A Sustainable Chesapeake

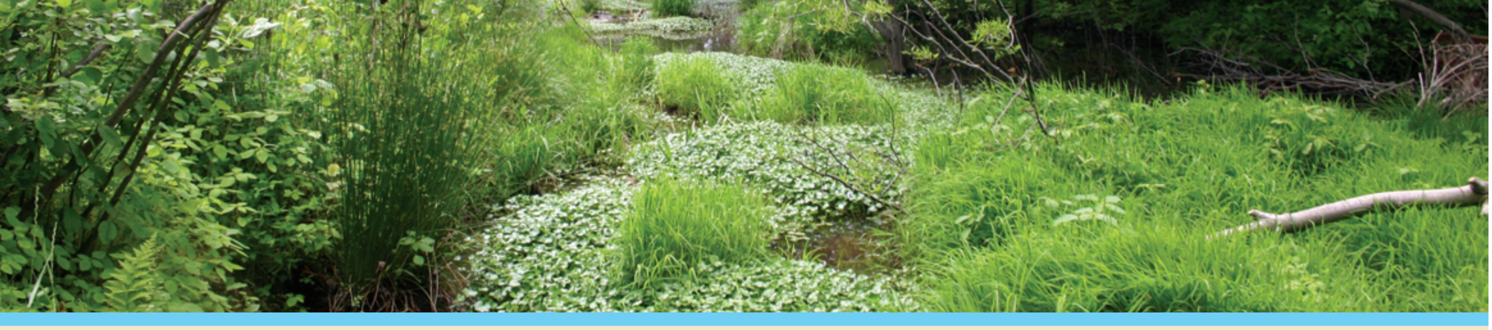
BETTER MODELS FOR CONSERVATION

Edited by David G. Burke and Joel E. Dunn

THE CONSERVATION FUND

The case study you have downloaded is highlighted below. Other case studies from this Chapter of *A Sustainable Chesapeake: Better Models for Conservation* can be individually downloaded. The editors encourage readers to explore the entire Chapter to understand the context and sustainability principles involved with this and other featured case studies. The full publication contains 6 Chapters in total: Climate Change Solutions, Stream Restoration, Green Infrastructure, Incentive Driven Conservation, Watershed Protection and Stewardship.

CHAPTER ② STREAM RESTORATION



A "Seepage Wetland" Design Approach to Stream Restoration

A Better Model for Urban Stormwater Management in Wilelinor Stream Watershed

The stream restoration work performed on Wilelinor Stream demonstrates how a historically prevalent native wetland community fits into a promising approach for improving water quality and managing stormwater, while providing a valued amenity to adjacent residents.

CASE STUDY SUMMARY

Anne Arundel County, Maryland, has approximately 1,500 miles of small streams (first- to third-order streams) with approximately 300 miles rated poor to very poor, which are in need of restoration. These degraded streams contribute excessive sediment loads to tidal waters, in addition to the pollution generated from the rest of the county's watersheds. One of these degraded streams is in the community of Wilelinor Estates, located below Maryland Route 2, just southwest of Annapolis. The Wilelinor Stream is the primary headwaters of the southern branch of Church Creek on the South River. Typical of urbanizing watersheds, stormwater velocities and peak flow volumes have increased as a result of increased impervious cover.

In 2005, the Maryland State Highway Administration Environmental Program, the Maryland Department of Natural Resources Watershed Restoration Program, Anne Arundel County Department of Public Works, and the Anne Arundel County Public School's Chesapeake Connections collaborated to develop a stream restoration project designed with water quality goals in mind. The partners used a "seepage wetland" design approach to address erosion and pollution problems.

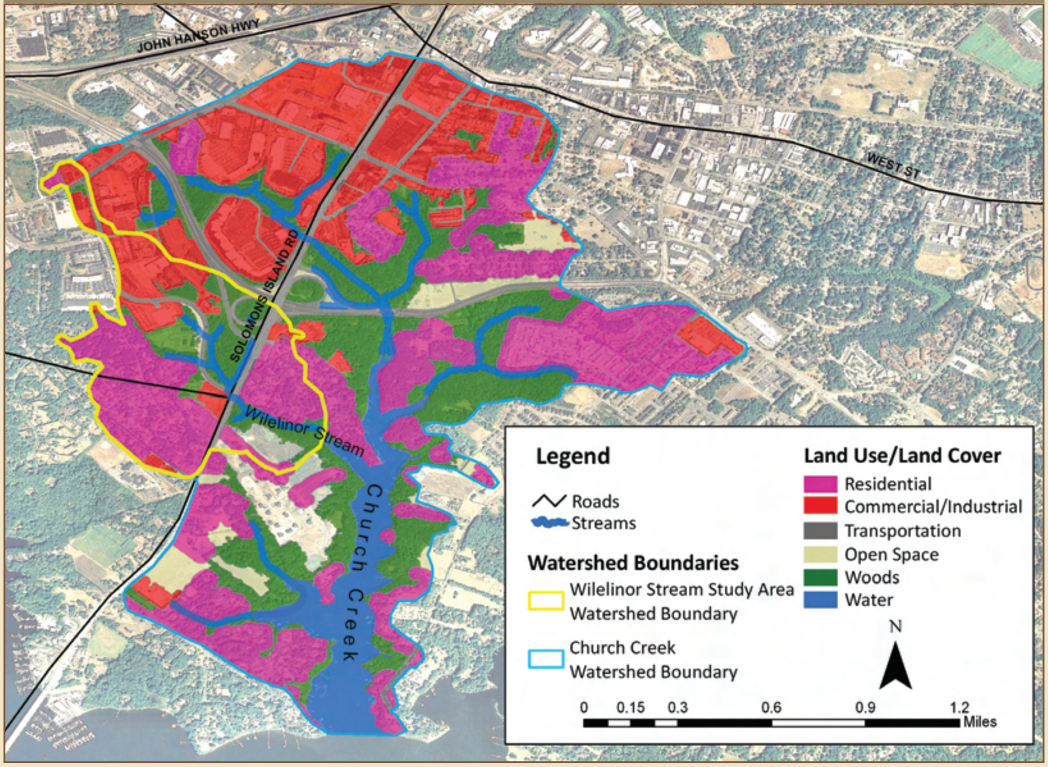
For the purposes of this case study, a "seepage wetland" design approach offers amenities associated with "soft" channel design, such as a connected floodplain and shallow step-pools, but also employs the use of permeable berms, seepage reservoirs, and off-line ponds to create wetland environments that interact with the main stream channel.

The site analysis and project design took several months to complete. Construction began in 2004 and was completed in April 2005. The project reestablished a stable stream profile, created capacity to convey peak discharges, restored aquatic habitat and ecological function, and reestablished

Comparison of Restoration Features Used in 3 Separate Stream Case Studies Featured in this Publication

	"Hard" Design Approach (Stony Run—see case study)	"Soft" Design Approach (Kingstowne—see case study)	"Seepage Wetland" Design Approach (Wilelinor—this case study)
Major Restoration Features:	➤ Cross vanes ➤ J-hook vanes ➤ Imbricated riprap ➤ Two-stage channels ➤ Step-pools	➤ Dry detention pond ➤ Plunge pools ➤ Soft meanders ➤ Live stakes ➤ Riparian buffer ➤ Step-pools (diverse cobble substrate)	➤ Sand berms ➤ Seepage reservoirs ➤ Off-line ponds ➤ Riffle weirs ➤ Shallow, aquatic step pools

Wilelinor Stream Watershed – Annapolis, Maryland



WATERSHED CHARACTERISTICS

- 214 acres on the Coastal Plain (Church Creek watershed is 1,217 acres)
- 37% covered by impervious surface (37% in the Church Creek watershed)
- 49% of the land is residential; 22% is wooded; 21% is commercial/industrial; 7% is for transportation; 1% is open space

native Atlantic white cedar swamps to the watershed. The restoration also satisfied public demand for recreation amenities in the community.

RESOURCE MANAGEMENT CHALLENGE

Two of the area's communities, including Wilelinor, were originally designed and constructed with in-stream architectural/recreational amenities (ponds) intended to provide fishing, canoeing, relaxation, etc.[1] Over time, as the watershed became increasingly developed, the dynamics changed. Greater runoff with less infiltration/evaporation, as well as sediment from upstream development, filled the ponds. The dams reached the point of imminent failure, and the community amenities were lost. Residents demanded their restoration, with support from other nearby communities. Together, they mounted a significant campaign focused at local government that emphasized their dissatisfaction with the degradation of their neighborhood waterways.

There is a substantial body of research that details the ability of restored streams and adjacent riparian buffers to store sediment to retain and transform nutrients and other toxic substances, and to create stable stream ecosystems.[2,3,4,5,6,7] Nevertheless, there is a paucity of post-restoration monitoring, and many water resource agencies do not have data indicative of stream restoration performance as a best management practice for reducing nitrogen and sediment export from urban watersheds.[8,9] Subsequently, there is low confidence in the ability of stream restoration design approaches to achieve desired water quality goals, which is the most commonly stated goal for stream restoration projects in the Bay watershed.[10] Post-restoration monitoring is needed to determine the effectiveness of the seepage wetland design approach to the restoration of water quality in the Wilelinor Stream.

CONSERVATION VISION

In an effort to address the strong public interest in restored recreational resources and improvement of water quality, the state agencies and local partners implemented a major restoration project on Wilelinor Stream. Although the community wanted the ponds returned to their original condition, current state policies no longer allow in-stream structures needed to restore the ponds. After a year-long process of education, dialogue and relationship-building, an agreement was made to restore the valley into a wetland complex, "designed to provide community access and enjoyment of the wildlife, amphibians, habitat and natural fish passage throughout the system."[11]

The partners used a "seepage wetland approach," which included off-line ponds, seepage reservoirs, and step pools, to create a baseflow discharge of 0.169 cubic feet per second and a 100 year discharge/design capacity of 873 cubic feet per second.

IMPLEMENTATION RESOURCES

The total cost of the 1,311 foot stream restoration project was $1.02 million (adjusted to 2008 dollars), which is $776/foot. The "seepage wetland" design approach restores the most ecosystem services for a reasonable cost per linear foot, relative to hard and soft stream restoration approaches. The project was funded by Anne Arundel County through the capital improvement budget; and the State of Maryland evenly cost-shared the project with the County.

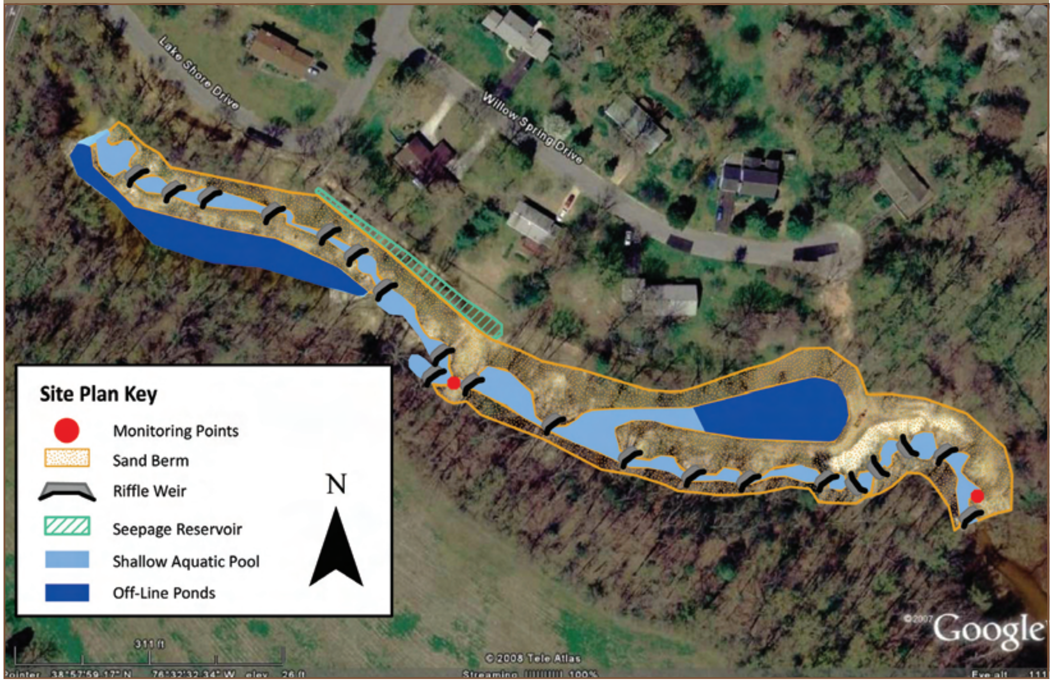
Students and staff planted more than 1,500 plants to help restore Wilelinor Stream.

Keith Underwood & Associates designed the stream restoration project, and Baltimore Pile Drivers, Inc. constructed it. In partnership with the Anne Arundel County Department of Public Works, the Wilelinor Community Association and the Arlington Echo Outdoor Education Center organized a community planting project in the stream valley post-restoration. Students and staff from area schools volunteered their time and planted more than 1,500 Atlantic White Cedar and other native plants in April 2005 to celebrate completion of the restoration project.

CONSERVATION STRATEGY

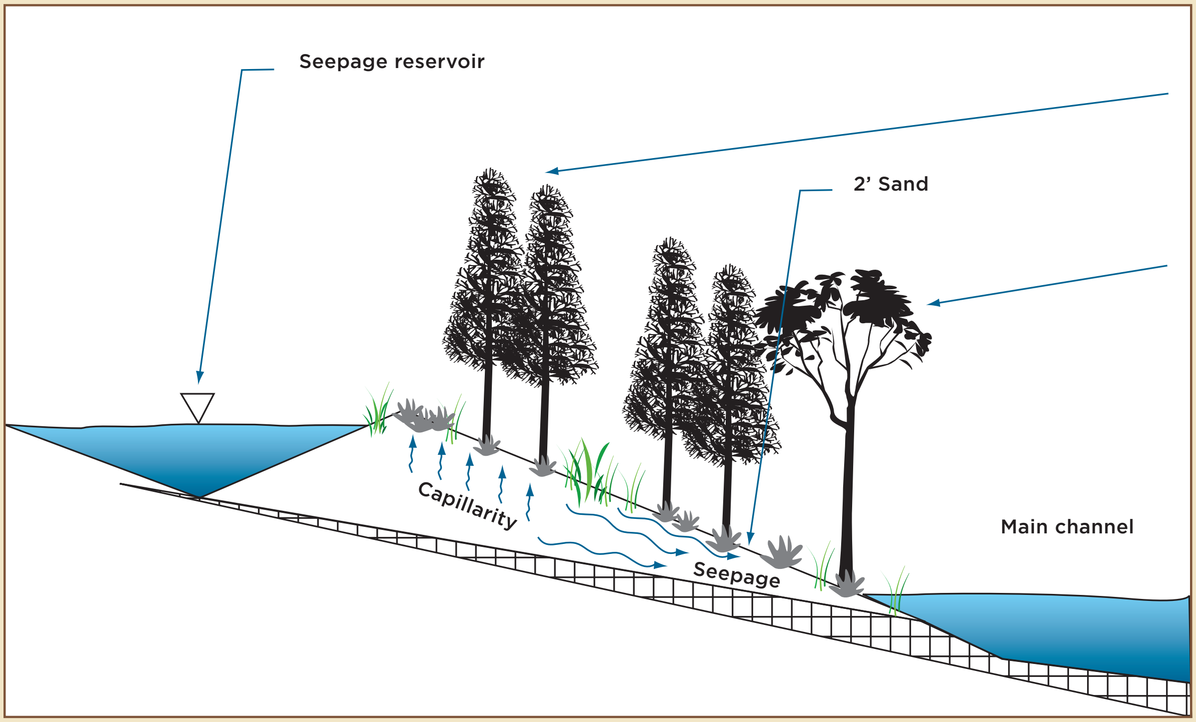
Keith Underwood & Associates developed a regenerative stormwater conveyance system (RSCS) to restore the stream. The RSCS collects then traverses stormwater runoff through a series of aquatic beds and riffle weir grading structures to treat, detain and infiltrate it to groundwater. The stormwater moves from drain outlets down a series of small plunge pools to the main stem of the receiving stream, achieving velocity reductions and interactions with the adjacent riparian buffer. Beyond reducing flow velocities, plunge

Wilelinor Stream Restoration, Generalized Site Plan Annapolis, Maryland



SEEPAGE RESERVOIR PHOTO AND SCHEMATIC

A seepage reservoir at Wilelinor Stream. The main stream channel is to the right.



A seepage reservoir engineering schematic.

A sand berm (center) and off-line pond (right) at Wilelinor Stream. The main stream channel is to the left.

pools create habitats for aquatic species.

The following section details the five principle restoration features that contributed to water quality improvement in the Wilelinor Stream.

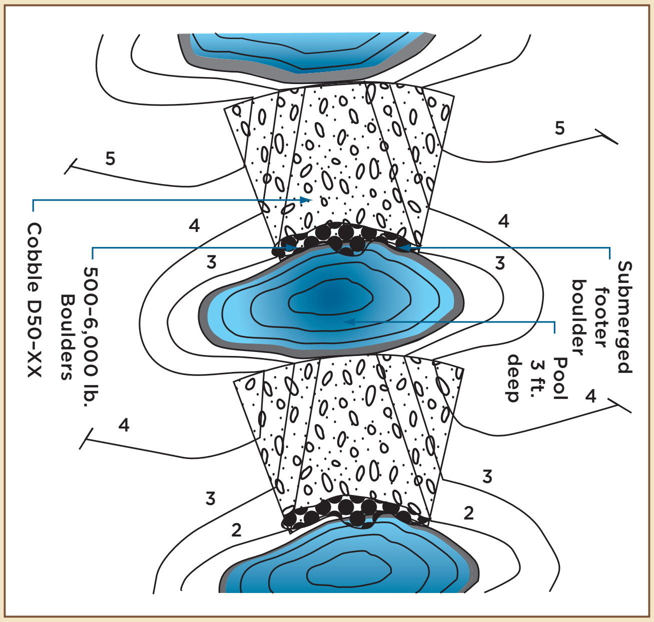
Sand Berms: Sand berms, or debris dams and gravel bars, create seepage reservoirs that allow infiltration from the water stored at a higher elevation to seep through sand and exfiltration into the stream channel as baseflow. A study of the denitrification potential of debris dams and gravel bars on several streams in the Baltimore metropolitan area demonstrated that structures with organic matter have higher denitrification potential, particularly structures with high organic matter content,[12] such as coarse woody debris.

Seepage Reservoirs: Seepage reservoirs are containment areas alongside streams where water is stored temporarily to dissipate energy from storm events; water may then exfiltrate from an area of higher elevation into the stream channel. Seepage reservoirs replicate functions occurring in natural riparian zones, such as dissipation of water energy and denitrification. A study of the denitrification potential in four urban and four rural riparian zones in the Baltimore metropolitan area demonstrated "strong positive relationships between soil moisture and organic matter content and denitrification potential."[13]

Off-Line Ponds: Off-line ponds temporarily collect water that has been diverted from the main stream channel. The water held in the ponds seeps through to lower a lower

Riffle Weir Photo and Schematic

A riffle weir at Wilelinor Stream.



A riffle weir and step-pool engineering schematic.

Shallow, aquatic step-pools at Wilelinor Stream.

elevation and acts as baseflow to the receiving stream. Constructing channels to off-line ponds helps water move between the main channel and the landscape, and can provide a three-fold benefit of dissipating stormwater energy before it reaches the stream channel, increasing contact time with bacteria and organic material, and promoting the removal of in-stream nitrogen.[14] Other studies have demonstrated that nitrogen removal was linked to slower waters.[15] Off-line ponds are an important tool for urban stream restoration because of these multiple benefits.[16]

Riffle Weirs: A riffle weir is used in a step-pool sequence to promote shallow and turgid conveyance of water. This promotes stream-subsurface water interaction and expands the extent of a relatively aerobic hyporheic exchange between the water in the stream channel and groundwater entering through the adjacent catchment.[17] The top weir at Wilelinor is specifically sized to control grade, to reduce velocity of water entering the main stream channel, and to deliver water to the main off-line pond for gradual release to the stream channel.

Shallow, Aquatic Step-Pool Sequences: These pools are created with the placement of a riffle weir grade control structure in a watercourse. Nitrogen removal can be increased by step pools such as these because they "increase topographic complexity, surface-to-area-volume ratio, and hydraulic retention to allow for greater contact between the water and the benthos (e.g., introduction of large, woody debris, construction of pool-riffle or step-pool sequences)."[18] Using step pools to slow and retain water may even be one of the best options for urban headwater streams.[19,20]

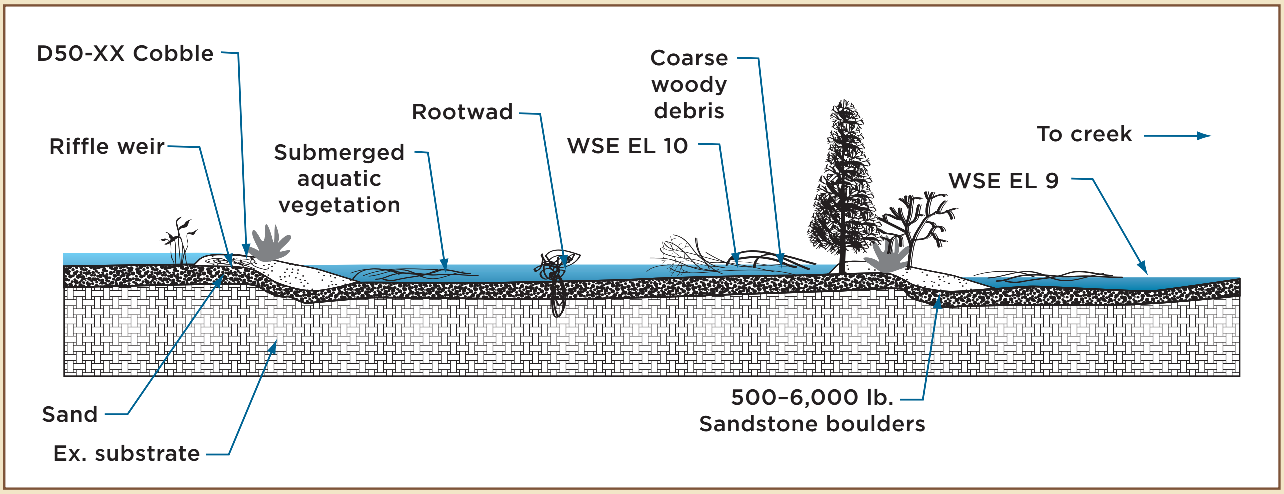
RESULTS

The Anne Arundel County Department of Public Works and its partners made significant improvements to the Wilelinor stream. In total, they restored 1,311 feet of the stream reach. They installed sand berms and seepage reservoirs, off-line ponds, riffle weirs and shallow aquatic step pools. These actions restored some of the natural function of the stream and slowed the flow of water running through the stream in heavy precipitation events, which reduced pollution and improved other water quality indicators, and produced some recreation amenities for the community.

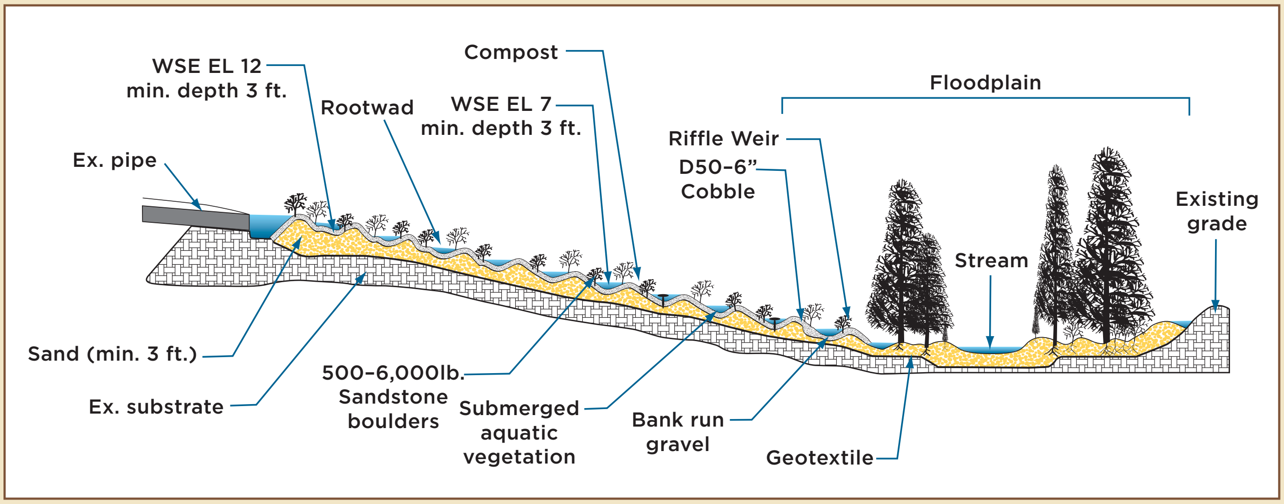
Monitoring events conducted by the author primarily during baseflow conditions between October 2007 and April 2008 found significant evidence of in-stream nitrogen processing, sediment uptake, and improved water quality at Wilelinor Stream. During this time period, the restoration (albeit with maintenance) retained its structural integrity through a 100-year flood event, when a water line broke in December 2007.[21] This quieted some concerns over the durability of this design during peak storm flows in the absence of more hardened stream banks. The water line break occurred in between sampling events and did not affect monitoring efforts.

Wilelinor Stream Results	
Mean Difference Between Upstream and Downstream:	-0.16 mg/L nitrate-N -0.06 mg/L ammonia- N -4.14 mg/L TSS +1.33 mg/L DO -0.93 °C
Statistically Significant Results:	*Upstream/downstream comparison:* nitrate-N, ammonia-N, TSS, DO, and temperature *Stream comparison:* nitrate-N percent difference between upstream and downstream samples are greater than "hard" and "soft" designs

Aquatic Step-Pool and Regenerative Stormwater Conveyance Schematics



An aquatic step-pool engineering schematic.



A regenerative stormwater conveyance engineering schematic.

While light penetration was not monitored as part of this study, Wilelinor Stream likely had the greatest light penetration of the three case studies because its young riparian forest was still evolving after its restoration. That said, the lowest stream temperatures and greatest temperature reductions between upstream and downstream monitoring locations were recorded at Wilelinor Stream, versus Stony Run or Kingstowne Stream—other case studies featured in the Streams chapter of this publication. This suggests that groundwater contributions to Wilelinor Stream's baseflow may be significant.

The following water quality criteria were found to have statistically significant differences between upstream and downstream concentrations:

Pollutant Load and Removal Efficiencies for Wilelinor Stream

	Baseflow Pollutant Load (lbs/day)	Baseflow Pollutant Load (kg/day)	Baseflow Removal Efficiency (lbs/ft/yr)	CBP Removal Efficiency (lbs/ft/yr)
Total N	0.51	0.23	0.11	0.02
TSS	13.67	6.20	2.37	2.55

Wilelinor Stream post-restoration.

Average nitrate-N: 0.48 milligrams per liter (mg/L) at the upstream monitoring location; 0.31 mg/L at the downstream monitoring location. These concentrations are much less than typical nitrogen pollutant concentrations for urban stormwater of 2.0 mg/L.[22] The average difference between upstream and downstream concentrations of nitrate-N was 0.17 mg/L (t(14) = 3.821, p = 0.002), resulting in a 39% overall removal efficiency of nitrate-N.

Average ammonia-N: 0.17 mg/L at the upstream monitoring location; 0.11 mg/L at the downstream monitoring location (t(14) = 3.521, p = 0.003).

Average total supsended solids (TSS): 13.49 mg/L at the upstream monitoring location; 9.35 mg/L at the downstream monitoring location (t(7) = 3.845, p = 0.006).

Average dissolved oxygen: 7.37 mg/L at the upstream monitoring location; 8.70 mg/L at the downstream monitoring location, resulting in an average difference of 0.93 mg/L (t(11) = -5.938, p = 0.000). Most aquatic fauna require dissolved oxygen concentrations greater than 5 mg/L for survival. Low dissolved oxygen also promotes accelerated release of phosphorus and toxins from sediments.

Average temperature: 9.67 °C at the upstream monitoring location; 8.74 °C at the downstream monitoring location (t(11) = 2.911, p = 0.013).

The following water quality criteria were not statistically significant but did demonstrate consistent trends between upstream and downstream monitoring points:

Average specific conductivity: 0.51 millisiemens (mS/cm) at the upstream monitoring location; 0.50 mS/cm at the downstream monitoring location (Z = -1.138, p = 0.255).

Average pH: 7.22 at the upstream monitoring location; 7.17 at the downstream monitoring location (Z = -0.392, p = 0.695).

Baseflow pollutant loads were calculated for the sum of nitrate-N and ammonia-N concentrations (total N) and TSS in pounds per day (lbs/day) and kilograms per day (kgs/day) for comparison to traditional Total Maximum Daily Loads (TMDLs).[23] Removal efficiencies were calculated in pounds per foot per year (lbs/ft/yr) for comparison to Chesapeake Bay Program removal efficiencies for urban stream restoration.[24]

Water Quality Statistical Abbreviations

The statistical abbreviations used in the water quality summary above have the following meanings:

- t = The t-test is the most commonly used method to evaluate the difference in means between two groups. The number in parenthesis is the number of pairs used in that particular paired t-test e.g. t(14) = 3.821.
- p = p-value. The p-value is a statistical measure for the probability that the results observed in a study could have occurred by chance. Conventionally, a p-value of 0.05 (5%) or below is accepted as being statistically significant.
- z = The z-value used in this summary is the statistic resulting from the nonparametric Wilcoxon test for significance. The Wilcoxon test can be used as an alternative to the t-test when the population cannot be assumed to be normally distributed.

These pollutant loads and efficiency claims are rough estimations based on limited hydraulic monitoring (primarily baseflow conditions) without consideration of rainfall characteristics, runoff patterns, and total annual flow volume passing through the reach.

KEYS TO SUCCESS

- **System Resilience:** During the sampling period, Wilelinor Stream withstood a 100-year flood event when a water line broke in December 2007, demonstrating that the restoration techniques used at this site can handle peak discharge volumes. It is noted, however, that some maintenance may be required as the stream recovers from construction and the riparian buffer develops.
- **Slowing Water:** In-stream features that slow stormwater, thereby increasing water residence time and opportunities for hyporheic exchanges (i.e. movement of water between the stream and adjacent porous subsurface areas), have potential to increase in-stream processing of nitrogen.
- **Storing Water:** Restoration features such as seepage reservoirs and off-line ponds offer opportunities for groundwater recharge, freshwater storage, wetland creation, and valuable aquatic habitat.
- **Adding Woody Debris:** Addition of woody debris and other vegetation, such as those found along the sand berms at Wilelinor, may have the potential to improve soil carbon levels,[25] create benthic habitat, and enhance nitrogen removal and stream bank stability.[26]
- **Volunteers:** Several hundred volunteers, including school students, teachers, parents, and neighbors, helped to plant native vegetation throughout the wetland. The students propagated the native plants through the Arlington Echo Outdoor Education Center, which is part of the county school system. The community is thrilled with their new amenity and named it "Keith's Branch" in honor of the consultant who designed the restoration features and managed the construction.

PHOTOS AND FIGURES

Page 43, 46, 48, 50: Photos, David Burke
Page 44: Figure, Burke Environmental Associates/The Conservation Fund, using Google Earth image
Page 45: Photo, Underwood and Associates; figure, Burke Environmental Associates/The Conservation Fund, adapted from Underwood and Associates graphic using Google Earth image
Page 46: Figure, Underwood and Associates
Page 47: Photo (top), David Burke; photo (bottom) and Figure, Underwood and Associates
Page 49: Figure, Underwood and Associates

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