recognizing the critical value of leaves, branches, logs, and root masses to fish and wildlife, the Stream Institute routinely adds these organic materials to their restoration projects. Parola encourages contractors to “keep their chainsaw in their truck” when cutting logs for streams. The artificial appearances of a chainsaw cut last for years, while the log that is broken using the excavator looks natural, providing habitat for insects that are eaten by birds, and roosting sites for bats.

Vernal pools, a type of ephemeral wetland, provide critical habitat to crustaceans such as fairy shrimp and amphibians such as wood frogs and spotted salamanders. These shallow pools dry in the fall, and do not contain fish that prey on other species that require wetlands for breeding. The Stream Institute builds a number of vernal pools to complement each stream restoration project they complete.

The Stream Institute is also developing techniques to restore forested wetlands from old fields. They had found that one of the critical steps necessary for restoration involves locating and disabling the open drainage ditches and buried wood, rock, clay, and plastic drainage structures that were buried when the area was farmed. The land is then reshaped with natural appearing ridges, swales, pits, mounds, and vernal pools. The higher ground is then planted to bottomland hardwood trees such as pin oak, swamp white oak, shumard oak, and burr oak. These forested wetlands will someday provide habitat for wood ducks, mallards, and black ducks, along with streamside salamanders, tiger salamanders, and wood frogs.

This ephemeral wetland is one of many restored at Dix River. The wetland provides breeding habitat for amphibians and helps to recharge groundwater.

Heavy equipment is used in the restoration process at Dix River in Lincoln County, Kentucky.

STREAM INSTITUTE PROJECTS

Engineers with the Stream Institute are actively involved with the design and implementation of key ecosystem reconstruction projects across Kentucky. The following is a snapshot describing their program's accomplishments.

Wilson Creek Stream and Wetland Restoration Project

Location: Bernheim Forest

Partners: Bernheim Forest, Kentucky Department of Fish and Wildlife Resources, University of Louisville Stream Institute.

Major Accomplishments: Restoration of moved and straightened stream that was flowing along the base of the hill on bedrock into a sinuous stream with deep pools and gravel riffles now flowing in a natural meandering pathway down the center of the valley. Trees and shrubs native to Kentucky were planted in the floodplain to restore bottomland hardwood habitat for wildlife.

Specialized Techniques: The restoration of small wetlands on the floodplain was introduced to stream restoration. The historic straightened Wilson Creek channel was transformed into a series of wetlands that provide breeding habitat for amphibians and infuse waters into the restored creek. Isolated ephemeral wetlands were established in areas where excess soils had been piled.

Mill Branch Stream Restoration Project

Location: Knox County, Kentucky

Partners: Cumberland Valley RC&D, Eastern Kentucky University, Kentucky Department of Fish and Wildlife Resources, USDA Kentucky Natural Resources Conservation Service, US Fish and Wildlife Service, Bluegrass Streams, LLC, and University of Louisville Stream Institute.

Major Accomplishments: Restoration of stream and the improving of conditions for the federally threatened blackside dace, a small fish that is shrinking in numbers. The species had been restricted to two exceedingly small artificial pools in the creek prior to restoration. Now there is water in the creek year round, and more than ten pools during drought. Fish and wildlife habitat was improved by restoring wetlands in the valley.

Specialized Techniques: The restoration of surface water and groundwater in the creek was accomplished by constructing two groundwater dams to raise the elevation of the water table and lengthen the time that water remains in the creek. A culvert that was a barrier to aquatic organism passage in the creek was changed to be fish friendly. A neighboring farmer's field was improved with soils that had been removed to create a floodplain for Mill Branch.

One of many restored stream pools at Mill Creek Elementary School.

Dix River Stream and Wetland Restoration Project

Location: Lincoln County, Kentucky

Partners: Kentucky Transportation Cabinet, US Fish and Wildlife Service, Advanced Enterprises, Inc., US Forest Service, and University of Louisville Stream Institute.

Major accomplishments: Restoration of more than 55 acres of forested, shrub, emergent, ephemeral, and wet-meadow wetlands and four streams totaling 9,740 feet.

Specialized Techniques: A groundwater dam, over 20 feet deep and 6,500 feet long was constructed to raise the elevation of the water table over a 70-acre area. The groundwater dam was designed to prevent crayfish from draining the wetlands via a subsurface gravel layer, and to block an estimated 60 buried wood and clay drainage structures.

The gravel that needed for stream restoration was mined on site. Dead, large trees were placed vertically in the floodplain to provide habitat for birds. A new valley was constructed to provide long term aquatic organism passage between the deeply incised Dix River and the restored streams.

Mill Creek Stream and Wetland Restoration Project

Location: Millcreek Elementary School, Fayette County, Kentucky

Partners: Fayette County Public Schools, Kentucky Department of Fish and Wildlife Resources, Ridgewater, LLC., EcoGrow, LLC., Sheltowee Environmental Education Coalition, University of Kentucky, US EPA Five Star Wetland Program, US Fish and Wildlife Service, and University of Louisville Stream Institute.

Major Accomplishments: The project transformed 700 feet of eroding ditch on a school grounds into a naturally appearing and functioning Bluegrass stream containing pools and riffles that students can investigate for science and mathematics education. Wetland nursery areas for fish and feeding sites for herons were restored in the floodplain. An ephemeral wetland was established above the stream for amphibian breeding.

Specialized Techniques: Two-dimensional computer modeling was used to design the floodplain and channel. The flat limestone rock needed for steam restoration was mined on site. Groundwater dams were used to raise the elevation of the water table to near the surface, and are preventing waters in the stream from mixing with a buried sewer line. Over 1,000 cubic yards of wood chips left over from an ice storm were mixed into the soils on the floodplain to improve water quality. Hibernation sites for turtles were restored from springs that had been placed in drain pipes.

The University of Kentucky Tracy Farmer Institute for Sustainability and the Environment provided training to Millcreek Elementary School teachers and students about streams and wetlands before, during, and after the project was completed.

Awards: The Millcreek Elementary School Wetland and Stream Restoration Project Team received two awards in 2010: the Earth Day Award from the Kentucky Environmental Quality Commission and the Lexington Environmental Commission Award.

Obion Creek Stream and Wetland Restoration Project

Location: Hickman County, Kentucky

Partners: Kentucky Nature Preserves Commission, Kentucky Department of Fish and Wildlife Resources, Obion Creek Watershed Conservancy District, Jackson Purchase RC&D, Douglas Amphibious, and University of Louisville Stream Institute

This restored stream pool at Slabcamp Creek is ready to provide excellent habitat for fish.

Major Accomplishments: Restoration of a large floodplain that was once a bottomland hardwood forest by reversing the problems caused by the channelization of 1.5 miles of Obion Creek in the 1930s. Elimination of the damage being caused by a large debris jam at a bridge, the need for dredging massive deposits of fine sediment, flooded farmland, frequently flooded road, and dead and dying bottomland hardwood trees.

Specialized Techniques: Using an excavator mounted on pontoons instead of tracks to dig pilot stream channels that reconnected natural channels bypassed by channelization as a low cost and highly effective technique for restoring streams and wetlands on large floodplains.

Slabcamp Creek and Stonecoal Branch Stream and Wetland Restoration Project

Location: Rowan County in the Daniel Boone National Forest

Partners: Kentucky Department of Fish and Wildlife Resources, Sustainable Morehead, USDA Forest Service, US Fish and Wildlife Service, Advanced Enterprises, Inc, and University of Louisville Stream Institute

Major Accomplishments: Over 2.7 miles of stream, floodplain, and associated wetlands are being restored on National Forest System lands. Small, ephemeral wetlands are being restored within the floodplain for fish habitat, and above the floodplain for amphibian habitat.

Specialized Techniques: Large quantities of wood are being used to control gradients in the floodplain instead of rock. The gravels needed for stream riffles are being exposed in place by removing overlying legacy sediments. Sediment supply that is caused by head-cuts advancing upstream is being stopped by restoring small ephemeral and intermittent streams. Tree canopy cover is being maintained during the restoration of these small creeks. Volunteers are planting native bottomland hardwood trees and shrubs.

Awards: The U.S. Forest Service presented the Slabcamp and Stonecoal Stream and Wetland Restoration Team with their Regional Forester Natural Resource Honors Award in December 2010.

Future Program

The Stream Institute is investigating ways to restore streams and wetlands in urban areas, primarily to clean water. Many larger communities have problems with too much nitrogen and phosphorus in their storm water run-off, and are receiving large fines for violating clean water standards. The Stream Institute is helping to design a restoration project at Montessori Middle School of Kentucky in Lexington Working in partnership with Ridgewater, LLC, they plan to clean run-off by directing stream flow through massive filters of leaves, wood chips, and branches that are buried in the floodplain.

The projects that the Stream Institute is completing across Kentucky are improving the environment by increasing fish and wildlife habitat, cleaning run-off, recharging groundwater, and reducing flooding. The dedicated members of the program are training and assisting natural resource managers across the Nation how to design and build stream restoration projects that are self-sustaining and enhance the beauty of their community. The Stream Institute is having a major impact on the present and future health of our habitat and watersheds through its research, teaching and service.

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Floodplain Restoration: Basics, Benefits, and Practical Applications

Mark A, Gutshall, Restoration Ecologist and Ward L. Oberholtzer, P.E., Water Resources Engineer

For some years we have known that all is not well with our rivers and streams but, until recently, we focused our efforts primarily on the water channels. Through the field work we have done and observations we have made at LandStudies, Inc. in Lancaster County, Pa., coupled with the invaluable research of our colleagues, Dr. Arthur Parola at the University of Louisville, and Drs. Dorothy Merritts and Robert Walter at Franklin and Marshall College in Lancaster, we now know that much of the work to repair our streams should first be focused on the floodplains or stream valleys and the "legacy sediments" or post-European settlement alluvium that have filled them.

Floodplain restoration, as described and discussed in the following pages, is based on returning stream channels and floodplains to their historical elevations and locations and creating frequent interactions between the stream, floodplain, and groundwater. The following pages tell the story of stream systems – stream channels and their adjacent floodplains – in the Eastern United States, particularly in the region known as the Piedmont Province (In a renewed effort to restore the Chesapeake Bay to better health, the Environmental Protection Agency has especially targeted three areas in this region as major contributors of sediment and nutrient pollution to the bay: Lancaster and York counties in Pennsylvania, the Delmarva Peninsula in Delaware and the eastern shores of Maryland and Virginia, and the Shenandoah Valley in Virginia and West Virginia).

The Basics describes how stream systems are supposed to work, what happened to our stream systems when we began to settle the East Coast, and why it is important to restore them.

The Benefits describes the multiple benefits of fully functioning stream systems and how they can be realized through reconnecting the interactive components of those systems.

Practical Applications describes how different constituents have benefited from floodplain restoration and details how the golf course industry, specifically, has benefited.

THE BASICS

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, 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 Colonial streams, valleys, and floodplains. Thousands of mills

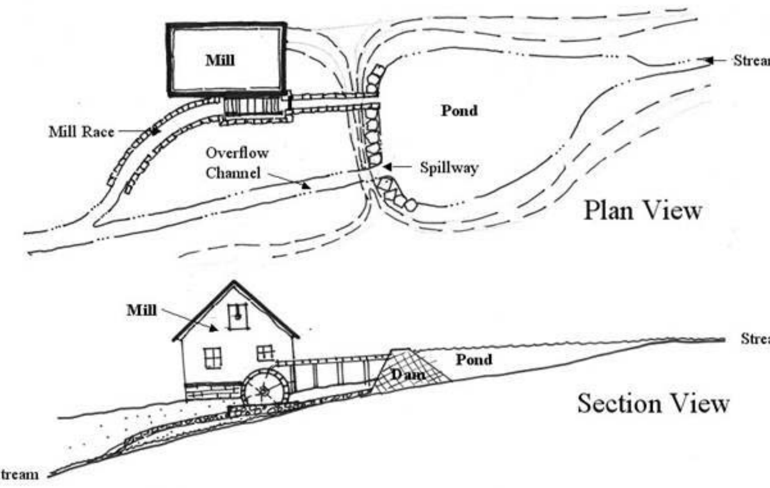

Figure 1. Mill and Dam Construction
Plan and section views make it easy to see how water slows and ponds behind dams allowing sediments to build up behind the dams.

Figure 2. Remains of Breached Dam
This photograph was taken looking downstream at the breached dam breast of a late 19th century dam in Sands Creek, Town of Hancock, New York. Note the high floodplain on the upstream side of the dam.

and dams along waterways caused ponding behind the dams and thus the deposit of additional tons of fine sediments. (See Figure 1.) These sediments, deposited throughout our stream and river valleys within the past two centuries, are what we call “Legacy Sediments.”

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 reduction of flood water detention along with increased flood levels or elevations, all of which are common in the streams of many watersheds 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, Pa., 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. (See Figure 2.) Stream channels today are still cutting rapidly through thick

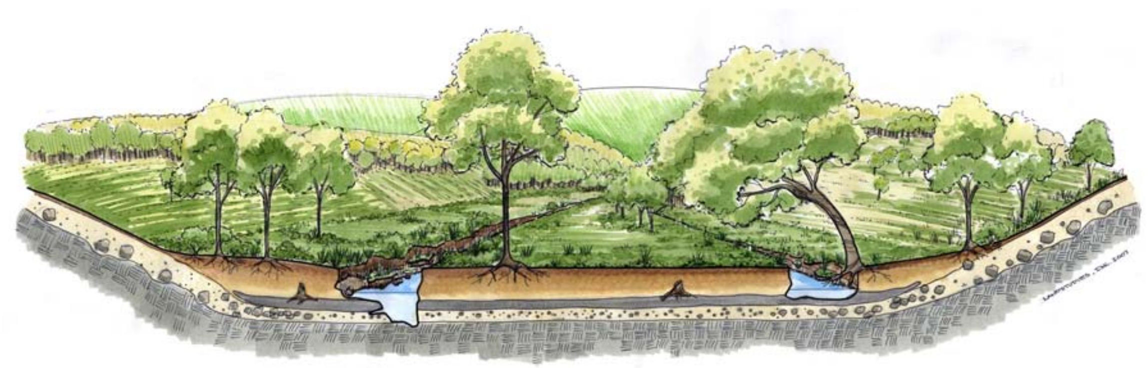

Figure 3. Existing Conditions
Stream channels are eroding or have eroded down through sediments that collected behind mill dams, leaving their alluvial floodplains high above the current base flow water elevation, and disconnecting riparian root systems from groundwater flows. The processes of frequent 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.

stacks of legacy sediments, exposing peats, sands, and gravels of the submerged, pre-settlement valley floors. (See Figure 3.)

After breaching of the dams, the channel eventually cuts down through the legacy sediments to its historical, pre-settlement floor. As a result of the increased channel depth, the gravels along the floor erode easily, allowing the stream to begin undercutting its banks also consisting of fine grained legacy sediments. In Lancaster County, Pa., for example, 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. (See Figure 4.)

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. Prehistoric floodplain areas that are naturally intended to store water and filter nutrients 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 re-charging the aquifer, especially in limestone streams. Flow, sediment and nutrients are directed, instead, into the channel and transported into 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.

Figure 4. Channel Bank Erosion and Exposed Legacy Sediment. Channel bank erosion and exposed legacy sediments are evident after dam removal in Mount Holly Springs, PA.

Old floodplains hold pre-settlement, 17th 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 less than 15 to 24 inches (0.3 to 0.6 m) above the gravels or bedrock are, because of legacy sediments, three to 20 feet (1 to 6 m) high. The result is bank erosion during storm events and long-term effects on fish and other aquatic life due to increased turbidity that persists from the 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 and carbon, associated with the root zones and woody debris along the river bottom, 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 (See Table 1, which compares observed erosion rates in Pennsylvania and Maryland watersheds with those predicted by a widely used model that does not account for legacy sediments).

Table 1. Measured vs. predicted "problem area" erosion rates from stream banks in various areas of Pennsylvania and Maryland

Creek (County or State)	Length of Stream Studied (feet)	Measured Erosion Rates (tons per year) for study area	Predicted "Problem" Area Erosion Rates* (tons per year) for study area
Choconut (Susquehanna)	7,920	50,000	110 – 2,194
Codorus - East Branch (York)	5,410	2,070	90 – 1,794
Codorus Creek- South Branch Granary Rd. (York)	2,200	2900	56 – 1,122
Codorus Creek- South Branch SBCC 026 (York)	400	450	9 – 180
Codorus Creek- South Branch SBCC 015 (York)	550	578	8 – 160
Codorus Creek- South Branch SBCC 025 (York)	600	1200	15 – 300
Codorus Creek- South Branch Phase I (York)	1,770	1,083	15 – 304
Codorus Creek- South Branch Phase II (York)	2,050	500	15 – 298
Codorus Creek- South Branch Phase III (York)	4,170	2,180	33 – 654
Conewago (Adams)	800	8,000	20 – 400
Cowanshannock (Armstrong)	80	31	1 – 20
Cowanshannock (Armstrong)	50	52	1 – 20
Crabby (Chester)	400	1,444	4 – 80
Long Draught Branch (Maryland)	1,607	427	19 - 380
Octoraro -West Branch (Lancaster)	1,650	1,200	4 – 84
Meetinghouse Creek	43,058	4,764-5,928	188 – 3,766
Nickel Mines Run	53,704	5,195-6,438	206 – 4,110
Stewart Run	60,429	4,415-5,459	187 – 3,744
Total for Octoraro WBR Headwaters (Lancaster)	157,191	14,374-17,825	573 – 11,458
Santo Domingo (Lancaster)	193	80	2 – 32
Spencer Run (Blair)	16,250	3,200-3,900	133 – 2,666
Stony Run (Maryland)	1,392	912	12 – 238
Trout Run (Chester)	50	20.5	1 – 20

* These values were calculated using lateral erosion rates of 1.0 x 10^{-2} to 2.0 x 10^{-1} meters/year as suggested by Evans *et al*, 2003.

Figure 5. 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.

In order to restore a stream, we must first understand what the stream looked like before settlement and land-clearing. (See Figure 5.)

Most streams will never be fully restored to their pre-settlement state, but we argue that any remediation effort must "connect" a stream to its pre-settlement valley floor, where feasible, otherwise the primary functions and interaction of the stream and floodplain are lost. The streams may 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 use water power throughout the region. In other words, the current channel geometries (bank height and channel width) are merely temporary as a result of the streams evolution to stability from the previous historical impacts.

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 which includes ensuring the channel bed is located immediately within the gravels/bedrock and groundwater. It is fundamentally necessary, then, to identify which reaches have streambeds that are too high and which are at the historical bed elevation. Frequently, the location of historical stream bed levels requires trenches or subsurface investigation. Other typical problems include existing dams or culverts and utility cross-

ings 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 coarse – grained or large bed material that must not be transported to maintain a stable profile and maximize aquatic habitat including spawning areas for trout. The restored reaches are designed to only transport the finer material for all flows including the flood events and not the large material carried under degraded conditions.

Our belief is that flow increases resulting from urbanization may require a wider floodplain and not a deeper channel. Flooding and bank erosion will not be exacerbated because of urbanization or development along streams restored in this manner, because shallow and wide floodplains maintain a relatively consistent low energy even for the larger flow events thus reducing transport of coarse grained particles. Stormwater best management practices (BMPs) may be required to address water quality and pollutant loads prior to entering the stream system. However, the frequent interaction of the floodplain will allow sediments and nutrients in the stream to access the floodplain and reduce the load carried to downstream waters.

THE BENEFITS

The benefits of stream and floodplain restoration are numerous and interconnected. Some of the benefits of restoration, such as reduced sediments and nutrients, reduced downstream flooding, and increased wetland acreage and function, are apparent soon after the restoration is complete. Others appear over time. And still others may never be visible, but their positive effects nevertheless will be operative.

Sediment and Nutrient Reduction

Sediment and nutrient reductions were calculated for the recently completed New Street Ecological Park Restoration Project on the Santo Domingo Creek in the Lititz Run watershed. Figures 6 through 10 show the project area before, during, and after restoration. Prior to restoration, based on measurements from monumented cross sections, 193 linear feet of the Santo Domingo Creek contributed, in only four months, 27.8 tons of sediment to downstream receiving waters. Those tons of sediment were calculated to contain 34.6 pounds of phosphorus and 96.3 pounds of nitrogen– the nutrients that contribute to the decline of the Chesapeake Bay as well as its upstream waters.

The 900-foot restoration, by virtue of cutting down the floodplain to a more natural elevation, immediately eliminated from the watershed 7,800 tons of sediment that contained more than 8,930 pounds of phosphorus and 26,080 pounds of nitrogen. The newly created wetland pockets will help trap incoming sediments and vegetatively filter incoming nutrients, adding to the long-term benefit of sediment and nutrient reduction.

Figure 6. Santo Domingo Creek in New Street Park, Lititz, PA - Before Restoration. The existing stream was channelized, unstable and eroding both vertically and horizontally.

Figure 7. Santo Domingo Creek in New Street Park, Lititz, PA - During Construction. Aerial view shows the new, meandering channel under construction as water continues to flow through the existing straightened channel.

Figure 8. Santo Domingo Creek in New Street Park, Lititz, PA - During Construction. The man is standing on restored floodplain, now attached to the restored channel. The old floodplain elevation, created by the deposition of legacy sediments, can be seen behind him.

Figure 9. Santo Domingo Creek in New Street Park, Lititz, PA - Post Restoration Restored Condition. The restored site during a late spring storm event.

Groundwater Recharge

As water from high stream flows comes out of the newly restored channel and onto the attached floodplain, the water collects in the created wetland areas, where it is vegetatively filtered and allowed to move slowly down through the soil to recharge the groundwater supply.

Stormwater Management

Stream corridor and floodplain restoration can be viewed as an ecologically harmonious, alternative method to address municipal stormwater management issues, including the National Pollutant Discharge Elimination System, known as NPDES II. A complete stream corridor and floodplain restoration immediately eliminates the sediments and nutrients held in the highly erosive, artificially high stream banks. Over the long term, the frequent flooding into the floodplain and the use of wetland areas throughout the floodplain helps trap and filter incoming floodwaters, thus eliminating not only excess water but also water-borne sediments and pollutants from downstream receiving waters.

Wetland Creation

Wetland pockets created along the length of a restoration have multiple benefits, including improved water quality, flood control, groundwater recharge, and wildlife habitat. Water from high flows settles in the wetlands, where water-borne sediments can drop out, nutrients can be used by the wetland plants, and nuisance flooding can be abated. Water in the wetlands gradually filters through the ground, recharging groundwater systems. Well-vegetated wetlands are prime habitat for a wide variety of aquatic and terrestrial wildlife.

Regional Flood Reduction

Wetland pockets and an expanded, accessible floodplain help alleviate nuisance flooding both in the immediate restoration area and downstream as well. During high flows, water that used to add to the downstream flow is now dispersed and slowed through the restoration site, where it filters slowly down through the soil. Acre-feet of sediment that filled the river valleys are now available for flood storage. This volume of flood storage created may total 50 to 100 acre-feet of storage equal to many stormwater management facilities

Riparian Buffer

Native plants, both herbaceous and woody, provide many benefits to the stream itself and to the water that moves into the floodplain. Trees and shrubs help shade the stream, keeping it cooler and healthier for aquatic wildlife. Leaf litter from these woody plants also provides a source of food for macroinvertebrate life in the stream. Herbaceous plants in the wetland pockets help reduce nutrients through nitrogen uptake.

Figure 10. Santo Domingo Creek in New Street Park – Post Restoration Restored Condition. The restored site during a late winter storm event. Notice the restored floodplain receiving flood flows in the now-attached floodplain, where the energy of high flows is dissipated and storage and infiltration can occur.

Wildlife Habitat Improvement

A cleaner stream, wetland pockets, and a variety of native plants create and improve habitat for both in-stream and terrestrial wildlife, starting with the macroinvertebrate life in the stream and continuing up the food web to birds and mammals (One day after workers vacated the completed New Street Ecological Park restoration site, we had our first-ever great egret sighting). The newly naturalized site will provide food, cover, and nesting sites for a variety of species.

Invasive Species Removal

Creating a more natural stream channel and floodplain and establishing the site with native plants results in the elimination of invasive species and helps discourage invasive, non-native plant species from overrunning the site. Extremely frequent flooding and long-term ponding (similar to beaver dams) minimize the type and frequency of invasive plant species capable of handling those conditions.

Aesthetic Enhancement

The naturalized landscape produces lush green vegetation, bright flowers, and seeds and nuts that look good and attract a variety of butterflies, birds, and other wildlife species.

Topsoil Generation

One of the immediate economic benefits that comes from excavating an abnormally high floodplain is the generation of high-quality, nutrient-rich topsoil. The topsoil removed from the New Street Park restoration site had an estimated retail value of $120,000 (It took 600 tri-axle truckloads, valued at $200 per truckload, to remove the 7,800 tons of soil excavated from the site).

Nutrient Trading Credit Generation

In Pennsylvania, there is great potential to generate financially viable credits through the implementation of stream and floodplain restoration projects. The Pennsylvania Nutrient Trading Program seeks to economically address NPDES compliance issues through the generation, buying and selling of nutrient credits. Stream and floodplain restoration projects significantly reduce the nutrients and sediments contributed to downstream waters through stream bed and bank erosion and subsequently has the potential to generate credits for sale.

PRACTICAL APPLICATIONS

Municipal governments, local watershed associations, private landowners, water authorities, developers, and others have used stream and floodplain restoration to expand and improve fisheries, improve water quality, reduce flooding, manage stormwater, generate nutrient trading credits, improve aquatic and terrestrial wildlife habitat, and enhance recreational and environmental education opportunities.

The golf course industry, in particular, has benefited from stream and floodplain restoration in correcting serious and often destructive problems of poor water quality, stream bank erosion and collapse, channel stabilization, and flooding. As a number of golf course personnel have discovered, this type of restoration can also improve play through channel relocation, wetland creation, improved and expanded native plant communities, and improved aesthetics.

Golf courses are rapidly evolving into biologically valuable, open-space opportunities for municipal and regional benefit. For example, flood reduction, reduced erosion, and water quality improvement achieved through floodplain restoration are benefits that extend far beyond the boundaries of the golf course. Wetland banking and regulatory compliance for stormwater management, water usage, and other water-related issues also contribute to the added value for golf courses and their surrounding communities resulting in mutually beneficial environmental partnerships.

Some years ago, Audubon International recognized that, with stewardship-based management, golf courses hold enormous value as environmental havens. The Audubon Society certifies golf courses that demonstrate they are maintaining the highest degree of environmental quality in several areas including environmental planning, wildlife and habitat management, outreach and education, chemical use reduction and safety, water conservation, and water quality management.

The Environmental Institute for Golf (http://www.eifg.org/) is the philanthropic arm of the Golf Course Superintendents Association of America and is “committed to strengthening the compatibility of the game of golf with our natural environment.”

Golf & The Environment, according to its web site (www.golfandenvironment.com), "is a partnership of the United States Golf Association, The PGA of America, and Audubon International dedicated to the game of golf and the protection and enhancement of our natural environment."

The Pennsylvania Environmental Council has published the Golf Course Water Resources Handbook of Best Management Practices (LandStudies Inc. and PEC, 2009) to help golf course superintendents increase their opportunities to improve their water resource management. Floodplain restoration is included as a BMP. Because of its multiple benefits, floodplain restoration helps address at least half of the other BMPs at the same time (riparian buffer installation, groundwater recharge, reduced water usage, reduced chemical usage, increased naturalized acreage, erosion control, etc.).

Many golf courses in the piedmont region of the United States are taking advantage of the multiple benefits associated with floodplain restoration. From environmentally aware clubs such as the Saucon Valley Country Club in eastern Pennsylvania to the prestigious Tournament Players Course Potomac at Avenel Farms in Maryland, floodplain restoration has improved their game and their communities.

The following are four recent examples.

Bedford Springs Golf Course - Stream and Floodplain Restoration

Bedford County, PA

The golf course associated with the historic Bedford Springs Resort was still in use, but many of the course features were threatened by flooding and erosion which impacted 12 separate holes along Shober's Run. LandStudies worked with the golf course architect, Forse Design, to incorporate the restoration of the floodplain and stream corridor into the overall design for the golf course. The project involved excavating the floodplain to original elevations to provide storage volume during storm events and to reconnect the floodplain with the stream system. Cart crossings were realigned and designed to accommodate the restoration. The result was 6,800 linear feet of stream restored to a natural flow pattern, 10 acres of created wetlands, and thousands of native plant species planted to restore the floodplain ecosystem. (See figures 11 and 12.)

Saucon Valley Country Club - Stream and Floodplain Restoration

Lehigh County, PA

Most of Saucon Creek and its tributaries have been constricted, built up and developed with infrastructure affecting the long-term stability of channel reaches within the Country Club site. The challenge was to provide a long-term solution that could be designed, permitted and constructed prior to the 2009 U.S. Women's Open. The goal of the project was to reduce non-point source pollution, including sediment and thermal pollution. This was achieved by restoring and stabilizing the stream channel and stream bank and improving the natural floodplain function. The project also re-established wider, more continuous vegetated riparian corridors using native vegetation. The result is improvements in aquatic and riparian habitats, migratory fish passage and wildlife corridors. This project also improved the golf course aesthetics and protects the property and infrastructure from damage from storm events and erosion. (See figures 13 and 14.)

Figure 11. Shobers Run at Bedford Springs Resort – Before Restoration

Figure 12. Shobers Run at Bedford Springs Resort - After Restoration

TPC Potomac at Avenel Farms - Stream and Floodplain Restoration

Potomac, MD

Flooding and Channel instability along Rock Run made the course unplayable during PGA events. The challenge was to provide solutions for long-term stability and flood mitigation while enhancing play and improving the aesthetics as part of the course renovation in anticipation of a major 2010 PGA event.

LandStudies worked directly with PGA designers to integrate the restoration of Rock Run into the reconstruction of the course. The goal was to improve the aesthetic of Rock Run

Figure 13. Saucon Creek at Saucon Valley Country Club – Before Restoration

Figure 14. Saucon Creek at Saucon Valley Country Club – After Restoration

Figure 15. Rock Run at TPC Potomac at Avenel Farms, Potomac, MD – Before Restoration

Figure 16. Rock Run at TPC Potomac at Avenel Farms, Potomac, MD – After Restoration

while providing stormwater management, reforestation, wetland mitigation and protection of course features during flood events. (See figures 15 and 16.) The result was 7,800 linear feet of stream restoration, 12 acres of floodplain restoration, 9 acres of created wetlands, reduction in the 2, 10, and 100year flood elevations, and native trees and plants were established to restore the floodplain ecosystem.

Mark Gutshall is the founder of LandStudies, a recognized leader in the field of environmental restoration and land planning. He has more than 24 years' professional experience in designing, permitting, and constructing ecological restoration projects in the Mid-Atlantic region. Mr. Gutshall researches and advocates pioneering land development and management techniques that are functional, cost effective, and environmentally beneficial. He has been a leading voice in the acceptance of "legacy sediments" along stream corridors as a major contributor of sediment and nutrient pollution in waterways throughout the Piedmont physiographic province. He also has been a groundbreaker in adopting regional or watershed-wide natural resource management as an effective way to create partnerships among private, public, regulatory, non-profit, and educational interests. His innovative approach to natural resource management and land planning has earned accolades for both himself and LandStudies. Mr. Gutshall has been responsible for the management and execution of numerous golf course planning and restoration projects.

Ward Oberholtzer is a Professional Engineer with expertise in applied stream morphology, hydrology/hydraulics, bridge scour, fluvial geomorphology, river mechanics and sediment transport investigations. In the last 9 years, he has worked for or closely with the Maryland State Highway Administration's Office of Bridge Development and the Structural Hydraulics Unit on projects within all of the Physiographic Regions within Maryland. Mr. Oberholtzer has spent the last 13 years concentrating on the review and design in application of fluvial morphology with and

without bridges/roadway crossings, historical analysis, fish passage, bridge scour, stream stability, stream/floodplain restoration, river mechanics and bedload/sediment transport. He has completed and reviewed stream stability designs from the planning phase and conceptual design through final design and provided construction management and post-construction monitoring studies. He has made numerous presentations to the American Society of Civil Engineers and the Transportation Research Board "Hydrology, Hydraulics & Water Quality" on the application of stream morphology and stream/floodplain restoration on waterway crossings.

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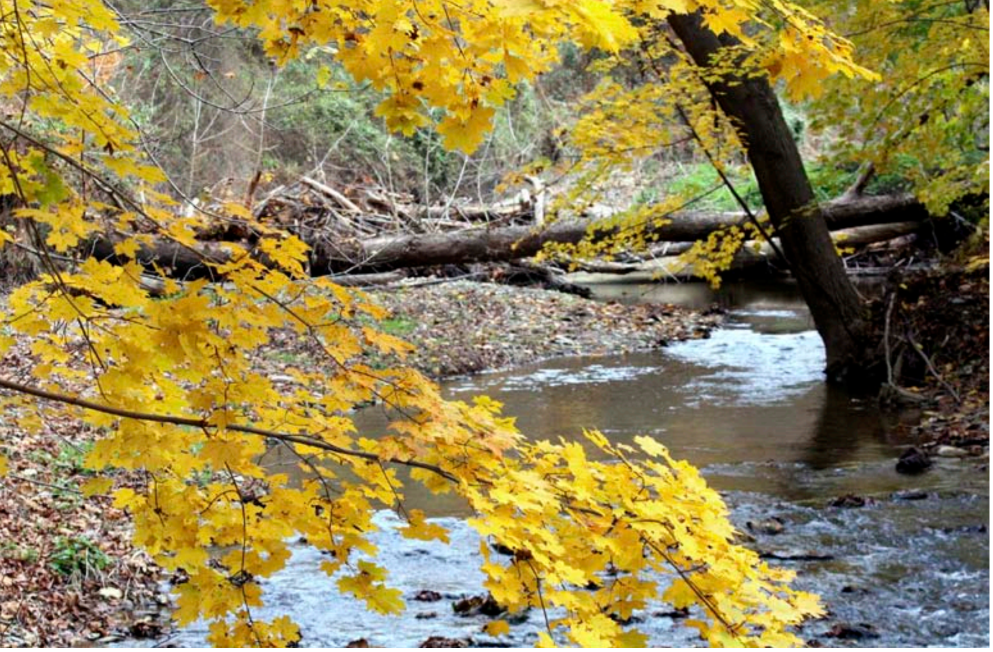

The Big Spring Run Restoration Experiment: Policy, Geomorphology, and Aquatic Ecosystems in the Big Spring Run Watershed, Lancaster County, PA

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Dorothy J. Merritts, Professor, Franklin and Marshall College
Robert C. Walter, Associate Professor, Franklin and Marshall College
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The need to better understand natural and anthropogenic controls on water quality has imminent global significance. The Chesapeake Bay, for example, has experienced over a half century of poor water quality despite extensive restoration efforts and is estimated to have achieved less than 25 percent of water quality goals established by the US Environmental Protection Agency (USEPA, 2011). In 2009, the President of the United States issued Executive Order 13508 that calls on the US Environmental Protection Agency (EPA) to define a new generation of tools and to refine policies that will reduce sediment and nutrient loads to the Chesapeake Bay. Identifying and quantifying the relative contribution of the many sources of sediment and nutrients to the Chesapeake Bay has substantial scientific value for understanding complex biogeochemical and physical interactions that control sediment and nutrient mobility. Such investigations also will assist resource managers to identify and possibly control sources of sediment and nutrients that pollute streams and waterways. Pennsylvania's Chesapeake Watershed Implementation Plan was developed in order to address EPA's expectations for the Chesapeake Bay Total Maximum Daily Load (TMDL)[1]. *The Natural Floodplain, Stream, and Riparian Wetland Restoration Best Management Practice* (*NFSRWR-BMP*) proposed by the Pennsylvania Department of Environmental Protection (PADEP), and discussed here, is included in PA's strategies for reaching nutrient and sediment reduction goals[2].

The unglaciated mid-Atlantic region is a hotspot of stream restoration in terms of cost and number of projects (Bernhardt et al, 2005; Hassett et al, 2005), but the practice of aquatic ecosystem restoration has outpaced scientific investigation and our understanding of the full benefits (NRC, 2010). As noted by Palmer and Filoso (2009), stream restoration practices to date consist largely of "reshaping a channel and adding wood or rocks", but actual improvements to water quality or biodiversity are uncertain (Bernhardt et al, 2005; Palmer, 2009). Due to insufficient monitoring, it is difficult to assess most of these restorations. In the Chesapeake Bay watershed, for example, less than 6% of recent river restoration projects reported that monitoring occurred (Bernhardt et al, 2005; Hassett et al, 2005).

While scientific investigations that involve pre- and post-restoration monitoring of multiple physical, biological, and chemical parameters are rare (Bernhardt et al. 2005), some studies have evaluated individual stream ecosystem functions, such as denitrification. Previous work indicates that 1st to 3rd order streams have the highest potential for nitrogen removal post-restoration (Ensign and Doyle, 2006; Craig et al, 2008). Furthermore, denitrification is enhanced when floodplains are "reconnected" to surface water flow and increasing groundwater-surface water interactions within the hyporheic zone (Kaushal et al, 2008). Hyporheic exchange is fundamental to restoring ecological services and functions (Craig et al, 2008; Hester and Gooseff, 2010). Recent studies conclude that stream restoration must go beyond merely modifying stream channel form, and include approaches that are designed to improve water quality and ecosystems (Mitsch and Jorgensen, 2004).

Prerequisite to designing sustainable aquatic ecosystem restorations with high potential for improved ecosystem services is a better understanding of how ecosystems evolve and respond to environmental change and human impacts (NRC, 2010). Single-thread meandering channels, once deemed "natural" for the mid-Atlantic Piedmont (c.f., Leopold, 1973) are instead the result of human manipulation of valley bottoms for water-power and are decidedly "un-natural" (Walter and Merritts, 2008a; Merritts et al, 2011). Previous workers recognized widespread historic sedimentation in mid-Atlantic valleys, but interpreted it to be the result of overbank deposition by single-thread channels with an

excess supply of upland sediment (e.g., Costa, 1975; Jacobson and Coleman, 1986). Incised channels—now prevalent in the mid-Atlantic region—were thought to indicate a decrease in sediment supply and/or increase in storm water runoff in the 20th century due to increased urbanization, yet in many places modern sediment loads are high regardless of land use (Gellis et al, 2005, 2009; Merritts et al, 2011).

Instead, our research reveals that historic sedimentation resulted from increased upland soil erosion in combination with base-level rise due to the construction of tens of thousands of milldams on 1st-3rd order streams in this region (Walter and Merritts, 2008a). Holocene (pre-settlement) streams were much different than today and the legacies of human impacts (post-settlement) are more complex than previously realized (Wohl and Merritts, 2008; Walter and Merritts, 2008a, 2008b, 2008c; Pizzuto and O'Neal, 2009; Merritts et al, 2011). At Watts Branch in Maryland, once held as a model for natural meandering stream evolution (Leopold, 1973), stream channel incision formed only after early 20th c. base-level fall from milldam breaching, and decades before urbanization and increased storm water runoff (Walter and Merritts, 2008a; Merritts et al, 2011).

Our research reveals that many current models of "natural" floodplains, channels and riparian ecosystems are of limited value in the low-relief, humid-temperate mid-Atlantic region. We have documented that milldams and other structures built across valley bottoms trapped sediment and buried pre-existing anastomosing channel valley bottom floodplain systems (ACFS) and toe-of-slope colluvial deposits (Walter and Merritts 2008a; Merritts et al, 2011). Sediment trapping in reservoirs upstream of dams is not directly correlated to upland land use because reservoirs add a lag time in sediment storage that is a function of trap efficiency, which depends on parameters including discharge, dam height, and reservoir geometry and age. Rate of sediment release depends on time since dam breaching and depth of post-breach incision (Merritts et al, 2011). These hydrologic changes are not merely the result of changes in upland runoff or sediment supply, but also of substantial changes to valley bottom landscapes and ecosystems.

We postulate that 1st to 3rd order Piedmont pre-settlement ACFS, in which shallow vegetated channels were well-connected with floodplains and the groundwater table, had greater hyporheic fluxes and biogeochemical reaction rates than modern deeply incised streams. Whereas modern incised channels infrequently flood the entire valley bottom (depending on thickness of post-settlement sediment and bank height), the pre-settlement streams flowed overbank often and at relatively low-flow stages.

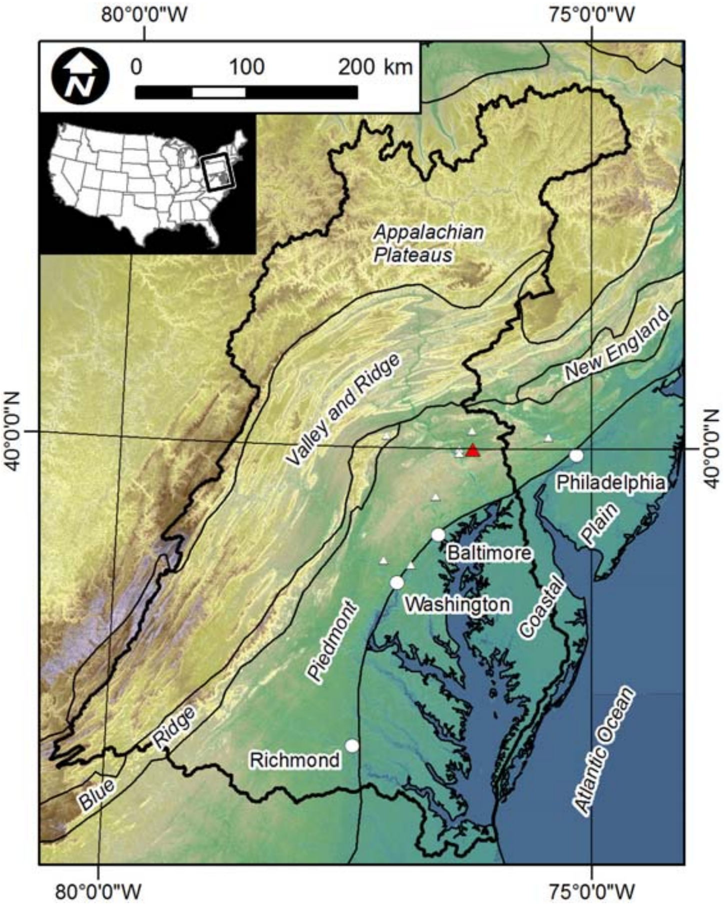

Figure 1. Big Spring Run (red triangle) is a Piedmont stream in the lower Susquehanna River basin, Chesapeake Bay watershed (heavy black line). White triangles: Key field sites for research on historic sediment, incised streams, buried ecosystems, and Pleistocene-Holocene landscape evolution.

Understanding a stream's evolutionary trajectory and response to historical land use change is relevant to correctly diagnosing the causes of modern impairments such as bank erosion and high suspended sediment loads, as well as to developing restoration approaches that are likely to be sustainable. The majority of once widespread indigenous aquatic ecosystems located in valley bottoms of the mid-Atlantic piedmont were not drained during settlement in the late 1600s to 1800s, but instead were ponded and then buried by historic sediment as valleys were dammed for milling (i.e., hydropower). Spaced 2-5 km apart, milldams led to a decrease in water surface slopes along valley bottoms by as much as 50%, while upland deforestation for farming and mining led to a simultaneous increase in sediment supplies. Other grade control structures that affected sedimentation included dams built for purposes such as ice ponds, and bridges with embankments that crossed valleys. Eventual breaching of these various structures during the 20th c. has generated incised, high-banked, meandering channels which expose the post-settlement sediment, buried paleo-wetland organic layer, periglacial basal gravels, and underlying valley bedrock (Walter and Merritts, 2008a; Merritts et al, 2011).

Our findings support the proposition of Brantley et al (2011) that restoring Critical Zone (CZ) ecosystem function requires restoring synergistic interactions among physical, biological, and chemical processes. Brantley et al (2011) propose that biodiversity and biogeochemical processes cannot be restored until

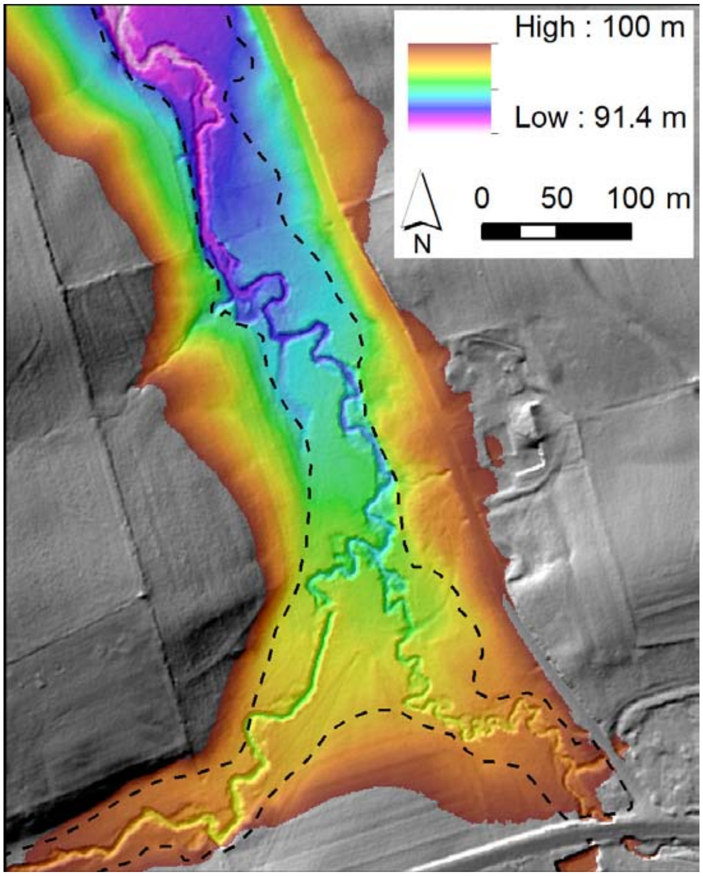

Figure 2. Lidar-derived shaded relief illustrates sub-planar surface of historic sediment fill (bounded by dashed lines) sloping gently downstream. Note incised, sinuous modern channel. USGS stream flow gaging stations are located at upstream ends of two tributaries in BSR headwaters to monitor incoming suspended sediment load and discharge; another gaging station is located just downstream of the restoration area on the main stem (flow toward top, to north). (Lidar data provided by the NSF funded National Center for Airborne Laser Mapping, 2008.)

essential physical attributes (e.g., hydrologic pathways, valley morphology) are re-established. Once ecosystem physical attributes are re-established, there will be a lag time of years before hydrological processes recover and perhaps longer to recover biodiversity and biogeochemical processes. Thus, restoring natural floodplains, streams, and riparian wetlands to their pre-settlement morphology by removing historic sediment should be the foundation for restoring ecosystem function and services (US EPA, 2000).

Big Spring Run (BSR), PA, a low-relief (~30 m) 2nd-order Piedmont stream (drainage area 15 km2) located in the Chesapeake Bay (CB) watershed, is a national test-case for a new and innovative approach to restoring aquatic ecosystems (Fig. 1, 2). The United States Geological Survey (USGS) conducted a nearly 8-year paired-watershed study at BSR from 1993-2001 (Galeone et al, 2006). The study documented stream flow, nutrient and sediment loads from several gaging stations, 17 piezometers, and 2 wells in both "treated" and control basins. The current restoration experiment at BSR is located in the same basin used as the "control" basin in the earlier paired watershed study. The pre-existing scientific research and hydrologic (surface and ground water) monitoring data at BSR was an important factor in PA Department of Environmental Protection's (PADEP) decision to evaluate a new approach to aquatic ecosystem restoration at this site.

At present, BSR is an incised, single-thread meandering channel that has cut ca. 1.5 m into several generations of historic sediment during the 20th century and now flows on either highly weathered bedrock or Pleistocene toe-of-slope gravelly colluvium (Fig. 3a). We are investigating whether restoring an ACFS, a rarely studied type of stream and floodplain ecosystem, can effectively restore CZ functions. Our approach includes the following three steps: (1) Developing significant metrics to assess CZ processes; (2) Developing, implementing, and monitoring a restoration project that diagnoses the cause(s) of CZ impairments; and (3) Working with resource managers and scientists at PA DEP, USGS, and EPA to evaluate the implications of this restoration strategy. The BSR restoration experiment provides an ideal opportunity to test hypotheses about the natural functioning of mid-Atlantic Piedmont streams and wetlands. We know of no other site for which interactions among ground and surface water, sediment transport, sedimentation, geomorphic processes, ecology, and biogeochemistry have been monitored both pre- and post-restoration.

With a multidisciplinary team of 26 scientists and resource managers from 12 agencies and academic institutions, we are collaborating to accomplish essential monitoring of ecological, hydrological, and geomorphic processes at BSR. Currently, we are completing the 3rd yr of pre-restoration monitoring at BSR. In the summer of 2011, about two km of valley bottom will undergo restoration[3] activities. The BSR restoration experiment will test a new paradigm of ecological restoration of aquatic landscapes and resources that have been buried beneath historic sediment, and will provide better understanding of the mechanisms responsible for development and stability of landscape patterns in ACFS. This paradigm is based on an investigation of the conditions that existed prior to ecosystem degradation.

Our previous work documented that a wet meadow ACFS existed at BSR for thousands of years prior to 18th-19th century sedimentation and 20th century stream channel incision into post-settlement sediment (Walter and Merritts, 2008a; Voli et al, 2009; and Merritts et al, 2011). The wet meadow ACFS with organic-rich wetland-floodplain transported water, sediment, and nutrients down-valley through multiple hydrologic pathways at the surface and subsurface, with substantial amounts of hyporheic exchange and frequent inundation of the valley bottom. Hydro-ecological mechanisms and feedbacks among vegetation, flow transport capacity, and sediment supply are responsible for the development and stability of different landscape patterns in shallow vegetated flow (Larsen and Harvey, 2010). Paleogeography

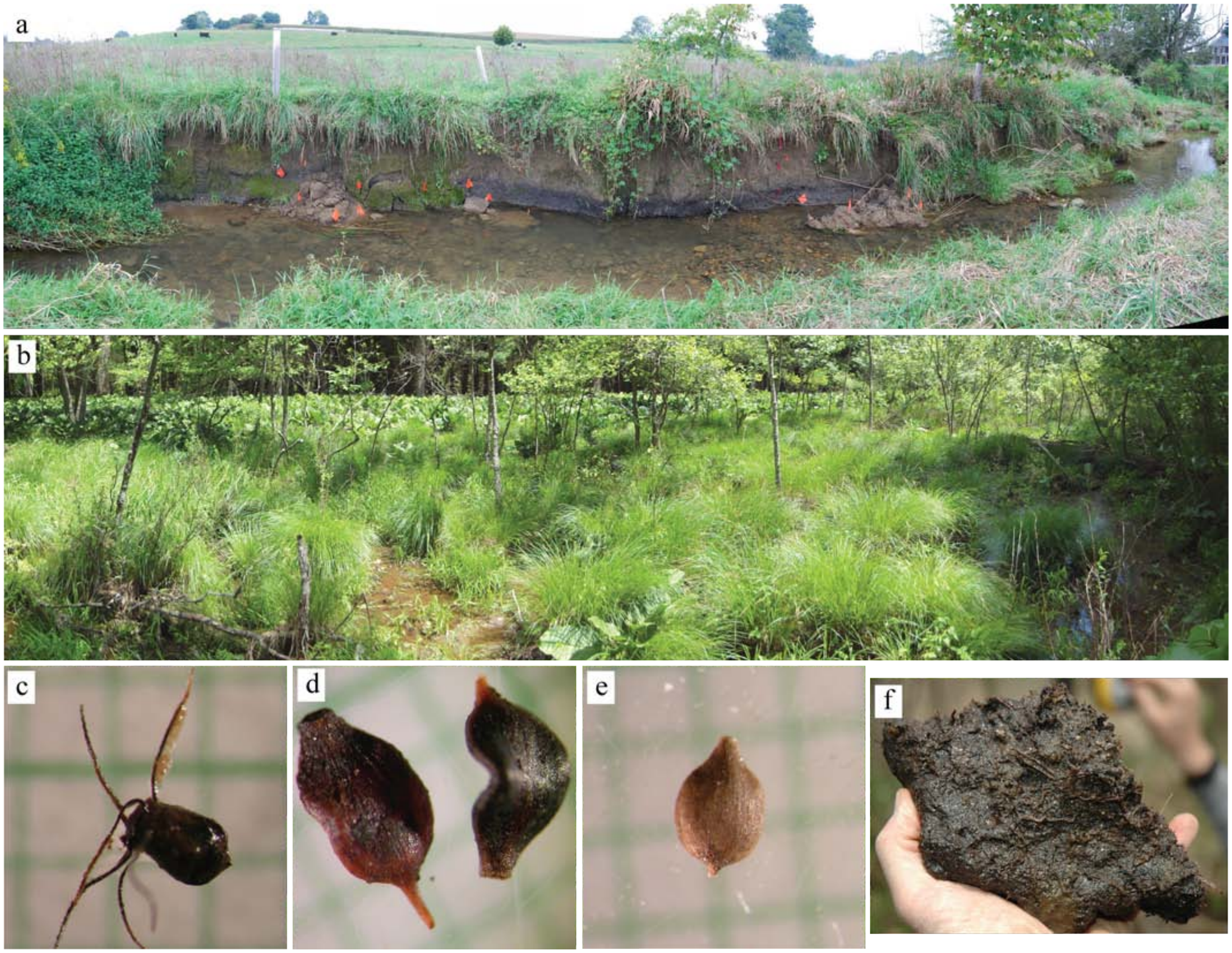

Figure 3. (a) Incised stream bank, BSR. Dark, organic-rich hydric soil buried by historic sediment exposed at base of bank; collapse blocks from recent wetting-drying of high-stage flood. Flow to right. (b) Rare patches of historic valley-bottom wetlands not covered by millpond sediment include tussock sedge meadows with low-energy channels and sloughs (Gunpowder Falls, MD) and species identical to palaeoseeds in buried hydric soils. Microscope photos of seeds from buried hydric soil at BSR: (c) *Eleocharis obtusa* (blunt spikerush), (d) *Carex crinita* (fringed sedge) and (e) *Carex stricta* (tussock sedge), obligate wetland species. Grid markings are mm spacing. (f) Organic-rich hydric paleosol.

and paleoecology for the period of time spanning ~10,000 yrs ago to 1700 AD, as reconstructed from six years of field mapping, backhoe trenching, stratigraphic analysis, paleoseed analysis, and multiple radiocarbon dates at BSR, serve as guides to restore a wet meadow and associated channel system (Walter and Merritts, 2008a; Voli et al, 2009; Merritts et al, 2011).

The wet meadow ACFS, now rare in the mid-Atlantic Piedmont, was widespread before post-European settlement landscape changes that led to valley-wide sedimentation and subsequent incision (Walter and Merritts, 2008a; Merritts et al, 2011). At several places not impacted by mill damming and sedimentation, remnants of such wet meadow ACFS ecosystems--with plant communities similar to those archived by seeds in buried hydric soils--still exist in Maryland and Pennsylvania (c.f., Martin, 1958) despite upland land use that includes agriculture and urbanization (Fig. 3b). A similar wet meadow ACFS was re-established and persists after historic sediment and remnants of a small dam were removed during a restoration by LandStudies, Inc., along Lititz Run, PA, in 2004.

Paleoseed analysis of buried hydric soils at multiple sites (including BSR) indicates that the plant communities of wet meadow ACFS included obligate wetland species (99% probability of occurrence within wetland conditions; c.f., Hilgartner et al, 2010). The suite of species at BSR includes *Carex (C) prasina, C. hystericina, C. stricta, C. stipata, and Eleocharis obtusa* (Fig. 3c-e). These species within a plant community are indicative of a wet meadow herbaceous environment (Voli et al, 2009; Merritts et al, 2011) with waterlogged soil near the surface, but without

standing water most of the year (Mitsch and Gosselink, 2007).

At BSR, carbon, nitrogen, and phosphorous accumulated to form a hydric soil that contains 10-200 wetland paleoseeds per cm3. More than 1000 paleoseeds extracted to date provide a rich record of wetland plant communities and hydrologic conditions (see Fig. 3c-f). Well-preserved seeds, leaves, stalks, insect remains, and other organic matter in the hydric soil indicate that low energy conditions persisted throughout the valley bottom for at least 3300 yrs. We postulate that the large surface area of wetland plant matter, and roughness imparted by mounded vegetation (e.g., from tussock forming sedges) diminished water flow velocity, bed shear stress, and sediment transport.

Coupled interactions between biota and geomorphic processes resulted in stable, resilient landforms and ecosystems that stored sediment, nitrogen (N), carbon (C), and other nutrients. The primary sink for sediment and nutrients at BSR was a cohesive hydric soil, or "muck", that accumulated on the colluvial rubble substrate for thousands of years during the Holocene interglacial period (Fig. 3f). Carbon in the <2 mm fraction ranges from 4.7-9.4% C (47,000-94,000 mg-C/kg soil), with average C content 7.2% (72,000 mg-C/kg soil). Total N in the <2 mm fraction ranges from 0.32-0.57% N (3200-5700 mg-N/kg soil), with average N content 0.43% (4300 mg-N/kg soil). These findings indicate that restoring the valley morphology of BSR is likely to increase organic carbon production in the system (i.e., restoring wetland habitat) and increase spatial and temporal contact of surface and groundwater with carbon (i.e., enlarging floodplain area and increasing hyporheic exchange by removing historic sediment). These changes could significantly increase anaerobic denitrification processes, potentially having a large effect on biogeochemical cycling of nutrients in surface and groundwater and the ecosystems through which they flow.

Ongoing monitoring and instrumentation at BSR include multiple USGS gaging stations with turbidity sensors and sediment samplers, piezometers, soil temperature/moisture sensors, monumented channel cross sections, bank erosion pins, and sediment deposition pads. A network of 18 piezometers was installed by the USGS at six locations in 2008. USGS stream flow gaging stations are located on both tributaries entering the proposed restoration area and on the main stem just downstream of the proposed restoration area. Samples are collected routinely for both surface and ground water chemistry at the BSR restoration site.

The significance of the BSR monitoring stems from its unique position as a long-term scientific investigation of ecosystem restoration based on understanding geomorphic context and response to land-use change. Three years of continuous pre-restoration data, and almost eight years of previously collected USGS data from the same watershed, will be used as a baseline by a multidisciplinary team of scientists that includes ecologists, hydrologists, geomorphologists, and geochemists, to evaluate the response of a suite of CZ processes to restoration. We will be able to determine, for example, changes in plant communities (ongoing repeat vegetation transects), suspended sediment load, bed load transport, and hyporheic exchange and denitrification in the floodplain, surface water, and groundwater. We know of no other restoration site for which interactions among so many CZ process have been monitored for such a long-duration experiment.

As we develop, implement, and monitor this restoration project, we are establishing meaningful, statistically significant metrics to evaluate healthy and degraded CZ systems in landscapes with substantial anthropogenic alterations and impacts. We anticipate that the results of this work will provide better understanding of the mechanisms responsible for development and stability of landscape patterns in ACFS. This landscape-scale experiment will enable us to assess whether a new restoration approach optimizes ecosystem function and restores ecosystem services. Our long-term monitoring will determine whether reshaping floodplains, streams, and riparian wetlands that have been buried beneath legacy sediment for several centuries will not only restore historical landscape structure, but improve ecosystem function and water quality as well.

Jeffrey Hartranft (B.S., Susquehanna University; M.A., Connecticut College) is a biologist, botanist, and ecologist. He is a Water Program Specialist with the Pennsylvania Department of Environmental Protection in the Bureau of Waterways Engineering, Division of Dam Safety. Since its inception in 2006, he has been the Co-Chair of the Legacy Sediment Workgroup that continues to develop strategies to address legacy sediment issues in Pennsylvania.

Dorothy Merritts (B. S., Indiana University of Pennsylvania; M.S. Stanford University; Ph. D. University of Arizona) is a geomorphologist who has conducted research throughout the U. S., Indonesia, South Korea, East Timor, Australia, and Costa Rica. She is the recipient of the Dewey Award for Outstanding Scholarship at Franklin and Marshall College, and was chair of the National Research Council Committee on Opportunities and Challenges in Earth Surface Processes (2007-2010). In 2008, she and her colleague Robert Walter were the recipients of *Pennsylvania Senate Resolution 283* for their research on post-settlement ('legacy') sediment, stream restoration, and water quality improvements to the Chesapeake Bay.

Robert Walter (B.A., Franklin and Marshall College; Ph.D. Case Western Reserve University) is a geologist, geochemist and geochronologist. He has conducted field research in East Africa, North America, and around the Pacific Rim. He is a Fellow of the California Academy of Science, and is a former AAAS Diplomacy Fellow to the U.S. Department of State. Currently, he is Associate Professor of Geosciences in the Department of Earth and Environment at Franklin and Marshall College, where his research has focused on soil-sediment-bedrock-water interactions, and human disturbances of these systems.

Micahel Rahnis (B.A., Franklin & Marshall College; M.A., The University of Texas at Austin) is a sedimentologist and works as GIS research specialist at Franklin & Marshall College, Department of Earth and Environment.

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Endnotes

1 http://www.portal.state.pa.us/portal/server.pt/community/chesapeake_bay_program/10513

2 http://www.portal.state.pa.us/portal/server.pt/community/chesapeake_bay_program/10513/workgroup_proceedings/553510#legacy

3 As used here, 'restoration' refers to actions taken in a degraded natural wetland, and associated streams, that result in reestablishment of ecological processes, functions, and biotic/abiotic linkages and lead to a persistent, resilient system integrated within its landscape (from the Society of Wetland Scientists, www.sws.org).

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Definitions

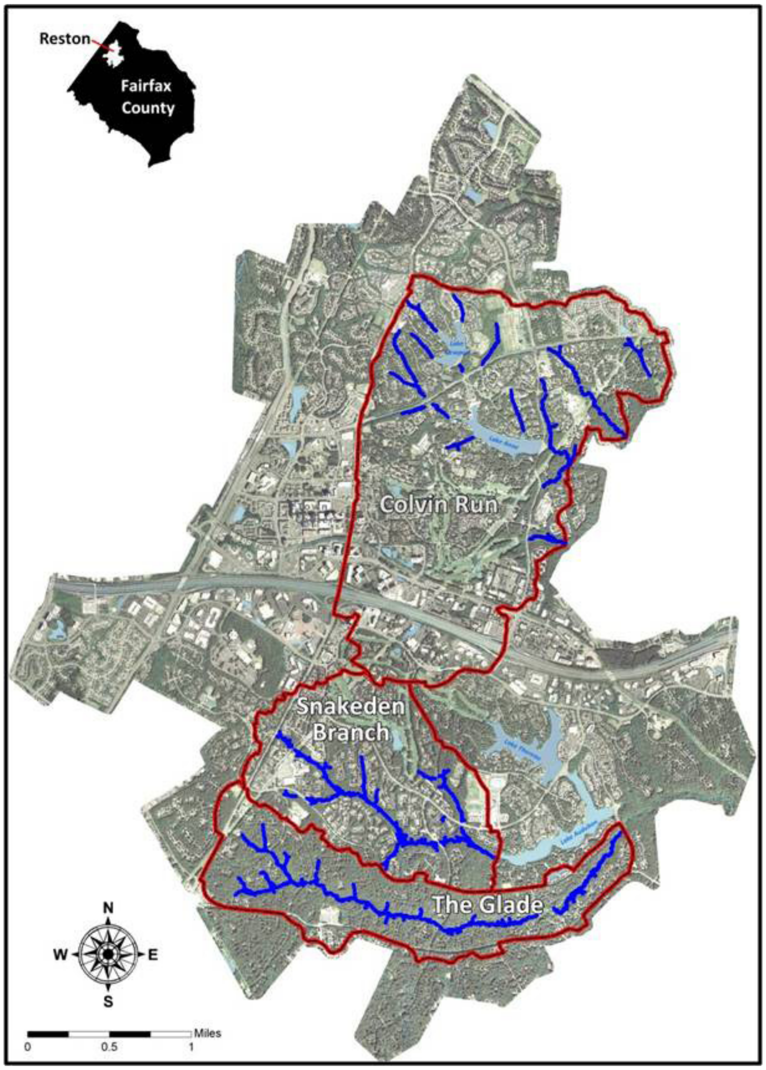
Denitrification--A microbially facilitated process by which nitrates are converted to nitrogen-containing gases that can be lost from the soil or water column to the atmosphere.

Colluvium--Loose sediment that is transported down slope by gravity and deposited or built up at the toe, or base, of a slope. In periglacial areas with permafrost, freeze-thaw processes are significant to colluvial processes.

Anastomosing--A multi-thread network of stream channels that both branch out and reconnect to form a netlike pattern. As used here, it refers to multi-thread channels in a wetland environment.

Hyporheic zone--A region beneath and lateral to a stream, where shallow groundwater and surface water can mix together.

Paleoseed analysis—The extraction and identification of seeds from paleo-sediments, those that were deposited in the past, or "ancient" times. For this paper, the past refers to ~10,000 to 300 years ago, just prior to Colonial settlement in the mid-Atlantic region.



An Urban Stream Restoration Case Study: The Northern Virginia Stream Restoration Bank

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Wetland Strudies and Solutions, Inc.

Background

The community of Reston is located in Northern Virginia, approximately 20 miles west of Washington D.C. It is home to approximately 60,000 residents and is one of the largest community associations in the country. Reston Association (RA) manages over 1,350 acres of open space, much of it located in protected stream valleys that are an integral and valued part of the community. Reston was developed primarily in the 1960's and 1970's, prior to the adoption of stormwater management controls. At that time, the philosophy for dealing with storm water was to route it as quickly as possible to the stream valleys – as such, there are virtually no stormwater management facilities within the community.

The predictable result is that the stream channels have been severely degraded, transporting thousands of tons of sediment downstream annually. This sediment either deposits in the large community lakes or is carried further downstream to the Potomac River and eventually to the Chesapeake Bay. In addition to the environmental impact of the sediment erosion and subsequent deposition, there are also significant impacts to infrastructure (primarily trails, sewers, and bridges), as well as to the immediate riparian areas as the streams incise and become disconnected from the floodplain.

Given the severely degraded condition of the channels and the high value placed on them by the residents of Reston, a citizens environmental advisory committee published a white paper in 2000 entitled "Reston's Watersheds: An Assessment of Conditions and Management Strategies". Two years later, a more formal watershed plan was developed by outside consultants, citing the degradation of the community streams as a top concern. However, with approximately 26 miles of stream channels within Reston and the high cost of restoring streams (especially in this an urban setting), the amount of money that would be necessary to correct the problem could not realistically be raised by the community.

Development of the Northern Virginia Stream Restoration Bank (NVSRB)

Wetland Studies and Solutions, Inc. (WSSI) is a natural and cultural resource consulting firm located in Gainesville, VA. WSSI has been involved in the community of Reston for many years, having obtained the wetland permits for build-out of the community when new regulations came onto the scene in the early 1990's and designed the required mitigation area (Sunrise Valley Nature Preserve). Our Principals have also been heavily involved in the regulatory process related to streams and wetlands for many years at all levels of government (federal, state, and local).

Exposed sanitary manhole.

WSSI LEED Gold Facility, Gainesville, VA.

In 2002, the Virginia Department of Environmental Quality (DEQ) and the U.S. Army Corps of Engineers (COE) changed their interpretation of existing regulations regarding compensation for impacts to streams and wetlands. Prior to 2002, compensation for either resource (streams or wetlands) was mitigated through creation of additional wetland acreage or open water (i.e. ponds). This new interpretation, however, required that impacts to streams be compensated through creation of new or restoration of existing streams (i.e. "in-kind" mitigation). A demand for stream mitigation was thus created. This regulatory change, coupled with our knowledge of the Reston community and its desire to restore the badly degraded stream channels, combined to create the impetus behind the creation of the NVSRB.

The concept of a stream mitigation bank is fairly simple. Whenever a public works agency or private landowner needs to impact streams on its property, they are required to mitigate, or compensate, for this impact. One option is for them to restore other streams located either on or off-site. Another option is to pay into a fund that is used by state agencies to restore streams. The preferred method since a federal regulation was adopted in 2008, however, is to purchase "credits" from a mitigation "bank" that has been developed by a bank sponsor. This bank restores impaired streams within the service area of the bank (as defined by the rivershed and physiographic province). Stream restorers use this pooled money to create much larger, well designed, and ecologically valuable conservation projects.

Because the NVSRB was to be the first stream mitigation bank in the state, many issues arose in its development. The first and most difficult was the fact that no methodology had yet been created for determining how to "credit" compensation for impacts to streams. At the suggestion of a DEQ representative during a stakeholders meeting, WSSI developed the Virginia Stream Impact Assessment Manual (SIAM) and was successful in getting it approved for use in Phase I of the NVSRB (± 14 miles). With this major hurdle crossed, the Mitigation Banking Instrument (MBI, which governs the operation of the bank) was finally approved by the COE and DEQ over 2 years after the process was begun.

Data Collection

Collection of data on the existing conditions of the stream valleys began prior to the final approval of the bank. The most significant effort was related to the collection of survey data. Aerial topography of the stream valleys to be restored was obtained specifically for the project at a contour interval of 6-inches, to include any areas where access would potentially be necessary. This aerial topography was supplemented with a field run survey of the channel thalweg (the deepest portion of the channel), along with survey location of all culverts, utilities (manholes, outfalls, exposed wires, etc.), and property boundaries. Another extensive survey undertaken was the collection of tree data. WSSI located, tagged, and determined the size and species of all trees ≥ 4-in. dbh (diameter measured at breast height) within the stream valley (a Reston Association requirement). To date, nearly 39,000 trees have been surveyed in this manner.

STREAM IMPACT ASSESSMENT MANUAL FOR THE NORTHERN VIRGINIA STREAM BANK

Stream Assessments

Stream Impacts

Stream Compensation

Version 1.3

February 2006

Crediting methodology developed by WSSI for use in the NVSRB.

Survey of exisiting infrastructure.

In addition to the extensive survey data, the stream valleys were also investigated for potential conflicts with wetlands and cultural resources. Wildlife evaluations were also conducted in order to identify potential habitat that could then be avoided when possible.

Restoration Design

Phase I of the NVSRB includes approximately 14 miles of urban stream channels in three separate watersheds: *Snakeden Branch, The Glade,* and *Colvin Run*. One benefit of restoring the streams in Reston was the ability to begin the restorations at the top of their respective watersheds, greatly reducing the potential for problems related to sediment deposition that can arise from excessive bank erosion upstream from the project site. The impervious area in the watersheds ranges from about 40% in *Snakeden Branch* and *Colvin Run* to about 15% in *The Glade*, with much higher percentages in certain sub-watersheds. Higher percentages of impervious area results in higher runoff volumes as less precipitation is able to infiltrate into the ground – this is the primary cause of urban stream degradation.

The chosen method of restoration of the streams was to raise the incised channels to re-connect them with the existing floodplain. The alternative and preferred approach by some would be to excavate a floodplain at the current incised level of the stream bed. While this does provide a firm channel bottom, such a methodology was not practicable for several reasons. First, utilities run adjacent to and crisscross the stream valley and floodplain and would therefore have to be relocated. Second, excavation of a floodplain would have resulted in significantly more tree loss in these narrow, wooded stream valleys and would not have been acceptable to the community. And third, there would have been significant additional expense to remove and dispose of massive quantities of soil. Thus, the decision to raise the channels rather than lower the floodplain was an easy one.

The next task was to determine a methodology for sizing the restored channels to account for the extreme hydrologic condition experienced in these urban watersheds. There are various methods available – some of these include hydrologic and hydraulic modeling, sizing based on the dimensions of stable streams under similar conditions (known as "reference streams"), and/or the use of "regional curves" that provide channel dimensions based on contributing drainage area which are derived from empirical measurements.

The chosen method employed in the NVSRB was a multi-step process. First, we compared published regional curve information (McCandless and Everett, 2002) to reference reach data collected by WSSI in the Northern Virginia area to assess whether the data collected in other areas (the piedmont region of Maryland) could be considered applicable to the streams in Reston. This analysis provided reasonable assurance that the data collected to develop the MD regional curves was applicable to the NVSRB streams. However, the average impervious area in

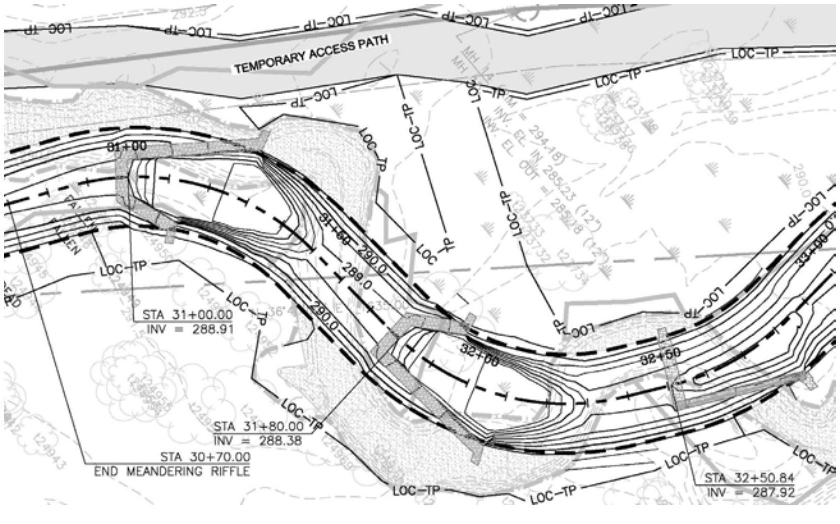
Before - Channel is incised.

After - Channel is raised to provide floodplain access.

the watersheds of the streams in that study was about 8%. This fact prohibited direct application of the design parameters – the higher level of imperviousness and resulting higher flow rates for a given watershed size in this urban setting requires much larger channels. Our solution to this problem was to apply a channel “enlargement factor” that is based on the percent impervious area in the watershed (MacRae and DeAndrea, 1999 and Brown and Claytor, 2000). This enlargement factor was then applied to the piedmont MD stream data to provide a design curve tailored to each watershed in Reston.

Determining the design flow rate began the process of sizing the restored channels, but was not the sole consideration. Given the confined nature of the stream valleys and the desire to preserve as many existing trees as possible, it was necessary to keep the restored channel in essentially the same footprint as the existing channel. However, in instances where the geometry of a particular meander bend was too tight to remain stable given the increased flow rates, or if the existing channel was encroaching on a trail or utility (primarily sanitary sewers), the channel alignment was adjusted to alleviate the conflict. Other factors also played a role, including the locations of trails and utilities, impacts to adjacent trees, a lack of sediment supply (i.e. clear water discharges), and consistency with our reference reach data, among others.

Thus designing the restored channels was an iterative process - a process that was greatly facilitated by our proprietary stream design automation software, *StreamDesigner*. This system allows for sizing and layout of the basic channel components (cross-section size and shape, stream profile, and structure placement) using Microsoft Excel spreadsheets. This information is then imported into AutoCAD Civil 3D® where the channel grading is automatically performed. This level of automation allows for numerous design iterations with relative ease, resulting in a level of optimization not previously possible given typical project timelines and budget constraints.



Typical grading plan in the NVSRB.

Public Outreach

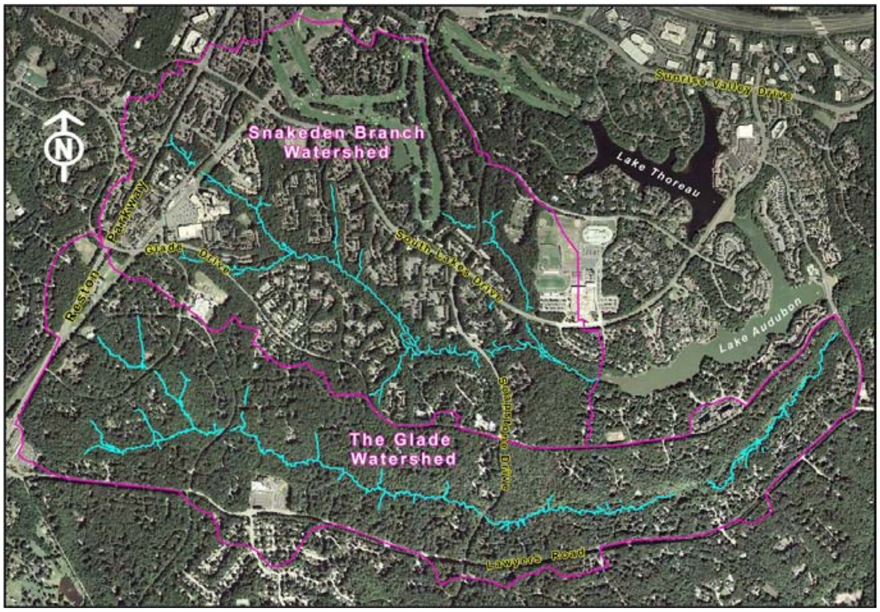
The system of streams and trails in wooded stream valleys is a centerpiece of the Reston community and is often cited by residents as one of the main reasons for wanting to live there. As such, any perceived threat to this wonderful amenity is met with resistance – even when the project is intended to enhance and improve the condition of these resources. Thus, effective public education and outreach became a key component in the success of the NVSRB. This outreach began as announcements on the Reston website; community meetings advertised with general emails, postings on the website, and signs placed in the community; articles in the local newspaper; and interviews on a local cable station. Several presentations to the Reston Design Review Board (DRB), which has local review and approval authority for each restoration plan, were also made well in advance of submitting the first restoration plan set.

This outreach campaign seemed to be effective as the project began and continued for much of the first year. As the project neared the bottom of the first stream to be restored (*Snakeden Branch*) and designs for the streams in the neighboring *The Glade* stream valley were underway, it became apparent that some residents in that watershed were relatively unaware of the project. This lack of familiarity led to rumors and misunderstandings about the project, resulting in significant community opposition. At least some of the issue had to do with the character of each of the two watersheds – *Snakeden Branch* consisted of largely commercial and multi-family residences and has an impervious area of approximately 40%. Access to the stream was achieved by using adjacent sanitary sewer easements – an added benefit of this approach was to clear the largely wooded easements, which is desirable as tree roots can damage the underlying pipes.

The Glade watershed, by contrast, consists of older single family residences, with many of the residents having lived there since the homes were built in the 1970’s. The watershed is much less impervious (about 18%) and therefore produces a much lower flow rate (and, therefore, smaller channels). The residents of *The Glade* are perhaps more involved in and protective of the care and use of their stream valley than any other community in Reston. They heard about and observed the clearing that was underway in *Snakeden Branch* and assumed the size of the channels and amount of tree clearing would be comparable in their watershed, which was not the case.

In response to the mounting public outcry, WSSI altered the course of action relating to the methods of public outreach and made some changes to certain elements of the design to accommodate citizen concerns. First, whenever possible, access was moved from the sanitary sewer easements to existing trails. There was a vigorous community debate over this issue, as many residents felt that closing the trails during construction would be a significant imposition. In

the end, this approach was selected for access to the stream in order to minimize tree loss in areas where the trails are closer to the stream than the sanitary easement. We also reduced the dimensions of the access paths to the absolute minimum width that would allow the construction equipment to pass. This resulted in a more difficult project to construct, but was a necessary concession in order to gain public support.



Aerial photo of *The Glade* and *Snakeden Branch* watersheds.

On the public outreach program, we began regular citizen meetings that included stream walks prior to the commencement of the design to explain first-hand to residents why the streams needed to be restored and to solicit their suggestions/concerns. We then proceeded by developing a detailed preliminary plan that depicted all clearing, grading, and access for the particular stream reach. Another meeting was then held to review the plan and to walk the stream with the proposed limits of clearing and all the trees proposed to be removed denoted by flagging ribbon. We would once again explain our design and why we approached it the way we did and solicited comments and/or suggestions. If at all possible, their suggestions were incorporated into a final preliminary plan which was once again presented to the community in a similar fashion. The final preliminary plan was then presented to the Reston DRB in order to obtain official approval from the community. This same process was repeated for the full stream restoration planset, including two more citizen meetings and walks as well as final approval by DRB.

Community meeting to review plans prior to a stream walk.

In addition to the numerous meetings, each of which was announced through letters sent to every resident in the watershed, we increased the amount of project information that was available on our website. This information included all information required by the regulatory agencies (wetland delineations, wildlife reports, benthics reports, etc.), the preliminary and final stream restoration plansets, all presentations, project photos, meeting schedules, etc. Virtually everything related to the project was posted online. We also set up an email hotline for people to voice their concerns to which we would respond within 24-hours. All of these adaptations to the particular concerns of the community were successful in gaining its support and resulted in a better overall project.

Along with approval from the community of Reston in the form of the DRB, the restoration plans also had to be approved by COE, DEQ, and the Fairfax County Department of Public Works and Environmental Services (DPWES). A permit from the Virginia Department of Transportation (VDOT) was also required to allow entrances to the construction sites from public roads.

Construction Phase

Construction in the NVSRB began in February 2008 at the top of the Snakeden Branch watershed. Within one year, all of Snakeden Branch (20,038 linear feet) was complete. By the end of 2010, another 20,068 linear feet was completed, which included all of The Glade. Work has since begun in the Colvin Run watershed, which is likely to proceed at a slower pace as the slowdown in the economy has reduced demand for stream "credits".

The construction phase of any particular reach begins with placement of orange safety/tree protection fencing around the limits of clearing. This is followed by tree clearing throughout the entire stream reach, as opposed to clearing as the project progresses. Once the construction entrances are installed and the access road is put in place (timber deck-mats are used along the entire length of the haul road to reduce impact to adjacent tree roots), work in the stream is commenced.

Timber deck mats along access path in *The Glade*.

Traced carrier with structure rocks.

The restoration work is performed using various sizes of track hoes equipped with a hydraulic thumb (a necessity for picking up and placing rocks weighing 2 tons each). Materials are transported from the stockpile areas to the active stream work via rubber-tracked carriers with rotating beds – a very helpful feature when working in tight quarters. Restoration is performed in the channel itself, with a pump-around system keeping the work area "dry" while work is underway.

As previously mentioned, the selected method of restoration is to raise the bed of the incised channel in order to reconnect it with the former floodplain. For deeply incised channels, much of the necessary fill material is comprised of suitable soil (containing minimal organic materials, large rocks, or other debris) that is placed and compacted by the tracked equipment. The top layer of the channel bed (approximately 1-ft) is lined with a reinforced bed material that is comprised of crushed diabase rock (with an average diameter of about 7"), bank run gravel, sand, and topsoil. This reinforced bed material is mixed in specified proportions by the rock supplier for the project, Cedar Mountain Stone Corporation located in Mitchells, VA. In addition to the reinforced bed, rock structures were also employed, including cross-vanes, step pools, and rock steps. These structures provide stability for the channel bed and banks, as well as create a riffle-pool complex that promotes biodiversity within the streambed. Wood has also been incorporated into the design as components in some of the structures as well as buried in the bed of the stream to create smaller pool features.

Another important component for creating a stable and ecologically viable restoration project is planting. All disturbed areas are over-seeded with a riparian seed mix that contains dozens of native species, including 6 grass, 21 forb, 5 shrub, and 5 tree species. In addition, native trees and shrubs (8 tree and 10 shrub species) are planted in appropriate hydrologic zones in the form of tubelings (streamside) and 1-gal container grown materials. Our successful establishment of a healthy and diverse riparian cor-

Tributary to Snakeden Branch immediately after construction and 1.5 years later - note the culvert in the background.

ridor is attributed to not only the diversity of our planting palette, but also to the heavy seeding and planting densities at which it is applied.

Monitoring and Maintenance

Following the completion of construction and approval of the as-built drawing, the MBI requires that the project be monitored and maintained for a period of 10-yrs to ensure the success criteria contained in the MBI are met. This monitoring includes assessment of the success of the vegetation (percent coverage as well as adequate numbers of woody stems per acre and per linear ft of stream edge) as well as survey monitoring of the channel shape and alignment and the stability of the installed structures. While there are no success criteria, biological monitoring is also being performed to develop information regarding the response of benthic organisms in restored urban streams. Improvements are not expected due to the poor water quality and temperature spikes in these urban watersheds – which this project is not designed to address. Hopefully, future public investments will target these watersheds for SWM/BMP retrofits to improve the water quality entering into these restored streams. In addition to the annual monitoring discussed above, we are also required to inspect the project after larger storms that meet the criteria specified in the MBI.

Nature camp activities in *Snadeden Branch*.

Thus far, the NVSRB has been extremely successful. All as-built and monitoring criteria have been met and exceeded since the first reaches were completed in March 2008. The completed streams have successfully handled several significant storm events, including tropical storm Hannah which was a 100-yr event. The measure of success that has been achieved, not only in the results of the restorations themselves but also in the manner in which we have worked very closely with the community, was recognized by our receipt of the 2010 Best of Reston Award. Our success is also evident through less tangible means – the new-found use and enjoyment of the restored streams by the community.

Frank Graziano, P.E. is a VP-Engineering with Wetland Studies and Solutions, Inc., a natural and cultural resource consulting firm located in Gainesville, VA. He also serves as the Project Manager for the Northern Virginia Stream Restoration Bank.

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Affecting the Fate of Artificial Ponds by Assessment of Their Values

**Dr.-Ing. Wolfgang Frey,
Prof. Dr.-Ing. Gero Koehler,
Holger Hauptlorenz and
Dr. rer. nat. Holger Schindler**

Figure 1. Secondary biotope with high ecological value at an abandoned pond.

Introduction

The Palatinate Forest (Pfälzerwald) in the Southwest of Germany (State Rhineland-Palatinate) is a heavily forested low mountain region and forms together with the adjacent French Vosges Mountains the UNESCO Biosphere reserve "Palatinate Forest-Vosges du Nord".

In the Palatinate Forest there are practically no natural bodies of standing water, but there are more than 1,000 artificial ponds (Koehler & Gramberg, 2004). The ponds were originally built for fish or for hydropower, but are increasingly being abandoned. Only a few are currently used for fish breeding, recreation, and water sports. In some cases, the related secondary biotopes have developed high ecological value, as shown in figure 1.

Mainly because of the effects of pollution, the forest administration has chosen not to renew the land leases of a high percentage of ponds, leading to abandonment, and the responsibility for the ponds thereby reverts to the forest administration or the municipality. These public owners don't have the resources to maintain all of these bodies of water, and some of these biotopes have been or will be lost. Many of the remaining ponds are in danger of disappearing within the next few years.

On the other hand, these unused ponds can still have a negative influence on the associated watercourse, particularly on the movement of animals. Most of them are centered in the watercourse so that the watercourse is interrupted. No management concept exists for these barrier structures, particularly in terms of the requirements of the European Community Water Framework Directive (EU 2000). This directive demands the achievement of a good ecological status for all natural waters, which is defined by bioindicators like fish or invertebrate communities. Therefore the biological passability for streams is required by law.

Roweck, Auer and Betz (1988) conducted a very detailed investigation of 19 ponds in the Palatinate Forest with a special focus on vegetation, and offered proposals for management and maintenance of them. Beyond this work, only monographs about individual ponds within this landscape exist. Recommendations for the management of standing bodies of water in the low mountain regions of Germany are very general (e.g. Rahmann, Zintz & Hollnaicher, 1988) or deal only with specific impacts such as periodic draining of ponds (e.g. Zeitz & Poschlod 1996).

In 2004 the Department of Hydraulic Engineering and Water Management at the University of Kaiserslautern proposed a 'concept for the ecological assessment and development of ponds in the Palatinate Forest' (Hauptlorenz, Frey, Koehler & Schindler 2007). The Deutsche Bundesstiftung Umwelt (German Federal Foundation for Environment) decided to support this project financially from 2007 to 2010.

There are three main goals of the project:

- Development of an assessment system taking into account the cultural-historical value, the function for recreation, the scenic landscape value, the ecological quality, and the influence of the ponds on the river system.
- Creation of a management concept and a decision-support system based on the assessment.
- Planning and realization of first measures on chosen examples.

Data collection

A base data collection protocol was developed to guide the on-site survey. Its parameters are shown in table 1. In the years 2007 and 2008, 235 ponds were documented using the protocol.

In addition to the parameters in table 1, vegetation, dragonflies, and benthic invertebrates were documented. Vegetation and dragonflies were chosen as indicators for the ecological quality of a pond in support of the development of the eco-morphological assessment system. Benthic invertebrates collected in the watercourse up- and downstream of the ponds were used to get

information about the effects of the ponds on life conditions of the streams. The number of ponds in which each aspect of data collection was undertaken is shown in table 2.

The ecological quality of the streams and the real and potential watercourse interconnectedness were determined according to existing morphological assessments. A literature search was made to determine the cultural and historical importance of the ponds.

All of the base information was merged and prepared for a database to be used for the subsequent analysis and assessments.

Morphological and hydrochemical description

The surface areas of the ponds range from a few square metres up to 12 ha. The dimensions reflect their uses and are presented in table 3. The height of the dam walls mostly ranges from 2 to 4 m and the maximum water depths are 1–2 m. The most common outlet structure is shown in figure 2. Some of the outlets were designed to support hydropower, mill, or “drift” usage and consist of an overfall or a tube (Table 4). Drift refers to the practice of rafting small pieces of timber. To do this, the watercourses were built into channels with bricked walls during the 19th century, and ponds were built along them to drive the floating system.

More than 80% of the ponds are centered in the watercourse, and therefore are of high relevance for the stream systems (Table 5). Considering this in combination with the structure of the most common outlet (Figure 2), it is clear that the ponds have a strong influence on the interconnectedness of the streams.

Almost all of the watercourses of the Palatinate Forest are located on sandstone (bunter). Only a thin strip in the east shows the influence of calcium carbonate. The variegated sandstone is lacking in bases and nutrients. The pH values range mostly from 5 to 7, and the conductivity is about 100 µS.

The ponds with low pH and low conductivity are mostly dystrophic and are located in forests. Ponds in meadows have higher pH and conductivity values and are

Table 1: Parameters of the data collection protocol

Main parameters	Sub-parameters
Pond morphology	Dimension, location, supply, water body, banks
Man-made structures	Inlet, outlet, dam wall, floodwater overfall
Use	Kind and intensity, infrastructure
History	Historical use, age, historical construction
Description of the biotope	Aggradation, shading, vegetation, special structures
Surroundings	Type of forest, land use, settlements, adjacent biotopes, riparian zone
Stream biotope	Stream morphology, passability, adjacent migration barriers
Hydrological chemistry	pH, O_2 concentration, temperature, conductance, trophic condition

Table 2: Number of ponds in which data were gathered

Investigations	Investigated ponds
Base data collection	235 of about 1000 ponds
Vegetation	200 of the 235 base data collection ponds
Dragonflies	32 of the 235 base data collection ponds
Benthic invertebrates	11 test points upstream and downstream of 5 different ponds or pond groups

Table 3. Typical uses of ponds of different dimensions

Size	Use	Percentage
> 1 ha	Old fish ponds, waterpower ponds, recreation	3%
0.1 to 1 ha	Old fish ponds, mill ponds	38%
< 0.1 ha	Drift ponds, new fish breeding ponds	59%

Table 4. Outlet structures

Structure type	Typical use	Percentage
As in fig. 2, additionally other structures possible	All fish ponds	74%
Only overfall or tube	Hydropower, mill, and drift ponds	25%
None remaining or designed with no outlet		1%

Table 5. Position of the ponds in relation to the watercourse

Type	Description	Percentage
Centred	Centred in the watercourse, holding back all of the water, the watercourse is interrupted	82%
Bypass	Pond and watercourse are located in a parallel connection, holding back some of the water, the watercourse is continuous (bypass channel)	13%
Spring supply	Pond is located next to the watercourse, supply is only from backed-up or piped springs; the natural spring biotopes have been disturbed or destroyed	5%

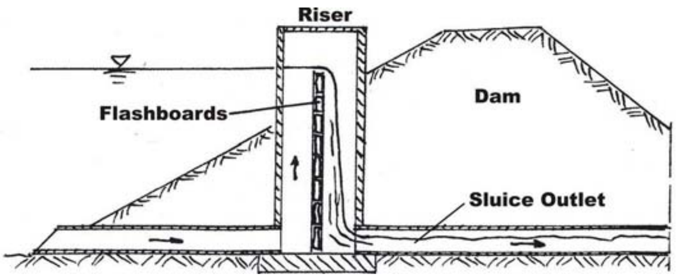


Figure 2. Principle of the most common outlet construction.

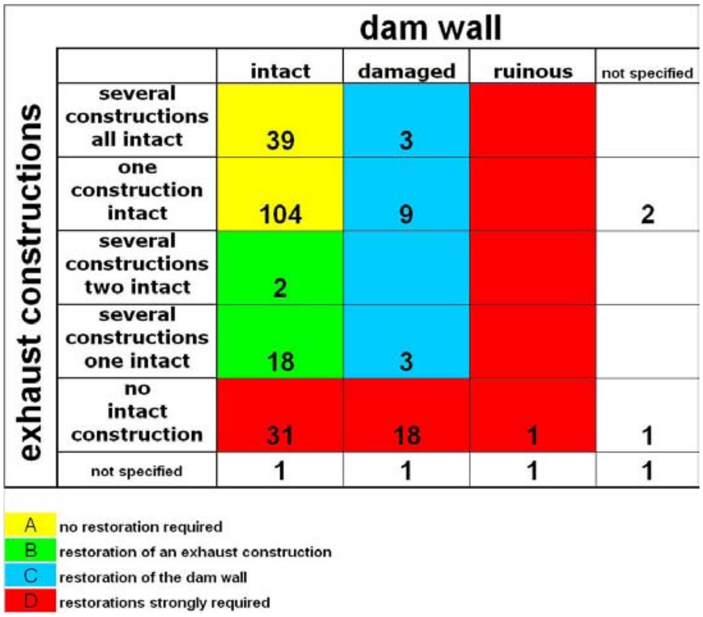
rarely dystrophic. The intensity of fish breeding is connected with even higher pH and conductivity values. The highest values are found in ponds that contain saline runoff from roads and in ponds that are located in the calcium carbonate area where viticulture is practiced.

Pond Assessments

Existing assessment systems for standing water bodies in Germany focus on aspects of nature protection. In most cases there are only general proposals for an assessment (e.g. Schoknecht, Doerpinghaus, Köhler, Neukirchen, Pardey, Peterson, Schönfelder, Schröder & Uhlemann 2004), and the assessment systems are restricted to natural lakes (e.g. LAWA 1998). Assessment approaches for small artificial bodies of water can be found in Mayer, Brozio, Gahsche & Münch (2003) for a lowland area in the state of Brandenburg but not for the low mountain regions of Germany.

Rahmann, Zintz & Hollnaicher (1988) recognized the necessity of considering the following aspects in a management concept for small bodies of standing water: the historical facts and scenic landscape conditions as well as concerns regarding nature protection, agriculture, recreational and professional fishing, and tourism. Additionally the effects of the ponds on the ecological state of the stream according to the Water Framework Directive (see above) must be taken into account. Based on this, five assessment systems were created:

1. Condition of the structures
2. Eco-morphological assessment
3. Influence on the watercourse
4. Cultural and historical assessment
5. Scenic landscape and recreation impacts



exhaust constructions	dam wall			
	intact	damaged	ruinous	not specified
several constructions all intact	🟨 39	🟦 3	🟥	
one construction intact	🟨 104	🟦 9	🟥	2
several constructions two intact	🟩 2	🟦	🟥	
several constructions one intact	🟩 18	🟦 3	🟥	
no intact construction	🟥 31	🟥 18	🟥 1	1
not specified	1	1	1	1

🟨 A no restoration required
🟩 B restoration of an exhaust construction
🟦 C restoration of the dam wall
🟥 D restorations strongly required

Figure 3. Condition of the structures in the 235 observed ponds and conclusions for their restoration.

Each assessment uses the data collection protocol as the main database supplemented with additional data such as historical facts. All five assessment systems are independent from each other, and in all but the first, the ponds are rated on a five-point scale from very high to very low.

Condition of the structures

The dam walls and the outlets of the ponds exist in different conditions. The current condition of the structures was assessed as intact, damaged, or ruined (Figure 3). Damaged dam walls endanger the whole pond and the area below. Damaged outlets degrade the pond.

Eco-morphological assessment

A crucial difficulty in developing an ecological assessment is that there is no natural model for the ponds due to their artificial origin. Therefore we used habitat limiting structures, the diversity of natural structures, and the naturalness of banks and surroundings as assessment parameters as shown in figure 4.

The assessment scheme was evaluated with the help of biological investigations, primarily the comprehensive vegetation surveys. Correlations between the individual parameters of the data protocol and parameters of ecological quality generated from the biological investigations (such as number of Red List species, Red List vegetation communities, total number of dragonfly species) have been tested. No correlation, for example, was found between the grade of aggradation and any of the biological parameters, so this parameter was not used for the eco-morphological assessment. Also the "impression of the surveyor" regarding the ecological quality on site was used as guidance for emphasizing relevant parameters for this assessment.

Some parameters, such as oxygen and pH, are only relevant when they exceed critical values. Others are assessed in combination with each other (if-then relation). Some of the habitat limiting parameters are assessed pessimistically, only the worst are included in the overall assessment.

The results of the eco-morphological assessment are shown in Figure 5. Most of the investigated ponds have a moderate or low ecological value.

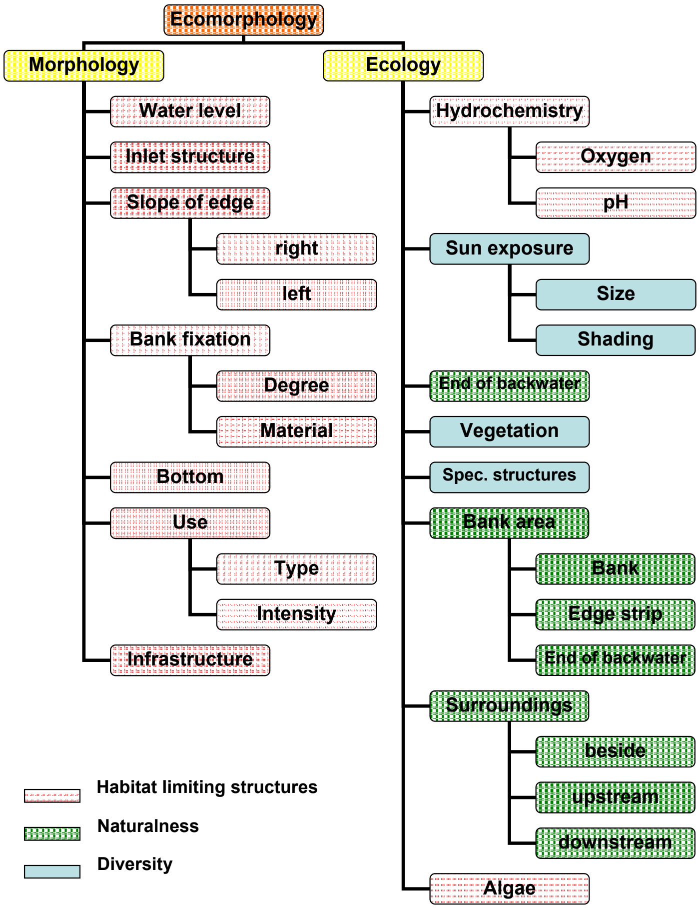


Figure 4. Eco-morphological assessment structure.

Influence on the watercourse

As mentioned above, ponds centred in the watercourse act as migration barriers. The water quality can also be disturbed under certain conditions. In addition, investigations showed that even slightly eutrophic ponds degrade invertebrate communities in streams. Another influence that must be taken into account is the loss of the stream biotope caused by backwater. Thus, the passability of the man-made structures, the interconnectedness of the stream system with and without the pond, the trophic state, and the morphological quality of the stream are used as parameters to assess the influence of the pond on the watercourse. All parameters can be determined from the observed attributes in the data collection protocol.

The execution of the developed assessment method at the 235 investigated ponds led to a fairly homogeneous distribution among five quality classes with a plurality rated as moderate (Figure 6). To better understand this, it is necessary to look at the individual assessment components to understand what aspect led to the rating and how significant it is for deriving measures. In 87% of all cases, there was an impassable structure, but mostly this was not a crucial aspect for the stream system. Due to the upstream location of the ponds and the presence of other existing barriers, the interconnectedness wouldn't improve significantly in three-quarters of the cases if the pond was removed.

Cultural and historical assessment

The history of the development and use of the ponds is diverse. Four main groups can be differentiated (Table 6).

The assessment system uses the age of the pond and the existence of significant cultural-historical structures as parameters. A third parameter is the history of the pond and asks if an individual pond has its "own story" (historical events, regional legends, outstanding use, or change of use), a "common story" of a special group of ponds such as drift ponds, or no special history.

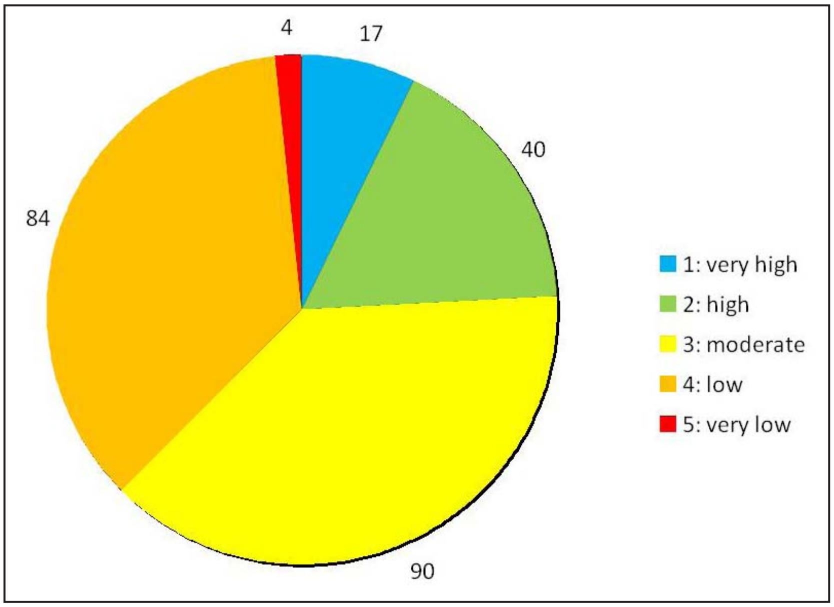


Figure 5. Distribution of the eco-morphological values of the 235 observed ponds.

Most of the observed ponds have only a low or very low cultural-historical value. Considering this, there is a growing need to preserve the few ponds with high or very high historical importance (Figure 7).

Scenic landscape value and recreation

The landscape assessment takes into account that the most important use for the ponds in the future will be passive recreation. The Palatinate Forest is famous for its hiking. The assessment considers the spatial diversity, the spatial perception, and the accessibility, estimated from observed attributes such as expanse of the water body, shading, vegetation, hiking trail proximity, special structures, and pond arrangement.

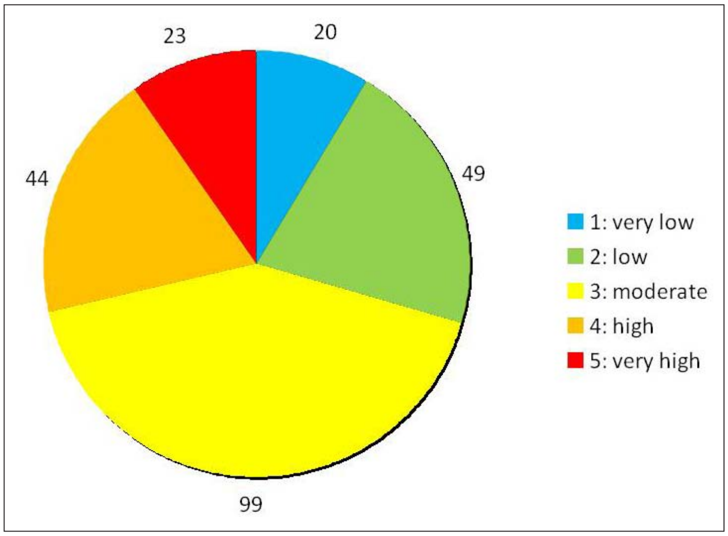


Figure 6. Distribution of the degree to which the pond influences the watercourse in the 235 observed ponds.

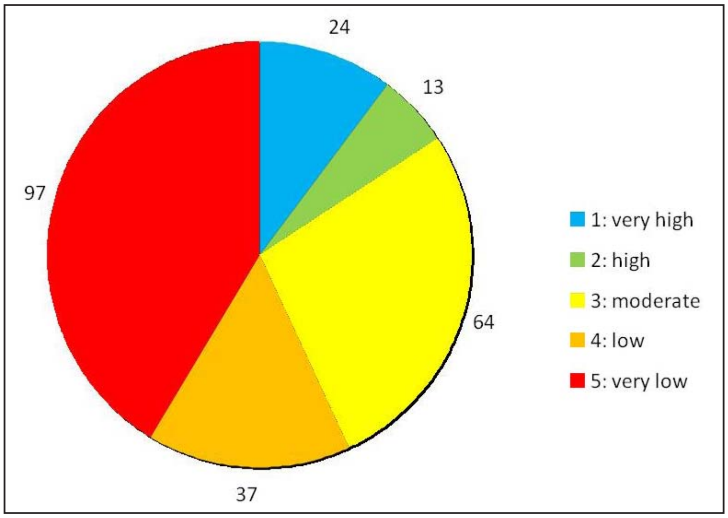


Figure 7. Distribution of the cultural-historical values of the 235 observed ponds.

Table 6. The four main uses of the ponds in the Palatinate Forest

Use	Description
Old fish ponds	Their existence can be documented to medieval times in a few cases. They are positioned in the centre of the watercourse and can be very large. Most of the ponds belong to this group.
New fish ponds	In most cases, some of the water is diverted from the watercourse to small ponds positioned alongside the stream. Sometimes the supply is only by springs, in particular at the edges of wide valleys. These ponds were mostly built in the 20th century.
Mill ponds	Built for hydropower, these ponds are mostly positioned in the center of the watercourse and the mill has been activated by a delivery channel or tube from the pond.
Drift ponds	Used for floating small pieces of timber, these ponds were built with sandstone at the beginning of the 19th century. They were abandoned at the end of the 19th century.

Most of the ponds show a high or moderate importance in scenic landscape terms (Figure 8).

Collective assessment and decision support

Each of the five assessment systems leads to different classes and different recommendations for action, e.g., the assessment of the condition of structures results in conclusions about the urgency of restoration measures, and the five classes of the eco-morphological assessment result in the proposals shown in table 7.

By assembling the recommendations resulting from the five assessment systems together, a management concept for each individual pond was generated. The eco-morphological assessment, the influence on the watercourse, the cultural-historical assessment, and the landscape and recreation assessment lead to decision support regarding the preservation or the removal of the pond and measures for improvement. The assessment of the condition of the structures leads to conclusions about the urgency of action when preservation is recommended based on the other assessments.

In addition, a calculated comparison between the eco-morphological value and the influence on the watercourse can be performed. Such an "ecological matrix" compares the ecological values of the pond and of the stream and tries to determine if the backwater is more of a hindrance or more of an enrichment from the ecological point of view. An "anthropogenic matrix" combining the cultural-historical assessment and landscape/recreation value ranks the relevance of the pond for human interests. This may be a more important reason—beyond the ecological argument—for the conservation of the pond.

Management Concept

The management concept derives from the results of the assessments as explained above and considers the existing rights and usages. The main goal is the conservation and maintenance of historically and ecologically valuable ponds. Undesirable uses should be identified and corrected (e.g., intensive fish breeding, retention basin for road drainage), and new options for use can also arise. The ecological value or the value for recreation can be enhanced with mostly low cost measures (e.g., removal of spruce or Douglas fir as not native trees) whereas in the case of damaged structures, the question of restoration versus decay or removal must be answered.

Possible measures for improvement include the following:

- **Installation** of a **bypass channel** next to the pond (conversion from a centered to a bypass pond)

- **Installation** of a solid **overfall** with rough-textured chute down to the tailwater to improve passage for stream-dwelling organisms
- Medium-term **maintenance and support** of ponds (e.g., conservation of structures, stocking regulation, improvement of the surrounding)
- **Restoration** of damaged structures
- Lowering of water table or **removal** of ponds
- Measures for **making the ponds visible for people** including infoboards, seating-accommodations etc.

Decisions regarding the individual ponds will be made in coordination with local authorities, owners, and users (forestry, municipality, environmental authorities, water management offices, fishing associations, fish farmers, private owners), who can make use of our recommendations for the observed ponds. For the larger number of ponds that have not yet been investigated, the data collection protocol and the assessment systems will enable the stakeholders to reach appropriate decisions.

First measures based on our management concept have been performed in cooperation with municipalities and forest administration.

Several measures are planned, for example, the rehabilitation of a historical drift pond with an existing sandstone outlet (Figure 11). The planning includes the construction of a fish pass to assure the biological passability of the structure.

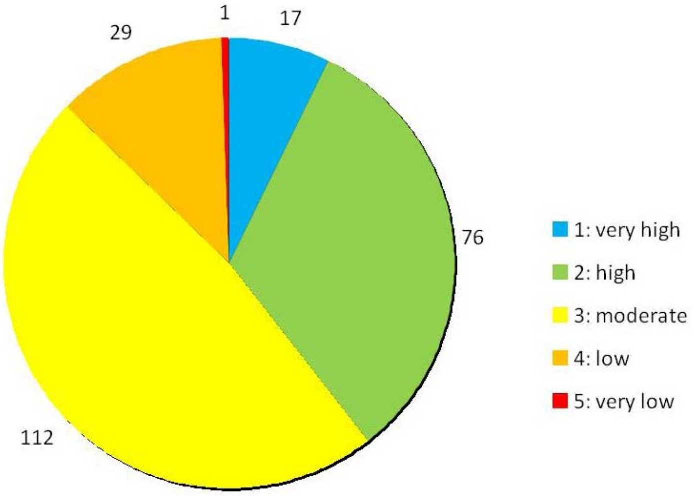


Figure 8. Distribution of the landscape values of the 235 observed ponds

Table 7. Decision support derived from the eco-morphological classes

Class	Management decision support	Measures for upgrading
1 Very high	Conservation of the pond, preservation has highest priority	None necessary
2 High	Conservation of the pond, preservation essential	Ecological support reasonable, but not a priority
3 Moderate	Conservation and preservation desirable	Ecological support measures desirable
4 Low	Not necessary	If preservation is desired for other reasons, ecological support should be provided
5 Very low	Pond can be shut down if there are no other arguments for conservation (decay permitted or removal required depending on other assessments)	If pond preservation is desired (for some other reasons), ecological support measures would likely not be cost-effective.

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Gero Koehler is an emeritus professor of Hydraulic Engineering and Water Management at the University of Kaiserslautern. After his retirement he works as a volunteer on the presented project involving the fate of the ponds in the region where he lives.

Holger Hauptlorenz is a biologist with a focus of vegetation doing most of the observations at the described project. He works for the University of Kaiserslautern and as a freelancer.

Figure 9. Renewal of a damaged dam wall because of a blocked outlet (left, beneath water level)

Figure 10. New outlet construction formed as an overfall with cascades into the tailwater

Figure 11. Drift pond dam from the 19th century with historical outlet structure (right side) and damage requiring restoration (left side)

Holger Schindler, Dr. rer. nat. (PhD) in Biology and associate of two consulting firms in the field of surface water and groundwater ecology is the chairman of BUND (Friends of the Earth) in the State of Rhineland-Palatinate.

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