A Sustainable Chesapeake

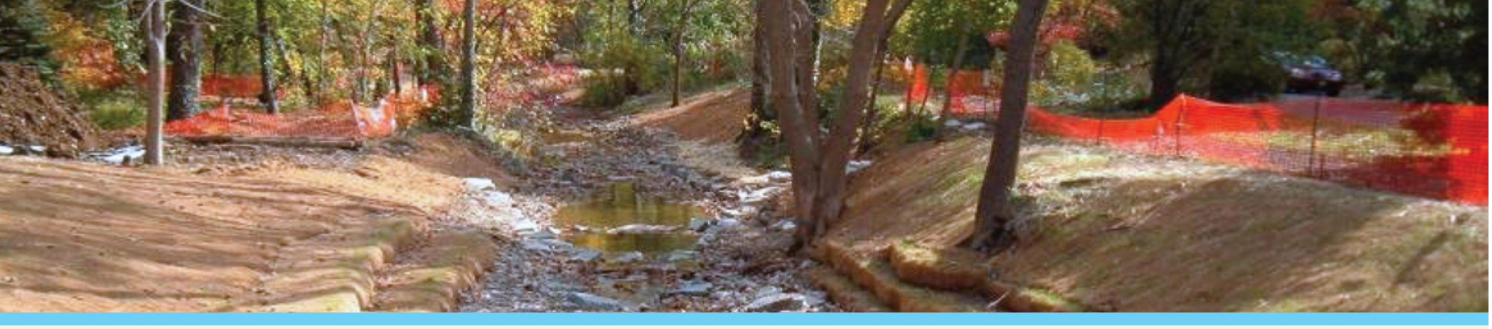
BETTER MODELS FOR CONSERVATION

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 “Hard” Design Approach to Stream Restoration

Making the Most of Confined Spaces in Baltimore’s Stony Run

Baltimore City, in partnership with their design team and in coordination with the Jones Falls Watershed Association, lead a successful effort to systematically evaluate and deploy the most effective stream restoration techniques in a highly urbanized setting to control stormwater, stabilize stream banks and contribute to water quality improvement in Stony Run.

CASE STUDY SUMMARY

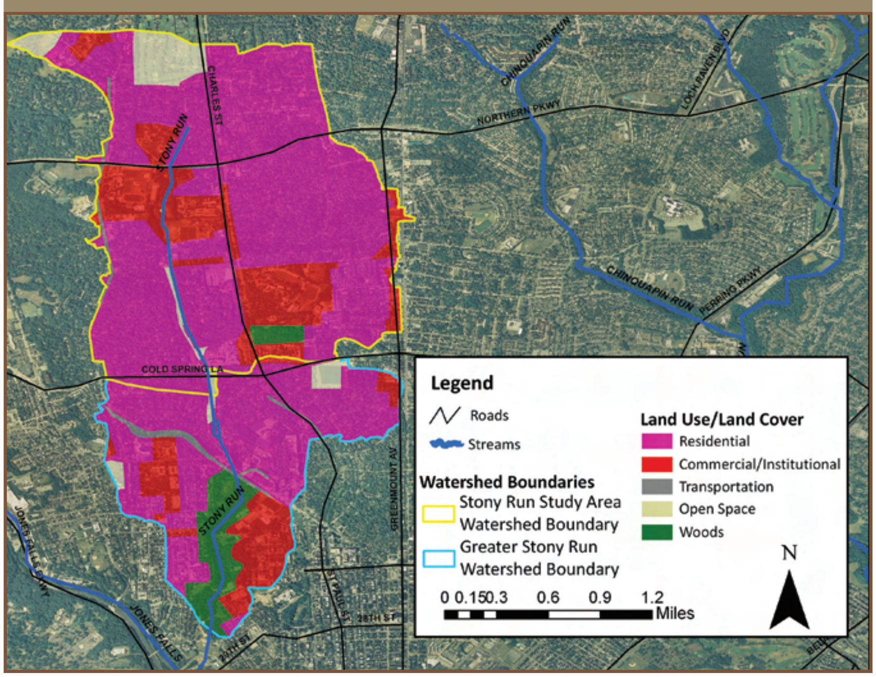
Stony Run is a small urban stream in the north-central portion of Baltimore City. A tributary of Jones Falls, it ultimately empties into Baltimore City’s Inner Harbor. The majority of the stream’s highly urban watershed is drained through under-ground pipes as part of the City’s stormwater management system. The above-ground stream has considerable erosion damage due to the structure of the stormwater system. This results in flashy flows and significant nutrient and sediment pollution downstream. These impacts are further accentu-ated by changes to the climate, such as increasingly intense storm events that produce unusually high volumes of runoff from impervious surfaces.

In 2006, the City of Baltimore Depart-ment of Public Works partnered with the Jones Falls Watershed Associa-tion to implement a demonstration project on Stony Run that would serve as a model for a “hard” design approach to address erosion and pollution problems.

For purposes of this case study, a “hard” design approach, which tends to be more industrial, uses significant rock vanes in the development of step-pool sequences and/or the placement of substantial amounts of riprap for bank stabilization. This was a better approach due to the need for a higher baseflow and 100-year discharge capacity.

The site analysis and project design took several months to complete. Construction began in October of 2006 and was completed the following winter. The stream banks of Middle Stony Run, from Coldspring

Stony Run Watershed



Lane to Wyndhurst Avenue, were stabilized using boulders, root wads, and live plantings. The project reduced erosion, improved water quality, enhanced in-channel and riparian areas associated with the free-flowing portion of the stream, and alleviated further damage to public utilities and roads. The project was part of a larger Stony Run restoration effort focused on minimizing impacts of the watershed's dominantly urban land uses.

RESOURCE MANAGEMENT CHALLENGE

Baltimore is a highly urbanized city. The City's history of development has dramatically altered Stony Run's natural drainage pattern and natural vegetation. Over 30% of the entire 2,112 acre Stony Run watershed is covered with impervious surface. Alternatively, only 5% of the watershed is open space and only 1% is wooded. The altered hydrology of the area has resulted in heavy flows of water during storm events that flood the stream with nutrient and sediment pollution and fuel erosion problems on the above-ground portion of the stream. In addition, there is very limited space for the restoration of natural functions. Climate change will only serve to accentuate these challenges and impacts.[1]

Baltimore also has several stormwater regulatory challenges, including compliance with conditions of their Municipal Separate Storm Sewer Systems (MS4) permit and Total Maximum Daily Loads (TMDLs) triggered by state and federal impaired waters listings, all which require the city to prevent the discharge of pollutants from the stormwater management system into waterways. In response, the city systematically evaluated the watershed and developed a watershed restoration plan for high priority streams in each of the city's three major watersheds, including Stony Run.[2]

The City's watershed restoration plan found that traditional structural stormwater management facilities (such as ponds, filters, and swales) are more difficult to install in an ultra-urban landscape, where space is limited and treatment of hardened environments is impractical. As such, the city was forced to explore more industrial stream restoration activities including excavation and fill placement in and along the stream channel, placement of boulders and imbricated rip-rap, and installation of vegetative plantings and bioengineering measures along the channel bed.

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,[3,4,5,6,7,8] 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.[9,10] 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.[11] Post-restoration monitoring is needed to determine the effective-

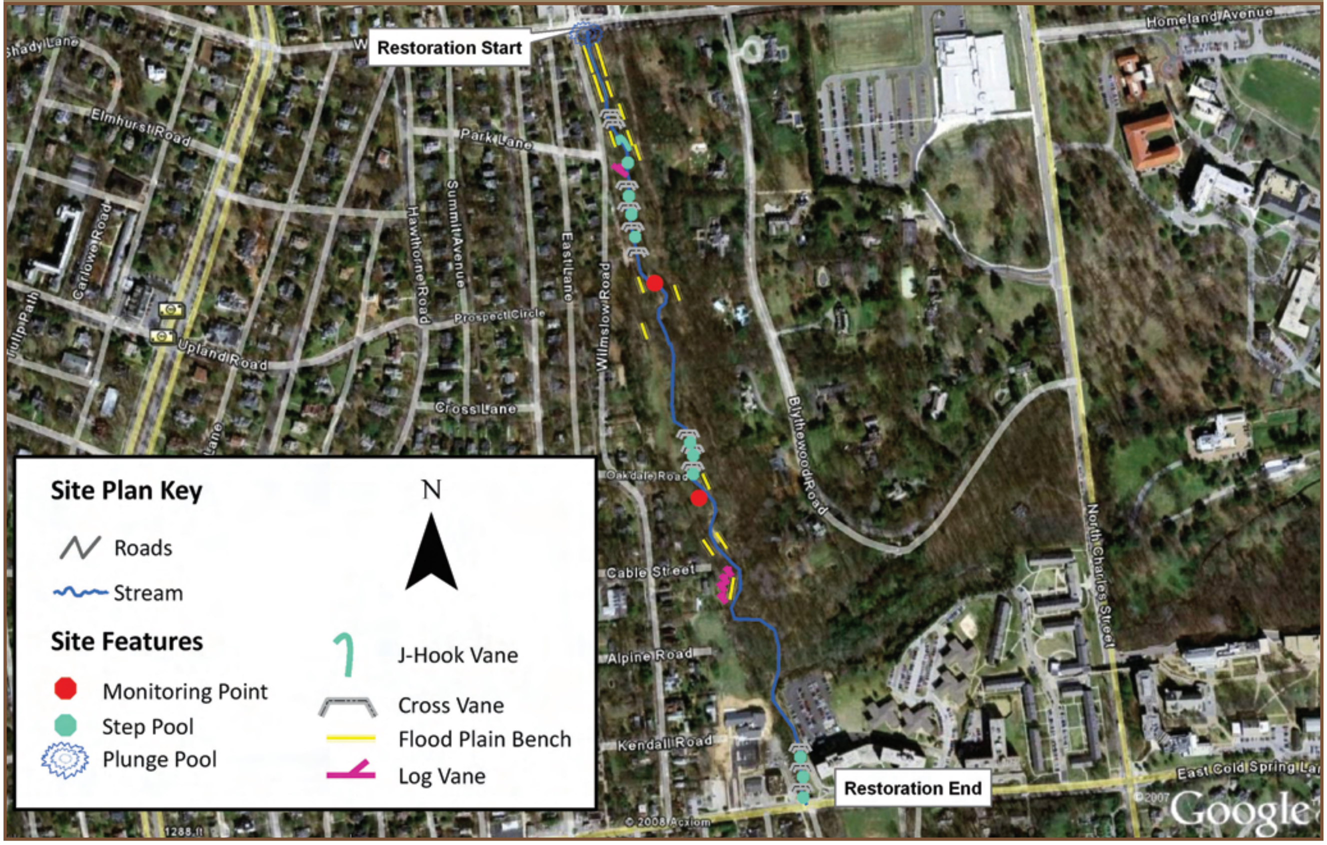
Stony Run Watershed Characteristics

- Watershed Size: 2,112 acres (Middle Stony Run is 1,512 acres)
- Percent Imperviousness: 31%
- Land Use: 73% residential; 20% commercial/institutional; 5% open space; 1% transportation; 1% woods.

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

	"Hard" Design Approach (Stony Run—this case study)	"Soft" Design Approach (Kingstowne—see case study)	"Seepage Wetland" Design Approach (Wilelinor—see 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

Stony Run Restoration Plan



ness of the hard design approach to the restoration of water quality in the stream.

CONSERVATION VISION

In an effort to improve water quality through effective management strategies and meet the City's federal and state permits, Baltimore City embraced a "hard" design approach to the Stony Run restoration as an alternative way to manage stormwater. The hard approach used step-pool sequences, mild stream meanders, and hardened stream banks to slow the flow of water in the stream to a baseflow discharge of 0.490 cubic feet per second and a 100-year discharge/design capacity of 170 cubic feet per second. This slower baseflow prevents the rushing water from scouring the stream banks and carrying nutrient and sediment pollution downstream.

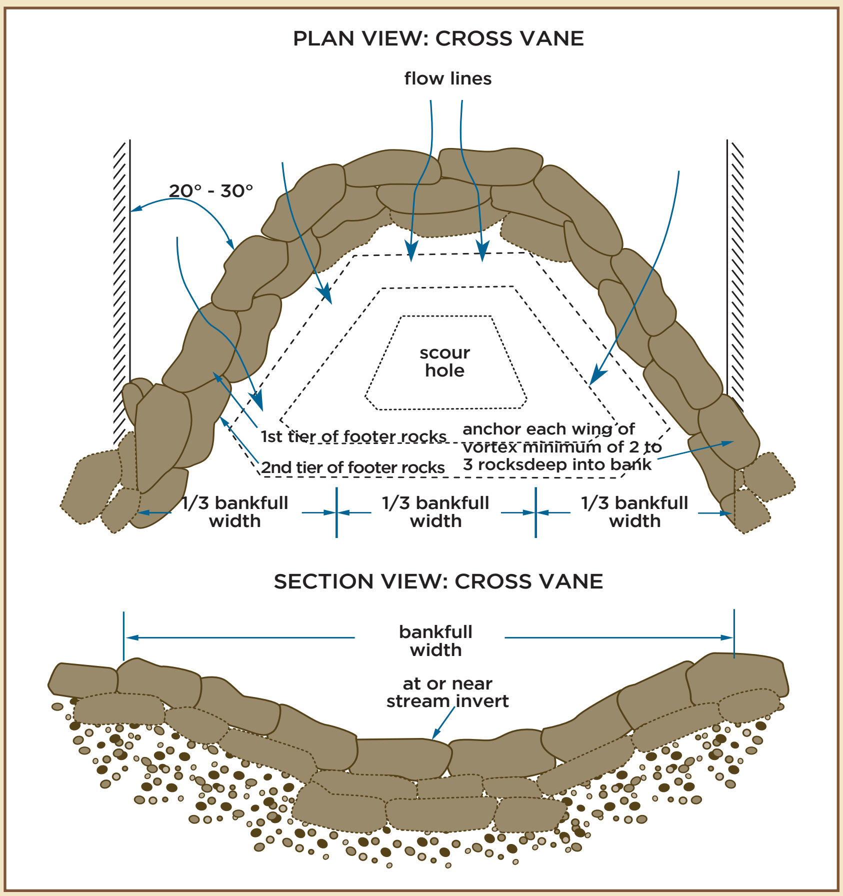
IMPLEMENTATION RESOURCES

The total cost of the 2,700 foot stream restoration project was $2.5 million (adjusted to 2008 dollars), which is $942 per linear foot. The funding for the project came from motor vehicle revenues in response to the stream's acceptance of a multitude of stormwater management pipes that drain the surrounding road network. Federal and State agencies are the most frequent primary funders of stream restoration projects.[12,13] In addition, urban, headwater streams receive the largest share of river restoration dollars and effort in the United States.[14]

The City of Baltimore Department of Public Works contracted with EA Engineering, Science and Technology, Inc. (EA Engineering) to develop a restoration plan for the entire Stony Run Watershed. EA Engineering conducted a stream and watershed assessment using GIS and the Rapid Stream Assessment Technique (RSAT) developed by the Metropolitan Washington Council of Governments in 1992. They also developed hydrologic and hydraulic models of Stony Run using the US Environmental Protection Agency's Storm Water Management Model (SWMM) and the US Army Corp of Engineers River Analysis System (HEC-RAS), respectively. EA Engineering recommended a list of best management practices and restoration alternatives for consideration by the City of Baltimore. The City solicited input from the local Jones Falls Watershed Association and the Maryland Department of Environment with the restoration alternatives as part of its deliberations. The City contracted with Clear Creeks Consulting of Jarrettsville, MD, Parsons Brinckerhoff, and EBA Engineering, Inc., both of Baltimore, to design the selected stream restoration. Consulting engineers from Rummel, Klepper & Kahl, LLP, EA Engineering, and Metra Industries, Inc. were also used during the implementation of the project.

Post-restoration, the neighborhood Wyndhurst Improvement Association worked in conjunction with the Jones Falls Watershed Association and the City of Baltimore's Department of Parks and Recreation to clear, grade, and plant trees along the Stony Run Trail which follows the restored Stony Run stream.

Cross Vane Engineering Schematic and Photo



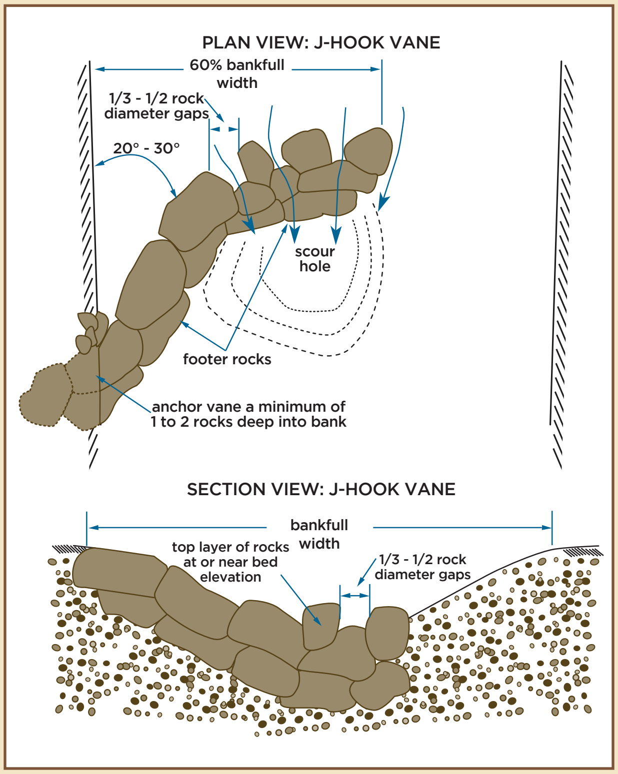
CONSERVATION STRATEGY

The following section details the six principle restoration design components that contributed to water quality improvement in Stony Run. The overall channel shape and dimensions were designed using classification and hydraulic geometry concepts promoted by Rosgen.[15]

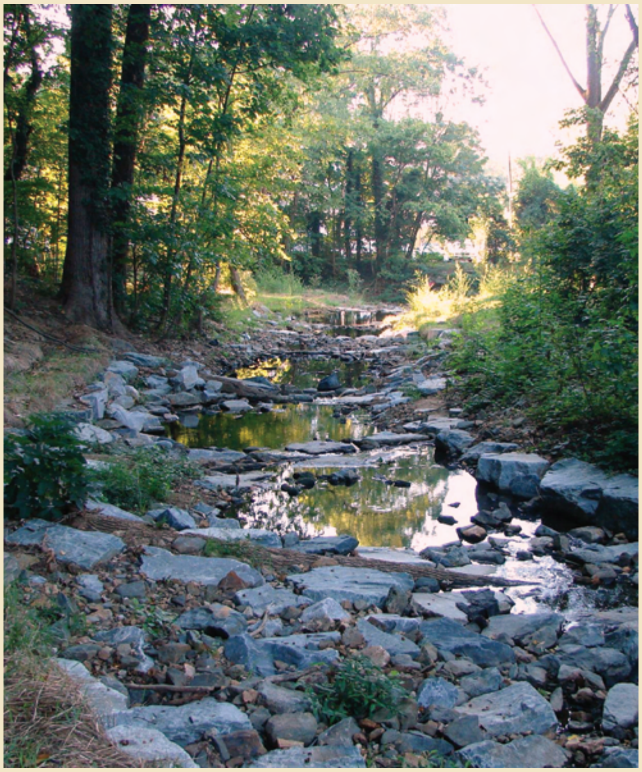
- **Cross Vanes:** Cross vanes act as grade control structures that reduce near-bank shear stress, velocity, and stream power, but increases the energy in the center of the channel. Cross vanes contribute to water quality improvement by reducing flow velocities and creating habitat for aquatic species via downstream pools.
- **J-Hook Vanes:** J-hook vanes are gently sloping structures located on the outside of stream bends and directed upstream. J-hooks reduce bank erosion by reducing near-bank slope velocity, velocity gradient, stream power, and shear stress.
- **Step-Pool Sequences:** Step pools result from a series of steps constructed from natural materials (rock, imbricated rip-rap, wood, or concrete) longitudinally through a stream reach. Step-pools can be shallow or deep. They contribute to water quality improvement by increasing hydrodynamic diversity, lowering stream velocity, and creating habitat.
- **Two-Stage Channel System (Floodplain Benches):** Two-stage channel systems incorporate benches that function as floodplains. They can accommodate baseflow conditions as well as larger storm-induced discharges—often double the width of the effective discharge channel.

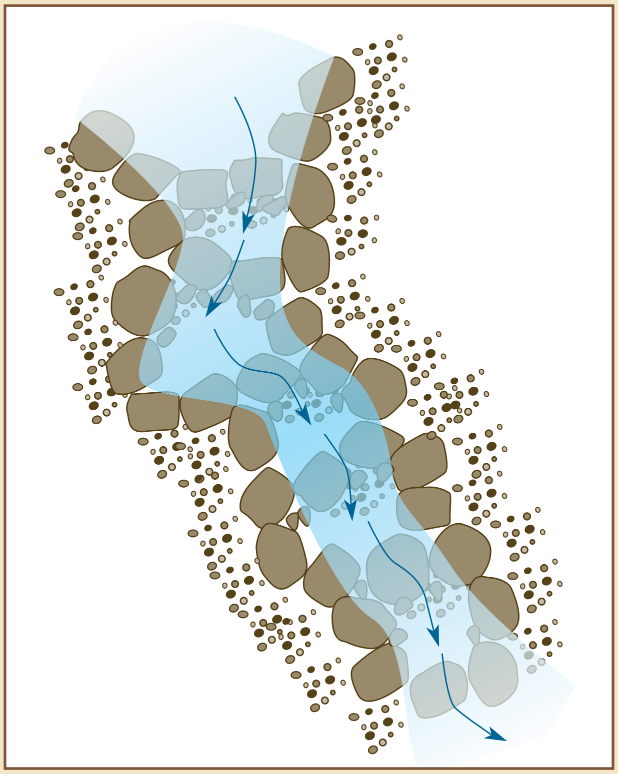
  The creation of a two-stage channel is a good option for streams in which most of the pollutant delivery occurs during high flows.[15] This may be the case at Stony

J-Hook Vane Engineering Schematic and Photo



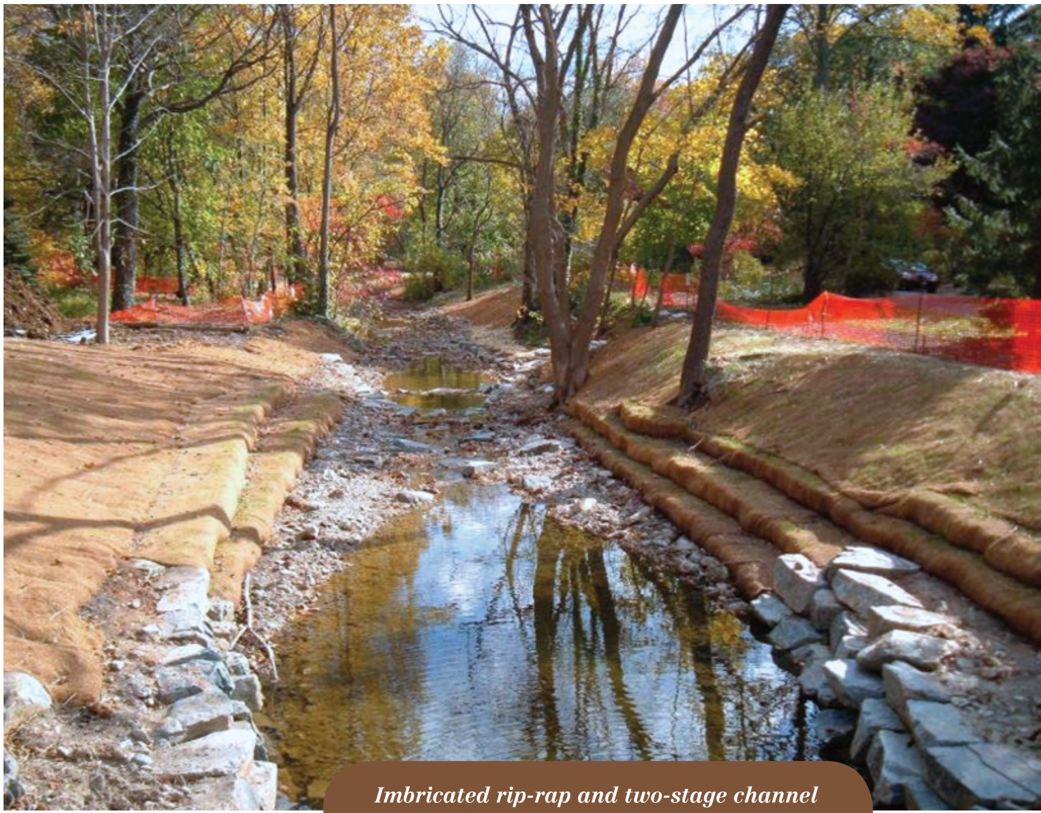
Step-pool Engineering Schematic and Photo





Run, based on the elevated total suspended solids, ammonia-N, and specific conductivity concentrations observed during a storm event over the duration of the case study. Further, "two-stage channels can provide opportunities for longer flowpaths and increased contact with riparian vegetation and OM [organic matter], while containing storm flows within the channel."[17] Also, a two-stage channel can potentially create and maintain better habitat. This is because the "narrow deep fluvial channel provides better water depth during periods of low flow. Grass on the [floodplain] benches can provide quality in-stream cover and shade."[18]

- **Imbricated Rip-Rap:** Imbricated rip-rap involves large, overlapping durable materials (usually rocks) used to protect a stream bank from erosion. A study of the Minebank Run stream restoration in Baltimore found that a restored reach designed after the Rosgen Method and using high armored banks had higher denitrification rates than the unrestored sites. However, denitrification rates were even higher at low-bank sites where the stream was connected to the adjacent floodplain.[19] Minebank Run is a second-order stream with 30 to 35% of its watershed covered by impervious surface.
- **Plunge Pools:** Plunge pools are simply basins used to slow flowing water. A small, deep plunge pool dissipates energy as water enters the pool from its upland source. Beyond reducing flow velocities, plunge pools create habitats for aquatic species. There is little question about the effectiveness of plunge pools as they have been used for many years as an important water management technique.



Imbricated rip-rap and two-stage channel system during construction at Stony Run.

RESULTS

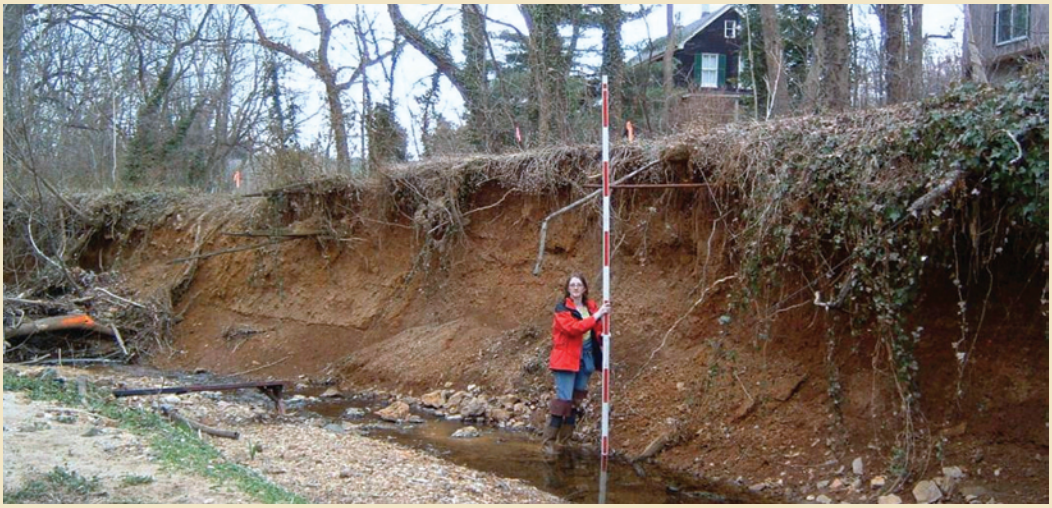
"People were upset when they tore some of the trees down during construction, but a lot of us understood the long-term gain of restoring the stream regardless of the short-term loss." - Local Resident

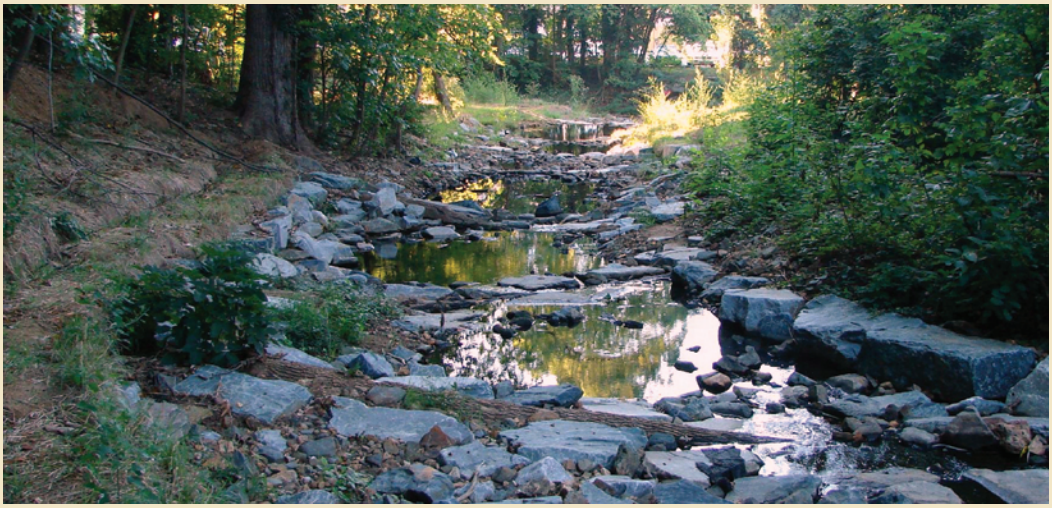
Stony Run Stream Results	
Mean Difference Between Upstream and Downstream:	-0.30 mg/L nitrate-N -0.02 mg/L ammonia- N +0.53 mg/L TSS +2.09 mg/L DO -0.91 °C
Statistically Significant Results:	*upstream/downstream differences:* nitrate-N, DO, pH, temperature and specific cond.

The City of Baltimore and its partners made significant improvements to the Stony Run stream. In total, they restored 2,700 feet of the stream reach. They installed cross vanes, j-hook vanes, step pool sequences, floodplain benches, imbricated rip-rap and plunge 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.

To investigate the efficacy of stream restoration approaches to improve water quality, stream water samples and field measurements were collected by the author at upstream and downstream monitoring points, separated longitudinally by 600 feet, of restored stream length. Monitoring was conducted bimonthly between

Stony Run Restoration Sequence





Stony Run showing pre-construction stream bank erosion (top); stream re-construction under way (middle); and a recent image of the streambed (bottom).

Pollutant Load and Removal Efficiencies for Middle Stony Run				
	Baseflow Pollutant Load (lbs/day)	Baseflow Pollutant Load (kg/day)	Baseflow Removal Efficiency (lbs/ft/yr)	CBP Removal Efficiency (lbs/ft/yr)
Total N	8.91	4.04	0.58	0.02
TSS	22.62	10.26	no removal	2.55

mid-October 2007 and April 2008, primarily during baseflow conditions. The data provided evidence of in-stream nitrogen processing and improved water quality within the restored reach at Middle Stony Run.

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

Average nitrate-N: 3.11 milligrams per liter (mg/L) at the upstream monitoring location; 2.81 mg/L at the downstream monitoring location. These concentrations are slightly elevated compared to typical nitrogen pollutant concentrations for urban stormwater of 2.0 mg/L.[20]

The average difference between upstream and downstream concentrations of nitrate-N was 0.30 mg/L (Z = -3.408, p = 0.001), resulting in an 11% overall removal efficiency of nitrate-N during baseflow conditions.

Average dissolved oxygen: 11.55 mg/L at the upstream monitoring location; 13.64 mg/L downstream at the monitoring location, resulting in an average difference of 2.09 mg/L (t(12) = -2.703, p = 0.019). 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: 9.60 °C at upstream monitoring location; 8.69 °C at downstream monitoring location (Z = -2.062, p = 0.039).

Average specific conductivity: 0.49 (mS/cm) at the upstream monitoring location; 0.58 (mS/cm) at the downstream monitoring location (Z = -2.271, p = 0.023).

Average pH: 7.77 at the upstream monitoring location; 7.98 at the downstream monitoring location (t(12)= -3.406, p = 0.005).

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

Average ammonia-N: 0.06 mg/L at the upstream monitoring location; 0.04 mg/L at the downstream monitoring location (Z = -1.278, p = 0.201), resulting in a 49% overall removal efficiency of ammonia-N.

Average TSS: 3.93 mg/L at the upstream monitoring location; 4.45 mg/L at the downstream monitoring location (Z = -0.447, p = 0.655).

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 in kilograms per day (kgs/day) for comparison to traditional Total Maximum Daily Loads (TMDLs).[21] Removal efficiencies were also calculated in pounds per foot per year (lbs/ft/yr) for comparison to Chesapeake Bay Program removal efficiencies for urban stream restoration.[22] These pollutant loads and efficiency claims are rough estimations based on limited hydraulic monitoring (primarily baseflow conditions) without con-

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.

sideration of rainfall characteristics, runoff patterns, and total annual flow volume passing through the reach.

The Baltimore City Water Quality Management Section conducted dry- and wet-weather monitoring of Middle Stony Run between June 2005 and December 2007 (pre- and mid-restoration of the Middle Stony Run restoration project). Key findings include the following:

Average nitrate-N: 2.246 mg/L during baseflow monitoring and 1.170 mg/L during storm-event monitoring; range during baseflow monitoring (1.136 to 3.978 mg/L); range during storm-event sampling (<0.05 to 4.5 mg/L).

Average ammonia-N: 0.173 mg/L during baseflow monitoring; range during baseflow sampling (0.008 to1.398 mg/L). No samples were analyzed for ammonia-N during storm-event monitoring.

Average TSS: 1.405 mg/L during baseflow monitoring and 171.649 mg/L during storm-event monitoring; range during baseflow sampling (0.9 to 6.7 mg/L); range during storm-event sampling (<2.5 to 1,400 mg/L).

KEYS TO SUCCESS

- **Alternative Restoration Options:** Tight spaces limited restoration options at the Middle Stony Run stream restoration, such as the use of a detention pond large enough to withhold flashy flows and reduce water residence time within the stream. Instead, engineers had to rely on hard bank stabilization techniques capable of withstanding large storm events. While hard restoration design approaches often divert flow successfully, many stream ecosystem functions can be lost, such as hyporheic interactions and habitat creation. However, the use of two-stage channel systems provided a compromise in some stream sections where the channel could not be connected to a floodplain, accommodating both baseflow and storm event conditions.
- **Public Awareness:** The Jones Falls Watershed Association worked with the City of Baltimore's Department of Public Works to help ensure that surrounding communities were notified about the progress of events and could give meaningful input to the process, design, and planting plan for the Middle Stony Run Stream restoration. For example, in February 2004, every home to be affected by the project was presented with a ballot to vote on where and how construction activities would be staged. Project managers ultimately followed the community preference for construction access to be in the stream's adjacent park rather than along Wilmslow Road.
- **Long Term Goals:** Although some members of the community were initially unhappy about the removal of several trees associated with the Upper Stony Run stream restoration to allow for construction access, community runners, cyclists, and dog walkers now frequent trails along the entire Stony Run stream bank.

PHOTOS AND FIGURES

All photos, Baltimore City Department of Public Works
Page 61: Figure, Burke Environmental Associates/The Conservation Fund, using Google Earth image
Page 63: Figure, Burke Environmental Associates/The Conservation Fund, adapted from graphic by Clear Creeks Consulting, Parsons Brinkerhoff, EBA Engineering, Inc., using Google Earth image
All other figures, adapted from Maryland Department of the Environment 2000[23]

REFERENCES

[1]U.S. Global Change Research Program. 2009. *Global Climate Change Impacts in the United States*. U.S. Global Change Research Program, Washington, D.C.

[2]EA Engineering, Science, and Technology, Inc. 2001. *Stony Run Watershed Restoration Plan*. Prepared for Baltimore Department of Public Works, Baltimore, Maryland.

[3]Ensign, S. H. and M. W. Doyle. 2006. Nutrient spiraling in streams and river networks. *Journal of Geophysical Research*. 111, G04009, doi:10.1029/2005JG000114.

[4]United States Army Corps of Engineers and North Carolina Department of Environment and Natural Resources. 2005. Information Regarding Stream Restoration in the Outer Coastal Plain of North Carolina.

[5,16,17]Craig, L., M. Palmer, D. Richardson, S. Filoso, E. Bernhardt, B. Bledsoe, M. Doyle, P. Groffman, B. Hassett, S. Kaushal, P. Mayer, S. Smith, and P. Wilcock. 2008. Stream restoration strategies for reducing river nitrogen loads. *Frontiers in Ecology and the Environment*, 6, doi:10.1890/070080.

[6]Peterson, B. W. Wollheim, P. Mulholland, J. Webster, J. Meyer, J. Tank, E. Martí, W. Bowden, H. M. Valett, A. Hershey,W. McDowell, W. Dodds, S. Hamilton, S. Gregory and D. Morrall. 2001. Control of nitrogen export from watersheds to headwater streams. *Science*. 292:86-90.

[7]Roberts, B., P. Mulholland, and J. Houser. 2007. Effects of upland disturbance and instream restoration on hydrodynamics and ammonium uptake in headwater streams. *Journal of North American Benthological Society*. 26(1):38-53.

[8]Riley, A. 2008. *Putting a Price on Riparian Corridors as Water Treatment Facilities*. California Regional Water Quality Control Board, San Francisco Bay Region, Oakland, California, pp. 1-16.

[9]Stack, W. 2007. Personal communication via email held on October 25, 2007, with Mr. William Stack, Chief Water Quality Engineer for Baltimore, MD.

[10]Simon, A., M. Doyle, M. Kondolf, F.D. Shields Jr., B. Rhoads, and M. McPhillips. 2007. Critical evaluation of how the Rosgen classification and associated "natural channel design" methods fail to integrate and quantify fluvial processes and channel response. *Journal of the American Water Resources Association*. 43(5):1-15.

[11,12]Hassett, B., M. Palmer, and E. Bernhardt. 2007. Evaluating stream restoration in the Chesapeake Bay watershed through practitioner interviews. *Restoration Ecology*. 15(3):563-572.

[13]Stack, W. 2008. Personal communication via in-person interview on March 27, 2008, with Mr. William Stack, Chief Water Quality Engineer for Baltimore, MD.

[14]Bernhardt, E. and M. Palmer. 2007. Restoring streams in an urbanizing world. *Freshwater Biology*. 52: 738-751.

[15]Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology Books, Pagosa Springs, Colorado.

[18]Ward, A.D., and D. Mecklenburg, G.E. Powell, A. D. Jayakaran, J. D'Ambrosio and J. Draper. 2008. Creating ditches with floodplains. 16th National Nonpoint Source Monitoring Workshop September 14-18, 2008 Columbus, Ohio.

[19]Kaushal, S., P. Groffman, P. Mayer, E. Striz and A. Gold. 2008. Effects of Stream Restoration on Denitrification in an Urbanizing Watershed. *Ecological Applications*. 18(3):789-804.

[20]Center for Watershed Protection. 2003. *Maryland Chesapeake and Atlantic Coastal Bays Critical Areas 10% Rule Guidance Manual*. Critical Area Commission for the Chesapeake and Atlantic Coastal Bays. 98 pp. + appendices.

[21]Environmental Protection Agency. 2007. *Total Maximum Daily Loads with Stormwater Sources: A Summary of 17 TMDLs*. Environmental Protection Agency, Washington, D.C. EOA 841-R-07-002.

[22]Chesapeake Bay Program. 2006. *Best Management Practices for Sediment Control and Water Clarity Enhancement*. U.S. Environmental Protection Agency, Annapolis, MD. CBP/TRS-282-06.

[23]Maryland Department of the Environment. 2000. Maryland Department of the Environment Waterway Construction Guidelines. Maryland Department of the Environment, Baltimore, MD.

FOR MORE INFORMATION

Project Contact
William Stack
Chief Water Quality Management Section
Department of Public Works
600 Abel Wolman Municipal Building
Baltimore, MD 21202
Phone: (410) 396-0732 | Email: stack@baltimorecity.gov

For water quality questions associated with this profile contact:

Maura Browning
Email: browning.maura@gmail.com