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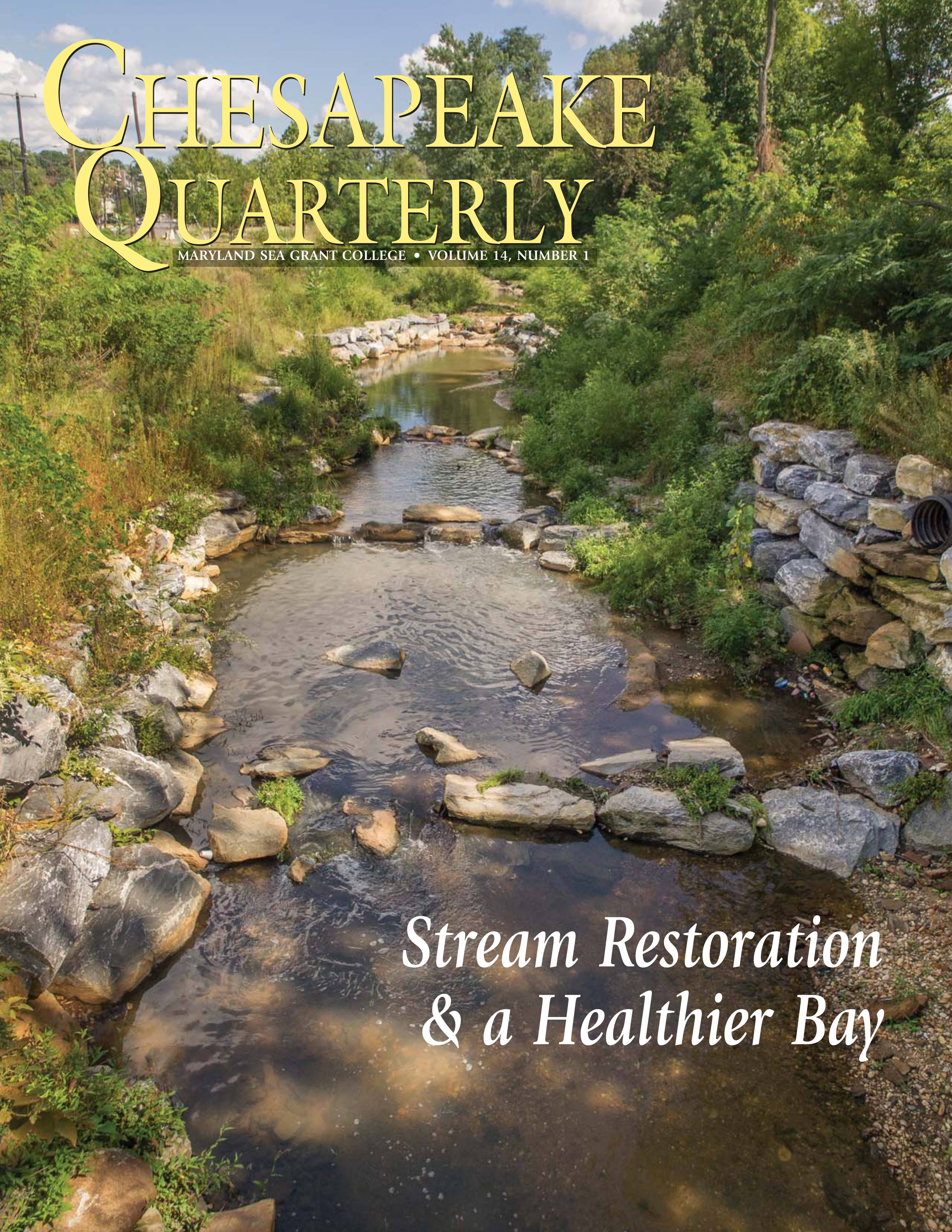

Stream Restoration & a Healthier Bay

contents

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Cover photo: *The Chesapeake Bay region is home to many stream restoration projects that seek to reduce erosion and improve water quality. Some have occurred in the middle of cities, like this one on Watts Branch, a tributary of the Anacostia River in Washington, D.C. In 2011, work was completed to install a series of pools and add rock structures to slow the flow of water.* ***Page 3:*** *White Clay Creek in rural southeastern Pennsylvania has been designated a wild and scenic river. It is also the site of a long-term research study, conducted by the Stroud Water Research Center and funded by the National Science Foundation, about the effects of stream restoration.* PHOTOGRAPHS: DAVID HARP

Science Heads Upstream

Typically, oceanographers look to the sea. And they ask questions about how the wind, the waves, the continents, and the atmosphere affect the physics, chemistry, and biology of the oceans. They study temperature and salinity, which are controlled primarily by the interaction of the ocean, the atmosphere, and the land. And they study sunlight, the energy source that warms the sea and drives photosynthesis, the basis for life on this planet.

As they expand our understanding of the sea, oceanographers strengthen our nation in many ways, enabling us to develop the resources of our coastal waters, to improve our forecasts of weather patterns and storm events, and to prepare our military to operate on, under, and above the world's oceans.

Oceanographers who study the Chesapeake Bay ask many of the same questions they ask of the sea: questions about temperature, salinity, and light, and how these interactions drive the Bay's ecosystem. But they also ask: how does the land alter the Bay? How does the flow of water and earth coming off this huge and heavily populated watershed affect conditions in the Chesapeake?

Over time this landscape changed. Much of the forestland gave way to farmland, and much of the farmland gave way to industrial, urban, and suburban developments. In building Maryland's modern economy, we engineered our streams to serve our needs. We built dams to power our mills and generate electricity, we drew drinking water for cities, cooling waters for power plants and industry, and irrigation for agriculture. Into those rivers, we sent sewage from our cities, pollutants from our industries, and runoff from farms. These efforts seemed essential for growth and development, but they altered — in ways we did not fully understand — how the water runs off of the land and into our Bay.

As the flow off the land changed, the Bay changed. Sea grasses and shad and oysters, once abundant, declined, while other plants and animals, some of them invasives, became plentiful. Algae and plankton proliferated, and dead zones of no oxygen made annual appearances in the Bay's mainstem and its major rivers.

Now, oceanographers and estuarine scientists are examining how we might re-engineer our rivers and streams in ways that enable us to maintain a strong economy and achieve a sustainable ecology for the Chesapeake Bay. They are looking farther upestuary, probing into the "subestuaries" of our rivers, including the Potomac, the Choptank, and Maryland's largest, wholly own, Patuxent River. And they ask the tough question: What are the consequences of how our streams and rivers connect the land to the Bay and to the ocean?

This issue of *Chesapeake Quarterly* takes a look at the relatively new science of stream restoration. We are highlighting the new generation of estuarine scientists who are teaming up with hydrologists and geomorphologists, scientists who specialize in tracing the small waterways that flow downstream from the land to the sea. They are designing and debating strategies for retaining rainwater on the land, for slowing river flow, for replenishing groundwater, and for reducing the urban, suburban, and agricultural runoff of sediments and nutrients into our waterways. These strategies, researchers hope, could contribute to much-needed progress toward improving water quality in the streams and rivers that flow off our land into the Chesapeake Bay.

— Fredrika Moser
Director, Maryland Sea Grant

When a Slow, Lazy River Is a Cleaner River

Scientists and engineers say much remains to be learned about how well restored streams help to improve water quality.

Jeffrey Brainard

You can walk just a few steps off Route 2, away from the cars steadily rumbling by the busy Severna Park Marketplace shopping center, and enter a peaceful-looking landscape. Tucked away in this suburban corner of Anne Arundel County, a stream meanders through a series of wide pools. A pair of Canada geese are sunning themselves as a blue heron flaps overhead. But the stream didn't always look that way. In 2012, it received the riverine equivalent of an extreme makeover.

North Cypress Branch had been identified by the county government as one of Anne Arundel's most degraded streams. Stormwater that drained into it had eaten away at its channel, leaving bare banks and exposing the roots of nearby trees.

The makeover began when contractors arrived to cut down trees along the stream, a sight which troubled some neighbors. After the tree cutters left, the bulldozers came next, maneuvering in and around the narrow channel. Contractors worked to change the stream channel so that it would function differently. Workers widened it to 50 yards in places and carved out a series of shallow, landscaped pools spaced along gentle contours stretching a half-mile. The project, completed in 2013, cost $1.7 million.

The point of this work was to slow the flow of water that sped through North Cypress Branch during and after storms. That could help reduce erosion and remove some of the pollutants carried downstream to the Magothy River and, eventually, the mainstem of the Chesapeake Bay. In the estuary, the pollutants — excess sediments and nitrogen and phosphorus — combine to degrade water quality, reduce the range of underwater grasses to shallow waters, and in deeper waters create dead zones of no oxygen that stress fish populations.

One of those watching the North Cypress restoration work was Solange Filoso. She is a watershed scientist at the Chesapeake Biological Lab, part of University of Maryland Center for Environmental Science (UMCES), who studies stream restoration, currently a much-debated topic in the multi-state master plan for improving water quality in the Chesapeake Bay. Filoso has been monitoring the water-quality effects of the North Cypress project for the county. Her monitoring began too recently to report results, but she says her findings suggest that other stream restorations may offer only modest reductions in the flow of nitrogen downstream. Restorations may, however, provide other benefits.

Lessons learned from one stream can be applied in others. Governments around the region are considering stream restoration as a way to comply with federal regulations calling for reduced pollution in the Chesapeake.

But to what extent stream restoration can improve water quality is a question that Filoso and a number of other scientists are working to quantify. The science of stream restoration is fairly young, only about two decades old. As research has begun to provide answers, new questions have arisen.

To Filoso, what's clear today is that a project like North Cypress turns a stream into something else. "Streams are being modified, sometimes dramatically, to the point that they are functioning as combinations of streams and wetlands," she says. Removing trees along stream channels, for example, may change how organic matter and nutrients are processed in the stream. "There are pros, cons, and tradeoffs in restoration," Filoso says. "We still need to fully understand them."

Maryland's Degraded Streams

Maryland has a lot of freshwater, non-tidal streams and rivers — more than 19,000 miles. And many streams in Maryland, and throughout the Chesapeake watershed, are in bad shape. The Maryland Department of the Environment issues a biennial report about the state's waterways and their compliance with federal water-quality regulations. In 2014 the department estimated that about half of the state's stream and river miles violated at least one of the water-quality standards — for example, to support healthy populations of fish and other aquatic life.

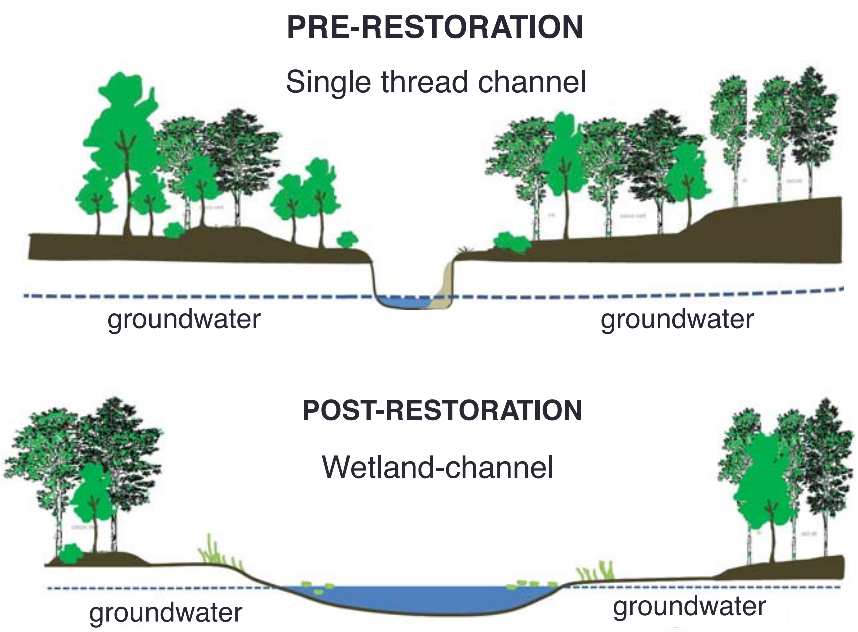
Many of the streams not meeting standards are located in built-up areas: metropolitan Baltimore, Washington, D.C., and other populated, urban areas of the Chesapeake watershed. Major culprits affecting stream water quality include the houses, malls, roads, and parking lots of modern life. Their hard surfaces prevent rainwater from percolating into the ground. Instead, the buildings and concrete funnel stormwater through drainage pipes and ditches and then into streams.

Much of this runoff is laden with sediments, nitrogen, and phosphorus from a variety of sources in the Chesapeake's drainage area, or watershed. Leaking sewer systems release nitrogen and phosphorus, for example; clearing land for parking lots sends sediments downstream. As water rushes through networks of streams, the runoff eats away at stream channels and banks, washing more sediments and nutrients downstream. Some stream ecologists use the term "hot, fast, and dirty" to describe not some off-color movie but the conditions of many Maryland streams after summer thunderstorms.

Improving this water quality is one reason that the Chesapeake Bay watershed has hosted the highest concentration of stream restoration projects in the nation. According to a 2005 study more than 4,700 projects cost $400 million from 1990 to 2003. Maryland alone had more than 2,300 such projects.

Now Maryland officials are planning more of these projects to help comply with mandatory federal targets for water quality that took effect in 2010. These targets are called the Total Maximum Daily Loads or TMDLs. To meet those requirements, Maryland counties pro-

***Rushing stormwater had eroded** a stream called Milkhouse Run in Washington, D.C.'s Rock Creek Park, exposing a sewer pipe and carrying soil downstream (above). In 2011, engineers reworked the stream channel, installing shallow pools, weirs, and native vegetation to slow water flow and reduce erosion (below). This type of restoration design is called a regenerative stormwater conveyance.* PHOTOGRAPHS, BIOHABITATS INC.



***A construction crew uses heavy equipment** in the channel of Jennifer Branch, Baltimore County, to rework its shape and function (photograph). Rushing stormwater can erode unrestored stream channels until they become narrow and deep (top illustration). Some stream restorations widen stream channels to make them shallower (bottom illustration) to slow stream flow and reduce erosion. These changes also create more contact between the stream water and groundwater, which increases the removal of nitrogen.* PHOTOGRAPH, BIOHABITATS INC.; ILLUSTRATION, SOLANGE FILOSO, UNIVERSITY OF MARYLAND CENTER FOR ENVIRONMENTAL SCIENCE (UMCES)

posed restoring some 410 miles of streams by 2025, in plans they submitted to the Chesapeake Bay Program. That is far more than any other of the six states in the Bay's watershed that are working to meet the TMDLs. Those 410 miles of stream restoration projects represent two-thirds of the total mileage of such projects planned in the entire watershed. The point of these projects is to try to convert these beat-up streams into assets to help the Bay.

Estimating the Reductions

So does improving a stream in Baltimore or Howard County or Pennsylvania help to improve water quality in the Bay? And if so by how much?

In 2011, the Chesapeake Bay Program asked an advisory panel to address those questions by reviewing the latest available science. The panel included state and local environmental officials, restoration contractors, and academic scientists. Knowing the answer could allow the Bay program managers to estimate with greater accuracy the contribution that each mile of restored stream makes toward meeting the TMDL targets.

The panel offered some answers in a 151-page report that received approval from the Chesapeake Bay Program in September 2014. The report highlighted the challenges of stream restoration but also described new studies that the panel said provided encouraging signs that restoration could make a meaningful impact on water quality. Evidence from Maryland and southeast Pennsylvania indicated that erosion of stream channels loaded more than 10 times the amount of nutrients and sediments into the stream water than was estimated only a decade ago. That suggested, the panel said, that stream restoration projects that reduced erosion could improve water quality more than was previously thought.

The report offered a set of methods for figuring how much reduction in nutrients and sediments could be chalked up to stream restoration projects. These methods represent the first such methodology approved in the United States to inform a set of TMDL targets. Counties may now use the methods to document that stream restoration projects are helping them to meet their TMDL targets.

But improvements in water quality shouldn't be the only goal of stream restoration projects, the panel added. It said these projects should also improve the biological quality of stream habitats, which is measured through indicators like the presence of certain species of fish and aquatic insects.

Accomplishing both of those goals is a challenge because "major scientific gaps still exist to our understanding of urban and non-urban stream restoration," the

Volunteers plant trees beside Tuscarora Creek *in Frederick County in 2009. Healthy streams are commonly surrounded by forested areas called riparian zones, and many restoration projects work to establish such zones. Planting trees and other vegetation improves the stream's water quality. The plants reduce excess sediments and nutrients flowing from the stream's upland drainage area into the stream channel.* PHOTOGRAPH, CHESAPEAKE BAY FOUNDATION

panel acknowledged. One such gap is that effects on water quality vary according to the restoration designs and methods chosen and a stream's location and size. To account for these differences, the panel's methods of estimating results included several stream-engineering techniques and offered ways to adjust the estimates to reflect conditions in individual streams.

Slower Currents Are Key

Broadly, the engineering techniques studied by the panel are variations on a single theme: they slow down the stream's flow. This reduces the energy of the water and its tendency to eat away at stream channels. A slower current, combined with other features of a stream restoration project, can help to remove excess nitrogen from the water and trap sediments. Putting the brakes on sediments also helps to restrain the downstream flow of phosphorus, which can attach to sediments.

One method for slowing down the water and protecting channels uses "natural channel design." This type of design transforms an eroded stream channel — which can look like a straight, box-shaped chute — into something that looks more natural: a stream dotted with rocks, boulders, and meandering curves. The channel's path is broken up by weirs, lines of stones called cross-vanes, and tree trunks.

Baltimore City and Baltimore County have carried out several of these projects at sites like Stony Run, which winds through Roland Park to the Inner Harbor. In 2010, the city completed a $10-million project to restore the stream and improve sewer and stormwater systems around it. The stream is now part of a park and trail system.

Despite the popularity of these projects, there is a long-running debate about whether this approach, sometimes described as "armoring" the stream channel, reliably reduces erosion and by how much.

The inventor and chief proponent of this approach, Dave Rosgen, a charismatic stream restoration consultant working in the western United States, developed a method of estimating erosion rates. His approach compares the stream with others that have similar characteristics like width, depth, and shape — and that have documented rates of erosion.

Peter Wilcock, now head of watershed sciences at Utah State University, was a professor at the Johns Hopkins University until 2014, and he takes issue with how Rosgen's approach has been applied in Maryland. For example, he says, it tends to identify streams as rapidly eroding because they have tall, bare banks. Some of these streams are indeed eroding, but others stopped eroding years ago and have remained stable since. "Bank erosion is too complex, too episodic, and controlled by too many factors to predict its rate based on the presence of bare banks," Wilcock says.

He says that to reliably measure erosion rates and pick which streams need restoration most, a different approach is required: you have to examine historical data. Old aerial photographs and land surveys can show observable signs of erosion over time. In its final report, the advisory panel on stream restoration endorsed using Rosgen's methods as one way to estimate sediment reductions. But the group also recommended using Wilcock's approach for confirming those estimates.

Once such restoration projects are completed, though, there's a lack of evidence about their effects, wrote Rebecca Lave, a geographer at Indiana University who analyzed Rosgen's methods in an article in the *Journal of the American Water Resources Association*. Funding for monitoring has been poor, she says, so "we in the stream restoration world are currently in the untenable position of spending more than a billion dollars of taxpayer money a year on restoration projects with no real idea of whether or not they are succeeding."

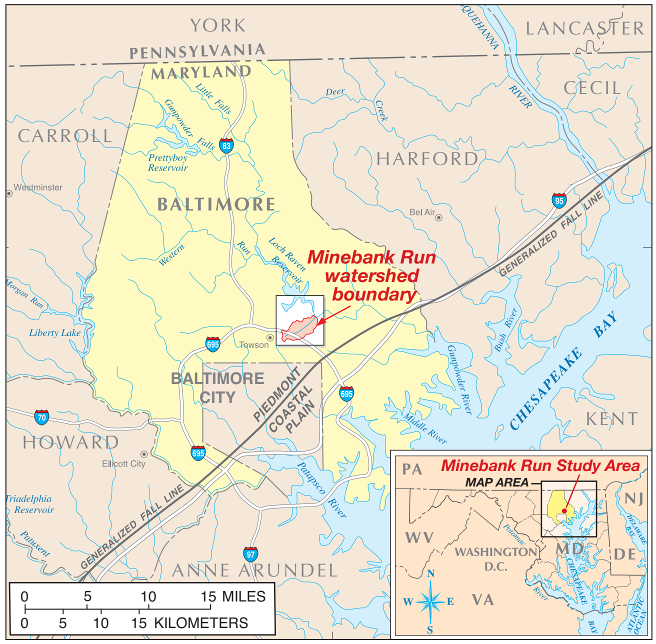
Removing the Nitrogen

Another kind of stream restoration design also slows the flow: it spreads it out. This approach creates a wider, shallower stream channel, like the one created at North Cypress Branch. When it rains and the flow rises higher in the channel, more water can move into adjacent side channels and wetlands.

The purpose of this widening and spreading is not only to reduce erosion but also help cleanse the stream of excess nitrogen. Increasing contact between the stream's water and the land in and around the channel can, under certain circumstances, increase an important biological activity called denitrification.

In this process, bacteria convert a molecule called nitrate (or NO_3^-, because it has one nitrogen atom and three of oxygen) into nitrogen gas (N_2). Once created, the nitrogen gas escapes from the stream into the atmosphere, reducing nitrogen levels in the stream and improving water quality. In a way, these streams are acting like nature's kidneys.

But scientists have also discovered that it can be a challenge to measure how much nitrogen is removed, and under what conditions — information that could inform our understanding of stream restoration's usefulness as a tool in the Bay cleanup effort.



Minebank Run, near Towson in Baltimore County, *was the focus of restoration work from 1999 to 2005 that modified the stream's channel. Scientists at the University of Maryland studied the effects of the modifications on water quality. They measured nitrogen amounts in the restored stretches of the stream using several techniques. The researchers found significant amounts of nitrogen were removed but also found that removal rates varied by location and over time. Removal rates can also vary over wider geological regions. The "fall line" shown here marks a boundary between two such regions, the Piedmont and Coastal Plain of Maryland.* MAP, U.S. GEOLOGICAL SURVEY

One scientist who has worked to find answers for those questions is Sujay Kaushal, an aquatic ecologist at the University of Maryland at College Park. Kaushal served on the Chesapeake Bay Program's advisory panel on stream restoration. For more than a decade, he and his colleagues have studied a series of urban streams in and around Baltimore, in the watersheds of the Patapsco and Gunpowder rivers, partly with funding from Maryland Sea Grant. Some of this ongoing research examined Minebank Run, a tributary of Gunpowder River that Baltimore County restored between 1999 and 2005.

Kaushal and his colleagues have used a variety of techniques to measure the amount of nitrogen that is removed from restored streams. One involved measuring how much nitrogen flowed into a stream reach (the length of the stream being studied) and how much flowed out. A reduction in nitrogen flowing out would be evidence for denitrification. However, that type of "mass balance" study can yield variable results depending on how the estimates are made, Kaushal says.

The scientists used other, complementary methods like studying rates of denitrification in the stream channel. To measure that, the researchers have used a special kind of nitrogen that they could track. They injected nitrate containing a rare natural form of nitrogen (N15) into the stream's surface water and in the groundwater beneath. This nitrate functioned as a tracer, allowing scientists to monitor its fate much the way a detective can follow a suspect's car by watching its license plate. A reduction in the amount of this tracer would provide evidence of denitrification at those locations. The researchers found that up to 40 percent of the tagged nitrate was converted to nitrogen gas along some reaches.

Kaushal and his colleagues found that denitrification rates were relatively high in areas of the stream channel, called the "hyporheic zones," where stream water could easily mix with groundwater and where denitrifying bacteria reside. (See illustration, p. 9.)

The scientists also observed that increasing connections between a stream's flowing water and nearby wetlands and oxbows (remnants of the original stream channel) could yield significant denitrification in those zones, reducing by up to 40 percent the daily load of nitrate in the stream.

But the effects of denitrification varied depending on location in the stream's watershed and on the restoration design, Kaushal adds. The variation can reflect "hot spots" of extra nitrogen entering the channel from leaky sewage system pipes and other sources. The pipes frequently run along streams to skirt buildings and arrive at collection points downhill. Designing projects to restore and preserve urban streams, he says, requires considering hot spots along the streams' entire length, which he and his colleagues call the "urban watershed continuum."

"If you couple the stream restoration along with sanitary infrastructure repairs because you're already digging and excavating all that stuff, it can probably have significant effects," he says. "We have aging infrastructure not only in Baltimore and D.C. [but in other cities, too]."

Findings by Kaushal and his colleagues about nitrogen removal within Minebank Run influenced the report of the Chesapeake Bay Program's advisory panel on stream restoration. Their results informed a method presented in the report for estimating the amount of nitrogen removed by restoration projects designed to promote denitrification in the hyporheic zones of streams.

Using a documented nitrogen-removal rate for this calculation "is a very good place to start," says Margaret Palmer, who has attracted national atten-

Through Rain and Cold, the Monitoring Must Go On

When we hear a summer thunderstorm at night, many of us roll over and go back to sleep. Solange Filoso, on the other hand, gets in her car and drives to a stream.

To study restored streams in Anne Arundel County, Filoso went driving by day and sometimes by night, in summer and in winter. Every two weeks, in daylight, she collected water samples from the streams for chemical analyses. She also measured the speed of stream flow during storms. "I remember being so wet once that I had to go to a store and buy new clothes and boots. I put them on and went back out there" to the stream to finish collecting data.

Long storms would send her out on night trips to check on her automated monitoring machines. Each held 24 bottles timed to collect samples as often as every 15 minutes. When longer storms would fill up the bottles, Filoso had to retrieve them and restock the machine with empties. That meant stashing all those full, one-liter bottles into a backpack — "It was heavy," she says — and then humping the whole load up some steep stream banks in the dark.

Now Filoso gets help with lugging her monitoring gear from her scientific colleagues. One of those helpers, Michael Williams of the University of Maryland Center for Environmental Science, is also her husband.

Watershed scientist Solange Filoso *is studying how stream restoration projects in Anne Arundel County affect water quality. One of her study locations is Cabin Branch in Annapolis (above). In a 2013 project, workers built berms of sand and wood chips in the stream and created a network of meandering channels to slow water flow. The waterway discharges into Saltworks Creek, then to the Severn River and the Chesapeake Bay.* PHOTOGRAPH, JEFFREY BRAINARD

Intensive monitoring like this is not only hard work, it can also be time consuming and expensive: it costs up to $80 per bottle to have a commercial laboratory chemically analyze each water sample. "Doing good monitoring requires investment," Filoso says. In fact, the three years she spent monitoring Howard's Branch and five other streams in Anne Arundel County, with funding from the county government, was a relatively long span; often, money is available for no more than one year of monitoring after a restoration is completed, she says.

When she started her work in Maryland's streams, Filoso had been no stranger to flowing water. A native of Brazil, she has done research on the Amazon, the world's largest river, and she hopes to apply aspects of what she's learning about stream restoration in Maryland to a project in that country. She says some of the same issues carry over from Maryland to Brazil, where the clearing of forested areas has jeopardized the quality and quantity of water supplies to the Brazilian population.

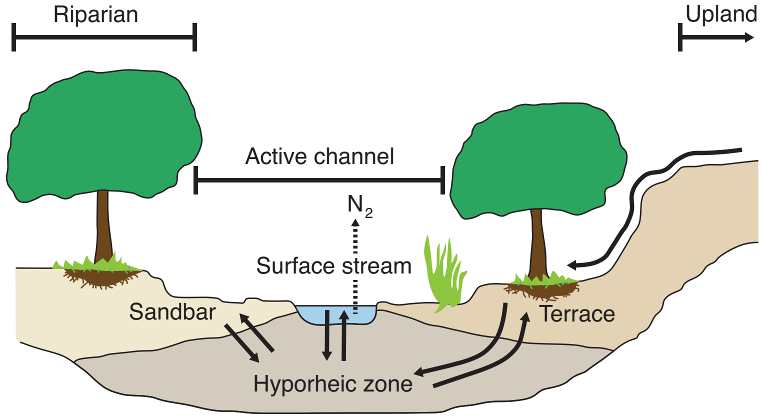
— *J.B.*

tion as an expert on stream restoration. She is a professor at the University of Maryland at College Park and the University of Maryland Center for Environmental Sciences (UMCES) and is now director of the National Socio-Environmental Synthesis Center in Annapolis. However, she continues, "the spatial variability in denitrification in streams is well known to be huge."

What Goes In, What Comes Out

Palmer has worked with Solange Filoso in another part of the Chesapeake watershed to study restored streams and their effects on water quality. The findings of this research are among the reasons both scientists voice caution about expecting restoration projects to significantly reduce nitrogen in streams.

From 2007 to 2010, Filoso, who was a member of the advisory panel on stream restoration, monitored conditions in six streams in Anne Arundel County that had been restored using different methods. Three of the restored stretches had been stabilized using natural channel design. Others were in lowland stream valleys and relied on the wide channel approach. Filoso worked to determine the "mass



***Anne Arundel County has supported** restoration projects (examples, left) that may promote the removal of nitrate from the stream's water. In a natural process, called denitrification, bacteria can convert nitrate into nitrogen gas (N_2) both in the groundwater below as well as along the sides of a stream bed, an area scientists call the "hyporheic zone" (right). A restoration project can increase denitrification by widening the stream channel to increase contact between the stream's surface water and groundwater.* MAPS, ANNE ARUNDEL COUNTY, GOOGLE DATA ©2015, (COUNTY OUTLINE AND STREAM LOCATIONS ADDED BY SANDY RODGERS); MARYLAND, ISTOCKPHOTO.COM/ TEXAS MAP LIBRARY; ILLUSTRATION (ABOVE), ADAPTED FROM FISHER ET AL., GEOMORPHOLOGY 89:84-96 (2007)

balance" — the amount of nitrogen flowing in and out — of restored stream reaches.

Filoso and Palmer found that only two of the six restored reaches showed statistically significant declines in nitrogen upstream versus downstream during normal water levels. And only one, Howard's Branch, reduced the amount of nitrogen exported downstream during storms.

The data also suggested that big storms tended to overwhelm the streams' ability to remove or retain nitrogen through natural processes. In the restored reach of Howard's Branch, the reduction in nitrogen occurred during storms with less than three-quarters of an inch of rainfall. However, larger storms that dumped more rain had an out-sized effect: although a minority of all storms, they contributed most of the water that moved downstream annually. And with that water went most of the nitrogen exported down the stream. At higher flows, dissolved nitrogen had less time and opportunity to come into contact with denitrifying bacteria, Filoso says.

So what was the overall amount of nitrogen that could be removed within a restored stream channel? Filoso and Palmer calculated that in a best-case scenario, a wide, restored stream could remove about 17 percent of all the nitrogen moving in the water within the stream channel annually. To put this removal rate into a broader perspective, such a restored stream was removing about 5 percent of all of the nitrogen loaded onto the surrounding land that drained into the stream. They assumed the nitrogen came from sources like sewage-system leaks, lawn fertilizer, pet waste, and atmospheric deposition in rainwater. (Some of the nitrogen deposited in a drainage area is retained there and never flows into a stream.)

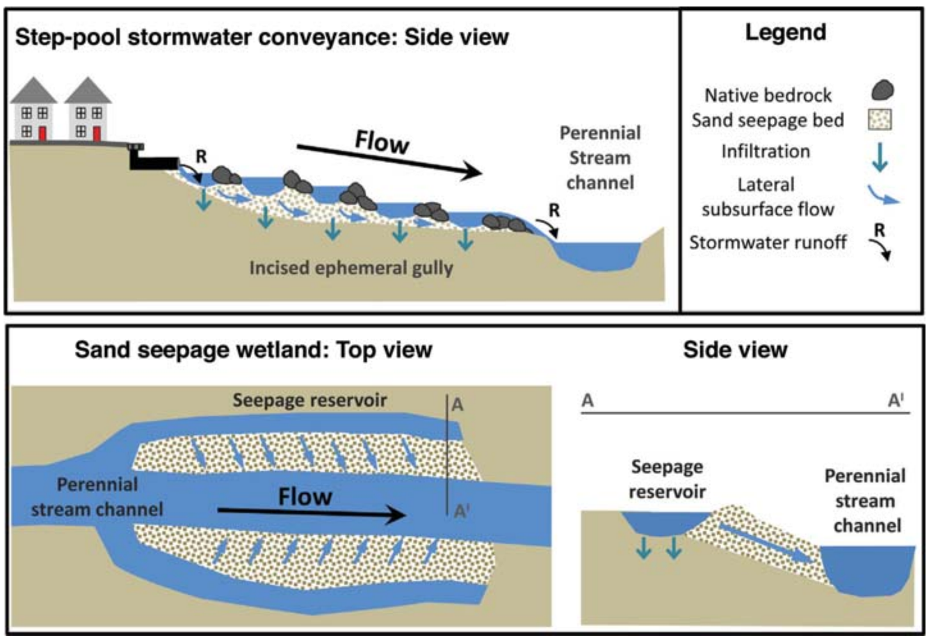
Filoso and Palmer also studied how well features of the restored streams trapped sediment moving downstream. In findings yet to be published, they found that retention of sediment by restored reaches was relatively small in relation to inputs of sediment flowing from upstream sources. The amount of sediment stored was variable; during some bigger storms, more sediment was washed out and sent downstream than was retained. And the restored streams didn't retain more sediment than unrestored streams nearby did.

Overall, Filoso says her research findings make her worried that we may be expecting streams to do more than they can naturally do — and that we may be relying on them as a last line of defense before polluted stormwater flows into the Chesapeake Bay. Restored stream channels are often relatively small compared with the total surrounding area that drains into them, she notes. The restored corridor of North Cypress Branch, for example, measures about nine acres compared with a drainage area of 475 acres.

Filoso suggests that by relying more on stormwater management practices located upland, outside of a stream channel, we can reduce the volume of stormwater flowing into the stream. And in turn, we can avoid over-relying on the cleansing effects of denitrification and other processes that remove pollutants from stream water, whose effects vary over time and by location.

"An analogy I make: if you have a sick patient, you don't go for the most invasive, extreme treatment right from the beginning," Filoso says. "You try to make an assessment of what may be causing the problem, and you try to eliminate causes. . . . When there's nothing more that you can do, then you go and do surgery. To me, stream restoration is more like surgery."

North Cypress Branch, a stream in Severna Park, *Anne Arundel County, had been eroded by stormwater runoff from a 475-acre drainage area (outlined in yellow), which includes a shopping center and its parking lot (left). In 2013, the county and its partners concluded a project to improve the stream by designing a variety of structures — such as terraced step pools and a "braided" network of channels — that work to slow and widen the stream flow.* AERIAL IMAGES: (LEFT) PROJECT DESIGNER BAYLAND CONSULTANTS AND DESIGNERS INC.; (RIGHT) PROJECT DESIGNERS BAYLAND, CLEAR CREEKS CONSULTING, AND UNDERWOOD & ASSOCIATES.



Stream restoration designs are selected *depending on a stream's topography and other circumstances. In regenerative stormwater conveyances (top), step-like pools are installed in steeply graded streams below the outfalls of stormwater drainage pipes to control water rushing out during rainstorms. By contrast, wetland seepage systems (bottom) are designed for flatter stream channels. Side channels are built parallel to the stream flow to store stormwater runoff. Water in these "seepage reservoirs" (A) slowly flows through a constructed "sand seepage bed" to the stream (A').* ILLUSTRATION, ADAPTED FROM PALMER ET AL., ECOLOGICAL ENGINEERING 65:62-70 (2014)

"It's funny, because when I came into this whole thing, I was really convinced that [stream] restoration could do more. I really thought, this makes sense. And I wanted it to work. But the data so far indicate that it doesn't do as much as I thought it would do."

Filoso adds that a fuller picture of the effects of stream restorations may emerge in future research projects that compare nutrients and sediments in the streams pre- and post-restoration. She wasn't commissioned to begin monitoring the six Anne Arundel streams until after restoration work there was completed. "Without long-term, good-quality data," she says, "it's really difficult to determine how the systems are working."

Crafting an Effective Toolkit

In its final report for the Chesapeake Bay Program, the advisory panel on stream restoration acknowledged concerns about its effectiveness as a tool to improve water quality and suggested ways to improve it. The report encouraged government managers and planners to couple stream restoration projects with management practices located upland to reduce stormwater flow into streams. (See Getting SMART about Clean Water, p. 12.)

But the upland practices, like installing drainage swales and removing impervious asphalt, present their own set of challenges — and costs, says Bill Stack. He served as a staff member for the advisory panel and is deputy director of the Center for Watershed Protection, a nonprofit based in Ellicott City, Maryland, that advises local governments and organizations. Previously he led stream restoration projects for the Baltimore City Department of Public Works. In that role, he oversaw an intensive effort to install stormwater-control measures in Watershed 263, an area of 930 acres encompassing 12 neighborhoods in West Baltimore. (For a detailed description of this project, see *Chesapeake Quarterly*, Vol. 7, No. 2.)

"I know how expensive these projects are. The cost is huge," Stack says. "The other issue is finding enough pub-

Two Takes on Stream Restoration

Designers of the North Cypress Branch *restoration project planned a series of constructed flood-plain wetlands like this one to help slow the stream's flow.* PHOTOGRAPH, JEFFREY BRAINARD

Bob Hahn Jr. and Patty Hinks live only a few houses away from each other in Severna Park in Anne Arundel County. Both of their back yards share the same, expansive view of North Cypress Branch and the stream restoration project completed there in 2013. But they hold very different views about the project's results.

"I think it's a good thing if the research pans out and it helps the Bay," says Hahn on a recent sunny afternoon on his back lawn, overlooking the restored channel. He grew up nearby and has good memories of spending time down by the stream years before the restoration project. But he also likes the new version and the wider space that the project created.

"It's real nice here in the summertime," he says, "and I think it's improved my property value."

But to Hinks, the beauty and privacy of the forested creek were what drew her to buy her house 30 years ago. "Now it's the Great Lakes," she says, referring to the wide, shallow pools the restoration created. "I wish they would have experimented somewhere else, because there was a lot of acreage [of trees] that they had to take out here."

— *J.B.*

For Further Information

Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects, Chesapeake Bay Program, 2014.

Longitudinal patterns in carbon and nitrogen fluxes and stream metabolism along an urban watershed continuum. S.S. Kaushal, K. Delaney-Newcomb, S.E.G. Findlay, T.A. Newcomer, S. Duan, M.J. Pennino, G.M. Sivirichi, A.M. Sides-Raley, M.R. Walbridge, K.T. Belt. *Biogeochemistry* 121(1):23-44, 2014.

Assessing stream restoration effectiveness at reducing nitrogen export to downstream waters. Solange Filoso and Margaret A. Palmer. *Ecological Applications* 21(6):1989-2006, 2011.

Renewing an Urban Watershed, *Chesapeake Quarterly*, Volume 7, Number 2, 2008.

The Storm over Drains, *Chesapeake Quarterly*, Volume 4, Number 4, 2006.

licly owned property where you can put these practices in the ground that will make a substantive difference. . . . As a rule of thumb, if you're limited to publicly owned property, at best you can treat about 15 percent of runoff volume."

Because of challenges like these, it could take decades to install enough stormwater control measures in upland areas to improve the Bay's water quality, Stack estimates. Using his own analogy about doctors, he says that projects that reduce stream-channel erosion today will help "staunch the bleeding" of excess sediments and nutrients to the Bay — and buy time to allow other treatments to work.

When the advisory panel recommended ways to estimate by how much stream restorations reduced nutrients and sediments, it said it was taking a conservative approach to account for variability and uncertainties in performance. For example, the panel said the estimated reductions in sediments using the natural channel design approach should be cut by 50 percent. And stream restoration projects receiving credit for reductions will have to be monitored every five years to determine that they are still working as originally designed.

This monitoring and assessment is crucial, Stack says. "I'm concerned that a lot of managers, a lot of [engineering firm] practitioners, they see the high credits that stream restoration gives, and they're just going to jump on the bandwagon and start putting these projects in the ground without using a scientifically based design process that we can learn from and refine and tweak."

The Chesapeake Bay Program is pursuing this kind of iterative learning process, dubbed "adaptive management," to tweak a variety of interventions besides stream restoration in order to improve water quality and make progress toward meeting the Total Maximum Daily Load water-quality targets by the deadline of 2025. In addition, the program's Science and Technical Advisory Committee has prepared a new report about using science-based principles to design sustainable, effective stream restoration projects in the Chesapeake Bay watershed.

Designing projects that are consistently effective will require further work, says Tom Schueler, executive director of the Chesapeake Stormwater Network. With Stack, he also worked as a staff member for the advisory panel. Says Schueler, "We need a lot more science, a lot more economics, a lot more research and practice to make the best policy decisions about how to restore streams and how to do these other restoration practices in watersheds."

— *brainard@mdsg.umd.edu*

Getting SMART about Clean Water

Online tool tracks where Marylanders are working to manage stormwater

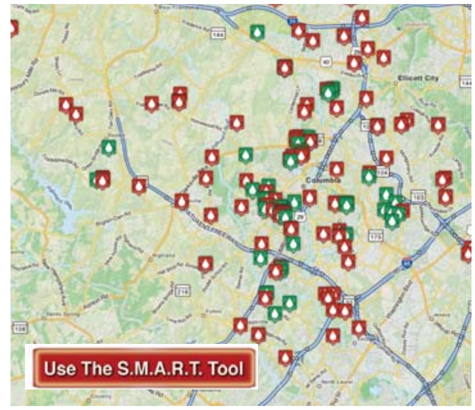
Daniel Strain

People use online maps for a lot of different tasks: to plot out their road trips or find a late-night pizza place. Now, a group from Maryland has created a site for mapping how Marylanders are working toward cleaning up their local waterways. It's called the Stormwater Management and Restoration Tracker (SMART) tool.

Local government officials in Maryland are hopeful that this new tool will help them meet the goals set out by a federal and state effort to clean up the Chesapeake Bay — by giving counties a way to count some of the small-scale efforts to improve water quality that might normally be overlooked.

Watershed restoration specialists in the Maryland Sea Grant Extension program are spearheading the effort, which is in its pilot-testing phase. They work with communities across the state to help them target a big problem in the region: stormwater runoff. During rainstorms, water runs off roofs and gushes down driveways, carrying nutrients and sediments toward small streams within the Bay watershed. That steady flow can worsen the health of local waterways and eventually trickles down to the Chesapeake itself.

Scientists, engineers, and landscape professionals have developed a number of practices for containing and controlling this runoff. These practices allow communities to capture stormwater before it ever reaches a brook or a creek. Rain barrels, for instance, are small cisterns that collect the water streaming out of home downspouts. Rain gardens are specialized plant beds that are designed to sop up stormwater like a piece of bread dipped in soup.



***Decorative and functional,** this rain barrel (left) helps homeowners to collect the stormwater flowing from their downspouts. When Maryland residents enter practices like this into the SMART tool site, they show up as red pins on a map (above). Green pins show the practices that have been verified by trained watershed stewards.*

PHOTOGRAPH, AMANDA ROCKLER; MAP, SMART TOOL MAP SHOWING AN AREA IN HOWARD COUNTY

Many homeowners around Maryland have already started installing practices like these in their front yards, says Jacqueline Takacs, a watershed restoration specialist at Maryland Sea Grant Extension who serves the southern Maryland region. The problem is that no record exists of where or when such efforts have been put into place. That's important, she and her colleagues argue. Marylanders want to help out with efforts to clean up the Bay, but they also ask "who is using my data?"

That's where the SMART tool comes in. Just as Google maps lets you see all of the pizza-by-the-slice places in your neighborhood, this tool maps out where Marylanders have installed rain gardens and similar stormwater management practices around the state. The team developed the tool in collaboration with experts in geographic information systems at the Center for GIS at Towson University in Maryland.

And it's easy to use: residents go to the tool's website and type in details about the sorts of stormwater management practices they've implemented at home. There are 11 different practices to choose from, including rain barrels and gardens.

The Maryland Sea Grant team will train volunteers to travel out to these homes to certify that the practices have been implemented correctly — that rain gardens, for instance, have been dug deep enough and are located where they can absorb the most stormwater. In the end, each home with a practice in place is marked on an online map with a colored pin.

Anyone in the region can use the tool, but the team is currently only verifying practices located in Howard County, Maryland. The site has already received around 400 submissions, and the team plans to expand the program to the entire state by late 2015.

It could also become an important piece of the multi-state effort to clean up the Bay called the Chesapeake Bay Total Maximum Daily Load. In 2014, the Chesapeake Bay Program, which oversees this effort, approved procedures that will allow local governments to include practices entered into the SMART tool toward meeting their cleanup goals. That could save Maryland counties money. And it would show homeowners that their efforts were contributing to a larger goal.

"Even 100 rain gardens may be a teeny-tiny piece" of what's needed to clean up the Bay, Takacs says. "But it's still a piece."

In addition to managing the SMART tool project, specialists with the Maryland Sea Grant Extension program have worked to combat stormwater runoff in a number of different arenas. They helped to launch four watershed steward academies in the state that train volunteers to carry out stormwater management projects. They also support a local green jobs program called the Restoring the Environment and Developing Youth (READY) program.

The specialists are working to develop a certification program for landscape contractors who install stormwater management practices called the Chesapeake Bay Landscape Professional Certification Program. They also designed the Maryland Watershed Restoration Assistance Directory, an online database of organizations that fund efforts to slow down runoff.

To learn more about the SMART tool or how Maryland Sea Grant Extension's watershed restoration experts can help your community visit:

http://www.extension.umd.edu/watershed/smart-tool

http://www.mdsg.umd.edu/water-issues-and-restoration

— *strain@mdsg.umd.edu*

To Map Streams for Restoration, First Go to the Source

Jeffrey Brainard

To protect streams flowing down towards the Chesapeake Bay, you sometimes have to journey up to the mountain tops.

That's what Andrew Elmore and his colleagues did. Again and again, in dozens of Maryland forests, the scientists scrambled uphill, tracking the course of small streams. It was part of a labor-intensive effort to build a novel, detailed map showing Maryland streams not recorded on other maps. By mapping the headwaters of small streams near the tops of forest ridges and hills, the researchers worked to create a computer model that predicts the locations of small streams across all of Maryland west of the Chesapeake Bay. The model offers a tool to protect streams from development and to improve the region's water quality.

***Geologist Andrew Elmore** and his colleagues tromped up mountain stream channels to record data about the locations of their headwaters. They merged that information with other data to build a new, detailed model of small and buried streams in Maryland west of the Chesapeake Bay.* PHOTOGRAPH, UMCES/CHERYL NEMAZIE

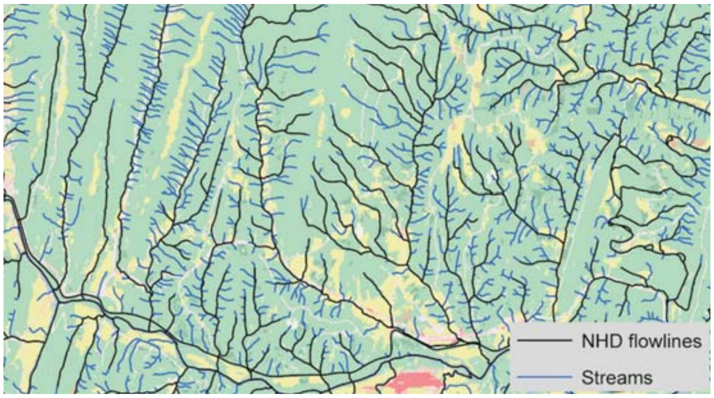
These small headwater streams are easy enough to ignore — many are small enough to step over as you walk through a forest. But knowing their locations is important for several reasons. First, they are important pockets of biodiversity. Biologists have found that relative to larger streams, the smaller ones support a more diverse array of aquatic species, like fish and insects. The mix of species can be different from stream to stream — and this diversity can be easily lost when construction of new homes and roads fills in or buries a stream.

Small streams are also important for water quality. Compared to large streams, more of the water in small streams makes contact with the soils in the channel. And more leaves are washed into small streams relative to the amount of water there. These conditions help to promote a biological process, denitrification, that removes nitrogen from the water. Mile for mile, small headwater streams are the most efficient at this among all streams. However, small streams are also the most likely to be filled in or buried by construction and development.

Elmore, a geologist, became interested in mapping streams after he came to work in 2006 at the Appalachian Laboratory, part of the University of Maryland Center for Environmental Science (UMCES), in Frostburg.

While developing a map of buried streams in Baltimore, he and a colleague, Sujay Kaushal of UMCES, noticed that many of them were not shown on the National Hydrography Dataset, an existing, widely used, nationwide database about surface waters. That database was created in the 1990s after streams in areas like Baltimore were already buried. They also noticed that small streams in non-urban areas weren't included on the NHD map, either.

Seeing an opportunity to create a more detailed map, Elmore used funding from Maryland Sea Grant to begin mapping streams across Maryland west of the Chesapeake. It was, Elmore says, "the most



The new model of stream locations, *created with funding from Maryland Sea Grant, shows previously unrecorded Maryland streams (blue), adding detail to stream maps previously created as part of the National Hydrography Dataset (black). In this map, forested areas are colored green, agricultural lands are yellow.* MAP, UMCES APPALACHIAN LABORATORY

ambitious attempt yet to model stream networks over a large region."

For this project, his scientific collaborators were Steven Guinn and Matthew Fitzpatrick of the Appalachian Laboratory and Jason Julian, now at Texas State University. Their approach was based on a fundamental idea: to know where buried streams might be located today, you have to know what the Maryland landscape must have looked like centuries ago, a landscape crisscrossed by streams, before suburbs and houses spread across the state. Parts of Maryland provide clues about that seemingly pristine landscape: the state's remaining forests.

The researchers figured that if they devised a computer model predicting where streams flow today within those Maryland forests, they could use the same model to accurately predict the location of stream channels elsewhere, including in non-forested suburban and urban locales where houses and roads now stand. They could create a road map to find small and buried streams.

To create that computer model, Elmore says, the scientists had to collect several types of data. They searched existing sources of information about terrain elevation and slope and soil characteristics, features that can indicate the presence of streams.

But they needed other information that was missing: the locations of a sample group of "channel heads" where stream headwaters begin. To map those headwaters, they had to drive and hike to the tops of mountains, like Dan's Mountain Wildlife Management Area in Alleghany County. And to the tops of hills, like those in Prince William Forest park in Virginia.

Elmore describes how the researchers literally followed the evidence.

"At each forested watershed, we would work in groups of two to three people to map," Elmore says. "We would start at a rather large stream and walk upstream to the first confluence. One of our group would start following the smaller stream, still walking uphill, and the rest of us would keep walking up the larger stream until we found another confluence and another small stream to walk up. The walking continued until we reached the channel head — channel heads are the most uphill evidence of a stream channel. When we found this location, we recorded the GPS coordinates."

The trio ended up often having to make their way through dense vegetation when there were no established trails to follow, Elmore recalls. "To make the bushwhacking easier, we only mapped streams in the spring, winter, and autumn, when undergrowth vegetation was sparse." In all, the scientists walked about 85 miles of stream length, and they found more than 250 channel heads. The new data came at some cost: they often emerged from the forest with many small cuts on their legs.

When the scientists put all of this data together, their computer model predicted the paths of streams as they flowed downhill from upland, forested areas. Elmore and his colleagues then extended the model to predict where streams would probably flow today across all of Maryland west of the Bay, including in non-forested areas. "The map is really a map of what the stream network would look like if the entire landscape had the same land use, and land use history, as our forests," Elmore says. In all, the map covers 23,000 square miles including the Potomac River watershed and five smaller watersheds.

To check the model's accuracy, the scientists used existing field data about the actual presence or absence of streams in more than 10,000 locations in Maryland. Eighty-four percent of the model's predicted stream locations correctly identified an actual stream, an improvement over the existing, nationwide map. Only 55 percent of stream locations shown in the National Hydrography Dataset (NHD) were correct.

Elmore's model filled in blank spots on the NHD map with many new, thin squiggly lines representing the probable location of streams. In some portions of Maryland, the "stream density" in Elmore's model (measured as kilometers of stream length per square kilometer) is 2.5 times the density shown in maps of the same area based on NHD data.

The differences between the two maps reflect several differences in how they were created, Elmore says. The U.S. Geological Survey (USGS) produced the NHD in the 1990s using aerial photographs, he notes. What's more, for the purpose of creating stream maps, the USGS defines a stream as a body of flowing water that contains water most of the time. However, some of the smaller streams shown in Elmore's model may flow only intermittently — during spring rains, for example.

Eventually, the national NHD dataset will evolve to include a higher level of detail similar to that in Elmore's model, says Jeffrey Simley, a USGS cartographer. "The only thing holding us back is the lack of funding for such development and the need for such detail in many parts of the country," he says.

Elmore and his colleagues published a description of the model in 2013 in the journal *PLoS One*.

Uses for the New Map

The model is "an important tool for improving our understanding of how to keep the Bay clean," says Christine Conn, director of the integrated policy and review unit of the Maryland Department of Natural Resources. "If we don't know where these streams are, we have difficulty managing the resource, both for conservation and restoration."

The department has begun using the model to review impacts from proposed construction projects and to identify small streams that are habitats for brook trout, which the agency manages. Conn adds that her agency may incorporate Elmore's data into its next update of the maps used to create its GreenPrint tool, a statewide map that identifies lands and watersheds with high ecological value as priorities for conservation.

Elmore says that the model could help inform decisions about where to locate conservation projects, such as artificial wetlands, to maximize benefits. "If you're looking at a broad region, you don't want to cluster all your restoration projects in one area, you want to distribute them on the landscape," he says.

Officials in several Maryland counties have contacted Elmore about using the model to help them comply with new rules, called TMDLs (Total Maximum Daily Loads), intended to improve the Bay's water quality. The model could help inform where to plant stream-side buffers of trees to help remove nutrients and sediments from runoff. The model "opens up the amount of land where we could potentially plant buffers to meet those TMDLs," he says.

And, Elmore jokes, "If you're in the business of water-proofing people's basements, I can give you a great map of who to send fliers to." The researchers posted the stream map on a website (http://streammapper.al.umces.edu) that shows local streets superimposed. Zoom in at the block level, and you might notice a buried stream running near or under your house.

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Knauss Fellows from Maryland for 2015

Daniel Strain

Three graduate students from Maryland will employ their scientific knowledge to help the federal government develop marine policy in 2015. With support from Maryland Sea Grant, these students began their year-long Knauss Marine Policy Fellowships in February. All three are working for the U.S. National Oceanic and Atmospheric Administration (NOAA) in the Washington, D.C. area.

Jeanette Davis has joined NOAA's National Marine Fisheries Service. She assists the Office of Science and Technology in its sea turtle conservation efforts, working to develop stock assessments for vulnerable populations.

Jeanette Davis assists *the National Marine Fisheries Service at NOAA.* PHOTOGRAPH, JEANETTE DAVIS

Davis is a doctoral student at the Institute of Marine and Environmental Technology in Baltimore, a part of the University of Maryland Center for Environmental Science (UMCES). She has explored the bacterial communities that are associated with tropical sea slugs that congregate near Hawaii every spring to mate. Some of these microbes may produce compounds that could have uses in human medicine, such as to fend off cancer.

Originally from Wilmington, Delaware, Davis received her bachelor's degree from Hampton University in Virginia. During that time, she lived for a month on a 53-foot sailboat as part of a research internship. She also participated in Maryland Sea Grant's National Science Foundation Research Experiences for Undergraduates program in 2006. She hopes that her Knauss Fellowship will give her a grounding in marine policy and help her to apply her scientific knowledge to developing policies that benefit the natural world.

Jessica Foley is spending her fellowship year in the Office of Oceanic and Atmospheric Research at NOAA. There, she works with members of the administration's leadership on diverse topics, including the oceans and Great Lakes, climate, and weather.

Jessica Foley is at *NOAA's Office of Oceanic and Atmospheric Research.* PHOTOGRAPH, JESSICA FOLEY

Foley is a master's student in the Marine Estuarine Environmental Sciences Program at the University of Maryland. Her research focuses on a mathematical model that addresses the growth of seagrass beds in the

Continued on p. 16

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Knauss Fellows, *cont. from p. 15*

Delmarva Peninsula's coastal lagoons, adjacent to the Atlantic Ocean. Foley's research will help scientists to track how changes in the future — such as rising temperatures associated with climate change — might affect the health of this important green life.

Foley's introduction to estuarine science came as an undergraduate student at the University of Rhode Island, where she studied mangrove trees growing in Puerto Rico for her senior thesis. She has also founded a student-run collegiate field hockey program, worked at a wastewater treatment facility, and spent many summers knee-deep in wetlands from bogs to salt marshes and mangroves.

Brittany Marsden serves as the inaugural Knauss Fellow in the Formulation and Congressional Analysis Division at NOAA. She helps the administration to develop its research priorities and communicate the significance of NOAA research to Congress. She also helps scientists get the funding they need to carry out their work.

Marsden is a doctoral student in the Marine Estuarine Environmental Sciences Program at the University of Maryland. Her research addresses the genetic diversity and growth patterns of submersed aquatic vegetation (SAV) growing in the Chesapeake Bay watershed.

Brittany Marsden is in *the Formulation and Congressional Analysis Division at NOAA.* PHOTOGRAPH, BRITTANY MARSDEN

After earning her undergraduate degree from the University of Richmond, she worked as an environmental educator, first with the Chesapeake Bay Foundation and later at the Patuxent Research Refuge in Maryland. Among other activities, Marsden organized and led educational experiences for young students, helping high schoolers, for instance, to search for arrowheads and other historic artifacts on eroding Bay islands. Those experiences sparked her desire to pursue an interdisciplinary career in marine conservation.

The Knauss Fellowship, begun in 1979, is designed to let outstanding graduate students spend a year working on science policy in Washington, D.C. The program, coordinated by the National Sea Grant Office, places fellows in legislative or executive branch offices in the federal government that work on ocean, coastal, and Great Lakes policy issues. Fellowships run from February 1 to January 31 and pay a yearly stipend plus an allowance for health insurance, moving, and travel. Applicants must apply through the Sea Grant program in their state. For more information, visit:

- Maryland Sea Grant Program, Knauss Fellowships: www.mdsg.umd.edu/education/knauss
- National Sea Grant Program, Knauss Fellowships: www.seagrant.noaa.gov/knauss

On the Bay Blog

At the end of March, a new blog called *On the Bay* was launched as a service from Maryland Sea Grant and *Chesapeake Quarterly* magazine. Posts will include short essays, slide shows, podcasts, occasional videos, and frequent reporting on marine and environmental issues. From time to time we will carry guest-written posts contributed by those with Bay memories to share and by those engaged in studying, managing, or protecting the Chesapeake Bay's ecosystem.

You can read *On the Bay* at:

www.mdsg.umd.edu/onthebay-blog