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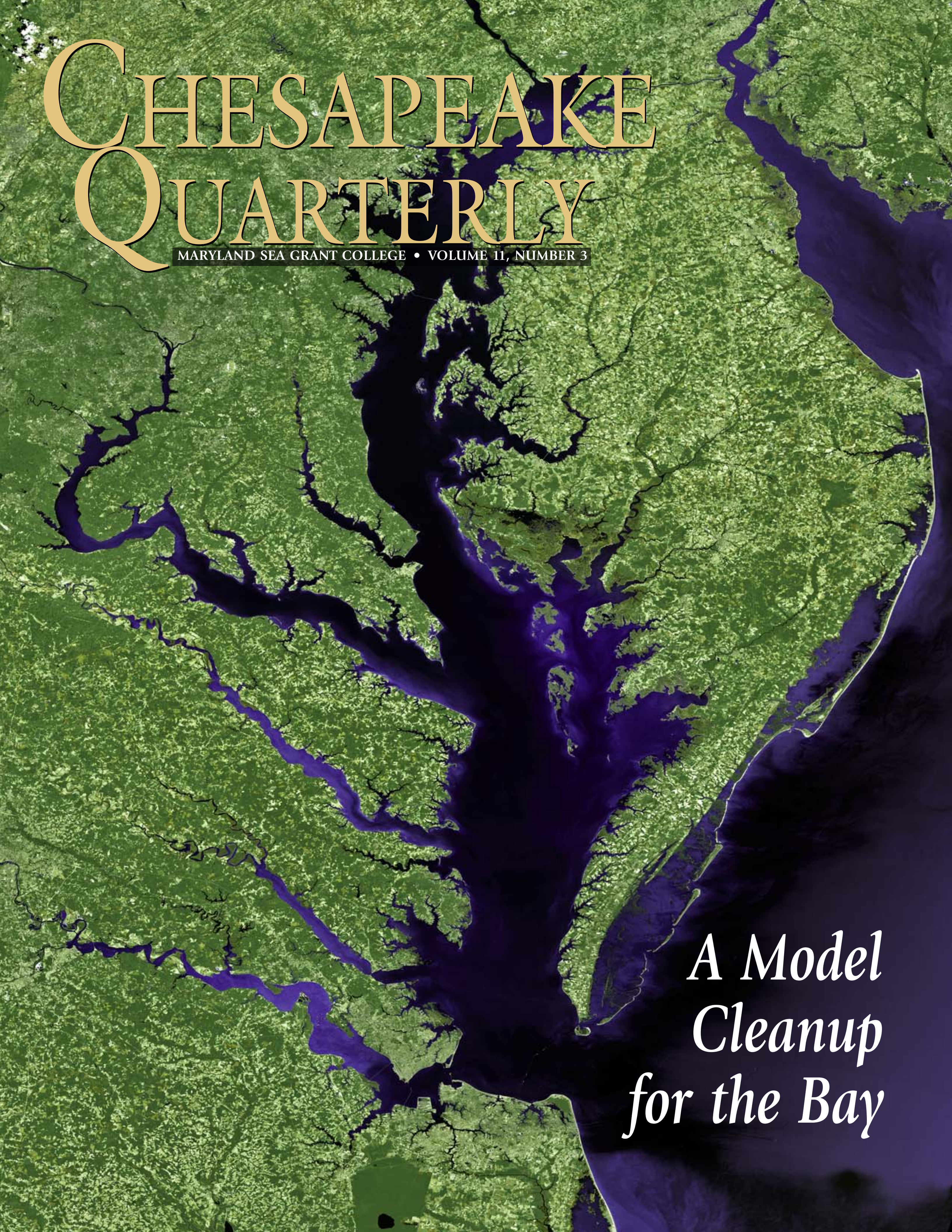

A Model Cleanup for the Bay

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Chesapeake Quarterly explores scientific, environmental, and cultural issues relevant to the Chesapeake Bay and its watershed.

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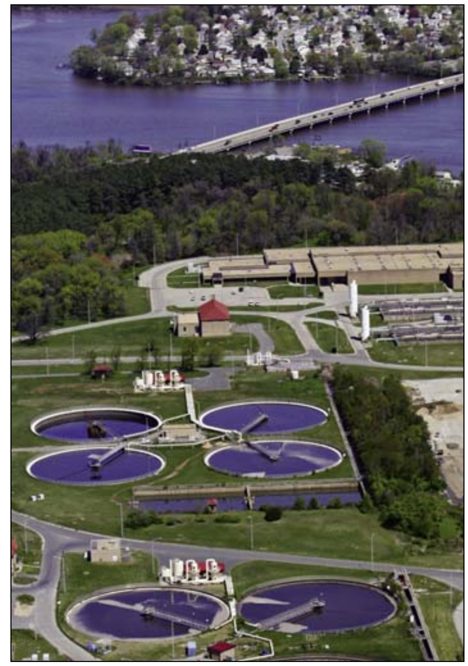
Cover photo: *Full of twists and turns that stand out in this satellite image, the Chesapeake Bay and its watershed make up a grand and complex ecosystem. Scientists in the region are working to represent that entire environment using computer simulations, efforts that are guiding a new push to clean up the Bay.* ***Page 2:*** *Two of the leading sources of excess nutrients entering the Bay are farms, like this one on the Eastern Shore, and wastewater treatment plants, like the Back River treatment plant near Baltimore, shown here.* *PHOTOGRAPHS: COVER, NASA SCIENTIFIC VISUALIZATION STUDIO; P. 2, (LEFT) SKIP BROWN, (RIGHT) JANE THOMAS.*

Cleaning Up the



Talking about the Chesapeake Bay, America's largest estuary, inevitably seems to require talking big. H.L. Mencken portrayed the Bay as a "great protein factory." And, before him, the Algonquins named it "Chesepiooc," meaning "great water."

Superlatives also apply easily to the ambitious project currently underway to clean up this vast estuary, tributary by tributary. Mandated in 2010 by the U.S. Environmental Protection Agency under a section of the Clean Water Act, the cleanup push will take place over the next decade and beyond. Federal and state officials will use a tool called the Chesapeake Bay Total Maximum Daily Load, or TMDL, to require major cuts to the excess nutrients and sediments streaming from the region's land and skies into the Bay. The limits set by TMDLs have been dubbed the Chesapeake's "pollution diet."

The enormous scale of this mandatory and expensive cleanup, involving the six states that make up the Bay's 64,000-square-mile watershed, makes the project the largest and most complex of its kind in U.S. history. On page 3, we offer a basic overview of the plan — its goals, history, and what, exactly, is a "TMDL."

Elsewhere in this issue of *Chesapeake Quarterly*, we examine a scientific tool that was used to construct the cleanup strategy (see A Model Plan, p. 4). The tool, computer modeling, allows experts to predict the behavior of complex systems like the Bay. Those predictions, in turn, enabled the cleanup plan's authors to set targets for improving water quality over such a big area of land and water. But because models are based on assumptions and field observations, the portrait of nature they offer is never perfect. The Chesapeake Bay Model has drawn public scrutiny for that reason and because so much money is riding on whether its predictions are accurate enough.

Another article, A Garden of Opportunities (p.11), explores one way in which this abstract set of model equations and data could literally come home and take root in your front lawn. The cleanup plan relies partly on reducing the flow of nitrogen-laden stormwater from urban and suburban areas, like parking lots and lawns, into the Bay's tributaries. Scientists are studying a variety of methods to do that, including the landscaping technique known as rain gardens.

Bay: Big Science, Big Plan

What is a "TMDL," and what does it have to do with the Bay's restoration?

TMDL means Total Maximum Daily Load. It's a legal term for the maximum amount of a pollutant that can be added to a water body — like a stream, a river, or the Bay — without violating federal and state government rules for water quality. Restrictions of those pollutants are aimed at making water bodies "fishable and swimmable." In the Chesapeake Bay, the U.S. Environmental Protection Agency led an effort, completed in 2010, to set TMDLs that would limit the flow of nitrogen, phosphorus, and sediment into the Bay and its tidal tributaries. The agency and its partners now require communities in the Chesapeake region to reduce levels of those nutrients and sediments by the year 2025.

What's the problem that needs fixing?

Too much nitrogen and phosphorus entering the estuary have increased the frequency of algae blooms in its waters. These blooms block sunlight from reaching and sustaining underwater grasses, which are important for maintaining a healthy ecology. When the algae decompose, they create "dead zones" in large parts of the Bay, areas where dissolved oxygen levels are too low to sustain fish and shellfish. Excess sediment also blocks sunlight, further degrading water quality. The result is a loss of habitat for aquatic species.

Why is this effort under way now?

States surrounding the Chesapeake began working together in 1983 to improve water quality, and yet scientists say that loads of nutrients and sediments are still too high today. The current levels exceed what researchers have estimated are the maximum for a healthy, sustainable ecosystem. Many parts of the estuary are still officially listed as degraded under federal standards for water quality. The states set goals for reducing nutrients but did not meet two major deadlines, in 2000 and 2010, for doing so. The latest cleanup plan is partly in response to lawsuits filed against the federal government — by environmental groups in Virginia and the District of Columbia — that accused the EPA of failing to enforce the Clean Water Act. Further momentum for change came in 2009 when President Obama issued an executive order directing federal agencies to speed up the Bay's restoration.

What does the cleanup plan require?

The TMDL plan calls for reducing approximately 25 percent of the nitrogen and phosphorus entering the Bay and 20 percent of the sediment. States were required to write documents called Watershed Implementation Plans, or WIPs, describing pollution control measures to be taken locally to accomplish those reductions. All measures are to be in place by the year 2025. States may need to take several steps to reduce the pollutants at the source, including upgrading sewage treatment plants, minimizing stormwater discharges, and reducing nutrients flowing from farms. Nutrient loads from stormwater and farm runoff are more difficult to measure accurately than those from the discharge of pipes at "point sources" like sewage plants. The actions cover the Bay's entire drainage area or "watershed," which includes 17 million people and 64,000 square miles in Maryland, Virginia, the District of Columbia, Delaware, Pennsylvania, New York, and West Virginia.

What if communities don't meet the reduction goals?

For the first time in the Bay's multi-year restoration effort, the EPA has said it will take enforcement actions that have teeth. For example, it could force a sewage treatment plant to install additional equipment to further reduce nutrient discharges in order to renew its operating permit. Or the federal government could withhold grants for water quality improvement projects. Every two years until 2025, the EPA will review each state's progress toward meeting its pollution-diet goals and take corrective action if needed. A major review is scheduled for 2017.

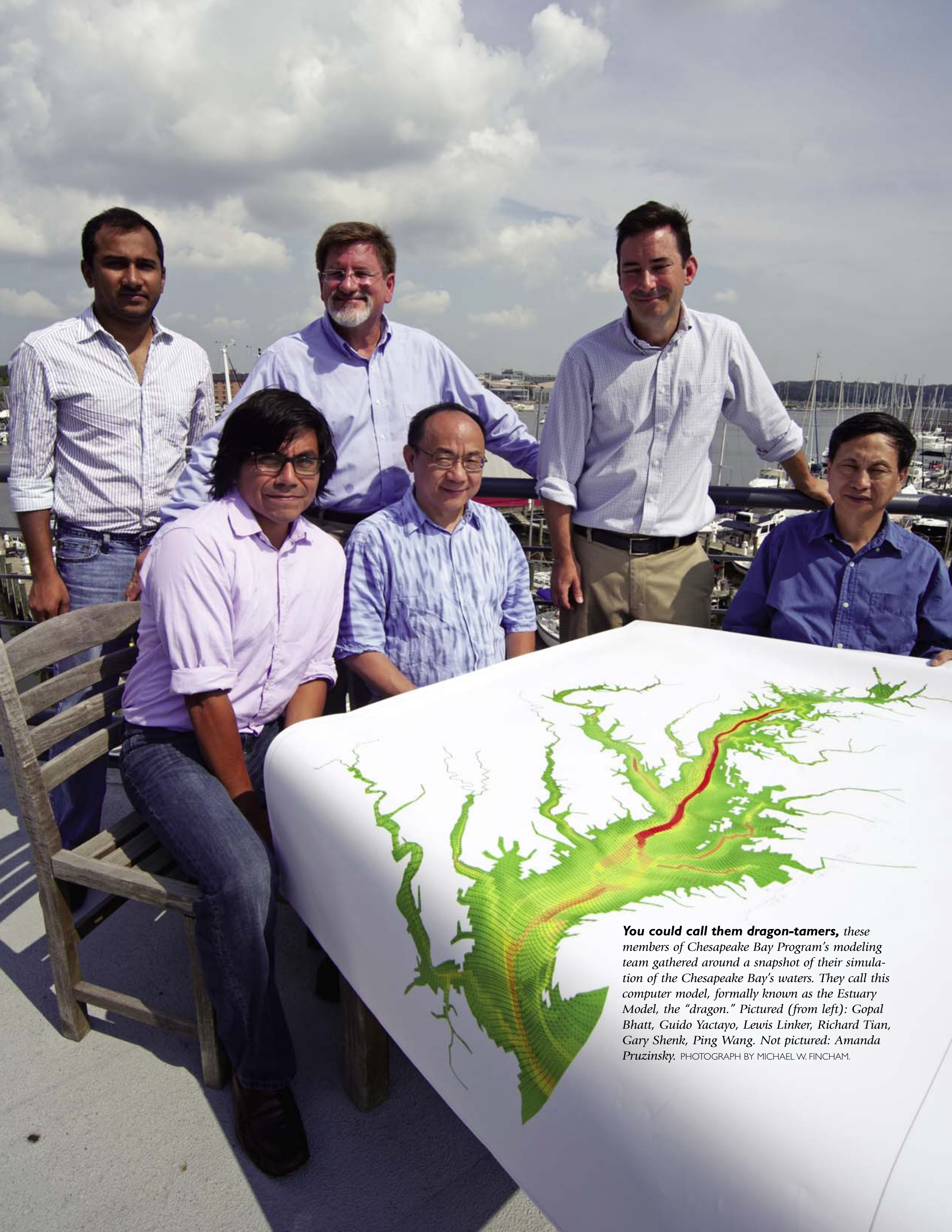
How much will the restoration cost? Who will pay? And will the cost be worth it?

Estimating the price tag and benefits of a Baywide cleanup has proven to be a complicated and uncertain accounting exercise. The state of Maryland alone has estimated nearly $15 billion in combined costs through 2025 for measures like upgrading municipal stormwater disposal systems (the single costliest measure) and building structures on farms to control manure runoff. State officials say that the grand total could fall as the cleanup strategy is refined and market-based incentives to lower costs are developed. Upgrades to sewage treatment plants will be passed on through utility bills; Maryland, for example, has already doubled its so-called "flush tax," a state surcharge that pays for upgrades, from $30 to $60 on average per household annually. Advocates of the cleanup plan say that, in return, it will yield economic gains from resuscitating the state's commercial fisheries, growing its aquaculture industry, and bolstering recreation and tourism businesses. And then there's the satisfaction and enjoyment that all area residents could take in helping to restore one of America's major natural resources.

How can I help the restoration?

Although many cleanup measures will be the responsibility of municipal utility officials and farmers, you can take additional steps that could help meet the cleanup targets. They include driving your car less, because auto emissions are another source of nitrogen entering the Bay's waters. Avoid using lawn fertilizer or apply it only once a year, in the fall. Install rain gardens and other home landscaping to keep rainwater on your property so it won't flow into streams and rivers. See page 15 for a list of resources for rain gardens.

— *Jeffrey Brainard*



You could call them dragon-tamers, *these members of Chesapeake Bay Program's modeling team gathered around a snapshot of their simulation of the Chesapeake Bay's waters. They call this computer model, formally known as the Estuary Model, the "dragon." Pictured (from left): Gopal Bhatt, Guido Yactayo, Lewis Linker, Richard Tian, Gary Shenk, Ping Wang. Not pictured: Amanda Pruzinsky.* PHOTOGRAPH BY MICHAEL W. FINCHAM.

A Model Plan
How Can We Gauge the Bay's Cleanup?

Daniel Strain

Billions of dollars and the fate of the Chesapeake Bay hinge on a few computer simulations. Who are the scientists behind these "models," and how are they being used to drive the biggest effort to clean up a body of water in U.S. history?

Picture this: a fortune-teller, dressed in jewels and a bandana, entertains a client. Between them sits a crystal ball. And in the corner, a multimillion-dollar supercomputer. "How do you want it?" the soothsayer asks. "The crystal mumbo-jumbo or statistical probability?"

That's the gist of an old cartoon by artist Sidney Harris. The joke may be tongue-in-cheek, but it gets to an ongoing debate in modern environmental science: when it comes to representing the ins-and-outs of natural ecosystems — say a river or an estuary — and predicting what they'll do, are computer models any better than a shot in the dark? Nature is, after all, almost dauntingly complex and, as any scientist will tell you, full of surprises. So the question arises, for making decisions about managing the environment, whom do you trust: the fortune-teller or the modelers?

That same question has driven much of Lewis Linker's career. This modest scientist works out of an office overlooking Spa Creek, a small waterway that meanders inland from Annapolis's harbor just off the Chesapeake. He's the modeling coordinator for the Chesapeake Bay Program, a partnership between state and federal agencies tasked with protecting the nation's largest estuary. With his colleagues in Annapolis, Linker builds computer simulations — or "models" in scientific parlance — to diagnose the Chesapeake's illnesses and investigate new cures. These models seek to represent the Bay's physics, chemistry, and biology using a series of mathematical calculations and some approximations. That's no small task.

The team's latest effort, the Phase 5.3 Watershed Model, represents an unprecedented attempt to simulate the inner workings of the entire Chesapeake Bay watershed — a 64,000-square-mile area that stretches from Virginia to the headwaters of the Susquehanna River in Cooperstown, New York. This model is at the heart of an equally ambitious effort to clean up the Chesapeake Bay, tributary by tributary. It will go like this: over the next 13 years, federal and state officials will employ a tool called the Chesapeake Bay Total Maximum Daily Load, or TMDL, to mandate major cuts to the excess nutrients and sediments streaming off the region's farms, cities, and skies. Linker's model is, in turn, setting those limits. They've been dubbed the Bay's "pollution diet."

This diet's vast reach and its uncertain costs (see Cleaning Up the Bay, p. 2) have, perhaps not surprisingly, brought intense scrutiny to Linker's work. Most scientists today acknowledge that all models are imperfect, but they're also invaluable tools that offer new ways to learn about and, yes, even predict the future of natural environments. And here in the Chesapeake watershed, researchers are working to develop and push for new ways to make Bay modeling better — and a bit less like the prophecies of Madame Fortuna.

The results from this modeling effort are especially important to those who've spent their lives fighting to clean up the Chesapeake. This federal and state push may be the Bay's last best chance for a healthier future, says Beth McGee, senior water quality scientist at the advocacy group the Chesapeake Bay Foundation. "I don't think we'll have another chance at this in our lifetimes," she says.

Cleaning the Bay

Miles away from Linker's quiet office, Kristen Heyer feeds a bundle of cables and hoses off the side of a small research boat, now idling just north of the Virginia border. The swells are tall this morning, picking up and dropping the *R/V Kerhin* like a bath toy. But Heyer, a biologist with the Maryland Department of Natural Resources (DNR), doesn't seem to mind. As far she she's concerned, the waves are calm today. "This is actually pretty good for here," she says.

She would know. Heyer's been to this exact spot at the mouth of the Potomac River about once a month — and sometimes more often — for the past 15 years.

She's one of a wide network of scientists across six states and the District of Columbia who collaborate with the Chesapeake Bay Program to monitor the Bay and its tributaries. Today, she and her crew are giving me a lesson in what's ailing the estuary.

Below deck, one of the DNR team suggests I take a whiff of a sample of Bay water. Now stored in an old milk jug, this particular sample had been sucked up from right above the Bay floor. I pick up the jug, unscrew the cap, and inhale deeply. The liquid smells like rotten eggs. More accurately, it smells like the hydrogen sulfide waste produced by bacteria that thrive in environments deprived of oxygen. It's the telltale odor of the Chesapeake Bay dead zone.

Balancing on the deck *of the* R/V Kerhin*, Kristen Heyer shows off a probe used to monitor water quality in the Chesapeake Bay. The Maryland Department of Natural Resources crewmembers lower this probe via a metal cable down into the choppy Bay, taking detailed readings of temperature, saltiness, and dissolved oxygen levels up and down the water column. Those data points are later fed into a computer model of the Bay.* PHOTOGRAPH BY DANIEL STRAIN.

That dead zone emerges every year as spring rains wash loose dirt and fertilizers off farms and towns across the Chesapeake watershed and into the region's major rivers — all of which eventually lead to the Bay. Those same pollutants, which are rich in basic nutrients like nitrogen and phosphorus, in turn, feed some of the estuary's tiniest residents, including algae and small crustaceans. But by the summer, this time of plenty takes its toll: as those organisms grow, then die and sink, bacteria feast on their remains and, in the process, sap the Chesapeake's oxygen supplies. That, in turn, creates wide regions of bottom-waters too low in oxygen to support much animal and plant life. In fact, between 1985 and 2011, nearly 17 percent of the waters in Maryland's portion of the Bay, on average, fit that description. They're part of the same dead zone I had smelled on board the *Kerhin*. Excess sediments mixed into the Bay play their part, too. They cloud the water, cutting off the sunlight that sustains aquatic plants, which produce the oxygen needed by fish and crabs.

Back in Annapolis, Linker may not be able to inhale that rotten egg smell, but he sure can model it. He and his colleagues — today, there are seven modelers at the Bay Program — draw on real-life data, including those gathered by the DNR crew, to build simulations of the Bay and its watershed over time. They've split the watershed into roughly 1,000 land segments. And so far, they've recreated past conditions on the Chesapeake from 1985 to 2005 and are making a push to extend the picture to 2011. Don't think of these models like a map — you can't find your home on them, and there are no computer avatars sailing the Choptank River. Instead, they're a string of equations meant to capture the environment's physical and biological processes, everything from how much riverbanks erode to how quickly microbes digest nitrogen molecules. "It takes a big problem and breaks it down into little tiny blocks," Linker says.

The scientist, whose short-cropped goatee has now turned gray, has seen a lot of models come and go. He joined the Bay Program in 1984, a year after the partnership began and just as scientists were beginning to understand the role that nutrients and sediments play in the Bay's ills. These days, he mostly coordinates, talking to researchers and his colleagues to make sure that the program's various models incorporate the best science out there. The now-veteran modeler — who has a warm smile and a tendency to belly laugh — also spends many of his weekends on Virginia's Rappahannock River. He owns what he calls "the humblest little cabin in the world," just a place to keep a few canoes and kayaks.

And that serene environment is, ultimately, what Linker says he's trying to protect. When his sons, now grown men, were little, he used to tell them that he cleaned the Bay. So they assumed that when he went to work, "I would put on some sort of orange outfit," he says. "And I would go out, and I would start cleaning the Bay."

For him, models help to do just that. At their core, he says, they're tools that allow people to ask questions — such as how much of this pollution is my fault, and what can I do to help? "It doesn't

Chesapeake Bay TMDL Goals for 2025

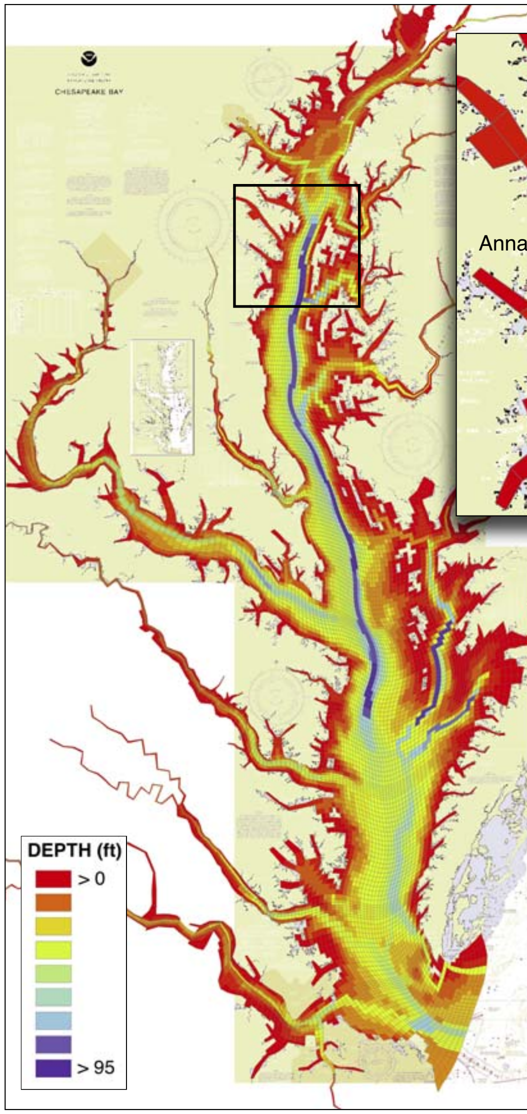
	2025 Goal (million lbs. per year)	2009 Baseline (million lbs. per year)	% Reduction
Nitrogen	186	248	25
Phosphorus	12.5	16	22
Sediment	6454	7980	19

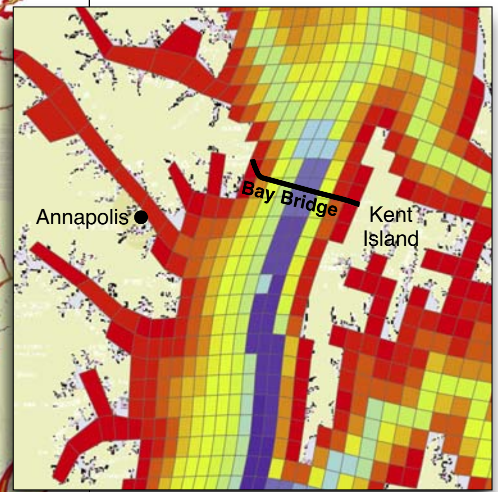
***In order to meet the water quality goals** set by the Chesapeake Bay TMDL, states in the watershed are required to cut the nitrogen, phosphorus, and sediment loads they deliver to the Bay. To develop baseline figures, Bay Program scientists used their Watershed Model to estimate the loads that were delivered to the estuary in 2009. The team also announced targets in 2010 — the TMDL "allocations" — that states in the watershed must address by 2025.* SOURCE: CHESAPEAKE BAY PROGRAM.

matter where you are in time, early on in the Bay Program or now," he says. "Those are the questions that people ask. So you need this synthesis tool."

By synthesis, Linker means that models can offer a big-picture view of the Bay and its health as an integrated whole. Scientists can then ask the model "what if" questions — questions such as: what if we change one particular aspect of the Bay in a certain way? Over time, the modelers' "what if" questions have gotten more and more complex. Here's an example of that complexity: researchers can pick one region of the watershed and, in a computer simulation, "install" more acres of streamside trees, also known as forest buffers. These trees should be able to take up some of the nutrients coming off the nearby landscape. And the model will simulate by how much, drawing from estimates that other scientists have taken of the nutrient appetites of such buffers.

Next, the modeling crew feeds that new estimate of the Bay's total pollution burden into a second model. It's dubbed the Estuary Model, but Linker calls it "the dragon" because it produces an image that looks like a snaking sea creature (see map at right). The dragon essentially mimics the Chesapeake Bay's churning waters, showing what will happen to every pound of pollution that mixes in — how much will sink to the bottom and how much will be devoured on sight by algae. And on and on. In other words, do those





The Estuary Model

Like any dragon, the Chesapeake Bay Program's Estuary Model has scales. These scales are "cells," simulated 3-D sections of the Bay. The visualization of the model pictured here shows only the 11,000 cells sitting on the estuary's surface — nearly 46,000 other cells represent the waters below. As currents flow across the Chesapeake, the model simulates the fate of the nutrients, sediments, and algae within these small conceptual chambers. MAP COURTESY OF THE CHESAPEAKE BAY PROGRAM.

The Evolution of the Watershed Model

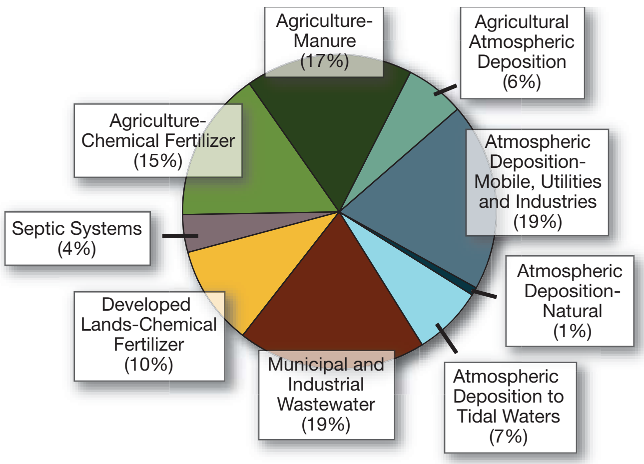
As our understanding of what makes the Chesapeake Bay work the way it does has evolved, so has the Chesapeake Bay Program's Watershed Model. Over time, its modelers have simulated more of the physics, chemistry, and biology that drive the estuary and have built in more detail, showing the Bay at smaller and smaller scales. Here is a summary of that evolution.

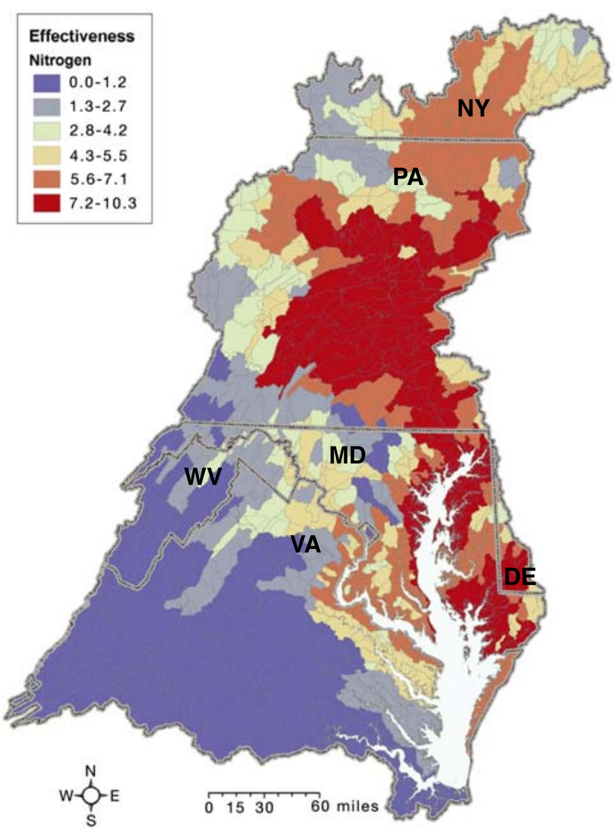
1982	1985	1992	2002	2010
Beginnings The Watershed Model was first launched using proprietary software.	**Phase 1** The first model to use public domain code estimated how much nutrients from nonpoint sources, i.e., farmland, contributed to the Bay relative to point sources, i.e., pipes at sewage plants.	**Phase 2** The first model to include a simulation showing how sources of nitrogen in the air could contribute to the Bay's nutrient burden.	**Phase 4.3** Estimated the nutrient and sediment loads over the watershed, split into 94 land segments.	**Phase 5.3** Divided the watershed into about 1,000 land segments, giving a more in-depth look at the sources of nutrients and sediments.

SOURCE: CHESAPEAKE BAY PROGRAM.

Where Does All That Nitrogen Come From?

Not all of the watershed's moving parts contribute equally to the Bay's poor water quality. Scientists at the Chesapeake Bay Program used earlier watershed and airshed model simulations (considering land use and pollution control measures in place as of 2007) to estimate where the excess nitrogen delivered to the Bay comes from (pie chart, below). While much of that nitrogen comes from the land, some of it, often in the form of nitrous oxide, comes from the atmosphere. Some regions also affect water quality in the Bay more than others, as shown on the map below. Because of how water moves in the watershed and the estuary, cuts to nitrogen loads made in some regions (shown in red) will reduce nitrogen in the Bay by more than will equal cuts made in other areas (blue). Bay Program scientists, who created the map in 2010 using their newest watershed model, quantified this tendency on a scale termed "relative effectiveness." SOURCE: PIE CHART, NATIONAL RESEARCH COUNCIL; MAP, CHESAPEAKE BAY PROGRAM.





***Scientist and Maryland native Lewis Linker** always makes time for the real Chesapeake Bay — he's an experienced kayaker and likes spending time close to the water. Recently, he wrote a research paper about his modeling work while sitting on the front porch of his cabin on the Rappahannock River in Virginia. "It just felt so productive," he says.* PHOTOGRAPH BY MICHAEL W. FINCHAM.

new acres of trees help the Bay? How much cleaner might the water be when they're planted?

In the end, the point is to help state governments develop strategies for cutting their nutrient and sediment wastes. "That's where the rubber meets the road in this model," says Gary Shenk, an environmental engineer by training who oversees watershed modeling in Linker's group. "The real output of this model is the change in [nutrient and sediment] loads due to management actions."

Today, that rubber is meeting the road in a big way. Based on rules laid out by the Clean Water Act, states in the watershed must ensure that their waterways meet certain requirements, working under the direction of the Environmental Protection Agency. Traces of chlorophyll — a molecule that helps many algae conduct photosynthesis — can only get so high, for instance. Dissolved oxygen supplies, on the other hand, can only dip so low. For decades, the mainstem of the Chesapeake and many of its tributaries have failed to live up to these standards, often miserably. Linker and Shenk calculated in 2010 that, to get these waters back to their legal limits, states must reduce their total deliveries of nitrogen to the estuary from 248 to 186 million pounds per year — a 25 percent cut. And they have until 2025 to put in place measures to achieve that goal.

Walter Boynton, an ecologist at the University of Maryland Center for Environmental Science (UMCES), says the goal isn't to restore the Bay to its state when John Smith landed in America four hundred years ago, when, accounts suggest, some of the Bay's shallower tributaries were so clear you could see right down to the bottom. Instead, the idea is to restore an environment in which underwater grasses can again flourish and blooms of algae will become less common. When asked if these are goals worth meeting, Boynton, one of the scientists who first illustrated the dangers of nutrient and sediment pollutants in the Bay, puts it simply: "It's very important," he says.

An effort so important, however, is bound to draw its challengers.

Different Model, Different Results

Many lawmakers and organizations, most notably the American Farm Bureau Federation, have challenged the cleanup plan on economic grounds. But one of the most potent challenges to the science behind the Phase 5.3 Watershed Model came in December 2010. That month, a Washington-based environmental consulting firm called LimnoTech published a report arguing that not all models agreed with the Bay Program's. Hired by an interest group called the Agricultural Nutrient Policy Council, LimnoTech used a simulation designed by the U.S. Department of Agriculture (USDA) to calculate completely different estimates of the Bay's pollution burden. The company reported that nitrogen wastes delivered to the Bay could be as much as 30 percent less than what Linker's team estimated.

And many took note. In March 2011, a U.S. House of Representatives subcommittee convened a hearing to discuss the cleanup plan, addressing the LimnoTech report and its findings in depth. Linker and Shenk were suddenly thrust into the spotlight.

Still, their science stood up to the attention. A group of independent scientists advising the Bay Program eventually refuted much of the LimnoTech report. For starters, they concluded that the report had exaggerated the differences between the models. Once corrected, the estimates of nitrogen pollution diverged by only about 15 percent. Panelists said that a discrepancy of that magnitude should be expected given that the models were built for different purposes and based on a different set of rules. The USDA effort, for instance, was designed to advise farmers on how to best conserve the nutrients in the soils on their individual plots, not dictate actions on a watershedwide scale.

Linker and Shenk take their critics in stride. Linker says the Bay Program's science has flourished because of just that — people pointing out what the team has done wrong. As the Watershed Model evolved over nearly 30 years, "We were able to rework and improve the model at every stage, not because we loved complexity but at the request of decision makers," Linker says. Still, he notes, "Criticism can be important, but you've got to get your facts right."

The problem ultimately comes down to models themselves. In short, models, especially those that capture complex and constantly changing natural environments, offer a portrait of reality that is incomplete — if only somewhat. "Models are never done," says Walter Boynton. Modelers simply "get them to a point where they draw a line in the sand and say, 'OK, that's good enough for now.' " No matter how many environmental processes you think you've captured, there are likely some that you've missed or couldn't measure accurately. As a result, models representing how the Bay works, and how it could be restored, carry with them some uncertainty that may be impossible to eliminate. The Bay Program hasn't measured the extent of this uncertainty in its own model.

Boynton says that the error is likely small, however. Linker and Shenk have tweaked and improved the model over decades, and their estimates seem to be in the ballpark. "It's good enough to go forward," he says. Kevin Sellner, who directs the Chesapeake Research Consortium, a group of research institutions, notes that

***Carefully avoiding stinging tentacles**, Maggie Sexton (left), a researcher working with scientist Raleigh Hood, and Jacqueline Tay, a graduate student, remove a jellyfish from a special net designed to catch floating sea life. The team, which works at the UMCES Horn Point Laboratory, comes to this spot on the Choptank River once a day to look for sea nettles, collecting data that may help improve how computer models predict where you can find jellyfish in the Bay.* PHOTOGRAPH BY DANIEL STRAIN.

Linker and Shenk's work has been reviewed by outside scientists. Their model has "gone as far as possible as far as complexity and its ability to represent reality," he says. It may be a murky crystal ball, but it's the best the Bay has.

Still, one crystal ball alone may not be enough.

A Multitude of Models

Raleigh Hood takes his small sport boat out onto the Chesapeake Bay almost every weekend. And when he does, he looks for sea nettles. Hood has the laid-back look of a man who's spent much of his life on the water and a mustache you'd expect to see on Wyatt Earp. But he's a modeler, working at the UMCES Horn Point Laboratory. In fact, he designed a computer model that forecasts how likely you are to see jellyfish at certain spots along the Bay, based mostly on how salty and warm the water is. So when he looks for jellyfish, he's not just trying to avoid getting stung. He's also seeing how right his model predictions were.

When Hood first arrived at Horn Point in the mid-1990s, however, the Bay Program was "the only game in town" when it came to modeling the Chesapeake Bay, he says. But he wasn't content to leave it at that. Hood built his own model to show how ocean currents influence the spread of floating sea creatures — one of the first independent models of the estuary. That work laid the foundation for his jellyfish forecaster. By the early 2000s, smaller simulations like this one had become commonplace. Or, as a jellyfish researcher would say, they bloomed. More scientists began using computers to ask questions about the Chesapeake ecosystem. Over a few years, modeling had turned democratic.

As far as Hood's concerned, that's a good thing. He believes the Bay Program won't solve its uncertainty problem solely by continuing to improve its Phase 5.3 Watershed Model. Instead, he says, scientists should take a new tack: embrace even more models, a whole slew of them, in fact. It's a strategy used by the Intergovernmental Panel on Climate Change, an organization convened by the United Nations. The group is well-known for publishing science-based predictions of how much the Earth will likely warm in the future. And it always gives those predictions in a range — one scenario forecasts 2 to 4.5 degrees Celsius by 2100 — based on a set of models that predict future temperatures in different ways based on different sets of calculations. Scientists then use the results from this multiplicity of models to suggest how much uncertainty lies in their forecasts of the global climate.

The Bay Program could do the same, Hood argues, considering alternative models that give different estimates of the severity of nutrient and sediment pollution in the Bay today. Many scientists agree. Kevin Sellner, who sits on a panel of independent scientists that advises the partnership, says the point isn't to pick the best model. But if multiple models agree fairly closely with each other, scientists like him and, perhaps, the broader community could feel much more comfortable with Linker and Shenk's estimates.

Sidney Harris

"How do you want it—the crystal mumbo-jumbo or statistical probability?"

Or, in other words, they could confirm that the Bay Program's model describes the Bay accurately — or accurately enough to justify pressing ahead with the partnership's expensive, multi-year cleanup plan.

Shenk is certainly open to the possibility of a multiple model future: "We are cautiously interested," he says. "We think it makes a lot of sense…but there are real limits in terms of what may be possible." In the end, the Bay Program would still have to pick one estimate of the Bay's nutrient and sediment burden to set its cleanup plan goals. So which one should Shenk choose? A high-ball estimate? Or a low-ball?

That gets back to the question of the fortune-teller and the computer model. Kenneth Reckhow, a well-known modeler from Duke University, has spent a lot of time pondering that choice. In fact, during a recent talk given to a group of water managers in Chicago, he led with Harris's old cartoon. He says that for all their faults and uncertainties, models are still the best tools to address problems like the Bay cleanup. The watershed is just too big to measure every bit of nitrogen, phosphorus, and sediment that winds into the Bay. Models are a necessary shortcut. In other words, "You'd go with the computer," he says.

As members of the Bay Program do just that, both the effort's critics and its supporters will be watching closely. In fact, the success or failure of this ambitious and risky plan may decide how the United States approaches its campaigns for cleaner water for decades. So everyone's curious. "I'm curious, too," Reckhow says.

For Linker, there's a lot riding on the TMDL. He says he's still only a scientist trying to clean the Bay. Ever the optimist, Linker says he's going to follow this effort to do just that to the last. "I want to see how the story is going to end," he says. "I really do." That's one outcome he can't model.

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A Garden of Opportunities for Cleansing Urban Storm Runoff

Daniel Strain

Amanda Tritinger has gotten an introduction to dirt this summer. Right now, the college student stands at the edge of a wide pit at the base of a parking lot in Columbia, Maryland. It's 80 feet long, 3 feet deep, and filled with loose soil and mud. In the pit, a few workers around Tritinger's age toil away in the heat, shoveling piles of dirt and breaking up the turf with pick-axes. Soon, they'll fill in this pit and turn it into a vibrant garden full of purple irises and other flowers. That final product will be what's called a rain garden — a tool for storing and filtering urban stormwater.

While this unusual construction team has built well over a dozen rain gardens so far this summer, few have been so big. Most could fit in a front lawn or next to a sidewalk. "This one's not a rain garden," says Tritinger, a crew leader on the project who attends the University of Central Florida in Orlando. "This one's a rain forest."

Last school year, Tritinger, who studies environmental engineering, took a class that dealt with hydrology, or how water flows over and under the land. Today, she's actually changing the hydrology of this suburban region with her own hands as part of a project funded by Howard County, Maryland, called Restoring the Environment and Developing Youth (READY). She's gotten good at it, too. At the start of the season, she hated swinging pickaxes. Now she loves it. "I don't know what changed. …I mean, I guess I do know what changed — the guns," she says, referring to her buff biceps, which she flexes to make her point.

Howard County is also flexing its muscles, showing that it's beginning to take its water and dirt seriously. And for good reason. As the multistate and federal effort to clean up the Chesapeake Bay

The beauty of a thriving rain garden *like the one above located in Centreville, Maryland, is a bonus. Its main purpose is to limit how much stormwater floods into local waterways during a big rain.* PHOTOGRAPH BY ERICA GOLDMAN.

Working through the heat, *Amanda Tritinger (above left) and Raymoan Clay, (below, seated) drop river rocks into a channel that makes up the border of their newest rain garden in this parking lot in Columbia, Maryland. Those rocks should act like the garden's first line of defense, filtering out some of the sediments caught in streams of stormwater. Watershed specialist Amanda Rockler (above right) helped to teach these two READY crew leaders about installing rain gardens. The scientist is proud of her Maryland roots. Earlier today, the two Amandas shared a high five after discovering that they both live in Montgomery County, at least for the summer. Rockler works with communities there and in Howard and Frederick counties.* PHOTOGRAPHS BY DANIEL STRAIN.

charges forward (See A Model Plan, p. 4), counties like this one will have to look for new ways to cut the excess nutrients streaming off their lands. Rain gardens trap the stormwater and, in the process, the nitrogen, phosphorus, and sediments that wash off parking lots, sidewalks, and other paved landscapes. And since rain gardens are usually small, individual homeowners can even dig their own, contributing a bit to the larger cleanup plan. But even as urban areas like Columbia get started building them, scientists are scrambling to find new ways of reducing nutrient and sediment pollution — and to make existing tools like rain gardens work better.

For towns and cities around the Bay, many of which face big bills for installing nutrient-control measures by 2025 as required by the Chesapeake Bay cleanup plan, these findings couldn't come soon enough. "It's going to be a Herculean effort to meet the 2025 goals, and I'm not sure we're going to be able to just because of the sheer number of management practices we have to put on the ground," says Bill Stack, the deputy director of programs for the Center for Watershed Protection in Ellicott City, Maryland. But "while it is a Herculean task, it's something that we have to address."

The Watershed Guy

Tom Schueler has been a big part of that effort for nearly 30 years. He uses the e-mail handle "watershed guy," which sums up his life's work. His career began in the 1980s when he was employed

***Rain gardens may look scraggly** when they're first installed, but within a season, the flowers, shrubs, and grasses planted inside may grow to fill every nook and cranny. Planted in suburban lawns and elsewhere, they could play an important role in improving water quality miles away in the Chesapeake Bay.* PHOTOGRAPH BY AMANDA ROCKLER.

by the Metropolitan Washington Council of Governments to help clean up the then heavily polluted Anacostia River. Today, he directs the Chesapeake Stormwater Network, a professional organization for those who specialize in managing urban stormwater.

Decades ago, experts focused much of their attention on the excess nutrients coming from the region's farms, usually through fertilizers or manure. Agricultural areas, after all, cover a lot more space than the watershed's cities and towns. But, as urban zones expanded across the region, scientists realized that the stormwater from developed lands also contributed a large share to the problem. Engineers like Schueler have begun to think more about how to design greener cities, a trend called the low-impact development movement. But the effort is hampered by its costs. Estimates suggest that, today, developed areas like Howard County may have to pay tens of thousands of dollars or more to trap the nutrients from each acre of land that sheds stormwater. And that could saddle the Bay cleanup plan with a price tag in the hundreds of millions of dollars — per county.

Schueler has dug five rain gardens on his own property in Catonsville, Maryland, so he's a believer in these measures. But Schueler's also mindful of the costs. He's part of a team that works with the Chesapeake Bay Program, which oversees the Bay cleanup effort, to help evaluate various tools, or "best management practices," for reducing excess nutrients. "It's a grave responsibility to sit there and try to assess which techniques or practices are the most effective because we're talking, ultimately, about billions of dollars of social investment over the next 15 years," he says.

Getting READY

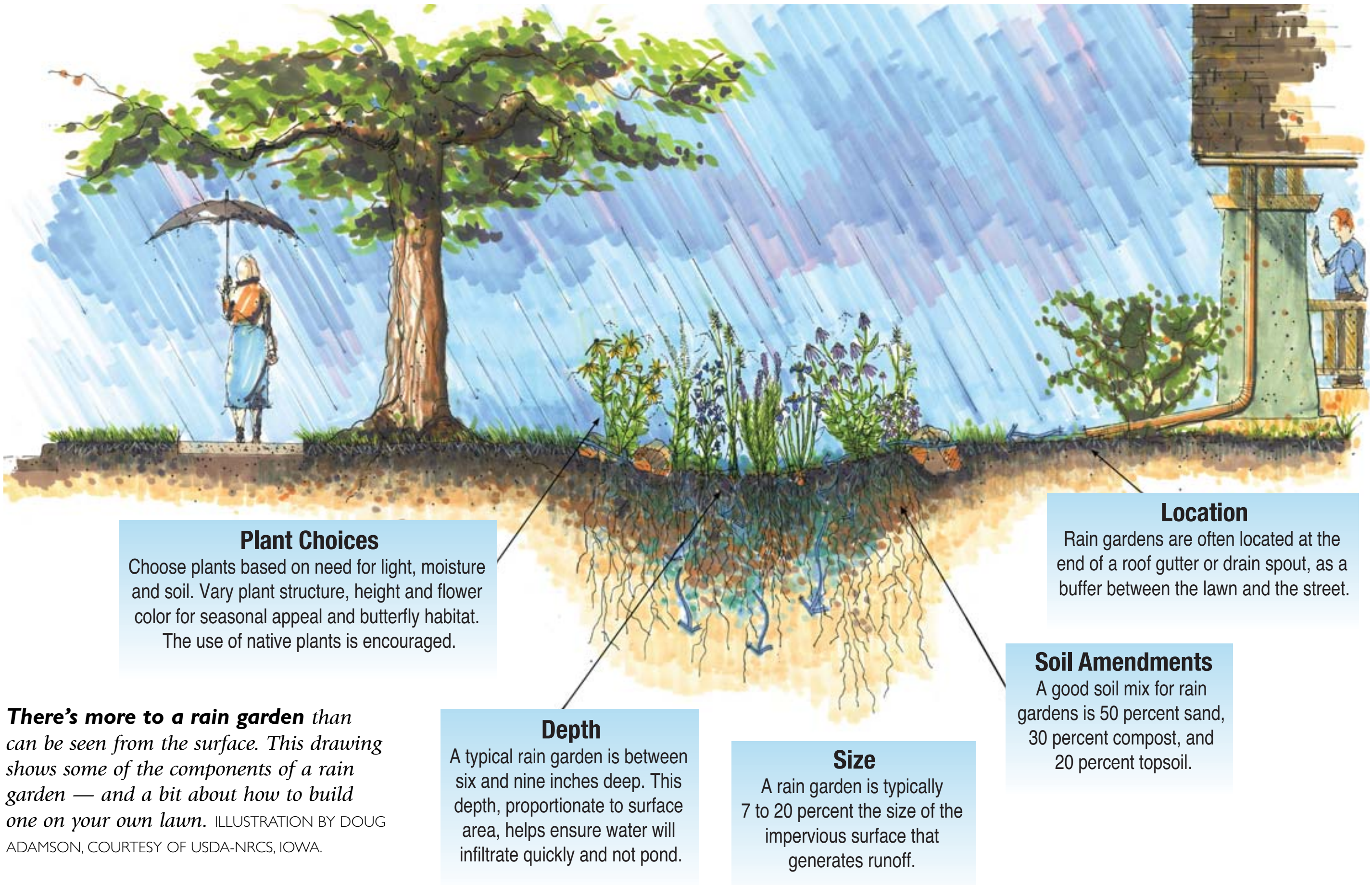
Back at the READY pit in Columbia, Amanda Rockler inspects some of that investment first-hand. If Schueler's the watershed guy, then she's a soil junkie. In fact, the young scientist sometimes corrects her colleagues when they call it dirt. "It's just so much more respectful to call it soil," she jokes.

As a watershed specialist for Maryland Sea Grant Extension, Rockler educates the public about the importance of rain gardens and other ways to control stormwater locally in order to improve water quality on the Baywide level. She also helped to train the READY team. Now she's observing roughly 15 students as they work, some piling river rocks at the edge of the parking lot, located in Columbia's Oakland Mills Village Center. Rockler is impressed by what she sees. Without a rain garden, the terrain here "would be slick," she says, shouting over the sound of falling rocks. Stormwater "would just run off into the street — into the storm drain system where the water is never treated." And from there, into the Bay. With a rain garden here, however, things should be different.

Rockler explains how this type of landscaping works. The gardens tend to be shallow depressions, like the pit behind us, although usually a lot smaller. They're filled in with a mixture of soil, compost, and sand. Such a concoction should act like a sponge, sopping up stormwater as it slides off parking lots or even common turf lawns, which, despite appearances, can't soak in much water. Once trapped in a rain garden, that stormwater will either evaporate, trickle out into the surrounding ground, or get sucked up by plants. That, in turn, limits how much water will flood into the Bay with each storm. "Hold water, slow it down, and soak it in. That's the motto we use," Rockler says.

But rain gardens also do something else — they treat the water. It often works like this: as rainwater rushes down sidewalks, it picks up particles of silt and sand. This sediment, in turn, carries a host of potential pollutants, including phosphorus molecules. But when those same sediments trickle into a rain garden, they're trapped by the rocks, soil, and mulch inside. And so are the pollutants they carry. Other, free-floating pollutants are also removed through a variety of different means. In a study conducted on the campus of the University of Maryland, College Park, scientists showed that two working rain gardens removed, on average, about three-quarters of the phosphorus they took in.

To remove nitrogen, however, you may need a bit of greenery. Rain gardens tend to be dotted with an array of native



***There's more to a rain garden** than can be seen from the surface. This drawing shows some of the components of a rain garden — and a bit about how to build one on your own lawn.* ILLUSTRATION BY DOUG ADAMSON, COURTESY OF USDA-NRCS, IOWA.

flowers and grasses, Rockler explains. In Maryland, it's plants like black-eyed Susan, blue flag iris, or tickseed. They're not just for show. Many of these plants also have long roots, capable of sucking in lots of water — and also nitrogen, which the plants then use to grow their stems and flowers. While estimates vary, studies suggest that rain gardens can remove more than half of the nitrogen they take in, some of it going to vegetation and some going to nitrogen-digesting microbes. No fancy pollution equipment is required, beyond what nature provides in the soil and the plants' green stems.

Or so say scientists working alongside the Bay Program. The partnership now recognizes rain gardens as effective tools to restore the watershed, estimating that these features can remove, on average, about 25 to 80 percent of the nitrogen they collect during big rains — depending on what kind of soil they've been dug into, among other factors. That means that counties like Howard can get credit from the Chesapeake Bay Program for installing these features. And that should help the county draw closer to meeting its targets for reducing nutrients and helping to restore the Bay. Other acceptable practices for urban and suburban areas include planting trees, restoring wetlands, and placing permeable pavement, porous surfaces that allow water to flow through and soak into the ground below.

Each of these practices has its pluses and minuses. Rain gardens, for instance, are expensive. It costs an average of $50,000 to $187,000 to build enough rain gardens to drain and treat stormwater from one acre of pavement, according to estimates released in 2011 by the Maryland Department of the Environment. And that's just the price of installation and planting — new mulch needs to be added every few years, and vegetation needs to be pruned back, too. There are cheaper options. It costs a Marylandwide average of $33,000 per acre treated to plant trees next to urban streams, but estimates suggest that these features may not remove as much nitrogen, on average, as certain rain gardens do.

Building a Better Toolbox

Towns could save money, however, if rain gardens did their job better, says Allen Davis. He's an environmental engineer from the University of Maryland, College Park, who specializes in managing urban stormwater. He experiments with different rain garden designs outdoors and in his lab. He takes long tubes, about 6 inches wide and 3 feet tall, piles them full with soil and wood chips, and studies what happens next.

When it comes to removing the nitrogen from stormwater, he says, plants are only a short-term solution. "Plants will take up nitrogen," he says. "But if you don't remove the plants, then the nitrogen doesn't really go anywhere." In fact, as plants decompose, the same nitrogen could reenter the Chesapeake Bay's waters. The better solution may be bacteria. But not just any bacteria — specifically, those that thrive in oxygenless, or anoxic, environments. These microbes can convert nitrate, a common type of nitrogen molecule, into nitrogen gas, the harmless gas that makes up most of our atmosphere. These organisms live in rain gardens already, Davis says. It's just a matter of growing more. "If you want to denitrify, you need anoxic conditions and time," he says.

To get both, you may need a sump. That can be a small hole that extends down like a nipple from the main rain garden. When a rain garden gets wet, water should trickle down into the sump and then pool there, creating a rich bacterial soup — something like a mini-cesspool. That soup should, in turn, digest large quantities of nitrogen. Davis plans to compare different designs for sumps to find out which produce the maximum ecological benefits. No matter what the research finds, he says, counties will likely have to rely on more than just rain gardens to meet their cleanup plan goals. That may include installing more swales, which are ditches, often next to roads, that collect and store stormwater. Rain gardens are "a tool in a toolbox," he says.

The engineer isn't alone, either, in investigating how to improve existing methods of removing nutrients from urban areas. Sujay Kaushal, a biogeochemist also at the University of Maryland, College Park, explores how restoring buried streams could help reduce the nutrients oozing from developed areas. "If you actually looked at a map of streams for New York City or Washington, D.C.," he says, "basically you see there are larger rivers that flow through those urban areas, but…there are no small streams." They've all been buried under dirt and cement over decades of development. He says that by digging these small waterways back up, it's possible to restore at least some of their ability to gobble up nitrogen.

Kaushal has been studying restored streams, such as Minebank Run just north of Baltimore, to learn how best to do that. Not every restoration is created equal, he notes. Streams with wide floodplains, for instance, give the water a chance to spread out and soak into the surrounding soil, where it's more easily treated by microbes and plant roots. Kaushal is currently working with the Chesapeake Bay Program to encourage them to consider stream restoration as an acceptable practice for reducing nutrient pollution.

The heavy costs of the Bay cleanup plan may wind up promoting the development of other new, affordable solutions for reducing nutrients on land before they reach the estuary. A new industry could expand to meet the need. "We have to let the market drive the innovation," says Bill Stack of the Center for Watershed Protection. "I think we're going to see costs come down because of it."

Researchers and companies are already starting to build a better toolbox, albeit slowly. Several new methods for reducing nutrients in urban areas are currently under review by the Bay Program or might be soon. These new projects include floating wetlands, rafts of plants that bob around in ponds, sucking up nutrients in the water through their roots.

Some of the most effective ways to clean the Bay also appear to be among the cheapest. Rain gardens, restored streams, and permeable pavements help — but so can simply changing your behavior, says Andrew Lazur of the University of Maryland Extension. You can avoid fertilizing your lawn because the nutrient-laden residue often winds up in the Bay. In fact, lawn fertilizers make up 10 to 25 percent of the nutrient contents in urban and suburban stormwater runoff, according to a 2011 report by the National Research Council. And you can pick up after your dog during walks, too, because that waste could also make its way into the Chesapeake's waters. "You take 18 million people on the watershed, and they take up one of these practices," Lazur says, "the impact is huge."

Call it a new way to flex those guns.

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For More Information

Modeling and the TMDL

EPA web page on the TMDL
www.epa.gov/chesapeakebaytmdl

Chesapeake Bay Program's modeling work
www.chesapeakebay.net/about/programs/modeling

Chesapeake Community Modeling Program, which supports modeling efforts across the Bay region
ches.communitymodeling.org/

Up-to-date sea nettle forecasts from up and down the Chesapeake Bay
buoybay.noaa.gov/news-listings/109

USGS web page on how excess nutrients can affect ecosystems
ga.water.usgs.gov/edu/nitrogen.html

Cleaning Up the Watershed

Maryland Sea Grant Extension's watershed restoration specialists
www.mdsg.umd.edu/programs/extension/communities/watershed/specialists

Maryland Sea Grant Extension videos on our YouTube channel – Step-by-step instructions for installing your own rain garden
bit.ly/QnhAGg

Rain garden design templates
www.lowimpactdevelopment.org/raingarden_design/whatisaraingarden.htm

Guide for installing a rain garden (from Worcester County, Maryland)
www.co.worcester.md.us/drp/natres/Rain_Gardens_Across_MD.pdf

Center for Watershed Protection – Rain garden installation and other things you can do to protect the watershed
www.cwp.org/your-watershed-101/what-you-can-do

Maryland Department of Natural Resources, Watershed Assistance Collaborative – Resources, services and technical assistance grants for nonpoint source pollution implementation and restoration efforts
dnr.maryland.gov/ccp/healthy_waters/wac.asp

Bay-friendly tips from the Chesapeake Stormwater Network
chesapeakestormwater.net/category/bay-friendly-tips

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MDSG Welcomes New Science Writer

Maryland Sea Grant has a new science writer, Daniel Strain. He will travel the Chesapeake Bay region reporting on the area's coastal research and its people and economy. His writing will include outreach and education projects supported by Maryland Sea Grant Extension. He succeeds Erica Goldman, who left for another position in 2010.

Strain brings to the job a passion for the natural world and a background in environmental science. "I'm really looking forward to starting here at Sea Grant and to just getting out and seeing more of the Bay," he says.

A 2010 graduate of the science communication graduate program at the University of California, Santa Cruz, Strain produced engaging news coverage as an intern for several high-profile employers. Most recently, he worked on the news staffs of the journal *Science* and *Science News* magazine, both based in Washington, D.C. At *Science*, he wrote a long feature story detailing efforts to remove invasive aquatic species from the millions of tons of ballast water dumped by cargo ships into the Chesapeake and other estuaries each year. Previously, he was with the National Park Service in California, where he produced a narrated slideshow about marshes and assembled other multimedia presentations. Look for similar, forthcoming projects by him about the Chesapeake region.

Strain, who grew up in Chicago, is an avid camper who remembers fondly his yearly trips to the Rockies with his parents. That love of the outdoors helps to explain his decision to study ecology and evolutionary biology during his undergraduate years, also spent at UC Santa Cruz. As a young student, Strain worked on a number of field studies. He spied on the behavior of woodpeckers in California forests and monitored invasive tree species in mucky woodlands in Illinois.

He says he's not only interested in reporting on the critters that swim along the Chesapeake's tributaries but also on the people who live and depend on the Bay. "Humans have lived on the Chesapeake for so long," he says. "I'm really hoping to explore how much the two are intertwined."

Picture Tells Story of Future Flooding

Seeing, and listening, really does equal believing when it comes to sea level rise and the risk that it will worsen flooding around the Chesapeake Bay.

A research team led by George Mason University recently tested new ways of communicating about these risks. The researchers invited 40 residents of Anne Arundel County, Maryland, to a daylong forum. The citizens were asked to view an interactive online map, which showed neighborhood-level details about the risks and possible property damage from increased coastal flooding predicted in the coming decades. Participants also asked the Maryland scientists and policy makers questions about sea level rise.

In polls given before and after the forum, attendees were more likely to label sea level rise a growing threat to the county after the event. The research team posted its findings and map online at: www.futurecoast.info. An online news article by Maryland Sea Grant about the project is at: www.mdsg.umd.edu/news/future_coast.