Mid-term Exams for the Bay Cleanup

contents

Looking north along Maryland's Kent Island toward the Bay Bridge, you can see a diversity of land uses. Excess nutrients and sediment washing off the Chesapeake Bay's watershed are causing harm to the estuary's ecosystem. Scientists are using computer simulations to quantify these causes and effects to help leaders find the right solutions.
PHOTOGRAPH BY DAVID HARP

Using Models and Science for Better Bay Decisions

Stories by Daniel Pendick

Since the 1980s, a federal–state partnership has labored to restore the nation's largest estuary. Known as the Chesapeake Bay Program, it is managed by the Environmental Protection Agency (EPA) and has more than 100 partners, including the six states and the District of Columbia whose waters drain into the Bay. All share an urgent goal: to improve the water quality of the Chesapeake Bay and restore the estuary's health to a sustainable level.

Now the Chesapeake Bay Program has reached an important milestone. The program is conducting a "midpoint assessment," a review of the Chesapeake Bay Model, the key tool the program uses to set cleanup goals for the rivers and mainstem of the Bay and to measure progress in achieving them. This midpoint assessment lies halfway between two other important dates — one past (2010), one to come (2025).

In 2010, in a new push to restore the Bay, the Chesapeake Bay Program adopted unprecedented mandatory limits on how much excess sediment and nutrient runoff could enter the estuary without exceeding water quality standards. The limits are called the total maximum daily load (TMDL) or "pollution diet." The TMDL is designed to remedy problems like the low-oxygen "dead zones" that plague the Chesapeake. The Bay's TMDL is the largest geographically and most complex in EPA history.

The EPA requires the six states and the District of Columbia to have in place all measures needed to achieve their pollution diets by 2025. Collectively, they must cut a quarter of the nitrogen and phosphorus entering the Chesapeake Bay and a fifth of the sediment coming in, compared with 2010 levels.

The midpoint assessment offers leaders the chance to make course corrections to achieve the 2025 goals. They may need to revise the region's watershed implementation plans — detailed strategies for reducing sediment and nutrient pollution, such as changing farming techniques and reducing the amount of polluted stormwater runoff.

And why does anyone believe these actions stand a chance of restoring the Bay? Because the Chesapeake Bay model says they will.

The Bay model is actually a set of computer simulations that together mimic the natural processes that sustain the estuary's ecosystem. The model was used to set the pollution diet; now scientists are working to incorporate the best science and data to improve the model as part of the midpoint assessment ("A Bay in a Box," page 4).

As scientists work to review the Bay model, they are also looking beyond the 2025 horizon. Where is the model headed next? According to Carl Cerco, the long-time lead modeler for EPA's Chesapeake Bay Program, the concepts underlying the model were developed during the mid-1980s. New research could now bring fundamental changes in the model's very foundations. It's about time, says Cerco. "Let's move on." ◢

Note from the editors: The future of the Bay model and the entire Bay restoration effort recently came into question when the White House proposed to Congress the elimination of all funding for the Chesapeake Bay Program and for the National Sea Grant College Program, including Maryland Sea Grant, the research, education, and outreach program which publishes *Chesapeake Quarterly.* It is up to Congress, though, to set spending levels in appropriations bills.

THE FIRST BAY MODEL
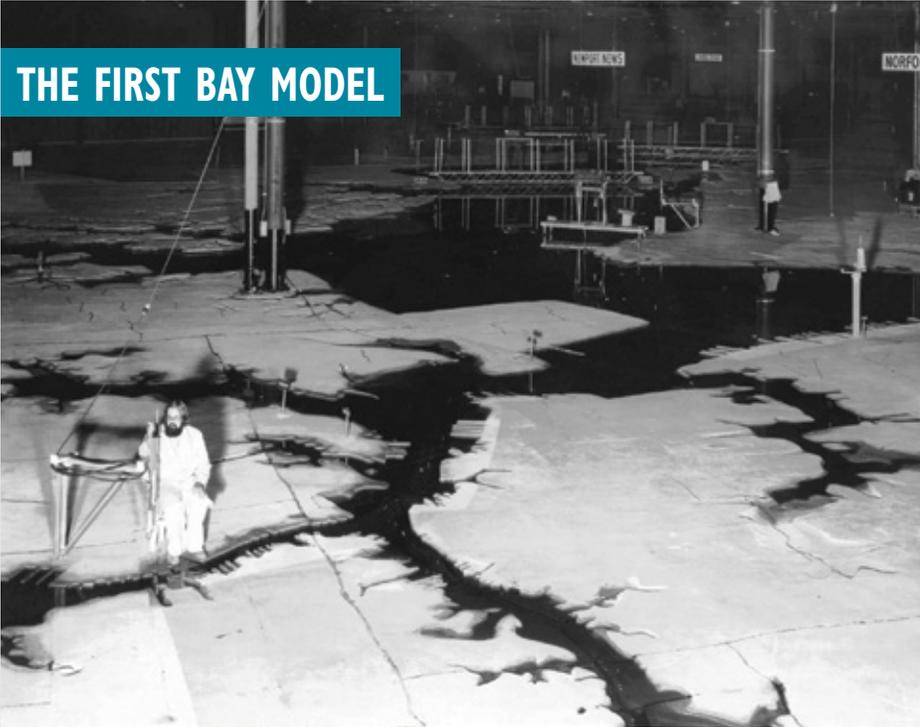
THE RISE AND FALL OF THE MATAPEAKE MONSTER

A computer model is a master mimic: it takes what nature does in all its complexity and tries to reproduce a believable version of it using mathematical equations. By the early 1980s, estuarine scientists and programmers were already developing the first computer models of the Chesapeake Bay. These models have become invaluable tools to inform key decisions in the ongoing federal-state partnership to clean up the largest estuary in the nation.

But as Chesapeake scientists and policy makers were saying hello to the new computer tools, they were waving a fond farewell to a very different kind of model: a physical mini-replica of the estuary called the Chesapeake Bay Hydraulic Model.

This Lilliputian estuary was not built with transistors and wires; instead it was a three-dimensional scale model made of concrete. The model covered nine acres within a 14-acre, metal-sheathed building in Matapeake, Maryland, just south of the Bay Bridge on the Eastern Shore. This scientifically designed tool, the largest indoor model of its kind ever built, was bigger than a city block — 1,050 feet long and 650 feet wide. Its depth ranged from mere inches in the shallows to about two feet in the deepest part of the Chesapeake's mainstem. When full, the model contained 450,000 gallons of water — enough to fill most of an Olympic swimming pool.

The press dubbed it the "Matapeake monster." To scientists, it was a test bed for asking "what if" questions about the Chesapeake Bay.

In 1965, Congress authorized the Chesapeake Bay Hydraulic Model in part to support a comprehensive study of the estuary. The research topics would include water use, navigation, flood control, water pollution, and beach erosion. Despite the efforts of project boosters, budget cuts, and redesigns delayed construction, which was not completed until 1976 at a cost of $15 million.

This model Bay was controlled by dozens of scientists and technicians working for the U.S. Army Corps of Engineers. By pumping artificially salted water into the model's mouth and flowing fresh water into its rivers, the operators could simulate the estuary's tidal cycle.

Research using the newly completed Matapeake monster kicked off in 1978 with a study to determine if deepening Baltimore Harbor would affect Bay salinity levels enough to harm the estuary's living resources. The research showed that dredging posed no threat, so the project went ahead.

But the Matapeake monster was heading for a showdown with the computer age. With every computing advance, the physical model became incrementally more obsolete. Legislators also balked at the high cost of running the model facility: $4,000 per day in 1980 dollars. Support ebbed for the facility, and it was finally shuttered in 1984.

For all its physical grandeur, the Chesapeake Bay Hydraulic Model may seem crude compared with the computer models that guide the ongoing cleanup of the Bay. Unlike these digital simulations, the physical model was limited in its ability to mimic the biology of the living Bay.

"Going back and comparing the current technology of computer models to the huge, cumbersome physical models helps us appreciate how powerful computer models are today," says Christine Keiner, a historian of science at the Rochester Institute of Technology who has written a comprehensive history of the Matapeake model project. Looking at this history, she says, shows "how fast the technology of computing has evolved over the past 40 years." ⌄

— *Daniel Pendick*
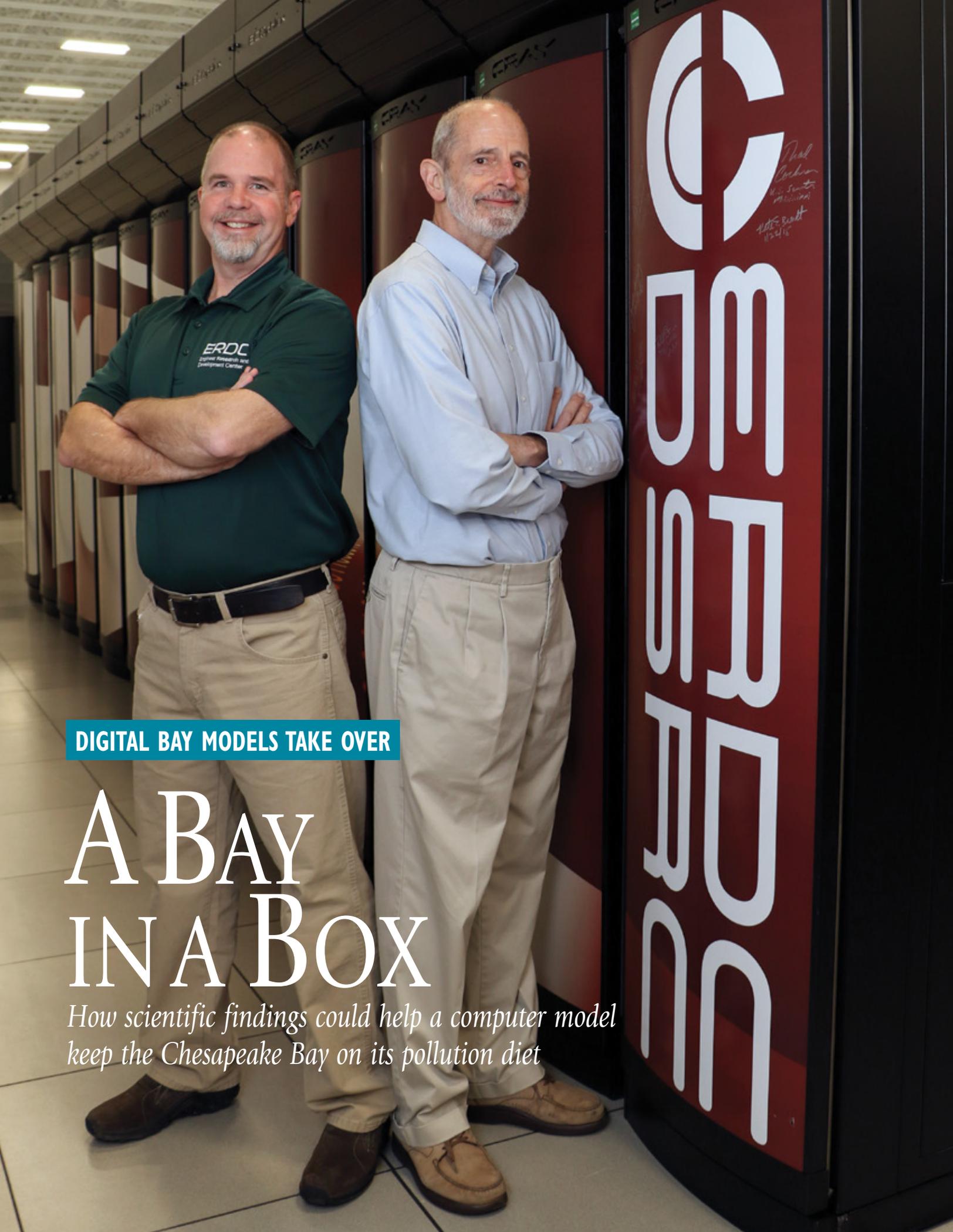
A Bay in a Box

How scientific findings could help a computer model keep the Chesapeake Bay on its pollution diet

Carl Cerco has a Chesapeake Bay in a box. It resides inside a supercomputer located in a windowless room not far from Cerco's office at a U.S. Army Corps of Engineers research facility in Vicksburg, Mississippi.

In the room, he can hear the low humming of power supplies and the whirring of cooling fans, but not the splash of waves lapping on the wetlands of the Eastern Shore, the slicing of sailboats through the swells, and the clacking of long-handled tongs plucking oysters off reefs.

Cerco is a hydrologist and engineer who has spent the past 30 years working to build the Bay in a box. It is a computer model consisting of thousands of lines of software code. It feeds on gigabytes of data about the water and land and air that make up the estuary's ecosystem, and it uses intertwined mathematical equations to mimic the inner workings of that ecosystem. Like all mimics, Cerco's digital estuary isn't the real thing any more than a miniature ship in a bottle is a functioning sailing vessel. However, both kinds of models can give you a good idea of how something in the real world works — whether it's a sailboat or an ecosystem.

The Bay-in-a-box model is supposed to simulate the Chesapeake accurately enough to help guide a major, multiyear effort to restore the Bay ecosystem to a more pristine state.

The Bay-in-a-box model is supposed to simulate the Chesapeake accurately enough to help guide a major, multiyear effort to restore the estuary's ecosystem to a more pristine state. Job one for the model is to help the states in the Chesapeake's watershed make adequate progress in cutting down on the main pollutants that undermine the ecosystem's health.

"The fundamental question is how much do we have to reduce the load of nutrients and sediment going into the Bay in order to fix the water quality?" says Raleigh Hood, an estuarine researcher and modeler at the Horn Point Laboratory of the University of Maryland Center for Environmental Science (UMCES).

The model has already come up with some answers to the "how much" question. Out of those answers came a "pollution diet" for the Bay. Established in 2010 by the U.S. Environmental Protection Agency, the diet mandates limits on how much nutrient and sediment, measured in millions of pounds per year, the estuary can absorb and still remain relatively healthy. Nutrients feed algae blooms, and when the algae decompose and sink to the Bay's bottom, oxygen is drawn out of the water. The results are extended low-oxygen "dead zones" that harm the estuary's living resources, like fish and crabs. In addition, sediment clouds the Chesapeake's waters and keeps underwater grasses from thriving.

A computer simulation of the Bay runs on Garnet (opposite page), a supercomputer at the Department of Defense Supercomputing Resource Center in Vicksburg, Mississippi. Carl Cerco, an estuary modeler at the U.S. Army Corps of Engineers (right), works with computer scientist Mark Noel (left) to run simulations of the Bay's water quality. PHOTOGRAPH BY OSCAR REIHSMANN, U.S. ARMY CORPS OF ENGINEERS

What's in the Bay Model?
Three Models in One

Scientists use a computer model to estimate the amounts of excess nutrients and sediments entering the Chesapeake Bay. They also use it to predict the effects of changing those amounts on the estuary's water quality.

The Bay model consists of three different computer simulations that work in sync to depict the Chesapeake ecosystem:

1 **In the sky:** The airshed model tracks airborne nitrogen pollutants from cars, power plants, and other sources and estimates how much of these nutrients rain down onto the Chesapeake's watershed and the estuary.

2 **On the land:** The watershed model tracks the quantity of pollutants draining into the Chesapeake Bay from its watershed, which covers 64,000 square miles in six states and the District of Columbia.

3 **In the water:** The water quality model simulates the effects of nutrients and sediment on water clarity, algae growth, and oxygen levels in the Chesapeake's mainstem and tidal areas. The model, for example, predicts the extent of low-oxygen "dead zones" in the Bay.
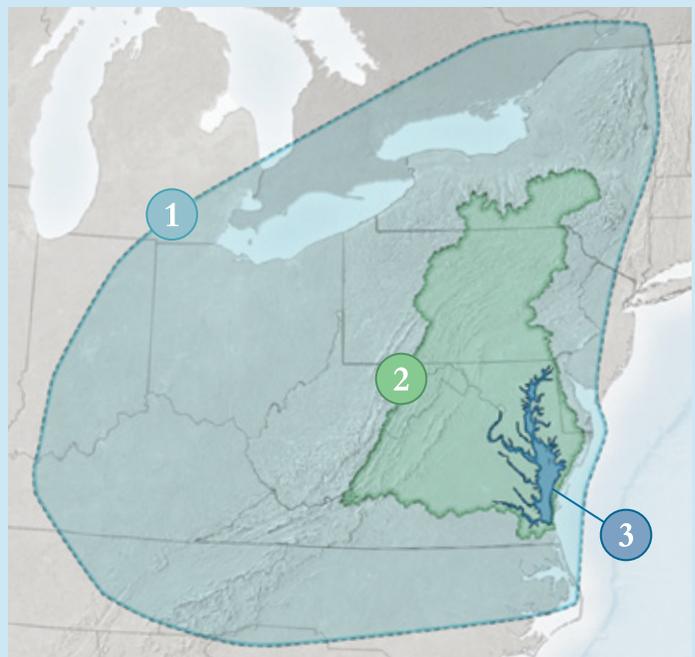
MAP COURTESY OF NASA GODDARD SPACE FLIGHT CENTER; AIRSHED BOUNDARIES ADAPTED FROM CHESAPEAKE BAY PROGRAM MAP
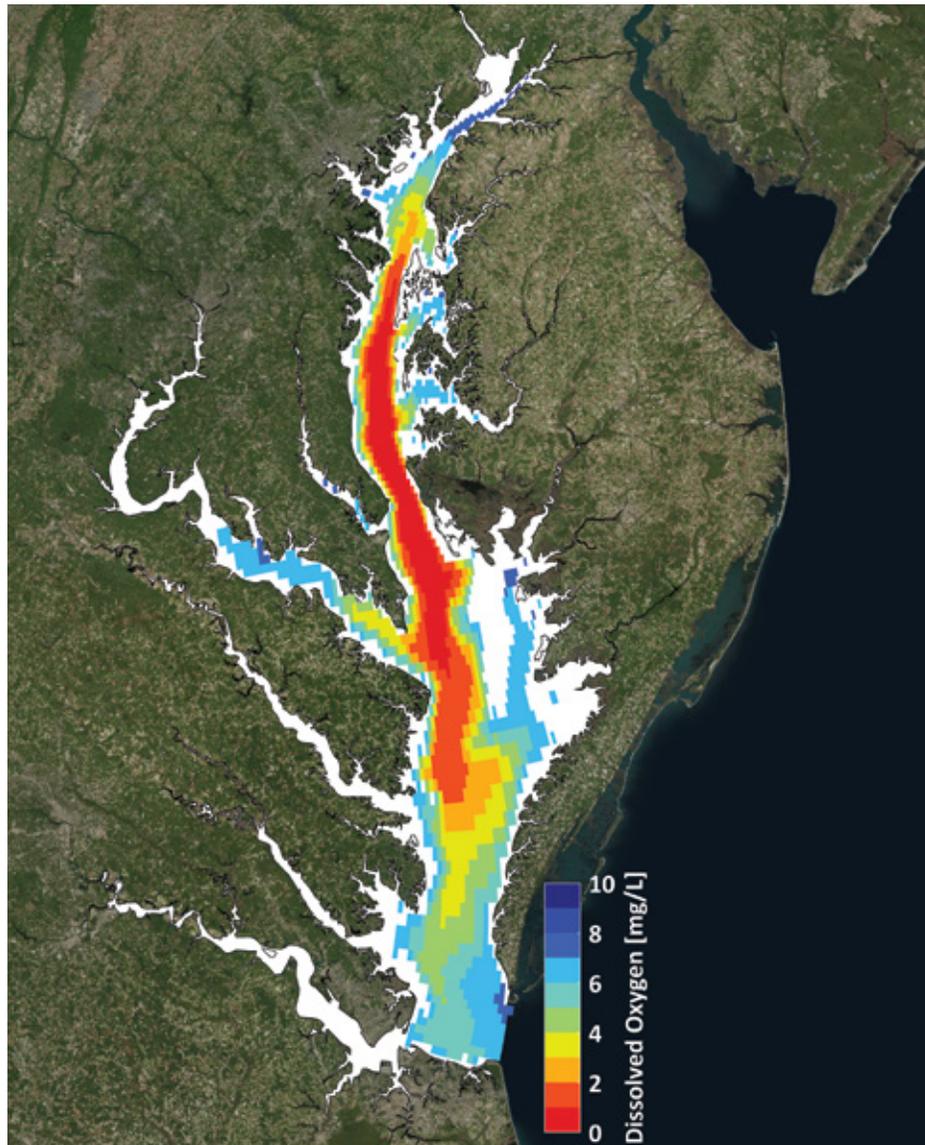
Oxygen levels are a key indicator of water quality. In this map generated from a computer simulation of summer 2015 conditions, red and dark orange indicate deep areas of the Chesapeake Bay's mainstem that are especially deprived of oxygen, creating "dead zones."
GRAPHIC BY AARON BEVER (ANCHOR QEA) AND MARJORIE FRIEDRICHS (VIRGINIA INSTITUTE OF MARINE SCIENCE)

Not everybody is happy with the model's answers or with the pollution diet. To comply with the pollution diet's deadline of 2025, cities have installed expensive upgrades to sewage treatment plants and farmers have increased efforts to reduce runoff of nutrients into the Bay. So a lot is riding on a review by the EPA and its partners in 2017 and 2018 of progress made at this mid-point in the pollution diet timetable. The review could determine whether states and their residents in the Chesapeake region will be required to do even more to restore the estuary.

To inform this review, Carl Cerco and other modelers working for the Chesapeake Bay Program, which is overseeing the pollution diet, are taking a mid-term exam of their own. They have been looking deep inside the Bay in a box to make sure its predictions are as accurate as possible. The modelers are working to incorporate new scientific findings and make upgrades to deal with several unexpected challenges created by natural and man-made changes in the Chesapeake watershed.

Their challenge is to build a better box — a box that can accurately mimic a changing estuary.

Conowingo Surprise

The modelers have built the Bay in a box based on a series of assumptions about how the estuary and its component parts work, assumptions informed by the best available data and analysis. When Cerco and his colleagues created the 2010 version of the Bay model, one of their key assumptions held that a mile-wide dam across the lower Susquehanna River was playing a key role in the estuary's water quality. It was a conclusion that, thanks in part to a tropical storm, modelers would later rethink.

The Conowingo Dam lies just north of where the river meets the head of the Chesapeake Bay. Opened in 1929, the dam stores water to run through the facility's turbines and create electricity. But the Conowingo has also provided a fortuitous benefit for the estuary's water quality. The dam has served as a bulwark; millions of tons of sediments and the nutrients bound to them have settled in the reservoir upstream of the dam instead of pouring into the Bay. For decades the nutrients and sediments had flowed from cities, subdivisions, and farms, traveled down the Susquehanna, and steadily accumulated as muck in the 9,000-acre reservoir behind the dam.

In 2010, when the Bay model was used to calculate the pollution diet, the best estimates available suggested that Conowingo might keep trapping nutrients and sediments for perhaps 15 to 30 more years.

But by 2011, new evidence suggested those estimates needed to be revised. Research by Robert Hirsch, a hydrologist for the U.S. Geological Survey, had raised concerns that the Conowingo's trapping capacity had declined.

"Then Tropical Storm Lee happened," Hirsch recalls.

In September 2011, Lee dumped as many as 12 inches of rain on parts of the Susquehanna basin, causing massive flooding on the river. A torrent of stormwater, turned earthy brown by suspended sediments, thundered through Conowingo's floodgates. The huge injection of stormwater during

For decades, the reservoir behind the Conowingo Dam (above) has trapped nutrients that otherwise would have fueled low-oxygen "dead zones" in the Bay. Studies after 2011's Tropical Storm Lee helped reveal that Conowingo's trapping powers are almost exhausted, requiring adjustments to the Bay model. Lee washed sediment into the Bay, turning its waters muddy brown (right). PHOTOGRAPH BY MICHAEL W. FINCHAM; SATELLITE IMAGE BY NASA

the tempest provided what Hirsch calls a "natural experiment" to confirm his earlier observation.

He looked at data from a monitoring station at Conowingo and found that phosphorus was escaping the dam's reservoir at a high rate. That by itself was not surprising. On average, about three-quarters of the phosphorus entering the Chesapeake Bay from the Susquehanna River hitchhikes on sediment particles. And during storms, large amounts of stored sediment are scoured off the riverbed and the Conowingo reservoir's bottom. Any nutrients stuck to those particles get carried into the Bay.

However, phosphorus was escaping the reservoir at a much higher rate than during other high-flow events a decade or more ago. "I was just flabbergasted about how high some of the numbers were," Hirsch says. "I thought, boy, something is going on here."

That prompted Hirsch to look more closely at what was going on, and over

a longer period of time than that covered by a single large storm. He had the benefit of a new software tool he and his colleagues at USGS had developed. The tool has a name only a statistician could love: WRTDS, meaning "weighted regressions on time, discharge, and season." The name tells you something about the problem the tool was meant to solve. It's a formidable scientific challenge to describe the long-term changes in the amounts of sediments and nutrients that rivers deliver to the Chesapeake, given the huge daily variations in river flow and the natural cycle of seasonal changes. In dry periods, the amount of sediments and nutrients falls;

during floods, it spikes. Flows change hour to hour, day to day, and year to year.

WRTDS removes the influence of river flow, revealing subtle long-term trends lost in the background like a whisper in a noisy restaurant. Thanks to advances in statistics and desktop computing power, WRTDS is a more sensitive tool for spotting such trends than previous techniques.

Using WRTDS, Hirsch found that over the past 30 years — from moderately high river flows to the highest floods recorded — the average annual amount of phosphorus delivered to the Bay by the Susquehanna was increasing

over time. The bottom line: Conowingo was running out of space to store sediments and the nutrients riding on them.

"It came out of the blue," says Lewis Linker, coordinator of modeling teams at the Chesapeake Bay Program. "We thought the dam would continue trapping for a long time, but we were wrong."

Because of the new evidence, Conowingo suddenly became a top-priority issue for Linker and managers of the Chesapeake Bay cleanup. Less trapping meant more sediments and more nutrients would reach the estuary. Additional phosphorus could feed dead zones, and extra sediments could hamper the growth of underwater grasses. As a result, the states might have to make additional cuts to reach their mandated pollution diets. To guide that decision, the modelers would need to use the new findings to adjust their Bay in a box.

Much work remained to be done to confirm Hirsch's findings and connect them to the Bay model. Fortunately, Hirsch was not the only detective on the Conowingo case. Qian Zhang, then a doctoral candidate in environmental engineering at the Johns Hopkins University, was working with his advisor, Professor Bill Ball, to study the flow of sediments and nutrients in the Susquehanna. With funding from Maryland Sea Grant, Zhang delved deeper into using WRTDS to expand on Hirsch's findings.

Hirsch had examined total nitrogen and phosphorus passing the Conowingo Dam. Zhang took that analysis a step further by estimating how much of the total was particle-bound hitchhikers and how much was nutrients dissolved in the water. The large majority of the dissolved nutrients flow by the dam without being trapped, so quantifying the amount of sediment-bound particles was important to Zhang — it could show whether the Conowingo was trapping less.

Sure enough, Zhang found that particle-bound nitrogen and phosphorus have both been rising in the flow exiting the Conowingo Dam, thus confirming what Hirsch's results suggested. Further studies by Zhang also pointed to the same conclusion: Conowingo is trapping less and less sediment as time goes on. The current estimate is that as little as six percent of the dam's total storage capacity is left.

Ashes and Oxygen

When the Conowingo stopped trapping nutrients, what would happen to water quality in the Bay? Would oxygen levels drop? To comply with the pollution diet, would the states surrounding the Bay have to tighten their belts further? "Now you will have to accommodate that loss of trapping by keeping [more of] that material on the landscape and not allowing it to move downstream," Hirsch says.

To inform those decisions, the modelers at the Chesapeake Bay Program got to work revising the Bay model. The watershed portion of the model was updated to include the extra nutrients flowing past the Conowingo. And Cerco, the program's lead estuary modeler, examined the effects in the estuary using the water quality model he helped create. He actually works with two models linked together: one that simulates the movement of water in the estuary and one that reproduces the chemical and biological processes in the water that determine algae growth, water clarity, and oxygen levels. In the linked model, a grid of rectangular boxes of water fill the Chesapeake

Jeff Cornwell, *a sediment chemistry researcher at the University of Maryland Center for Environmental Science, provided key data needed to calculate the impact of an increased influx of Susquehanna River nutrients on Bay water quality.*

Bay's volume from the bottom to the top. The model simulates the movement of water from box to box, shuttling nutrients and sediments between them like a firefighter's bucket brigade. Equations crunch the numbers, calculating the impacts of the sediments and nutrients on water quality in the boxes.

Cerco knew that a key determinant of water quality is how quickly the sediments release their hitchhiking nutrients into the estuary's water column, where they can foster algae blooms and potentially worsen low-oxygen conditions. Some of the Conowingo sediments are highly "reactive" and therefore tend to release nutrients more quickly and in greater amounts. Other sediments are chemically cold and just sit on the Bay's bottom and do nothing, like wood that has been burned to ashes in a campfire.

To understand the sediments' effects on Bay water quality, Cerco needed to know what percentages are hot (highly reactive), lukewarm (slightly reactive), and cold (inert). "Can the living parts of the Bay, like the algae, use it? Or has it been worn out and what's left is just ashes?" Cerco says. "If it's all highly reactive, you have a potential problem."

At Blackwater National Wildlife Refuge, forested lands are transitioning to marsh as sea levels gradually rise. Saltwater seeps into the soil, killing trees. Preliminary climate projections suggest that 50 years from now, rising water could begin to drown a significant area of the Chesapeake's tidal wetlands. PHOTOGRAPH BY NICOLE LEHMING

To provide Cerco with answers, Jeff Cornwell did some new research. Cornwell is an expert on sediment chemistry at the UMCES Horn Point Laboratory. Working with one of his master's-degree students, Zoe Vulgaropulos, he conducted experiments on samples of the ooze from the bottom of the Conowingo reservoir.

In 2015 and 2016, Cornwell and Vulgaropulos boated out on the reservoir five times, lowering sampling rigs to the bottom to punch out cores of sediment. In total, they collected about 70 cores and 20 water samples containing suspended particles.

Back at Horn Point Laboratory, the researchers placed sediment samples in sealed, glass vials that were incubated without oxygen for up to nine months. They periodically measured changes in the levels of nutrients and gases in the vials resulting from chemical reactions in the sediments.

Using these measurements, scientists could then work backward to calculate the reactivity of the sediments that had caused these changes. Jeremy Testa of UMCES' Chesapeake Biological Laboratory and Jim Fitzpatrick of the consulting firm HDR Inc. collaborated on calculations to quantify the relative portions of hot, lukewarm, and cold sediments in this mix. They determined that most of the sediments were only slightly reactive or not reactive at all — in other words, ashes.

With that information, Cerco calculated the effect of the Conowingo sediments on low-oxygen zones in the Chesapeake. The EPA's pollution diet is designed to make sure that dissolved oxygen in the deep waters of the estuary never falls below 1.0 milligram per liter of Bay water, particularly in the summer when hypoxia-creating conditions are at their peak. The water quality model found that Conowingo's escaped nutrients could fuel algae growth that would reduce oxygen levels in the deep waters by an average of 0.1 milligrams per liter over a summer season — a reduction of 10 percent.

It seems like a small reduction, but it has potential consequences for managers at the Chesapeake Bay Program. Reducing the volume of the estuary affected by hypoxia is one of the core goals of the pollution diet, so the managers pay close attention to anything that chips away at dissolved oxygen.

"A tenth of a milligram doesn't sound like a lot," says Johns Hopkins' Bill Ball, "but when it's at the borderline between being hypoxic and not being hypoxic, suddenly the volume [of the low-oxygen zone] goes up a lot." In some areas of the Bay at the knife-edge of hypoxia, even a small nutrient nudge could push the area out of compliance with EPA water quality standards. The Chesapeake Bay Program estimated that the extra nutrients flowing past the Conowingo could cause the deep channel regions of the Bay to miss the standard for dissolved oxygen one percent of the time during a summer season, on average.

What should states do about the Conowingo's decreased trapping of nutrients? It might require reducing nutrients by larger-than-expected amounts in other parts of the Chesapeake's watershed to compensate. But that decision is up to the managers of the Bay cleanup, not the modelers. The modelers work to describe the causes of degraded water quality and offer information to help figure out possible solutions. "The managers can look at the different options," says Linker, "and what it would take to address it."

A Warmer and Wetter Bay

In addition to the increasing flow of nutrients down the Susquehanna, the Chesapeake Bay Program's managers realized that the estuary was undergoing other changes that could require further refinements of the Bay in a box. A big one was the effects of climate change.

The Chesapeake Bay Program's managers asked the modelers to simulate those outcomes because climate change is expected to have wide-ranging and potentially harmful consequences for the estuary. Heavier rainfall and higher river flows could wash more nutrients and sediments into the Bay. Warming of the estuary's waters could make hypoxia

The Model's Next Generation

CURRENT MODEL

Three Depths (meters)

3 7 10

PROPOSED FUTURE MODEL
Unstructured Grid

Depth (meters)

0 4 8 12 16

Chester and Corsica Rivers

DC

MD

DE

MD

VA

VA
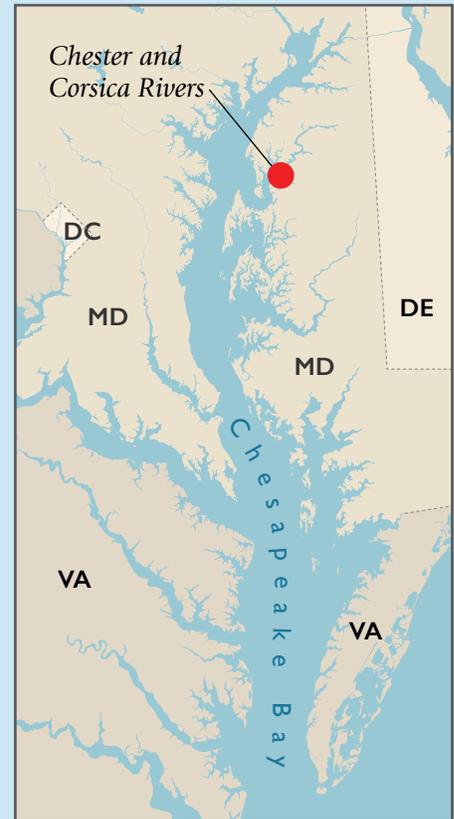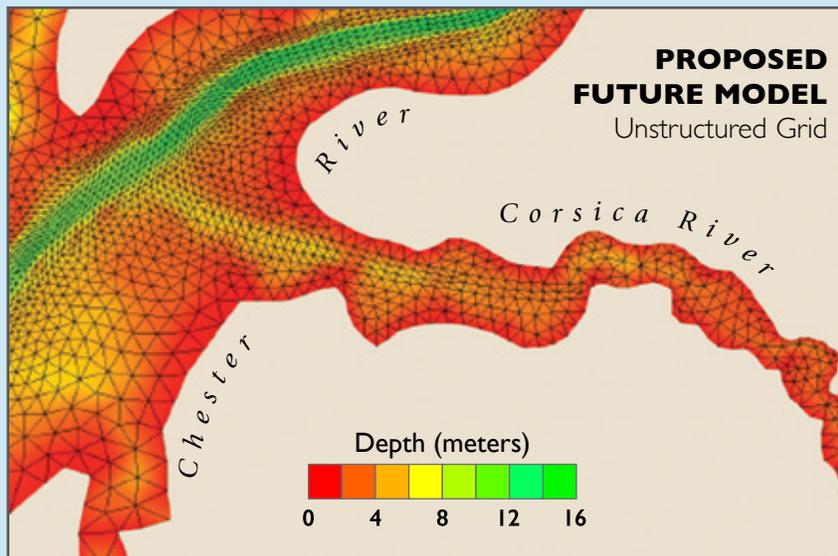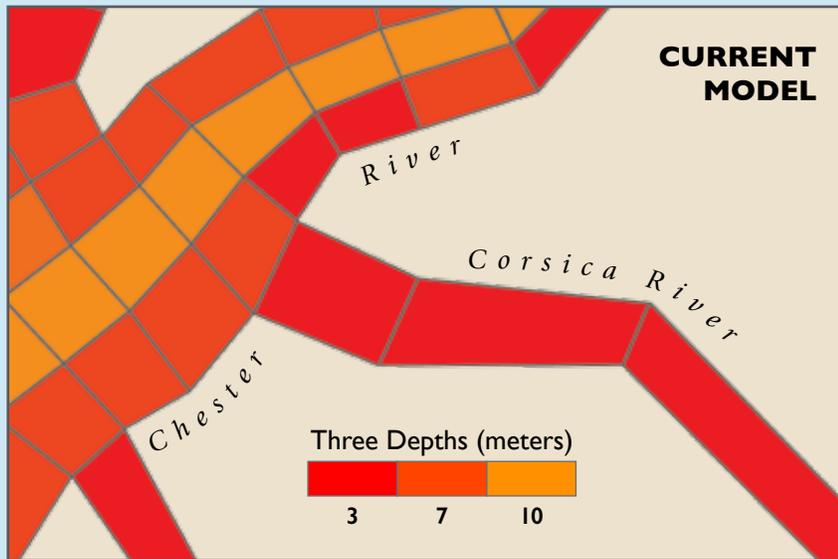
Chesapeake Bay

Today's simulations of the Chesapeake estuary divide the Bay's shoreline and shallow areas into relatively large boxes or "cells" (top, left). But this approach approximates roughly the complex physical features and processes of these zones. A new generation of models (left) may be coming that uses smaller, triangular cells to depict in finer detail the nooks and crannies in the shallow zones.

worse. And sea level rise could harm water quality by submerging and killing coastal wetlands, which capture nutrients and keep them from reaching the deep channels of the Bay.

The modelers looked at the effects of climate change over two time spans. One was the period up to the pollution-diet deadline of 2025. But the modelers were also asked to start projecting effects as far out as 2050 to give managers a sense of what lies ahead.

For the short-term, the modelers think they can give a reliable forecast by extrapolating from a reliable source

of long-term data: an 88-year record of rainfall in the Chesapeake Bay region. When they fed that data and some related assumptions into the model, it yielded a preliminary estimate that river flow would increase by 2025, and this flow would boost the amount of both nitrogen and phosphorus entering the estuary by up to two percent. The amount of sediment would rise by up to five percent. That could have an impact on pollution diets when Bay managers reexamine them in 2018.

A brighter bit of news was that a projected rise in sea level of one foot by

2025 would lead to minimal loss of the Bay's coastal wetlands overall.

But when the modelers looked beyond 2025, they quickly realized that it becomes much more difficult to make reliable predictions. That is because there are different scenarios about how much climate might change globally depending on how successful industrialized nations are at cutting carbon emissions. And across different scenarios, there are wide variations in likely increases in rainfall and temperatures and, to a lesser extent, sea level rise. Nevertheless, the various models tend to agree that after 2050, sea

level rise could begin to appreciably chip away at the Chesapeake Bay's wetlands.

The modelers plan to continue to incorporate a range of "what if" scenarios of climate change in 2050 and beyond. In part, they'll need to continue to make judgments about which of the various possible scenarios appears most likely based on the best available evidence — evidence that may emerge only gradually over time.

Hard work, but necessary, says Zoe Johnson, climate change coordinator for the Chesapeake Bay Program. "It's very important to keep abreast of the changes," she says, "so we can ensure that the Bay restoration and protection effort is built to be successful in the face of future impacts."

Lost in the Shallows

Besides incorporating the effects of climate change, the Chesapeake Bay modelers are eyeing other ways to use science to improve the Bay in a box after 2025. One such upgrade could improve the model's simulations of processes in the shallow regions on the fringes of the estuary, less than six feet deep. Modelers have long struggled to mimic these areas accurately using the Bay model.

It's important to simulate the shallows accurately because they provide critical habitat for fish, crabs, and oysters. But nutrients and oxygen levels predicted by the model weren't even close to actual measurements. "We have called them our problem children," Linker says.

The difficulty arises because the computer model can't accurately reproduce the fine physical details of these shallow areas, including the Bay's coastline, marshes, and tributaries. The underlying problem is the coarseness of the grid the model lays over the estuary to subdivide it in "boxes" of water in which the model's equations work their magic. Making the boxes small enough to fit into all the nooks and crannies in the shallow areas would vastly multiply the number of boxes of water the model's equations would need to crank through. As a result, the model would

take too much time and too many expensive computer resources to run.

Because the model's grid doesn't include all the nooks and crannies, it can't accurately track small-scale and fast-paced changes in water flow, salinity, and nutrients in shallow areas of the estuary. For example, one detail the model has trouble representing accurately is subtle rises and dips in the contours of river bottoms. "The topography of the river bottoms affects how salt water moves up the tributaries and how fresh water moves down," says Raleigh Hood of UMCES. "Simple things like that can affect how well the model works."

One possible solution the modelers have discussed is changing to a radically different way to segment the model Bay called an unstructured grid. It would allow them to use a fine grid of triangle-shaped compartments to simulate the complex shallows but use much larger triangles in areas like the open water. Applying a fine grid in open water would not make the model's projections there much more accurate and would unnecessarily lengthen the time it took to run the computer model.

Many Models

An even more fundamental proposed change in the art and science of Bay modeling: run multiple models in tandem to better inform the restoration effort.

Researchers have already started to use multiple models in hopes of improving the accuracy of the Bay in a box. For example, a project is underway to test new state-of-the-art models in the Chester River and compare them to the Bay model's predictions for that same tributary. The point of this modeling comparison is not to declare a single winner, but to identify the models' strengths and weaknesses. "What do different models do better or worse and why?" Hood asks. The answers could help to design a better Bay model.

Hood is a proponent of eventually running multiple Bay models in tandem to produce a range of projections to guide decisions about managing the

estuary. Using just one model makes it harder to get a handle on its uncertainties — the range of projections of water quality that the Bay model produces. Knowing the range would make it possible to estimate the potential for mismatches between model projections and real-world measurements.

This combination modeling approach is already the standard in climate science. "That ensemble tells you what the uncertainty is," Hood says. The ensemble tells you the range of variability in predictions of how much the climate will change. "And," he adds, "we can do exactly the same thing in estuarine modeling."

Carl Cerco, who helped create the present one-model approach to simulating the Chesapeake, sees advantages to running multiple Bay models, but he believes the approach raises new headaches for the managers. It might lead to conflicting recommendations about what measures are needed to improve water quality, inviting disagreements among competing interests in the restoration. If one model calls for expensive changes in farming practices and another model doesn't, would farmers push back against the expensive option? How would managers choose?

Model Reality Check

For the time being, the restoration partnership relies on everyone buying into a single model. To help assure trust in the accuracy of its projections, the modelers rely on a rigorous reality-check called calibration. They compare the model's simulations of how the estuary worked in recent decades to actual observations of how the Bay worked in reality during those years. The Chesapeake Bay Program's massive three-decade database of observations draws on a variety of sources — including monthly water sampling cruises down the waterway's mainstem to measure nutrient levels, dissolved oxygen, and water clarity. Monitoring stations on streams throughout the watershed also collect data.

Calibration ensures, for example, that the model's simulations of nutrient levels

in particular parts of the Chesapeake in past years match reasonably well the nutrient levels actually measured in those parts. A close fit provides confidence that the model can accurately predict the estuary's response to future reductions in nutrients — and that the simulated Bay and real Bay act similarly enough that the model can help to guide management decisions about how to restore the estuary to health. The closer the model is to reality, the better the tool is for measuring whether the pollution diet is on track to success.

It's never a perfect fit. The Bay in a box is a simplified version of a very complex system, and the real-world observations of the Chesapeake that modelers use to reality-check their digital Bay are incomplete and based on averages of daily, monthly, and annual conditions in the estuary. The creators of the Bay model have carefully adjusted it to try to minimize mismatches between predicted and real-world nutrient levels by fine-tuning the model's equations and

Carl Cerco is one of the original architects of the computer model of the Chesapeake estuary that helps guide the Bay restoration. He retired in January 2017 after 30 years of work. Future generations of Chesapeake modelers will continue to build on Cerco's work but might make fundamental changes in how the model mimics the processes that determine water quality.
PHOTOGRAPH BY DAVE ROBERTS/ERDC PAO

underlying assumptions. The result is a digital Bay that can be made to behave enough like the real estuary to produce trustworthy projections and guide management decisions in the future.

Is the latest draft of the Bay model better than the last one? It's a difficult question to answer, says Gary Shenk, who oversees the watershed modeling effort for the Chesapeake Bay Program. "There isn't a simple number we can point to for measuring improvement," he says. However, all of the changes in the latest version of the model make it a more realistic representation of the estuary, Shenk adds, and so "they give us greater confidence that the predictions of load changes due to management scenarios are more accurate."

Hood says the model's ability to accurately predict the effect of changes in nutrients on oxygen levels indicates that the model responds like the real estuary, as the managers of the Chesapeake Bay cleanup effort need it to. And for oxygen, it's not a trivial task.

"The model simulates oxygen drawdowns very well," Hood says. "If you increase nutrient loads, oxygen goes down; if you decrease nutrient load, it goes up."

Dominic Di Toro, a professor at the University of Delaware and one of the architects of the original model of the

Bay, takes a longer view of the model's accuracy. The early version, he admits, was crude, but he has watched the model's sophistication and scientific foundations grow substantially since then.

Di Toro's verdict on this history: "It's important to realize that the model has withstood multiple calibrations, multiple scientific studies, and multiple reviews," he says. "It has been punched around a lot and it doesn't fall apart."

Cerco's Final Draft

Before completing a full-scale calibration of the new and improved version of the Bay model, Carl Cerco still had quite a bit of tinkering left to do with his Bay in a box. For the first time, the model would be able to explicitly mimic the effect of tidal wetlands in removing nitrogen from the estuary's waters. He would also add the ability to simulate how the increasing numbers of oyster-growing operations and sanctuaries are affecting water quality by removing nutrients and organic particles.

The to-do list is long but time is short. Cerco officially retired in January 2017 but is staying on for a while to finish what he started. His career has entirely overlapped six generations of increasingly sophisticated Bay models, and the next guru of Chesapeake water-quality mimicry will likely end up building on what Cerco has laboriously constructed since the 1980s.

Modelers strive for progress — not perfection. "There is always more to do, but at some point you just have to move forward," Cerco says. "You have to take the best model you have and say, okay, it's done."

As he hands over the Bay model to the next generation, Cerco is grateful to have had the chance to contribute to building a model of the largest estuary in America and providing a science-based foundation for the most far-reaching and complex pollution diet in EPA history. "When this project came along it was the opportunity of lifetime," he says, "and it still is." ⌄

— *Daniel Pendick*
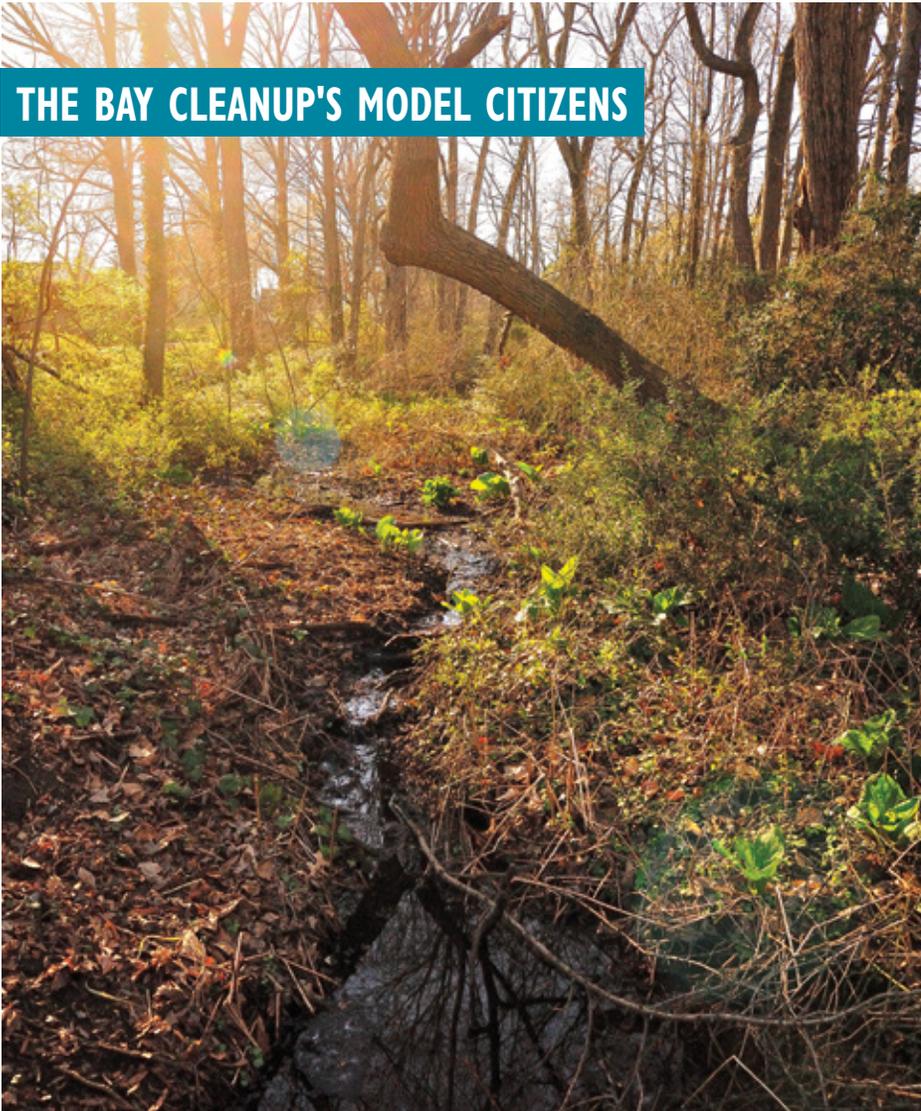
A streambed meanders through tangled woods behind St. Luke's Episcopal Church in Annapolis. Citizen stewards have taken on the challenges of restoring this stream's pollution-filtering function using a variety of "green" solutions that soak up and clean polluted stormwater before it reaches Back Creek behind the church and the Chesapeake Bay beyond.
PHOTOGRAPH BY MICHAEL W. FINCHAM

Cleaning Up Stormwater Pollution One Town at a Time

Citizen stewards of local water quality help the Bay

In 2013, Betsy Love and Alice Hall — two parishioners at St. Luke's Episcopal Church in Eastport, Annapolis — got an idea. In back of the church was an overgrown wooded area so tangled with invasive vines that tree trunks and boughs were deformed and twisted from struggling to reach for a taste of sunlight.

Love and Hall wanted to cut a nature trail through the 2.5-acre parcel. "So we marched into the woods to blaze a trail

and it was an amazing mass of jungle," Love says. "You could not even chop through it with a machete."

But Love, already an active member of the Severn River Association, soon had a much more ambitious rescue plan for the Eastport jungle. Her church should transform the property into a showcase of green stormwater management. It was an idea whose time had come. In 2014, the federal-state Bay Agreement that guides the ongoing

Chesapeake Bay cleanup included for the first time this explicit goal: to "increase the number of trained and equipped citizen leaders."

St. Luke's was in the right place to help clean up the Bay: Back Creek, behind the church, feeds the Severn, and the Severn empties into the Bay.

A retired non-profit manager, Love did not feel equipped to pull off a major watershed restoration at St. Luke's. Fortunately, her Crownsville home lies in Anne Arundel County, birthplace of a training program called the Watershed Stewards Academy (WSA). Love joined the program, which offered her a chance to gain essential technical knowledge and contacts with stormwater management professionals and potential funders.

The restoration project at St. Luke's, now budgeted at $1.2 million, is the largest ever led by a WSA graduate. Slated for completion in 2017, the project will remove pollutants from local stormwater that could otherwise reach the Bay. It's the kind of grass-roots project that could, if repeated in enough communities, keep the Bay healthy in decades to come.

"I think everyone is going to be very pleased by what this is going to be," Love says, "[in] this little piece of paradise."

Watershed Restoration 101

The Watershed Stewards Academy that first trained Love sprouted in 2008 at Arlington Echo Outdoor Education Center in Millersville, Maryland. "There weren't any resources in county government to provide technical assistance and leadership needed to move ideas from intention to action," says Suzanne Etgen, one of the founders of the academy and presently its executive director.

The Anne Arundel WSA accepted its first 32 trainees in spring 2009. For

more than a year, WSA participants attend a weekly comprehensive boot camp on watershed restoration. Their classes and field trips culminate with community-based capstone projects.

The program has also provided the model for academies in other counties. Amanda Rockler, a Maryland Sea Grant Extension watershed restoration specialist, helped make that happen. Rockler works with local governments, community groups, and citizens in Frederick, Howard, and Montgomery Counties to help improve water quality locally and ultimately in Chesapeake Bay.

Working with Etgen, she helped develop resources and guidelines enabling the new academies to follow Anne Arundel's core curriculum while customizing their training to local watershed issues. Some of the trainees attended that inaugural Anne Arundel's academy with the goal of spreading the gospel of watershed protection in and around the District of Columbia. Today, WSAs are thriving in the National Capital Region, covering Washington as well as Montgomery and Prince George's Counties in Maryland. There are also WSA's in Cecil, Howard, and St. Mary's Counties.

A Citizen Steps Up

Betsy Love graduated in 2014 from Anne Arundel's WSA, but the germ of the restoration at St. Luke's came to her a year earlier as she walked around the property. Behind the church woods she discovered a 42-inch-wide municipal stormwater pipe draining into Back Creek, and something in the lay of the land stood out to her. "There was a sort of valley running down the slope of the property leading to the outfall," Love recalls. "The topography seemed to show an old stream bed."

She was right: a 1944 U.S. Army Corps of Engineers map confirmed that a stream had once meandered from St. Luke's backyard to Back Creek. A municipal stormwater pipe beneath the south edge of the St. Luke's property had essentially replaced that stream.

Master Watershed Steward *Betsy Love has led an effort to install sustainable stormwater management features on five acres of land behind St. Luke's Episcopal Church. The improvements will help to clean stormwater that flows onto the church's property from 28 acres of the surrounding, densely developed Annapolis neighborhood of Eastport.* PHOTOGRAPH BY DANIEL PENDICK

Love thought the stream should be restored using a technology called a regenerative stormwater conveyance. A restored stream would remove nutrients and sediments through a series of pools that trap sediment and allow natural processes to break down nutrients.

The 1,000-foot-long restored stream Betsy dreamed of would flow through St. Luke's property, cascading into a small wetland on the St. Luke's property and onward to a restored tidal marsh and 270 feet of living shoreline at the former outfall of the stormwater pipe.

Anne Arundel's growing cadre of master watershed stewards have also contributed to the greening of St. Luke's. Besides Love, four other parishioners have graduated from the WSA. The stewards targeted approximately 23,000 square feet on the church property and planted a conservation landscape to soak up stormwater. They also removed invasive plants that had strangled many trees and put in more than 300 native plants. Love says all of these measures will also collectively treat the stormwater runoff from 28 acres of a densely developed

Annapolis neighborhood surrounding St. Luke's five-acre property.

None of this could have happened without getting the church behind the project. Years ago St. Luke's considered developing the land. But now, says Love, "Church leaders and the congregation agreed we should give back to Creation."

The project would take money, and lots of it. Eventually, thanks to Love's leadership, the Maryland Department of Natural Resources offered to fund most of the restoration, although it required matching funds from numerous other donors and additional fundraising and community volunteer support.

Finally, St. Luke's would need to obtain permits from the city, the state, and even the U.S. Army Corps of Engineers. Not even Love's WSA training fully prepared her for how much energy it would take to navigate the bureaucratic labyrinth. "It's not for the faint of heart," she says.

Love says the Watershed Stewards Academy made it all possible. "I really don't think I could have done this without that course," she says. "They helped me connect all the dots."

WSAs and the Chesapeake

Building a corps of citizen stewards is now an integral part of the ongoing effort to restore the Chesapeake Bay. Many graduates of that first academy class continue to lead community watershed restoration projects. In all, more than 300 master watershed stewards have been trained in Maryland.

Love's project may seem like a drop in the bucket in the Chesapeake's watershed of more than 40 million acres. But Suzanne Etgen emphasizes that master watershed stewards play a critical role as educators and leaders.

Many of them work directly with owners of businesses and private lands. "It's going to take everyone making sure stormwater doesn't leave their property," Love says. "The problem is so big it's going to take everybody getting involved." ⌄

— *Daniel Pendick*

MARYLAND'S 2017 KNAUSS FELLOWS

Five graduate students supported by Maryland Sea Grant have begun working for federal agencies in Washington, D.C., as 2017 Knauss Marine Policy Fellows — our largest class ever. They will spend one year on projects that include improving international partnerships, fisheries management, and monitoring of water pollutants.

Katie Geddes is working in the Office of International Activities of the Office of Oceanic and Atmospheric Research at the National Oceanic and Atmospheric Administration (NOAA).

Geddes, who grew up in Solomons, Maryland, earned a master's degree in environmental anthropology from the University of Maryland at College Park and is passionate about helping those disproportionally affected by climate change. She discovered her interest in policy as an intern at the White House Council on Environmental Quality.

Aimee Hoover is serving in the Office of Science and Technology with NOAA's National Marine Fisheries Service (NMFS). As part of the National Observer Program, she is working on the National Bycatch Report Update, hoping to improve the work environment for fisheries observers.

Hoover is studying fisheries science at the Chesapeake Biological Laboratory of the University of Maryland Center for Environmental Science (UMCES). Her master's degree will be in the Marine Estuarine Environmental Sciences (MEES), a graduate program jointly administered by UMCES and the University of Maryland at College Park. She is studying the movement of Costa Rican sea turtles to improve management and conservation of these endangered species.

Rebecca Peters is the fisheries habitat and ecosystem science coordinator in NOAA's NMFS Office of Science and Technology. Her focus includes learning how habitat science is incorporated into ecosystem-based fisheries management.

Peters completed her M.S. degree in the Marine Estuarine Environmental Sciences (MEES) graduate program at the University of Maryland Eastern Shore. Her thesis focused on delineating essential fish habitat for juvenile black sea bass in the Maryland coastal bays.

She interned with the National Marine Fisheries Service's Shark Population Assessment Group in Panama City, Florida.

Stephen Gray Redding is a fisheries management specialist with NOAA's Highly Migratory Species Division. He is collaborating with stakeholders and decision makers to ensure sustainable management of valuable fish populations.

As an undergraduate and later a research technician at the University of North Carolina at Chapel Hill, Gray worked on projects studying the response of oyster reefs and other coastal habitats to environmental changes.

While enrolled in the UMCES-College Park MEES graduate program, Redding focused on fisheries science for his master's degree at the UMCES Chesapeake Biological Laboratory, using chemical techniques to study the movement and migration patterns of juvenile Atlantic mackerel, work that may improve management of the species.

Yini Shangguan is the first Knauss fellow to work with the Nutrient Team in the Office of Water of the U.S. Environmental Protection Agency (EPA). The team's goal is to better understand the overall condition of estuarine, near-coastal, and coral reef environments.

Shangguan received her Ph.D. degree from the UMCES-College Park MEES graduate program while studying at the UMCES Horn Point Laboratory. For her dissertation research, she helped evaluate the impact of the Comprehensive Everglades Restoration Plan on freshwater discharge, nutrient loading, and algal blooms in Florida Bay.

Originally from China, Shangguan hopes that working at the EPA will provide practical experience in environmental management and more opportunities for communication with the public.

The Knauss Marine Policy Fellowship, begun in 1979, is designed to enable outstanding graduate students to spend a year working in federal legislative- or executive-branch offices that focus 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. Students can apply through the Sea Grant program in their state. For more information, visit:

Maryland Sea Grant Program
mdsg.umd.edu/education/knauss

National Sea Grant Program
seagrant.noaa.gov/FundingFellowships/KnaussFellowship.aspx

Grace Brush Traces the Bay's Ecological History
A new Maryland Sea Grant book

The sediments of Chesapeake Bay harbor a record of the Bay's ecology, from its "natural functioning" thousands of years before European colonization through post–Colonial settlement up to the current, continuing forest clearance across the watershed. Translating that record into a history of ecological change has been the focus of Grace Brush's research at the Johns Hopkins University for more than thirty years.

Brush explains the nature of these studies in her new book, *Decoding the Deep Sediments: The Ecological History of Chesapeake Bay,* published by Maryland Sea Grant as the fifth installment in our *Chesapeake Perspectives* series.

Brush takes readers on a tour on the methods and findings of this fascinating work, including accounts of how she and her colleagues analyzed hundreds of core samples they took throughout the Bay. The research has demonstrated how the forest cutting and large-scale land-use changes have affected the estuary's ecosystem by causing massive runoff of sediments and nutrients, all of which have contributed to the decline of water quality. A major effect has been the shift from a Bay ecosystem once dominated by benthic processes to one now dominated by pelagic processes.

Brush, a winner of the Mathias Medal, also writes about how she came to do aquatic research in the first place and about how she and other women scientists of her time had to deal with difficult challenges in male-dominated fields. As Maryland Sea Grant Director Fredrika Moser writes in the foreword, Brush has an important story to tell: "I think all readers will admire her remarkable story, her fortitude, and, not least of all, the students she has attracted to continue this work."

Maryland Sea Grant's *Chesapeake Perspectives* series features the insights of researchers, scholars, and other thinkers who examined the unique culture and ecology of the Chesapeake Bay. Previous books were written by Edward D. Houde, a fisheries biologist at the University of Maryland Center for Environmental Science; William Matuszeski, former director of the Environmental Protection Agency Chesapeake Bay Program Office; and Erve Chambers and Michael Paolisso, both anthropologists at the University of Maryland at College Park.
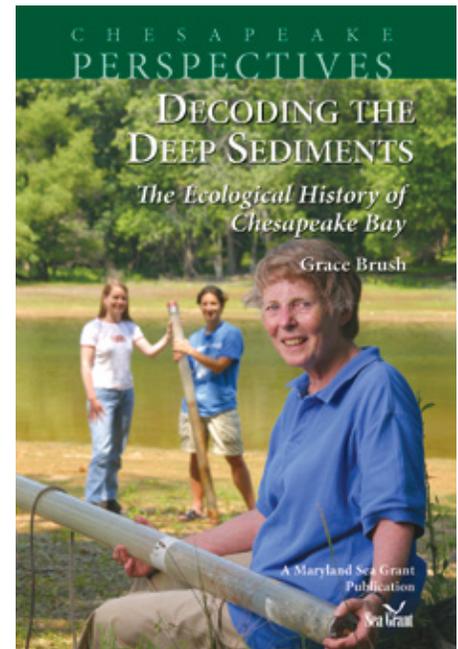
TO ORDER A COPY of *Decoding the Deep Sediments,* or to find out more about other books in the series, visit the Maryland Sea Grant Bookstore's *Chesapeake Perspectives* page:

www.mdsg.umd.edu/store/books/cp

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