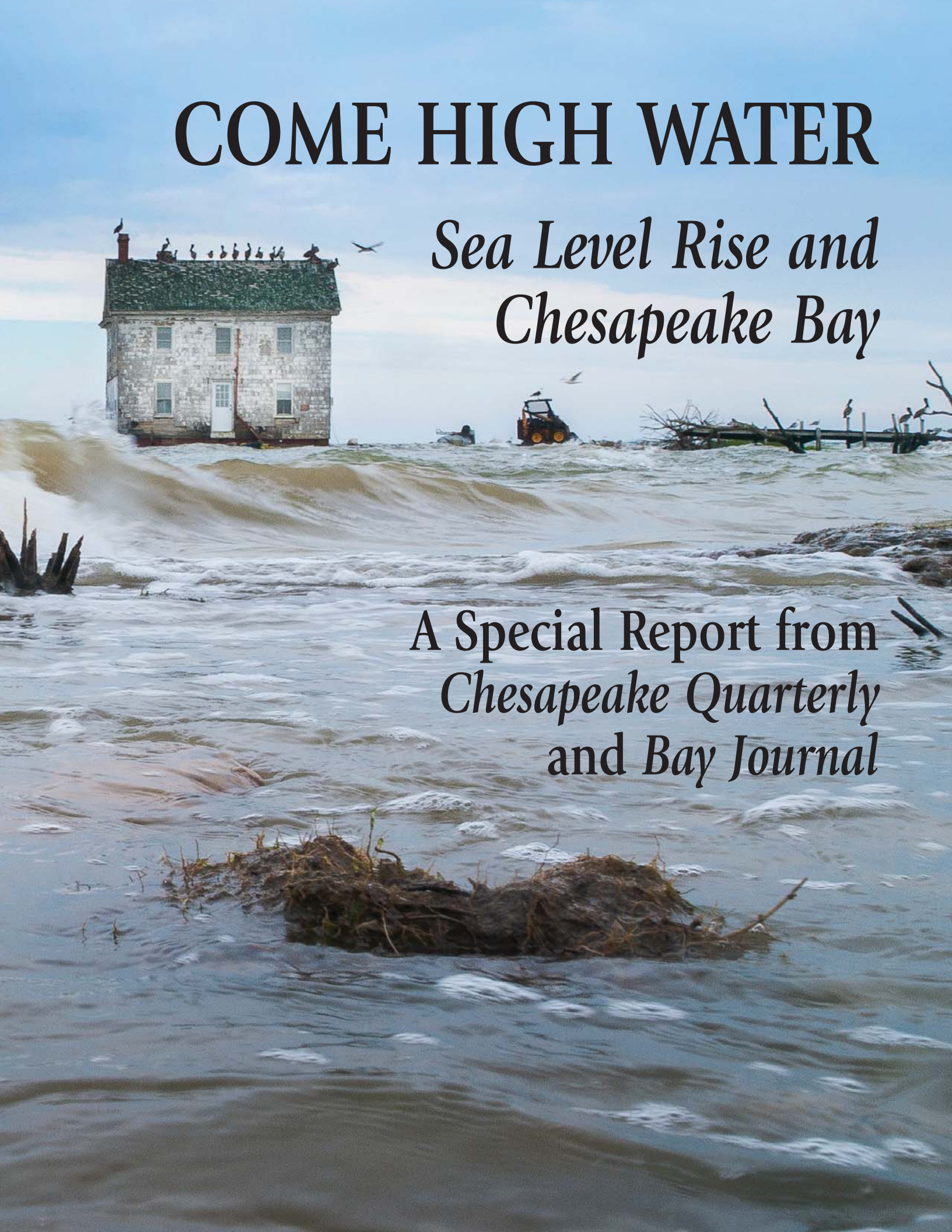

COME HIGH WATER

Sea Level Rise and Chesapeake Bay

A Special Report from
Chesapeake Quarterly
and *Bay Journal*

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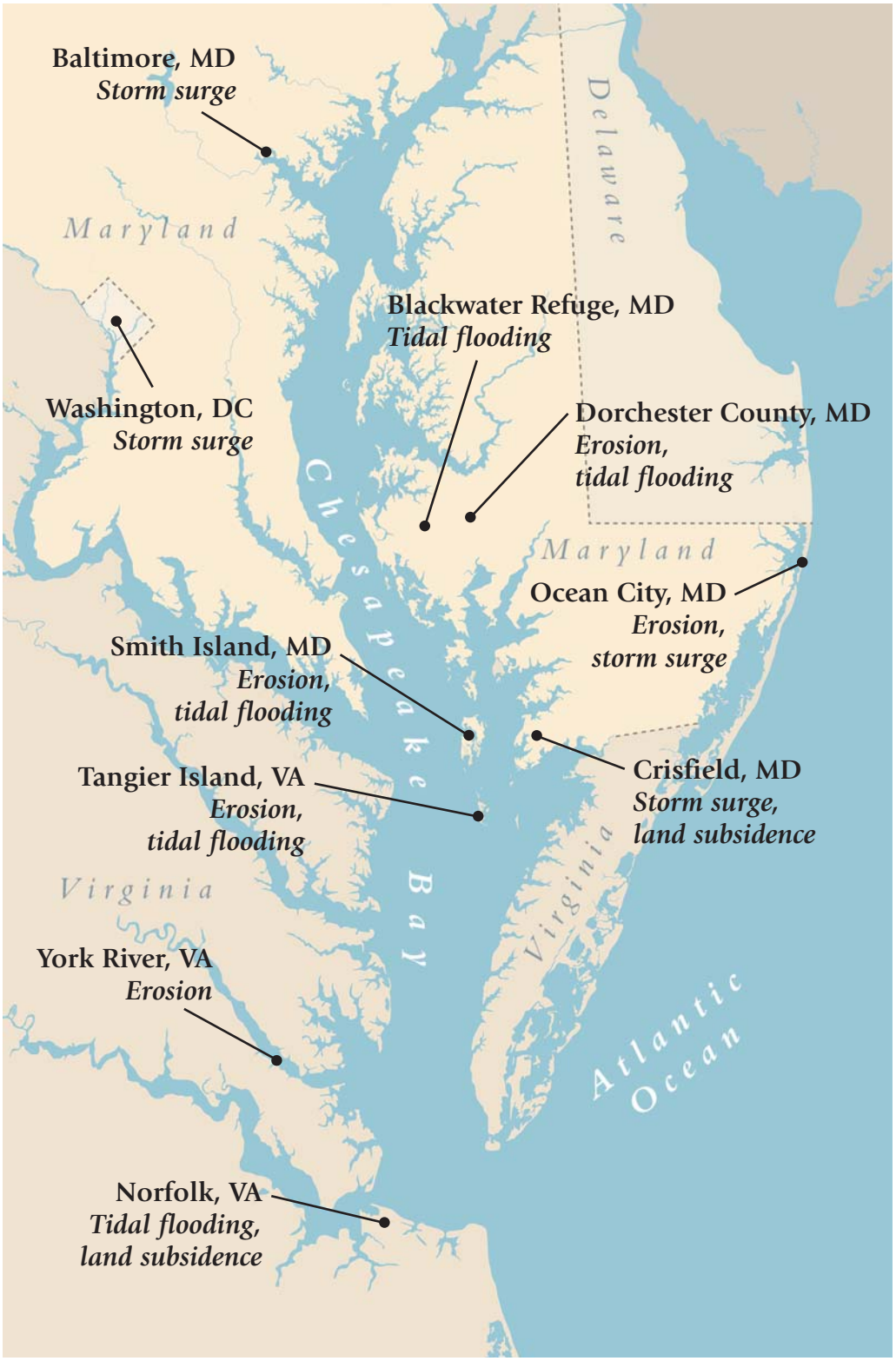


Rising waters will threaten different regions of the Chesapeake Bay in different ways: with storm surges and tidal flooding, with shoreline erosion and marshland losses and disappearing islands. The stories that follow highlight a few of those places and examine in detail the threats they may soon face. MAP, ISTOCKPHOTO.COM/ UNIVERSITY OF TEXAS MAP LIBRARY

FOREWORD

The Threat of Rising Seas to Chesapeake Bay

DAVID HARP

About 10,000 years ago, as the massive glaciers from the last Ice Age were rapidly melting, the expanding ocean began to flood lower river valleys along the Atlantic coast, initiating the Chesapeake Bay. The ocean continued to increase in volume over the next 7,000 years, creating the great bay that we know and love today. For most of the last 2,000 years, ocean levels have been relatively stable around the globe. Sea level in the Chesapeake, however, continued to rise very slowly relative to elevation of the land, largely because the land has been sinking slightly, a long-term consequence of the disappearance of Ice Age glaciers. Over the 400 years of European inhabitance, rising waters in the Chesapeake have continued to redraw our maps as shorelines retreated and islands vanished.

During the 20th century land continued sinking slowly, while the ocean itself began to rise at a faster rate as the Earth's atmosphere and oceans were unequivocally warming. The ocean is now rising at a rate nearly double the rate of that regional land sinking. And an increase in the rate of that rise is virtually certain. How fast will sea level rise in the Chesapeake in the future, what are the consequences, and what can we do about it?

This special report, *Come High Water: Sea Level Rise and Chesapeake Bay*, addresses these questions. It is a result of a unique and complementary collaboration between *Chesapeake Quarterly*, the magazine of our Maryland Sea Grant College, and the *Bay Journal* newspaper, two publications that are now widely recognized as the most authoritative sources of credible information and insight about the Chesapeake Bay available to the broad public. The gifted writers of these award-winning periodicals have the rare knack of capturing the essence of science from scientists and their publications, adding in human dimensions, and providing exceptionally informative and compelling prose and graphics.

This remarkable compendium of articles was inspired by my inviting *Chesapeake Quarterly* writers to observe the proverbial sausage factory as I assembled a group of scientific experts to respond to a directive by former Maryland governor Martin O'Malley. The governor wanted to make sure that Maryland's investments in public infrastructure took into account increasing risks due to sea level rise, and he insisted that this be based on reliable projections of future sea level based on the latest science.

Many of the experts involved in developing our projections are described or quoted on these pages. They help explain why such forecasts must take into account a surprising array of factors. The articles explain, for example, why the erosion of the edges of Antarctic ice shelves or the slowing down of the Gulf Stream — observations that have been recently prominent in the news — matter a great deal to Chesapeake Bay shorelines.

But the articles in this special report go well beyond sea level rise projections to illuminate how sea level rise increases the risks posed by tidal extremes and storm surges; how the consequences include changes for both the biota and the human communities along the coastal landscapes of the Chesapeake Bay region; and how we can become more resilient in the face of rising Bay levels. I strongly recommend that you read it cover to cover and put it on your coffee table for the enrichment of your family members and guests.

— Donald Boesch
President, University of Maryland Center for Environmental Science
June 2015

INTRODUCTION

Reckoning with the Rising

Seas are rising in the Chesapeake region, flooding Bay shores. This special report examines by how much, and what we can do.

When European settlers put down roots around this estuary in the 1600s, many likely didn't recognize how changeable the Chesapeake Bay could be.

They thought that the islands and curving shorelines had always been here, ready to provide an enduring home. But geological evidence tells a different story.

Global warmings and coolings over the millennia have brought the birth and decline of multiple Chesapeake Bays. When temperatures cooled, the great glaciers and ice sheets expanded and sea level fell. When temperatures warmed, the ice melted and sea level rose. As they rose, they drowned the valley of an ancient Susquehanna River, turning it into an estuary. About 10,000 years ago, rapidly rising ocean waters invaded the area near Norfolk and began to fill our current Chesapeake Bay. The rate of rise later slowed, and our estuary took its present shape only 3,000 years ago.

Today, the pace of sea level rise is increasing again. Tide gauges scattered up and down the Mid-Atlantic coast show that water levels here are already rising at the fastest rates seen in thousands of years and among the fastest in the United States. The rise is forecast to accelerate in coming decades. Scientists have documented a variety of causes, many of them driven mainly by human activities like emissions of greenhouse gases by industries and vehicles around the world.

The annual rise in the Bay's waters seems small, about four millimeters a year, and its effects are not very obvious to the occasional visitor. Look carefully, though, and you can see some of them. Woodlands on the lower Eastern Shore have become marshlands dotted with dead white tree trunks, victims of salt water flowing in from the Bay. In other places, the changes are more obvious. Shorelines like those on Maryland's Smith Island and Virginia's Tangier Island are steadily eroding.

The changes are even more conspicuous when big storms blow over. Higher sea level brings taller storm surges and more flooding. In October 2012, Hurricane Sandy pushed five feet of water into Crisfield, Maryland. It was an alarm call warning residents, builders, and government officials around the Bay to prepare for more high water in the future.

Adding to the urgency was a scientific analysis completed in 2013. A team of scientists projected that the sea level around Maryland might rise by 1.4 feet by 2050. Those numbers shoot up to estimates of 3.7 to 5.7 feet by the end of the century. The toll from such a rise would be vast: scientists with the organization Climate Central report that in Maryland alone, more than 55,000 people live in homes less than five feet above the local high-tide line. This zone holds 41,000 homes and $19.6 billion in property value.

To examine these forecasts and their implications in depth, *Chesapeake Quarterly*, Maryland Sea Grant's magazine, teamed up with the *Bay Journal* newspaper in 2014 and 2015 to produce the articles in this special report. Why are the oceans expanding and how high will they go? What are the best scientific explanations? We also looked at the effects on people, on Bayside residents who are seeing firsthand the loss of low-lying land.

The changes touch all of us, including those who don't live right on the Bay. Taxpayers are underwriting flood insurance programs. State and federal officials are planning sea walls and flood walls and changes to roads and other infrastructure — all with the hope of holding back the water.

An overriding, unanswered question: how much land, property, and heritage can be preserved? And at what cost?

The articles in this report and additional materials — including video interviews, a photo gallery, and a link to an interactive tool from Climate Central for gauging sea level rise in your area — are available on a special website: www.chesapeakequarterly.net/sealevel.

— The Editors, *Chesapeake Quarterly*

The Rising
Why Sea Level Is Increasing

DAVID HARP

Sea level rise is a global phenomenon, but one that can affect life around the Chesapeake Bay in many different ways. Scientists estimate that this region's rate of sea level rise will accelerate. They have also investigated the causes: ice sheets around the world are melting and land surfaces around the Chesapeake are sinking. What can we expect in the future?

The Antarctic Connection

New research shows that polar ice sheets could become a big contributor to sea level rise

Daniel Strain, *Chesapeake Quarterly*

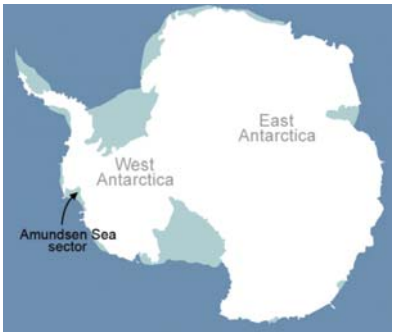
***Ice loss proceeds** at a staggering rate along the front of Thwaites Glacier (pictured here in 2012), part of the rapidly melting Amundsen Sea sector of Antarctica (map below). Ron Anderson (opposite page) of Oxford, Maryland, has seen the toll of these global changes on the state's coast.* PHOTO OF GLACIER AND MAP ILLUSTRATION, NASA; PHOTO OF RON ANDERSON (OPPOSITE PAGE), DANIEL STRAIN

When Ron Anderson was a teenager in the 1970s, he liked to watch the sun set over Benoni Point. The spit of land sat about a mile west of Oxford, Maryland, over the Tred Avon River. Even then, there wasn't much to it. "It was just this little point of land with just these big pine trees and nothing else," says Anderson, who grew up in Easton, not far from Oxford on Maryland's Eastern Shore.

Today, there's almost nothing left of Benoni Point. Over the decades, waves carved away at the land, and rising waters killed off the pine trees, leaving only a small sandy island behind.

Anderson is an aquatic toxicologist at the Wye Research and Education Center, a University of Maryland facility near Queenstown. The 55-year-old now lives in Oxford and is a member of the town's volunteer fire company. Stories like his are common up and down the Eastern Shore.

"Everyone who lives here has seen areas go back to the sea," he says, "or put up bulkheads where they didn't have to 40 years ago."



To be sure, the Bay has eroded land around the Delmarva Peninsula for as long as humans have lived here. But now, sea level rise is speeding up this give and take between land and water. As water levels climb around towns like Oxford, waves reach farther and farther inland, altering the landscape and posing risks to people.

After Tropical Storm Isabel swept through the region in 2003, for instance, the flooding was so bad that Anderson and members of his fire company rode small powerboats down streets to aid stranded residents.

Sea level is rising around the world, a trend scientists have attributed to climate change. Now, new observations are showing that levels on the Mid-Atlantic coast may be climbing at some of the fastest rates seen in the

United States. A number of factors are responsible for this rise in water around the Chesapeake Bay. Emerging research suggests that one of the biggest contributors to local sea level rise will come from what may seem an unlikely place: Antarctica.

"There are some pretty stark differences that you see if you compare the sea level rise at a place like Baltimore to, say, Juneau, Alaska," says John Boon, a physical oceanographer and a professor emeritus at the Virginia Institute of Marine Science in Gloucester. The question is, "What's the reason for this?"

Antarctica's Fingerprint

The question is an important one on the Bay and along the Mid-Atlantic coastline — an area that many scientists are now referring to as a "hot spot" for sea level rise.

Here, water levels as measured by tide gauges around Baltimore and other towns in the region seem to be climbing twice as fast as the global average increase. And by some estimates, the increase in certain areas is three to four times as fast. For most of the 20th century, that global average was around 1.7 millimeters a year, according to the Intergovernmental Panel on Climate Change, a group that disseminates the findings of climate science research.

Scientists expect that these rates of sea level rise will accelerate in the decades ahead. By 2050, researchers estimate that sea level off the coast of Maryland is likely to rise by a total of around 1.4 feet (0.4 meters). Or by at least 0.9 feet and as much as 2.1 feet. Those are the estimates of a 2013 scientific review led by the University of Maryland Center for Environmental Science.

Oceanographers have identified several factors contributing to this rapid rise in sea level locally. To start off, consider the chemistry of water itself. Because of how water molecules move and interact, warmer water tends to take up more space than colder water. That matters today because most of the earth's oceans are warmer than they used to be, mostly because of man-made climate change.

What is more, in the Chesapeake Bay and Mid-Atlantic regions, not only is the ocean rising, the land is also sinking. It's a natural change that has been going on since the end of the last ice age (see As the Land Sinks, p. 10).

In the case of these two factors — expanding oceans and sinking land — scientists have a good understanding of how much sea level rise we can expect as the world warms. Less certain is what the contribution will be from a third player: melting ice.

And there is a lot of ice sitting on top of the land masses of Greenland and Antarctica. Scientists refer to these ice sheets, along with other frozen parts of the globe, as the "cryosphere." The physics of how these environments melt are complicated, and scientists are working to better understand how the planet's glaciers are going to behave in a warming world.

It is clear, however, that Greenland and Antarctica are losing ice, and losing it fast, with some glaciers at the water's edge shrinking backward by hundreds or thousands of feet every year. As this ice melts, it adds water to oceans and raises global sea level — like turning on the faucet in your bathtub.

Antarctica is, in many ways, the king of the cryosphere. Greenland is melting at a faster rate, but the southern continent holds a lot more ice, says Christopher Shuman, a geoscientist at the Joint Center for Earth Systems Technology, a collaboration between the University of Maryland Baltimore County and the NASA Goddard Space Flight Center. In total, there's enough ice on Antarctica to raise the world's oceans by more than 200 feet.

"That's what makes it the 800-pound gorilla compared to the more rapidly changing parts of the cryosphere," Shuman says.

It may seem strange that Maryland's coasts could be threatened by a continent thousands of miles away at the earth's South Pole. But when ice sheets melt, sea level doesn't rise evenly across the globe — sea level off Baltimore is rising at a fast clip, and it's actually falling near Juneau, Alaska, for instance. Scientists describe the pattern of sea level rise caused by ice loss from a particular ice sheet as a melting "fingerprint."

Gravity is one of the main driving forces behind these fingerprints. "There's a number of things that happen when you melt an ice sheet that have to do with the fact that ice sheets are really big," says Robert Kopp, a climate scientist at Rutgers University in New Jersey.

He explains that ice sheets, especially those sitting on top of Greenland and Antarctica, are so big that they carry their own gravitational pull that draws water toward them. When those ice sheets melt, their gravitational pull weakens, and all the water that had been drawn toward them starts to flow away. The result is that sea level will drop in areas close to the glacier.

"So if you melt Greenland, you cause a sea level fall in Scotland," Kopp says. "If you melt a glacier in Alaska, you cause a sea level fall in Seattle."

But if sea level drops in those locations, then it has to rise somewhere else. Water will tend to build up as far away from the melting ice sheet as possible, Kopp says. That doesn't mean, however, that sea level rise from Antarctica is concentrated around the North Pole. A number of gravitational forces, in fact, add together to put the East Coast of the United States right in the middle of Antarctica's melting fingerprint — in particular, the fingerprint from glaciers on the western, and more rapidly melting, half of the continent called the West Antarctic Ice Sheet.

Because of this fingerprint, melting of ice on Antarctica adds more to sea level near the Chesapeake than melting on Greenland, pound for pound — even though Greenland is a lot closer. For every one millimeter that melting glaciers on the West Antarctic Ice Sheet add to global sea level, waters along the Mid-Atlantic coast rise by around 1.2 millimeters, an increase of 20 percent.

It's a small bump. But over time, it could contribute to the fast rates of sea level rise observed in the Mid-Atlantic. "The United States East Coast is poorly located in terms of ice sheet melting," says Carling Hay, a postdoctoral researcher at Harvard University.

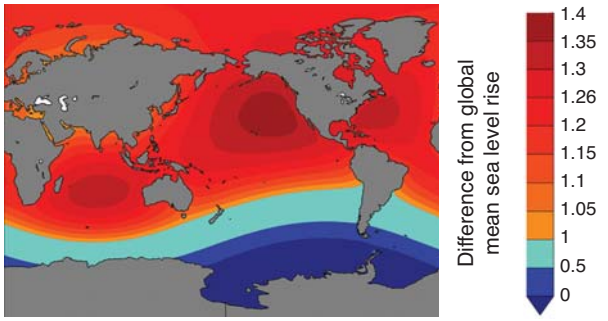
Which makes it all the more worrisome that the 800-pound gorilla that Christopher Shuman describes seems to be waking up.

What's Driving Sea Level Rise

Sea level is rising along Maryland's coasts faster than the global average increase. Scientists identified causes and estimated the likely contribution of each.

	Maryland							World-wide
Year	Amount of sea level rise (in feet)							(in feet)
	Ocean thermal expansion	Antarctica melting	Greenland melting	Other glaciers melting	Gulf Stream change	Sinking land	Total	Total
By 2050	0.3	0.3	0.1	0.2	0.3	0.2	1.4	0.9
By 2100	0.8	1.0	0.3	0.4	0.6	0.5	3.7	2.7

Note: Subtotals are rounded and so may not sum to total.



Sea Level Rise Fingerprint

The map at left depicts the melting "fingerprint" that would arise if the West Antarctic Ice Sheet collapsed today. Dark red zones show areas where the sea level would rise by up to 40 percent more than the average change in sea level around the globe. Dark blue zones show where the level would actually fall.

A dangerous mix, sea level rise along the Chesapeake Bay *stems from a variety of factors, according to a scientific review led by the University of Maryland Center for Environmental Science (table, above). Together, these factors make the region a "hot spot" for sea level rise and include the impacts of sinking land, melting ice in Antarctica, and changes to the flow of the Gulf Stream.* TABLE SOURCE, "UPDATING MARYLAND'S SEA-LEVEL RISE PROJECTIONS" REPORT; MAP, COURTESY OF CARLING HAY AND ELSEVIER

Hanging by its Fingertips

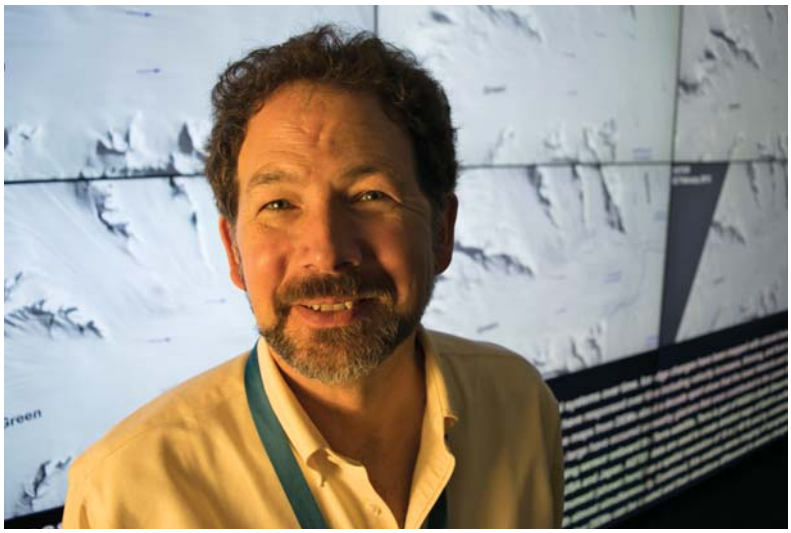
Shuman specializes in studying ice loss on Antarctica. But like Ron Anderson from Oxford, he's seen the evidence of sea level rise closer to home.

The geoscientist grew up in the Philadelphia area and spent family vacations in his grandparents' cabin on the Elk River near Cecilton, Maryland. Today, some of his cousins own the house. Like so many other property owners in Maryland, they've seen the handiwork of rising waters. These days, when a big storm hits the Chesapeake, waves often wash over the family's dock.

"It's a special place to us," Shuman says. "It's also a pretty good vantage point for appreciating the world that's evolving around us."

In recent years, scientists have learned more about the role that Antarctica will play in this evolving world. Their research points to big losses in the years to come.

In one study published in June 2014, for instance, a group of British researchers used satellite data to measure the pace of ice loss across Antarctica. Based on their results, which appeared in the journal *Geophysical*



Using satellites, scientists like Christopher Shuman *gain a bird's-eye view of melting ice in Antarctica and Greenland. Here, the NASA scientist stands in front of a visualization of ice loss from the Antarctic Peninsula. Like in other parts of the southern continent, segments of this stretch of ice have been retreating away from the ocean by tens of feet or more every year.* PHOTO, MICHAEL W. FINCHAM

Research Letters, that loss is proceeding at a gallop. Between 2010 and 2013, the West Antarctic Ice Sheet alone lost close to 150 billion tons of ice each year on average, the team reported. That's enough ice to add nearly four-tenths of a millimeter to global sea level annually.

Even small increases in sea level like these can worsen flooding and the damage it causes in coastal communities, especially during big storms like Isabel, scientists say. "You don't need a very large amount of sea level rise when you couple it to something like a storm surge," says Sridhar Anandakrishnan, who studies glaciers at Pennsylvania State University.

In a second paper published in 2014, a team led by Eric Rignot at the University of California, Irvine, explored the fate of a handful of glaciers on the West Antarctic Ice Sheet — most notably the massive Thwaites Glacier. These chunks of frozen water border the Amundsen Sea Embayment, a large body of water that has grown increasingly warm over the years.

The glaciers may also be beyond saving. According to the team's analysis, Thwaites and a handful of neighboring ice masses may have melted by so much already that they passed what scientists call a "tipping point" — huge portions of the region could collapse into the sea no matter what happens to the climate. In all, that might be enough melted ice to raise the world's oceans by four feet. That's enough to permanently drown whole segments of the Eastern Shore of Maryland.

The good news for those who live on the Eastern Shore is that because these glaciers are so big, the process will likely take hundreds to more than a thousand years to play out. That's a long time for people, but a blink of an eye in the lifetime of a glacier like Thwaites.

The findings by Rignot and his colleagues were also published in *Geophysical Research Letters*. A second scientific team reached similar conclusions in a study published on the same day in the journal *Science*.

Despite findings like these, Anandakrishnan says he's an optimist. Even if the loss of the Amundsen Sea Embayment glaciers is unavoidable, other glaciers in Antarctica and elsewhere don't have to endure the same fate. "There are certainly a lot of glaciers that could be saved if you were to take action," he says. Humans can, in other words, slow the melting of the world's ice by combatting climate change, through actions like reducing the use of fossil fuels.

In the end, the loss of glaciers on Antarctica is a global problem. But it's one that can affect life in coastal communities across the planet. Here on the Chesapeake Bay, the way of life in towns like Oxford is tied to what happens to these blocks of ice thousands of miles away. While the science on sea level rise isn't complete yet, it's clear that the general trend presents unpleasant prospects for people who live near the Bay's waters.

Ron Anderson, the toxicologist who lives in Oxford, saw a number of his neighbors lose their homes after Tropical Storm Isabel swept through town. He was in slightly better shape. His house sits about six feet above sea level, which saved it from the bulk of the flooding. Anderson says that he and his wife don't have any plans to move any time soon. But he still worries about what is going to happen in the lifetime of his daughter, who is now in college.

"It might be easier for us to just stipulate in our will that our house be sold versus letting our daughter move in and get flooded in the future," Anderson says. "Because it's a horrible thing. I've seen it happen to many people and I'd hate to see my daughter go through that."

As the Land Sinks

Around the Chesapeake Bay, sinking land is exacerbating the effects of sea level rise

Daniel Strain, *Chesapeake Quarterly*

As tourism slogans go, "Hampton Roads: Where the Land Sinks" probably won't draw in crowds of visitors. But among scientists, that's the reputation that this region of Virginia is building.

Manmade climate change is driving up water levels all around the world. But communities on the Chesapeake Bay, including those in the densely populated Hampton Roads area near the estuary's mouth, have to contend with another threat that worsens the effect of rising water. Across Maryland and Virginia, the land is gradually sinking, a process that scientists call subsidence. These changes are caused by long-term geological shifts occurring across the Mid-Atlantic region. New research also suggests that human activities may be making the situation worse.

Subsidence adds to what is known as relative sea level rise, a term that describes the combined effects of rising oceans and the sinking of land surfaces. It's a bit like a ship going down in a gale: sinking towns dip closer down to the water, making them more vulnerable to storms and flooding. That's reason for concern in an area like Hampton Roads, where some towns already flood during run-of-the-mill high-tide events.

"When the next big hurricane hits, it will be worse because of the land subsidence," says Jack Eggleston, a hydrologist with the U.S. Geological Survey (USGS) in Reston, Virginia.

This subsidence results from natural processes thousands of years old whose effects resemble a game of teeter-totter.

During the last ice age, a massive glacier called the Laurentide Ice Sheet stretched from Canada down into Pennsylvania and New Jersey. The ice was so heavy that it pushed down the land underneath it. At the same time, the land just outside of the glacier's edge — what we now call the Mid-Atlantic coast — reacted like the other end of a playground seesaw: it was forced up into what's called a glacial forebulge.

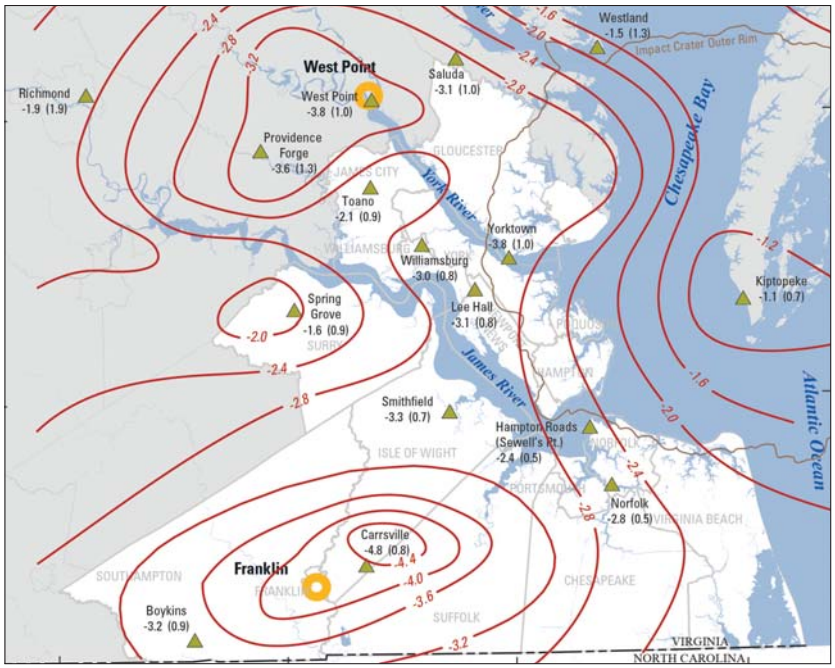
Then, around 18,000 years ago, all that ice started to melt, and the seesaw started to flip back. "Now that the ice has been removed, there's a rebound" in the land to the north of the Mid-Atlantic, says John Boon, an oceanographer and professor emeritus at the Virginia Institute of Marine Science in Gloucester. Similarly, "the forebulge that we have here is . . . going back down."

In Maryland and Virginia, a network of GPS stations, operated by the National Geodetic Survey, has tracked this shifting in the land for several decades. Based on this and other data, researchers estimate that land surfaces around the estuary are falling by around 1.5 millimeters each year because of the ongoing rebound from the last ice age. But some towns on the estuary seem to be sinking a lot faster: the number for the Hampton Roads area is closer to 4 millimeters each year on average.

"This question kept coming up of what was causing this land subsidence," says Whitney Katchmark. She heads up the Water Resources Department in the Hampton Roads Planning District Commission, which advises towns in the region.

The most obvious answer was groundwater withdrawal by municipal water utilities and other users.

To understand why, think of a jelly doughnut. Like



Floodwater seeps onto streets during a high-water event *in the Ghent neighborhood of Norfolk, Virginia (opposite page). Scientists say that patterns of subsidence in coastal Virginia will make floods like this one more common. The rates of land sinking, however, vary from place to place based on how much groundwater towns and businesses draw up, as this map shows. The red contour lines show the rates of subsidence, in millimeters per year, from 1940 to 1971. The fastest sinking sites are centered around the towns of West Point and Franklin. Both communities are home to large paper mills that pull up a lot of water from wells.* PHOTO (OPPOSITE PAGE), DAVID HARP; MAP, U.S. GEOLOGICAL SURVEY

the raspberry filling inside these morning treats, groundwater is stored in aquifers. That's the name for large formations of sand and clay that sit tens to hundreds of feet below the land surface. The Hampton Roads area gets its groundwater from the Potomac Aquifer, a formation that extends from North Carolina up into New Jersey. When you tap a well into one of these formations and draw out water continuously, it's a bit like removing the filling from your doughnut. Like with the pastry, if you remove too much water from an aquifer, the aquifer can collapse down on itself. When it does, the land above it will also begin to sag.

Researchers have observed this phenomenon in action across the country, most notably in the Houston-Galveston area of Texas. There, residents saw the land fall by as much as 10 feet during the course of the 20th century.

Coastal Virginia uses less groundwater than Houston and Galveston but still depends on wells to slake thirsts and support industries. In 2012 the Hampton Roads area, which is home to about 1.7 million people, got about 16 percent of its water from wells, Katchmark says. That added up to around 45 million gallons of groundwater drawn per day.

In 2013, Eggleston and a USGS colleague, Jason Pope, wrote a report issued by the agency on the causes of land subsidence in the southern Bay region — or from Gloucester County, Virginia, on the York River, to the North Carolina border. The report was commissioned by Katchmark's planning district. In it, the USGS scientists summarized a number of existing studies on the connection between groundwater withdrawal and the sinking of land surfaces in Virginia. While a few other factors can influence subsidence patterns to a small degree, a number of lines of evidence point the finger at water usage.

Eggleston and Pope reported, for instance, that areas where the land is falling the fastest tend to line up with where people have pumped out the most groundwater. In all, the scientists estimated that groundwater withdrawal caused about half of the subsidence seen around coastal Virginia during the last several decades. Groundwater withdrawal could also be worsening subsidence in Maryland, but scientists have not studied the problem there as thoroughly as they have in Virginia.

In that more southern state, some small solutions to this problem may be brewing, says Scott Kudlas, director of the Office of Water Supply in the Virginia Department of Environmental Quality (DEQ). In order to safeguard its water supply, the state set up a permitting program for groundwater withdrawal in 1992. Today, businesses and residential developments in coastal Virginia that use more than 300,000 gallons of well water in any one month out of the year are required to apply for a groundwater permit. To put that number into perspective, the average household uses around 9,000 gallons of water in a month.

As of 2013, Kudlas's department had issued close to 170 groundwater permits in the Hampton Roads region. A large number happen to be up for renewal in coming years. That could give the DEQ an opportunity to try to put new caps on how much water those big users draw up, Kudlas says: "A lot of decisions will be made in the next two years."

What's Happening to the Gulf Stream?

The great offshore current could be increasing sea level on the Chesapeake Bay, but not all scientists are convinced

Daniel Strain, *Chesapeake Quarterly*

One of the uncertainties underlying how much sea levels will rise along the Chesapeake Bay comes down to a nagging question: how is the Gulf Stream going to behave?

This famous ocean current is a giant. More than 3,000 feet deep in places and as much as 90 miles wide, the Gulf Stream begins near the Bahama Islands and curls up the East Coast of the United States from Florida to North Carolina. There, it takes a dogleg to the northeast, carrying warm, tropical waters into the deeper parts of the northern Atlantic Ocean.

Because of how much water it moves, the Gulf Stream has a small but noticeable effect on water levels along the Mid-Atlantic, starting at Cape Hatteras in North Carolina. Through a mix of ocean and planetary physics, the current lowers sea levels at sites like the Chesapeake Bay by about three to five feet. If the current weren't there, many shoreline neighborhoods in Maryland and Virginia would be underwater.

Standing in front of a historic church, *built in 1902, Tal Ezer surveys flooding during high tide in the Ghent neighborhood of Norfolk, Virginia. Ezer, an oceanographer at Old Dominion University, sees the connection between floods like these and his research, which focuses on sea level rise. Flooding "affects everyone here in Norfolk," he says.* PHOTO, COURTESY OF OLD DOMINION UNIVERSITY

This relationship has put the Gulf Stream at the center of a scientific debate — one that has large implications for towns across the Chesapeake region. Up and down the Mid-Atlantic coastline, data collected by tide gauges are showing that sea levels aren't just climbing. They're rising at what seems to be an accelerating pace. This rapid uptick goes beyond what researchers have found along the rest of North America's coasts.

Some scientists are putting the blame, at least in part, on the Gulf Stream. The current, they argue, could be losing speed because of manmade climate change — like warming temperatures caused by the greenhouse gases emitted by cars and other human sources. This slowdown, in turn, might be helping to drive up sea levels across a long stretch of the Atlantic Coast of North America. Other scientists, however, contend that it's too early to say whether the Gulf Stream will become a major player in long-term sea level rise on the Chesapeake Bay.

Researchers want to know more about what's happening to the Gulf Stream. A growing body of research indicates that as climate change alters the world's oceans, some of those changes will be felt close to home. "If you are worried about the Chesapeake Bay, you cannot just look at the Bay by itself but its connections to the large-scale climate change in the Atlantic

One of many photos of flooding in Norfolk *that Tal Ezer has taken with his smart phone. High water events along the city's waterfront neighborhoods, like the Ghent, shown here, have become increasingly common since the 1980s.*
PHOTO, TAL EZER.

Ocean," says Tal Ezer, an oceanographer at Old Dominion University. "You have to look much larger."

The Acceleration

Ezer keeps his eye out for those larger connections during his morning jogs. The scientist lives and works in Norfolk, Virginia. Most days, he gets up early to run, picking a route that takes him through town. Sometimes during these runs, he encounters flooded streets and stops to snap a few photos.

These opportunities come often. Norfolk has struggled with flooding over its history, and the situation is only getting worse. Consider one of the city's low-lying neighborhoods, called The Hague. In 2009, a year that saw a big nor'easter hit coastal Virginia, streets in this part of town were flooded for the equivalent of 12 full days. Before the 1970s, the city rarely saw more than two days of flooding in a single year. In some parts of Norfolk today, all it takes is a spring high tide to overflow the city's shoreline.

Ezer presents his photos of Norfolk flooding in talks he gives about his research, which delves into sea level rise. These high-water events, he says, are part of a larger pattern of sea level rise on the Mid-Atlantic coast.

The oceanographer was intrigued in 2012 when a team of scientists at the U.S. Geological Survey (USGS) published a landmark paper exploring that pattern in the journal *Nature Climate Change*. In it, the researchers analyzed sea level rise data taken along the Atlantic coastline by tide gauges. These instruments, often installed off docks, measure changes in water height over time.

When the USGS team dug deep into these records, they found something surprising: on a 600-mile stretch of coast beginning off North Carolina and ending in Canada, sea levels were not only rising, they were rising faster and faster over time.

Between 1950 and 2009, the group found, sea levels in this region rose at about two millimeters per year on average. If you looked at the same sites between 1970 and 2009, however, those rates were much higher, or around four millimeters each year. The shift indicated that at some point in the last few decades, sea level rise on the Mid-Atlantic had kicked into a higher gear.

None of the traditional causes of sea level rise, including melting ice sheets or sinking land surfaces, could explain such a sudden shift.

Less than a year after that first study, two independent teams analyzed tide gauge data using different methods and reached similar results. "We both got to the same conclusion that along the Mid-Atlantic and Chesapeake Bay area, sea level rise is accelerating," says Ezer, who led one of the studies.

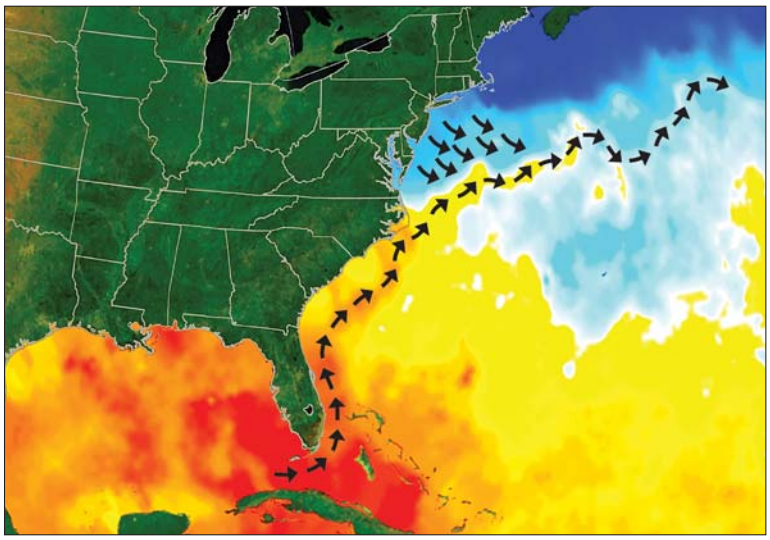
Many scientists suspected that the Gulf Stream was behind this shift.

Bad Behavior

Their suspicion came from their knowledge of the long history of research on Atlantic Ocean currents. The Gulf Stream is just one leg of a larger pattern of circulation in the northern Atlantic. This pattern, called the Atlantic Meridional Overturning Circulation (AMOC), is the ocean's great mixer: it brings warm water from the tropics north toward the Arctic. There, the water cools and sinks, eventually moving back toward the equator. Think of a hamster running around and around its exercise wheel.

Climate change, however, could throw off the dynamics of this system, including the flow of the Gulf Stream. That's because as the planet heats up and ice melts throughout the Arctic, the Atlantic Ocean's northernmost regions will become warmer and less salty. Theoretically, these conditions could make it harder for water carried north by the Gulf Stream to sink, forcing it and the entire circulatory pattern to slow down.

"We are still working out how [the Gulf Stream] is going to behave" as climate change continues, says Hali Kilbourne, a paleoclimatologist at the Chesapeake



The Gulf Stream is shown here *— arrows indicating the stream's flow were added to a satellite image that depicts water temperatures in the Atlantic Ocean. The current carries warm tropical water (orange and yellow) from the Bahama Islands toward the northern reaches of the ocean, where water temperatures are much cooler (blue). The ocean current is one step in a larger circulation pattern called the Atlantic Meridional Overturning Circulation.* MAP, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION VISUALIZATION STUDIO; ARROWS ADDED BY SANDY RODGERS

Biological Laboratory of the University of Maryland Center for Environmental Science.

How the Gulf Stream behaves is a worry because a slowdown of the Gulf Stream could have consequences for towns on the Mid-Atlantic coast like Norfolk. That's largely because of the current's influence on local sea levels.

The effect exists because as the Gulf Stream flows away from the shore near North Carolina, it draws water away from the coast and moves it toward the middle of the ocean. It's the result of how the rotation of the planet distributes water in the Atlantic. This shifting, in turn, causes the surface of the ocean to tilt up off the coast of the Mid-Atlantic — sea levels dip close to shore and rise the farther you get out to sea, like a surf board with its front end slightly higher than its back end.

This tilt in the Atlantic Ocean is tied to the Gulf Stream's speed. The Gulf Stream moves at an average of about four miles an hour. But over periods of months and years, it can also gain speed or slow down for a variety of reasons, such as wind patterns. More than a decade ago, Ezer published research that showed that when the Gulf Stream slows down, sea levels along the Mid-Atlantic rise. That's because the current draws away less water from shore. That, in turn, lowers the tilt of the ocean's surface.

And that's what seemed to be happening along the Mid-Atlantic.

"Clearly the Gulf Stream has been doing something over the last 40 years," says Robert Kopp, a climate scientist at Rutgers University in New Jersey. "You need that to explain what you see in the tide gauges."

The Slowdown

But scientists can't say for sure whether the Gulf Stream is slowing down.

The difficulty stems from the fact that the ocean is a complex place, Kopp says. So many factors, such as natural shifts in wind patterns over the Atlantic, may influence the flow of the Gulf Stream at any one time, he says. And that can make it difficult for scientists to tease out how manmade impacts on the world's climate are affecting the Gulf Stream.

Tal Ezer, however, wanted to get beyond those confounding factors. To begin, he joined up with other scientists at Old Dominion University to analyze data from tide gauges on the Mid-Atlantic. The researchers compared these data to records of how fast the Gulf Stream was moving as measured by an underwater cable off the coast of Florida. Next the scientists employed new statistical tools to try to remove from the data many of the natural influences on the speed of the Gulf Stream, to quantify the portion contributed by manmade climate change.

And the group discovered that "there are signs in the data that this slowdown has already started," Ezer says.

The scientists' analysis suggested that the Gulf Stream had slowed down beginning around 2004, although by how much wasn't clear. The loss of speed also seemed to be closely tied to a recent acceleration in sea level rise in the Mid-Atlantic. The team published its results in 2013 in the *Journal of Geophysical Research: Oceans*.

But some scientists pushed back. Thomas Rossby is a veteran oceanographer and a professor emeritus at the University of Rhode Island. He's also one of the leaders of a scientific study called the Oleander Project, a long-running effort to directly measure the speed and other attributes of the Gulf Stream.

The project relies on an unusual tool: a cargo ship. This commercial vessel, called the *Oleander*, makes weekly trips from New Jersey to Bermuda, crossing the Gulf Stream as it goes. More than 20 years ago, Rossby and his colleagues installed a set of specialized instru-

ments on the ship. These instruments use sound waves to track the motion of water below the boat's hull. It's a bit like how dolphins use sonar to track objects underwater. With every voyage that the Oleander makes, Rossby gets a snapshot of how fast the Gulf Stream is moving.

"Here with the Oleander there are no ifs, buts, or maybes," Rossby says. "We are measuring the Gulf Stream."

And in a paper published in 2014, the oceanographer and his colleagues summarized their analysis of about two decades' worth of data: a big, fat nothing. Based on their observations, the Gulf Stream didn't seem to be slowing down or speeding up. "That's not to say that it won't change at some point in the future," Rossby says. But so far, the Gulf Stream's speed has been "as solid as it can be." The team's results appeared in the journal *Geophysical Research Letters*.

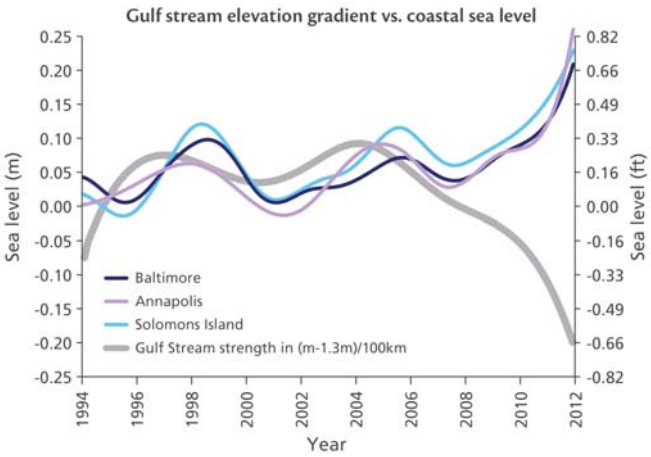
Those results may sound contradictory, but Ezer and Rossby agree on more than they disagree. Neither scientist disputes the fact that sea level rise is accelerating on the Mid-Atlantic. Nor do they shed doubt on the science underlying climate change. How the Gulf Stream will behave in a warmer world, however, is still a new field of study.

"It's a natural progression of science," says Benjamin Horton, a paleoclimatologist at Rutgers who has studied change in sea levels along the Mid-Atlantic coast. "Someone proposes a hypothesis, and we go out and test it."

The differences in Ezer's and Rossby's conclusions may stem largely from differences in how they tested the hypothesis that the Gulf Stream was losing speed. In his research, Ezer used statistics to try to single out what climate change alone was doing to the current. Rossby didn't. Instead, his research focused on how the Gulf Stream's speed as a whole had changed over two decades.

Today, it's common for researchers to turn to math, as Ezer did, to try to find patterns in complex arenas like the oceans, a method sometimes dubbed "big data," says Robert Kopp of Rutgers University. But even the best statistical tools have their limits, he notes. "My preferred approach is [to gather the best] statistics as you can, and then go out and get more data," he says.

Kopp says that there's an alternative explanation for what may have happened to the Gulf Stream. Speed may have nothing to do with it. Instead, the answer may lie in the Gulf Stream's location. Scientists know that



The tilt of the Gulf Stream, *which lowers sea levels along the Mid-Atlantic coastline by about three to five feet, is connected to its speed. According to an analysis by Tal Ezer, that tilt may have begun to dip starting around 2004 (wide gray line) suggesting that the current could be slowing down. At roughly the same time, rates of sea level rise accelerated at sites around the Chesapeake Bay (narrow lines).* GRAPH, FROM UPDATING MARYLAND'S SEA-LEVEL RISE PROJECTIONS REPORT, P. 12

the path of the current's flow can change for natural reasons over months or years, shifting a little to the north or the south. Such wiggles can, in theory, change the effect of the Gulf Stream on sea levels along the East Coast of the United States.

Scientists have gotten hints that the current's path shifted to the north in recent years. Kopp explains that such a move could create higher sea level rise patterns in the Mid-Atlantic similar to those scientists were seeing. The seas might look like they were rising at an accelerating pace — even if the Gulf Stream's speed remained unchanged.

In the end, it will take more time to get to the bottom of the Gulf Stream's behavior, Kopp says. He released his own research study in 2013 on sea level rise in states like Maryland and Virginia. In that paper, Kopp argued that it could take 20 more years of tide gauge data for scientists to know for sure what's happening to the current: is it slowing down, or did it just take a temporary excursion to the north?

For now, the role that the Gulf Stream plays in sea level rise up and down the Mid-Atlantic remains unclear. Ezer feels confident that his finding that the Gulf Stream appears to be slowing will be confirmed. "I think, eventually, that if we have long enough records that all the data will show similar trends."

Until then, there may be a lot more photos of flooding for him to take around Norfolk.

The Perfect Surge: Blowing Baltimore Away

Michael W. Fincham, ***Chesapeake Quarterly***

It sounded like a joke, what could pass for a wisecrack among serious scientists. And this was a roomful of scientists in a serious mood. There were 11 of them and they were trying to figure out how high and how fast the sea level would be rising around the Chesapeake Bay and along the Atlantic coast. The governor of Maryland wanted an updated projection for sea level rise around the state.

The issue at the moment was storm surge. The example was Hurricane Isabel, the storm tide that ran eight feet above normal in 2003, the surge that brought Baltimore its worst flooding in 70 years. The question was, "What can we say about how sea level rise affects storm surge?" This from the group leader, Don Boesch, president of the University of Maryland Center for Environmental Science (UMCES).

Hurricane Isabel put bikes and cars *out of commission when its storm surge flooded Baltimore's Fells Point and Inner Harbor.* PHOTO, COURTESY OF MAXIMILLIAN FRANZ/THE DAILY RECORD

The men on the spot were two oceanographers from UMCES: Bill Boicourt and Ming Li, representing the right brain/left brain halves of the science: Boicourt the observationalist who got into oceanography so he can gear up, get out on the water, and collect data, Li the modeler who likes to pull together reams of data so he can build computer simulations of what might be happening in the real world.

The wisecrack came from Boicourt. If the right kind of storm came up the left side of the Bay, if that storm surge was timed just right, if it moved up the Bay in synchrony with a high tide, with a north-moving wave called a seiche, with a north-moving low-pressure zone, and if the sea level — as predicted — were higher, if all those waves are tuned just right, then there could be big flooding in the upper reaches of the Chesapeake Bay. "If it happens to hit it just right — and it could," said Boicourt, "there are calculations where you can blow Baltimore away with the right tuning."

It got a laugh from the room. And this from Boesch: "We're not going to put that in the report." Which got a bigger laugh.

Comedy depends on timing, and tragedy could also, at least in the case of Baltimore. Think of the timing of waves in the Bay as similar to the tuning of musical instruments. Tuning is the process of adjusting an instrument to one pitch, with an orchestra it's the process of adjusting multiple instruments to one instrument, usually the principal first violin.

The best way to blow Baltimore away is not just the

Don Boesch (standing) brought together experts *from Maryland and the Mid-Atlantic in 2013 to update projects for future sea level rise in the region. Bill Boicourt (far right) explained how a perfect storm surge could threaten Baltimore.* CREDIT: MICHAEL W. FINCHAM

This flooding map shows *areas of Baltimore's Inner Harbor that would submerge during a 100-year storm event. Map overlays such as this are created from FEMA's National Flood Hazard Layer using Google Earth images. For more information on how to create a map, click on FEMA's mapping web page: https://hazards.fema.gov/femaportal/wps/portal/NFHLWMSkmzdownload*
GRAPHIC, GOOGLE EARTH AND THE BALTIMORE OFFICE OF SUSTAINABILITY

perfect storm. It's the perfect storm tide, a tidal bulge that barges up the Bay, keeping time with a strong storm surge and with several other little-known surges, all of them tuned to the same frequency.

To build the perfect storm tide, start with a storm that tracks to the west of the Chesapeake. Like all storms in the Northern Hemisphere, a west-side storm carries counterclockwise winds that will push a surge of water up the mainstem of the Bay. Add to that a high full-moon tide, but think of the tide as a wave, a long wave that crosses the ocean. Each crest may only be two-feet high out in the open ocean, but those high and wide tide crests are hundreds of miles apart from each other. Think of the tidal crest as a bulge of water, a bulge heavy enough to deform the sea floor as it moves across it. The crest moves at high speeds in the deep ocean and as it moves, the sea floor, elastic as a waterbed you just left, rebounds behind it.

As it enters the mouth of the Chesapeake Bay, this long wave feels the bottom, and the friction from a shallow bottom slows it down. Moving north at about 15 knots an hour, the tidal wave takes 11 or 12 hours to move from Norfolk at the mouth of the Bay to Havre de Grace at the head of the Bay.

There's a second kind of bulge that bounces up and down the Bay, but has been little studied in estuaries. Scientists call it a seiche, but Boicourt likes to call it a sloshing. It often starts with the wind blowing water up or down the estuary. The wind from a nor'easter, for example, usually blows water down the Bay, creating a south-moving bulge that flows down past the mouth of the Chesapeake and out to the ocean. That creates a slope in the water surface along the Bay with a low point up north near Baltimore, a midpoint near Norfolk, and a high point, at least in theory, out in the ocean. Water tends to run downhill, both in theory and in fact, so once the wind stops, the water will slosh downhill from that high point, rolling back through the mouth of the Bay headed north toward Baltimore and on to the top of the Bay. Then, like a pendulum, the slosh swings back toward the lower Bay. The natural oscillation period for this back and forth is two days. There's a famous formula behind this estimate.

What if a rotating low-pressure weather system blows north, then south? And what if that two-day oscillation of the low-pressure system matches the two-day natural oscillation of the sloshing cycle? Scientists call that resonance: the effect of the storm and the effect of the slosh will both be magnified. "You are going to get a very efficient transfer of energy," says Boicourt. "And you are going to flood Baltimore."

Let's add another kind of resonance. What if the low-pressure center of the storm is moving up the Bay

Bill Boicourt and former research assistant Tom Wazniak *lower a ScanFish to measure temperature, salinity, dissolved oxygen, chlorophyll, and plankton. When the next hurricane approaches, Boicourt and other oceanographers will launch underwater gliders to capture subsurface temperatures, data that could improve predictions for storm surges.* PHOTO, MICHAEL W. FINCHAM

close to and in sync with the storm surge and with the long wave of a strong incoming tide — that would be an example of a little-studied phenomenon called a Proudman resonance. "If you have low pressure in the atmosphere, that means less air on top of the water," says Boicourt. Less pressure lets a wave grow taller. A low-pressure zone moving in sync with a wave is a rare event, named for the scientist who first identified it, but Boicourt now thinks a Proudman resonance might have been at work during Isabel. It may have helped raise water levels and swell the huge storm tide that flooded downtown Baltimore.

The long wave of the tide, the big slosh of the seiche, the low-pressure Proudman resonance. Add in the storm surge from a major hurricane (and there will be more major hurricanes), get all those waves in tune with each other, like musicians in an orchestra, and you'll amp up the energy of each player. You'll get a symphony that can evacuate downtown Baltimore.

Here's another player: the big squeeze. As a bulge from a storm surge, a rebounding slosh and a high tide moves north, the Bay narrows, and so do its major rivers, creating funnels that squeeze water into taller waves aimed at bayside and riverside cities. During Isabel, upper Bay towns like Annapolis and Baltimore ran higher tides than the mouth of the Chesapeake Bay. And upriver towns like Alexandria and Washington, D.C., saw higher water levels than the mouth of the Potomac River. Taller waves are also faster-moving waves. Remember friction, the bottom force that slows a wave down? As a wave grows taller, friction exerts a weaker force on it. Taller waves move faster than shorter waves.

What if you add sea level rise to the music (and there will be more sea level rise)? All those scientists sitting around a room in Annapolis sent a report to the governor projecting a probable sea level rise around Maryland of 2.1 feet by 2050 and nearly 4 feet by 2100.

If their projections prove true then every surge, slosh, and high-tide long wave would be magnified — but in a non-linear way. It's not a case of simple addition, says Ming Li, the oceanographer who's building models to answer questions like this. Consider the effect on storm surge. According to Li's calculations, if sea level rises 2.1 feet, you add an additional 20 percent to get the actual increase — 2.5 feet — in the size of the storm surge. The 8.3-foot storm tide from the last Isabel grows to a 10.8 foot, a one-story tide that could swamp Fells Point (again), flood the Inner Harbor, and invade parts of the downtown business district.

But the surge from the next Isabel could be larger still. What if the surge from the next Isabel is moving in sync with the long wave and the big slosh and perhaps the rare, low-pressure Proudman effect? As the Bay narrows, the surge grows taller, friction grows smaller, the surge moves faster. And one big bullseye would be Baltimore.

That's a lot of what-ifs that have to hit. "The chances of all those forces combining in sync are perhaps not high," says Boicourt. For most storm surges in most years, you won't get all those players in tune.

But there will be some opportunities for the whole orchestra to play together. Future hurricanes may not be more frequent, but they will probably be more ferocious, say most experts. They will pack more energy, unleash stronger winds, and push higher water levels into the city. Perhaps Isabel was only the overture.

Baltimore might want to move Camden Yards up on Federal Hill.

The Costs
Effects on People and the Land

DAVID HARP

Across the Chesapeake Bay region, diverse communities, both natural and human, are already feeling the toll of sea level rise. Wetlands disappear into the estuary as the water rises. Floods damage homes, businesses, shorelines, and roads. Local residents are looking for outside help and worrying about the future of their communities.

Snapshots from the Edge

In this eroding Eastern Shore region, flooding is a common sight, and not just after big storms.

Rona Kobell, *Bay Journal*

All over low-lying Dorchester County, residents are living on the edge. One skid off the road puts a car in a marsh. Parking in the wrong place during the wrong arc of a tide cycle can lead to a flooded car. Water that used to just graze residents' yards now comes up to the porches; it's just a matter of time, they know, before it comes into the houses.

Here, in the land of narrow marshes and proud working waterfront towns, the high water isn't just coming. It's already here.

School buses can't get down the road like they once did, and those roads need constant repair. Land at the edge of banks is fast disappearing, swept away in tides and storms. Forests are dying, inundated by rising salt water. New homes are being built at least a foot higher than in the past. And storms, particularly tropical systems and hurricanes with their attendant storm surges, push water ever higher along these shores.

But many longtime county residents don't connect the problems to the two underlying phenomena that scientists say lie at the root of rising waters here on the lower Delmarva Peninsula — climate change that raises sea level and sinking land.

They know what they are seeing, but many blame the problem on erosion, or "tides." Many don't want to talk about melting ice sheets or greenhouse gas emissions. They want to talk about fixes today that may help to get the water out of their yards, fixes such as the reconstruction of barrier islands in the Chesapeake Bay.

"I talk very carefully on the Eastern Shore," said Bill Boicourt, an oceanographer who has studied the area's rising waters and is based at the Horn Point Laboratory

at the University of Maryland Center for Environmental Science in Cambridge. Several times a year, Boicourt speaks to church groups and civic organizations about how climate change works, how temperatures and sea level and storm surges are rising while land along the Eastern Shore is sinking. Not everyone buys his message. "I respect their perspective," he said. "They range from an open skepticism (about climate change) to a closed skepticism."

It might seem surprising to find skepticism about sea level rise in Dorchester County. Stretching south from the Choptank River down to the Nanticoke, this low-lying county is laced with rivers, creeks, bays, and swamps that frequently flood the land.

And more high water is coming. A scientific panel concluded in 2013 that sea level on Maryland's coasts is likely to rise over the next century by 3.7 feet and as much as 5.7 feet. The current rate of increase is about twice the national average. Dorchester is especially vulnerable to higher waters because it is the second-lowest-lying county in Maryland (after neighboring Somerset County) and one of the lowest in the United States. More than half of Dorchester is less than five feet above sea level. Prevailing winds blow across the estuary from the northwest, building up wave energy aimed right at the lower Eastern Shore.

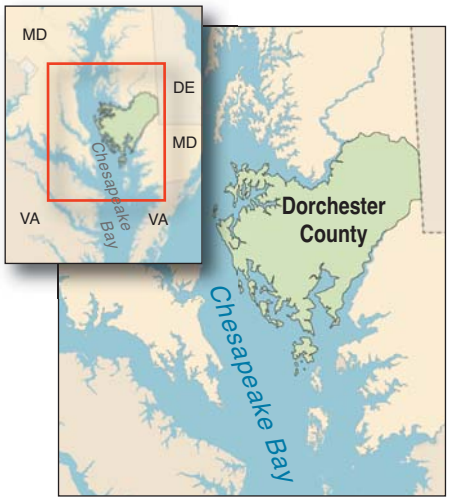
Looking around, it's easy to see what's already gone. On Hooper's Island, residents lose about 24 acres a year. Hooper's was once three islands: the high ground of Fishing Creek, the middle ground of Hoopersville, and the lower island, known as Applegarth. Islanders lost the bridge to Applegarth in a 1933 storm; fewer than 100 residents inhabit Hoopersville now, and more leave every year. Fishing Creek is on relatively high ground, but people there grapple with floods during high tides and even unnamed storms.

Jay Newcomb understands this problem all too well. He's the former president of the Dorchester County Council, the manager of Old Salty's, a popular Hooper's Island restaurant, and a longtime school bus driver in a place where buses never last long because of saltwater damage. Rare among his neighbors, Newcomb does think the rising waters in the Bay are related to melting polar ice.

One day in 2013, near Toddville, children riding his bus took off their shoes and hiked up their pants before wading through high water to get to their front doors. Another day, some children didn't bother riding the bus to school because of flooding from high storm tides. They weren't sure they'd get home.

It's a struggle to maintain the island's roads with the county's $3.6 million annual transportation budget. Trucks rumble down the road to Bishop's Head with fill and dirt and come back empty. The road gets repaired, but then like many other roads, it washes out again.

Septic fields and wells flood, too, and residents must worry about the contents of fuel tanks leaking out in the high waters and contaminating wells and soils.



Growing up in Dorchester County, *James Adkins (opposite page), adjutant general of the Maryland National Guard, explored Wroten Island, where his ancestors once lived and were buried. Today, their graves are underwater in the Chesapeake. And headstones like those shown here on Wroten and elsewhere on the lower Eastern Shore are at risk of being submerged.* PHOTO, DAVID HARP; CHESAPEAKE BAY MAP, ISTOCKPHOTO.COM/ UNIVERSITY OF TEXAS MAP LIBRARY

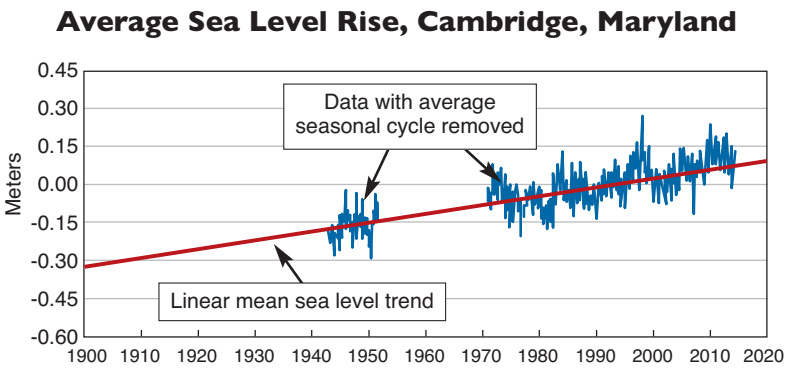
The conditions have prompted many people to leave.

"We have less kids here all the time," Newcomb said. "We used to have three buses taking kids to Cambridge for high school. Now, there's just one bus."

Disappearing trees are another stark example of sea level rise in the region, says Johnny Shockley, a 50-year-old entrepreneur who's stayed in the area to run the Hoopers Island Oyster Aquaculture Company. As a boy he ran along Wesley Church Road, through woods that are now marshes dotted with acres of dead trees, their long, sad trunks graying from the Bay's brackish waters.

Shockley, however, remains a skeptic about whether this is the product of climate change. He knows that scientists have presented evidence that warming temperatures globally are at least partly to blame for Dorchester's higher water. He's just not sure he believes it. "I understand the concept, the reasons why they're saying we got global warming," he said. "But I can't verify what they're saying is true."

Shockley loves his threatened island and wouldn't want to have his oyster farm anywhere else. He's got



Some waterfront property owners *around Maryland regard rising water and erosion as temporary trends. But tide gauges in the Chesapeake Bay have recorded a steady rise in water level, as shown by these data (graph, above) from a gauge on the Choptank River in Cambridge, Maryland. Here, sea level is shown on a relative scale. Extrapolating, the Cambridge data indicate a total rise of 1.14 feet in 100 years. During the 35 years that Harold Cartright (right) has lived on Hooper's Island in Dorchester County, his property has been flooded by Hurricanes Fran, Isabel, and Sandy. On a utility pole on his property, he recorded their names — and heights. Here he points to a tag for Isabel in 2003. "I want this as a permanent record," he said, "of what hurricanes did to this property."* PHOTO, DAVID HARP; GRAPH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

breakwaters reinforcing his waterside facility, which offers a panoramic view of what Shockley's father, Dorsey, describes as "waterfront and waterback." A tough businessman who's won just about every award for his innovations — even one from the White House — Johnny Shockley becomes surprisingly emotional remembering his now-lost boyhood woods. "Those trees are dying. It's obvious," Shockley said. "Where the marshes meet the woods, the marsh is taking over."

What are the options? Many of the residents along Dorchester's low-lying shoreline believe that the state and federal governments could do more to protect county residents. In particular, they advocate building up barrier islands in the Chesapeake that once offered this stretch of the Dorchester shoreline protection from storms and erosion. Many of these islands are gone, and others that remain are washing away.

A decade ago, the Army Corps of Engineers raised hopes of residents by proposing to use sediment dredged from the Bay's shipping channels to replenish two of these disappearing islands, Barren Island and neighboring James Island. A rebuilt Barren Island would help shield the shorelines along Hooper's Island. And an expanded James Island would protect Taylor's Island at the northern end of Dorchester County. The Corps has enjoyed success using this approach to replenish another barrier island, Poplar Island, offshore from Tilghman Island. Once a shrunken remnant measuring just four acres, Poplar now holds more than 1,000 acres of restored land. To do the same for Barren and James, the estimated price tag: $2.8 billion in 2008.

For years, funding for this proposed Mid-Chesapeake Bay Island project has been stalled. "Back in 1990, the Army Corps of Engineers did a study. They recommended protection for certain hot spots. Now, 24 years later, they haven't done a thing," lamented Bruce Colson, who owns the Taylor's Island Family Campground along Bay Shore Road, just 15 miles north of Hooper's Island. "It seems like it takes the government so long to get anything done."

The delays have cost Colson. He owns 15 acres, according to his deed. Five are now unusable, having been swallowed by rising water. Colson, too, says the sea level is not rising. He blames his problems on erosion.

As vice president of the Dorchester County Shoreline Erosion group, he leads a citizen organization that advises homeowners on options for property protections. There are state tax credits for shoreline protection, for example, as well as assistance for building a living shoreline (a buffer of natural vegetation, more environmentally friendly than hardened sea walls). The group also has been lobbying for the Corps to begin the Mid-Chesapeake Bay Island projects.

Now there's new hope. The Water Resources Reform and Development Act, which President Obama signed into law in June 2014, authorizes the work.

To reduce erosion along Dorchester's shoreline, *the government should build up two nearby barrier islands, Barren and James, says Bruce Colson (left), who owns the Taylor's Island Family Campground. On Hooper's Island (right), a dump truck plows through high water being pushed off the Bay and across the narrow bridge that connects the upper and middle parts of the island. Sea level rise allows storms to push water further inland.* PHOTOS, DAVID HARP

Congress hasn't appropriated the money, however. And despite the hopes of residents that the work may protect their shores, the project is listed as an environmental restoration project, rather than a hurricane and storm damage risk reduction project.

For those who can't armor their property against higher waters, the only other option is moving. That's what Jim Brown decided when the water began reaching the upper step in the home he shared with his girlfriend, Cynthia Thompson, near the Taylor's Island campground. Now they live in nearby Woolford — not high ground, but higher.

Brown, a construction worker, came to Maryland from North Carolina to rebuild homes after Tropical Storm Isabel struck here in 2003. An avid fisherman, he takes his boat, the Rock-Crazier, to the coves and inlets around James Island, searching its Jurassic-like terrain for wildlife. One day in 2013, he was fishing along a small beach at James Island. The next day, the beach was gone — erosion, Brown said.

Each spring, on the first nice day, Brown sets off for James to see what was lost during the winter. At times, he's estimated the loss at more than 100 feet. Trees grow out of the water, like dead sticks, to mark the places no longer there.

"She's washing away. Simple as that," Brown said. "She's washing away."

Perhaps no one understands both the devastation the floods can bring and the pull of these low-lying lands better than James Adkins. When Hurricane Sandy arrived in 2012, it flooded parts of Dorchester, and in neighboring Somerset County, it inundated almost all of Crisfield. As adjutant general of the Maryland National Guard, Adkins had the job of leading the Guard's rescue operation in Crisfield during a flood disaster that drove 500 people to shelters and damaged 700 homes.

Born in Dorchester County, Adkins grew up exploring the woods and nooks on Wroten Island, where his family came from. The island is near Crapo and Toddville, near marshes holding stands of dead trees. Today, the graves of Adkins' ancestors are underwater in the Chesapeake.

Adkins still comes back to the lower shore. He and his wife Mary Anne keep a condominium high above Crisfield's City Dock. From there he can see the Chesapeake glistening and the lights still on in the large peeler crab operations below. But also he sees a city in tatters. Handwritten "for sale" signs adorn many shop windows. The former Sterling Hardware Building on Main Street sold at auction for just $30,000 in June 2014. It had previously sold for $700,000. The city still calls itself the "seafood capital of the world," but it hardly resembles the thriving waterman's town where Mary Anne Adkins grew up in the 1960s and where her father operated a railroad that carried the Bay's bounty to market.

Sandy "surprised a lot of people," James Adkins said, and served as a wake-up call to longtime lower-shore residents. "We used to see loads of people who would come down here," Mary Anne Adkins said. "I don't see a lot of people anymore."

Asked how the counties can address the one-two punch of rising waters and sinking land, Adkins was quiet. Then, he said, "Can you really stop nature?"

The Future of Blackwater

Scientists are working to save the marshes at a wildlife refuge that's become a symbol for sea level rise

Daniel Strain, *Chesapeake Quarterly*

The observation deck at the edge of Lake Blackwater in the Blackwater National Wildlife Refuge gives visitors a view of an ecosystem on the move. Matt Whitbeck stands at the end of this wooden walkway now. It stretches over an expanse of green marsh grasses, putting tourists right in the middle of a vibrant wetland. Around the deck, you can spy red-winged blackbirds, buzzing insects, and the occasional jumping fish.

Whitbeck is a wildlife biologist at the Blackwater refuge, which occupies around 28,000 acres of forests, marshes, and water in Dorchester County on the Eastern Shore of Maryland. Today, he's interested in the transitions that are occurring across this landscape. Over the decades, Lake Blackwater — which occupies around 4,000 acres at the center portion of the refuge — has grown bigger and bigger, Whitbeck explains. And acres and acres that were once marshland have been covered in water, killing off the plants there.

But new marshes are forming here, too. Whitbeck points to a line of sickly looking loblolly pine trees in the distance. Because of the encroaching water, the area is now too salty for them, he explains. When those trees die, however, marsh plants will grow in around them.

"You can see, essentially, the habitat transition in action. I mean, you can see that line of dying trees. You can see the marsh encroaching," Whitbeck says. "It's happening in front of our eyes."

The driving force behind these transitions is sea level rise — brought on by manmade climate change and the sinking of land surfaces around the Eastern Shore. Rising waters have claimed more than 5,000 acres of marshland in the refuge since it was established in the 1930s. That's close to half of Blackwater's historic wetlands.

Whitbeck and others recently launched a new effort to stem the loss of marshes throughout Blackwater, which is operated by the U.S. Fish and Wildlife Service. Their strategy will take advantage of the ability of marshes to spread and move — just like you can see

Signs of sea level rise, *like these dying trees, can be seen in many locations around the Blackwater National Wildlife Refuge, located in lower Dorchester County, Maryland.* PHOTO, DAVID HARP

them doing from the observation deck. The success or failure of this venture could influence how natural resource managers work to conserve wetlands across the Chesapeake for decades to come.

Poster Child

Rick Abend first bought property in lower Dorchester County not too far from the Blackwater refuge in 1972. It started off as a weekend getaway spot for Abend, who lived on the western shore of Maryland. Now retired, the 64-year-old owns and operates a tree farm on this 106-acre plot near Madison, Maryland.

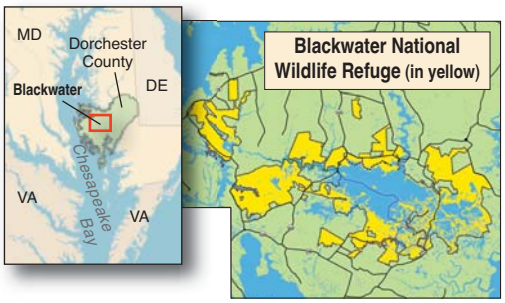
During his early years in lower Dorchester, Abend, who likes to hunt, mainly had his eye on the region's abundant waterfowl. But he says that living near the refuge gave him an education in wetlands. Today, he serves as president of the non-profit group Friends of Blackwater.

"I was looking for ducks and geese. But now I've just seen so much more with the egrets and herons," Abend says. "[Blackwater] has really opened up my eyes to what other things benefit from marshes."

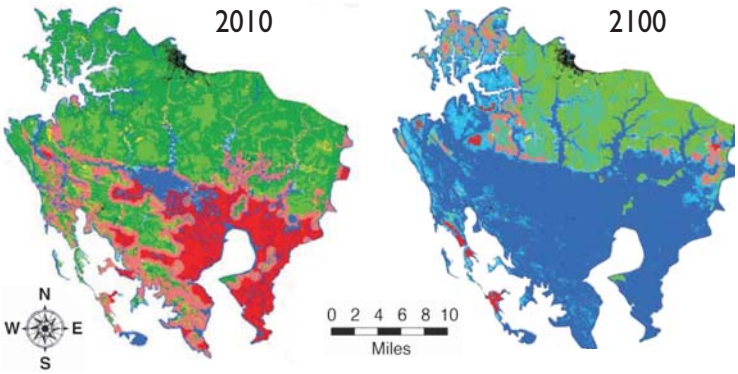
There are currently around 9,000 acres of wetlands in the Blackwater refuge. These marshes are home to an array of wildlife, as Abend suggests. But there are other benefits to having these ecosystems around, scientists say. Marshes help to improve water quality in the Chesapeake Bay by trapping nutrients and sediments flowing from rivers toward the estuary. They can also protect shorelines from the crashing waves generated by big storms. And they are important nurseries for various commercial fish species.

But around the Bay, these natural communities are also in danger of drowning. Scientists estimate that water levels in the Chesapeake could rise by three feet or more by the end of this century. And that's a problem for Blackwater. Under that scenario, nearly all of Blackwater's existing marshes could be underwater by 2100.

The scale of the marsh loss here has made Blackwater into what many consider a poster child for the toll of sea level rise on the Bay. The refuge has certainly felt the effects of rising waters sooner than other wetland locations around the estuary. One big reason is that in the 20th century, Blackwater was hit especially bad by colonies of an invasive species of rodent called nutria. These buck-toothed animals have a voracious appetite and stripped bare whole patches of wetlands in the region until they were eradicated from the refuge about a decade ago.



Blackwater Marsh Loss



Standing on an observation deck *in the Blackwater National Wildlife Refuge, biologist Matt Whitbeck (above) looks out over acres of green marsh grasses. Today, the refuge is home to bald eagles, red-winged blackbirds, and an array of other wildlife. But based on projections by scientists (visualizations, bottom) much of the marshland in and around the refuge (red and green) could become open water (blue) by the end of the century.* PHOTOS (OPPOSITE PAGE AND ABOVE), DAVID HARP; CHESAPEAKE BAY MAP, ISTOCKPHOTO.COM/ UNIVERSITY OF TEXAS MAP LIBRARY; MAP OF BLACKWATER, U.S. FISH AND WILDLIFE SERVICE; VISUALIZATIONS OF MARSH LOSS, BLACKWATER 2100 TEAM

Despite Blackwater's early-bird status, scientists are seeing indications that sea level rise may be taking a toll on other wetlands around the Chesapeake as well. According to data from the Maryland Department of Natural Resources, there are currently around 187,000

acres of "irregularly flooded marsh" around the Maryland portion of the estuary. That's a type of saltwater marsh that is common in Blackwater. The department estimates that nearly 90 percent of those wetlands could vanish by 2100 because of sea level rise.

Blackwater is "unique in a certain sense. Things happen earlier there than in the rest of the Bay," says Court Stevenson, a wetland ecologist at the Horn Point Laboratory of the University of Maryland Center for Environmental Science. "But I think other wetlands in the Bay are probably going down the road that Blackwater was at 50 or 60 years ago."

Which makes it all the more important that scientists and natural resource managers discover how to help marshes here to survive the rising waters.

Marsh Migration

In 2013, Matt Whitbeck, the refuge biologist, helped to write a report laying out a plan for securing the long-term survival of marshes in and around the Blackwater refuge. He co-authored the report, *Blackwater 2100: A Strategy For Salt Marsh Persistence In An Era Of Climate Change*, with Erik Meyers, vice president of an Arlington, Virginia-based conservation group called The Conservation Fund, and David Curson, director of bird conservation for the Maryland and Washington, D.C., chapter of the National Audubon Society.

To save these wetlands, Whitbeck and his colleagues proposed moving beyond traditional conservation strategies focused on protecting marshes in their current locations. The Blackwater refuge, for instance, installed a weir to reduce saltwater flow into its marshes. Instead, natural resource managers and others should work to help marshes to spread to new locations in and around the refuge, the report said.

"Things are changing, and they're changing fast here on the refuge," Whitbeck says. "We've got to figure out how to work with these changes."

One way is to help marshes to do what they have done for a long time. Sea level in the region has gradually risen for thousands of years, and geologic evidence collected from around the Bay shows that marshes have responded in two ways. They have grown upward by collecting enough sediment and decomposed plant matter to keep pace with the rising water. Marshes have also moved away from the water, farther inland.

Moving inland will likely be crucial if marshes are going to survive rising sea level. As the water rises, the lowest-lying marshes, or those closest to the Bay, will become submerged and die. Meanwhile, the Bay will move inland to dryer and higher land. This influx of salty water will kill off forests like the lines of loblolly pines near Lake Blackwater. Marshes, in turn, will replace those forests.

"The whole process has been going on for a long, long time," Whitbeck says. "The marshes we have here are currently riddled with old tree stumps."

The *Blackwater 2100* authors wanted to find out where the wetlands that exist today in the Blackwater refuge could flee to in the future. To do that, the team employed computer simulations based on elevation data and projections about how fast the Bay's waters are likely to rise.

In order to migrate successfully, and quickly, marshes need to have access to wide-open landscapes free of obstacles — obstacles like roads, towns, seawalls, and even natural features like steep hills. Ecologists and planners call such open spaces "migration corridors." Two such corridors stuck out in the *Blackwater 2100* analysis. The first, around the Nanticoke River at the east end of the Blackwater refuge, would be able to hold around 2,300 acres of marshes in 2100, the authors estimated. The second, around Coursey Creek to the west, could hold around 3,600 acres.

The hope is that by identifying these corridors, the refuge and conservation groups can focus their resources on preserving habitats in these areas. Many natural resource managers around the country looking to preserve coastal marshes elsewhere have jumped on the same bandwagon. The thinking goes that you can preserve wetlands in a region simply by giving them the chance to move into open land.

Scientists say this approach could help the marshes, but it also has its limits. One of the biggest is that it's not clear whether wetlands will be able to migrate fast enough to keep ahead of current rates of sea level rise. Marshes "can adapt and have adapted and built as sea level has risen since the last ice age," says Andrew Baldwin, a wetland ecologist at the University of Maryland, College Park. "It's more a question of can they deal with a higher rate of sea level rise."

No one has estimated how fast wetlands in Blackwater will be able to migrate as the Bay's waters rise. The *Blackwater 2100* team, however, acknowledged in their report that marsh migration may not be able to offset the full brunt of sea level rise on the refuge.

Still, if only some marshes wind up surviving to 2100, that's still better than none. The big challenge in

A tree farmer in Dorchester County, *Rick Abend (above) says that flooding has killed off pine trees across the county. The trees can't handle the influx of salt water. Eventually, dead snags, like these pictured near Lake Blackwater in the Blackwater refuge (above, right), are the only reminder that areas that are now marshland were once healthy forests. "We're just winding up with more and more open water all the time," Abend says.* PHOTOS: (LEFT), DAVID HARP; (RIGHT), DANIEL STRAIN

protecting as many of these natural communities as possible comes down to an old question in conservation: who owns the land?

Another Harvest

And it's a tricky one. The Coursey Creek migration corridor that Whitbeck's team identified, for instance, stretches over 14,000 acres. Today, only 3,182 acres of that land are protected from development in some fashion, although not all of these acres will make good marsh habitat. The rest is mostly working farmland, where marshes may not be welcome.

In order to address potential conflicts like these, the Maryland Department of Natural Resources (DNR) is spearheading an effort to protect marsh habitat into the future. The goal is to preserve land in the most important migration corridors for marshes along Maryland's coastline so that if wetlands need to migrate, they will face fewer obstacles. One of the key tools in this program will be formal agreements called conservation easements.

Under such easements, property owners, often farmers, volunteer to limit the amount of development that can occur on their land. In return for these and other conservation actions, the state pays the landowners a lump sum, usually equal to about 40 to 60 percent of the market value of their property. Proponents of conservation easements argue that they're a win-win: farmers can continue to work their land, while the state conserves upland areas to which marshes may be able to migrate in the future as sea level rises.

So far, the department has purchased only one easement, on a 221-acre property in lower Dorchester County. But other groups, including The Conservation Fund, have secured a large number of conservation easements around the Blackwater refuge. In the Coursey Creek migration corridor, there are currently around 812 acres of privately owned land under easements. And there are many more in the Nanticoke corridor: around 2,300 acres of land are protected by these agreements.

That's still shy of the roughly 5,000 acres that the *Blackwater 2100* authors highlighted as necessary to support future marsh habitat. The Conservation Fund, for its part, is pursuing opportunities to increase those numbers by securing conservation easements and supporting other conservation methods, says Erik Meyers, a vice president with the organization.

Because these efforts are just beginning, it's not clear how popular they will be with Marylanders on the Eastern Shore and elsewhere. At the moment, residents of lower Dorchester County are happy to have the Blackwater refuge around, says Nancy Hastings. She's a resident of the town of Church Creek and heads up a local volunteer effort called the South Dorchester Good Neighbor Project.

Hastings says that a large number of her neighbors like living in Dorchester for the same reason that wetland plants and wildlife do: there's plenty of room and not that many people. The big refuge in the heart of the region helps to keep that way of life from disappearing, she says. Lower Dorchester residents "don't want building. They don't want development," Hastings says. "Blackwater is a way of keeping things rural."

But Dorchester residents, like Rick Abend, are regularly reminded of the Bay's encroachment on the marsh and surrounding land. On the east end of the farmer's property, which is by the water, new trees that he planted haven't grown well — victims of the salt water that is creeping farther and farther inland.

When it comes to Abend's crop, "I imagine I will cut it before the saltwater gets it...but that's going to be years from now," he says. "I've got plenty of time for a couple more harvests."

Loss of Coastal Marshes to Sea Level Rise Often Goes Unnoticed

Karl Blankenship, ***Bay Journal***

Cormorants keep watch *over the misty waters of King Creek, a tributary of the York River.* PHOTO, DEBBIE STEINBERG, VIRGINIA INSTITUTE OF MARINE SCIENCE

For years, some researchers at the Virginia Institute of Marine Science sensed that the tidal wetlands in the York River, which flows past their Gloucester Point campus, were changing — but they couldn't say exactly how.

To find out, a research team surveyed all wetlands along the York and its two tidal tributaries, the Pamunkey and Mattaponi rivers, using sophisticated GPS equipment. They compared their results, gathered during the last few years, with detailed maps developed in the late 1970s, when fledgling regulatory programs sought to stem human disturbance to tidal marshes.

They discovered the marshlands had been disappearing before their eyes.

Altogether, the river lost almost nine percent of its tidal marshes in just a little more than 30 years — 1,794 acres since the late 1970s — largely due to sea level rise. That's about a third of the dramatic acreage loss experienced at the Blackwater National Wildlife Refuge in Maryland since the 1930s.

But, being spread over a larger area, the losses had gone largely unnoticed.

"It is always harder to get recognition of the impacts of cumulative losses than a catastrophic loss," said Molly Mitchell of the Virginia Institute of Marine Science (VIMS) Center for Coastal Resources Management, who analyzed the survey results. "A hundred square feet here, a hundred square feet there — none of them

by themselves are really critical, either from an ecological standpoint or a human impacts standpoint. It's when you start to add them up that it becomes more important."

The findings confirm that the insidious increase in water levels of just a few millimeters per year recorded in the Chesapeake region adds up to big losses in river systems.

Researchers have encountered challenges to understanding marsh losses except in a few well-studied areas such as Blackwater, which has lost 5,000 acres. In part, that's because even as marshes are lost, new marshes are being created — in low-lying areas, marshes can slowly migrate onto former upland areas as water levels rise. And, sediment deposited by rivers build up new areas that can become marshes. That makes it hard to understand the true status, and trends, of the Bay's vast marshlands.

The York River survey found that, indeed, new marshes were created in some places — 3,080 acres in all. But that was more than offset by losses, which totaled 4,875 acres.

The survey also found that marsh losses were not uniform. While all major marsh types declined in acreage, fringing marshes — long, narrow bands of wetlands along shorelines that are often only a few feet wide — were especially hard hit, suffering a net loss of nearly 30 percent. Although they are narrow, fringe marshes play important roles in many rivers, buffering shorelines from waves and filtering nutrients in runoff before they reach the river's main channel.

Wider marshes are important for a variety of mammals — in colonial times, they were a haven for black bears — as well as birds. But fringe marshes are thought to be especially important for many aquatic species, such as blue crabs, terrapins, and juvenile fish. Those species often only use the few feet of habitat along the edge of a marsh, and the interior area of larger marshes are off-limits, Mitchell said. "But a fringe marsh, they can really use most of it."

Fringe marshes are likely to be the first lost in the York and other systems because of rising sea level, she said. The land behind them often rises abruptly from the river, minimizing the potential for the marsh to migrate into the upland. And they are more likely than more expansive marshes to have hardened shorelines, either bulkheads or riprap, behind them. These shorelines not only restrict the movement of marshes, but also reflect wave energy back into the wetland.

The project also raised concerns that low-salinity tidal marshes, which declined by slightly more than ten percent during the study period, are also at great risk. Low-salinity marshes are typically the farthest upstream, and being upstream, they typically don't face the same wave action as saltier marshes, which protect themselves by growing taller, more deeply rooted plants on their exterior edges. Low-salinity marshes, in contrast, have shorter plants on the edge, which offer less protection and can be more vulnerable as water levels rise and expose upstream areas to more wave action.

"Those low herbaceous plants don't break wave energy," Mitchell said. "They don't have an issue with wave energy up there. So the structure of the two types of marshes is really different."

Tidal marshes are one of the defining features of the Chesapeake Bay landscape, in part because the Delmarva Peninsula creates a sheltered system that protects them from ocean wave energy, allowing them to flourish. As a result, the Bay is ringed by nearly 300,000 acres of tidal marshes — about two-fifths of all tidal marshes found on the Atlantic Coast.

Those marshes absorb nutrients, filter water, buffer shorelines from erosion, and serve as food for waterfowl and habitat for myriad aquatic and terrestrial species.

With a disproportionately high rate of sea level rise in the region, many of those marshes — and the species that depend upon them — are especially vulnerable.

Exactly what marsh losses mean for the Bay is hard to say. It's clear that marshes play an important role in buffering adjacent land from waves, and recent studies suggest the loss of fringe marshes could hurt species such as diamondback terrapins. But quantifying their exact value to fisheries and for services such as removing nutrients from rivers and streams remains elusive, said Carl Hershner, director of the of VIMS Center for Coastal Resources Management.

For instance, freshwater marshes are thought to be important for anadromous fish spawning — but it's difficult to say how important. Similarly, limited work suggests fringe marshes remove nitrogen coming from upland areas, but it's hard to say that happens in all — or even most — settings, Hershner said.

"We can say with some degree of confidence that we aren't going to have nearly as many wetlands as we do now," he said, "but what that implies for the Bay is a whole lot harder to demonstrate."

Some clues about the impact of tidal wetland losses

King rails, which live in freshwater *tidal marshes, are already suffering a steep population decline.* PHOTO, BRYAN WATTS, CENTER FOR CONSERVATION BIOLOGY

may come from marsh birds. The Chesapeake historically has been an important area for marsh birds because of its disproportionately high amount of tidal marshes, said Michael Wilson, an ornithologist at the Center for Conservation Biology, based in Williamsburg, Virginia. But that role will likely diminish in the coming century as the region faces a faster-than-average rate of sea level rise.

In the York River, the king rail, a bird species that is already suffering steep declines, and the small population of coastal plain swamp sparrows, which live in a narrow band of vegetation along freshwater tidal marshes, are likely to vanish, Wilson said.

That mirrors the problems faced by marsh birds in general, which have faced declining habitats for the last century — a trend expected to accelerate with sea level rise. Estimates by Wilson and colleagues show that by the end of this century, some rare species such as the clapper rail, Virginia rail, seaside sparrow, and marsh wren could lose 70 to 80 percent of their populations within the Bay if water levels rise one to two meters as expected.

Some species such as black rails and saltmarsh sparrows — which are already struggling in the region — are even worse off. They will likely be lost from the Chesapeake.

Populations of black rails, the smallest species of rail, have already declined sharply in recent years and are considered endangered in both Virginia and Maryland. "I don't see a good future for them here in the Bay because of sea level rise and salt marsh loss and salt marsh transformation to low marshes," Wilson said. "That's a species we could lose in our lifetime."

As dire as they are, Wilson said the marsh bird predictions are likely conservative — ornithologists often see marsh birds disappear even faster than they expect as the birds' habitat is lost outright or disturbed by nearby development. Part of the reason, Wilson said, is that areas thought to be "safe" are actually becoming inundated more frequently than was thought as water levels rise.

"There's areas out there that we believe have habitat and look fine on paper," he said. "But those areas are getting drowned out from an increase in the number of extreme high tide events. There's this silent killer that's ruining habitat by disrupting the breeding in those marshes. Birds are nesting, but their nests are getting drowned out repeatedly."

VIMS scientists hope to ultimately expand the survey techniques used on the York to other rivers to get a better handle on what's happening across Virginia. Their results may also offer some insights for management, Mitchell said. For instance, it might become more important to be more protective of existing marshes. "Reducing anthropogenic impacts might be even more important than we think it is," she said. "It is something you can control."

And alternative shoreline protection technologies, such as living shorelines, could get even more emphasis, especially near vulnerable fringe marshes. "They might be more important than we realize because they protect a resource that is being disproportionately impacted," Mitchell said.

Chesapeake's Rising Seas Place Extra Burden on Communities of Color

Rona Kobell, *Bay Journal*

Exclusivity defines the Maryland shoreline: large homes with gazebos and private beaches, quaint towns chockablock with designer handbags and chic dresses, restaurants serving $25 crab cake dinners.

Less seen are the tight-knit African-American communities that have endured since slavery. They are off the main roads. They are lower to the ground — often on land they got because few others wanted it. Vulnerable to both rising waters and declining populations, they struggle for resources to fix roads, rebuild homes, repair churches, and protect what remains.

The Rev. James Lane, *associate minister of Enon Baptist Church of Deliverance in Crisfield, Maryland, advocated for recovery assistance for the city's African American population after many homes were flooded and damaged by Superstorm Sandy in 2012. Lane's house was one of them — volunteers helped him to repair it.* PHOTO, EMILY WILL, MENNONITE DISASTER SERVICE

In the 1800s and early 1900s, the most desired settlement areas were away from the Chesapeake Bay's edge. Low-lying land close to the water was often unsanitary, its adjacent marsh filled with mosquitoes and its soil less hospitable for farming. The land flooded; its residents occasionally became sick from drinking polluted well water or from contact with sewage and industrial waste. A water view from on high was fine, as long as residents didn't get too close.

Because no one wanted that land, it went to African-Americans, who farmed its banks and plied its waters for fish, crabs, and oysters. They could buy it cheaply, and they did, building country churches and seafood plants that still exist there today.

Sea level rise doesn't discriminate based on race or income, and certainly the tony areas of the Eastern Shore have reason to worry based on recent predictions. But sea level rise places an added burden on the African-American pockets of the Chesapeake region — communities that are both lower to the ground and less wealthy.

Four years ago, Christy Miller Hesed, a University of Maryland doctoral candidate in anthropology, began to examine these communities. She worked to document their histories, and to determine better ways to connect them with the resources available to more affluent white communities. Those include grants for shoreline stabilization and protection, money to rebuild after flooding, and low-interest loans for property improvements. She's visited more than a dozen communities and interviewed more than 30 residents about their experiences living on the water's edge.

"Some would say, 'well, people just need to move,'" she said. "But it's not as easy for the communities that are so rooted in their place."

African Americans came to Maryland as slaves work-

ing on the vast tobacco plantations. After emancipation, many left for opportunities in Baltimore. But many also stayed. On the western shore just south of Annapolis, Frederick Douglass's son developed Highland Beach as a summer resort for African Americans at a time when they couldn't visit whites-only beaches. In Prince George's County, Maryland, developers turned the tiny community of Trueman Point into an incorporated summer resort in 1929. They named it Eagle Harbor.

Even as these communities provided a sense of identity for the African Americans who settled there, many were vulnerable because they did not incorporate. (Both Highland Beach and Eagle Harbor did, and they are among the smallest incorporated towns in Maryland.) Without incorporation, communities didn't have their own building codes or zoning rules that might help lessen the risk of coastal flooding; instead they were beholden to laws that governed the whole county. For unincorporated areas, assistance is harder to come by. State grants often require a government sponsor or a match; counties are more likely to support populous towns that need help than small hamlets with few voters. That meant residents had to help themselves in times of disaster; the Methodist church helped feed the hungry and coordinate rescues in floods. They were proud, self-reliant communities, where men worked the water and women picked crabs and raised families.

Now, many of those towns face the dangers of rising waters. Residents of Smithville, in lower Dorchester County, Maryland, worry about losing the graves at their church cemetery.

Within the nearby city of Crisfield, the African-American community felt forgotten in the aftermath of Superstorm Sandy, when much of the rebuilding attention and dollars went to more affluent areas downtown.

Somerset County, where Crisfield sits, has the lowest median income in the state. More than 40 percent of Crisfield's population is African American, according to the 2010 Census. Many African Americans live in the Tyler Street area, where water quickly flooded the streets. In the city, more than one-third of public housing units were declared uninhabitable.

Rev. James Lane, a one-time mayoral candidate and public housing commissioner and associate minister of Enon Baptist Church of Deliverance in the Tyler Street community, said African-American leaders had to keep pushing for help. The recovery money, he said, was headed downtown, to the condominiums that newcomers had bought. He and others stepped in to make sure African-American enclaves in the city were not left behind.

"There's a population in our city that needs attention, and they're not always able to express that, and my job was to make sure their voice is heard," Lane said. "If we had not rallied, we would still be in dire straits. We're still trying to fight our way back to survivability."

Miller Hesed wanted to make sure that, as communities adapt to sea level rise, the policymakers don't forget about the African-American towns. With funding from the National Oceanic and Atmospheric Administration (NOAA) and support from her advisor, University of Maryland anthropology professor Michael Paolisso, she organized a workshop in summer 2014 at Blackwater National Wildlife Refuge. In attendance were representatives from African-American churches, heads of environmental organizations, and state and federal policymakers who have a hand in granting money for adaptation and mitigation. On the agenda were the needs of unincorporated African-American communities for help in applying for this government assistance. Bringing together the parties involved in this issue was important, Miller Hesed said.

Kate Skaggs, a community planner for the Maryland Department of Natural Resources, said what she heard at the Blackwater meeting and others since then is helping to inform policy, albeit slowly. Skaggs is funded by NOAA to help communities improve their resiliency to coastal hazards like flooding. She said she's had many conversations with different partners about how to help unincorporated communities access the resources they need. The partners are trying to come up with more creative ideas on how to make that happen, whether that means relocating residents or building structures to help them stay where they are.

"There's no final end goal," she said. "We don't know what fixing looks like. We don't know what that means. This is our job, to continually work on these things."

Miller-Hesed said she plans to graduate within the next couple of years and would like to publish her research in some scientific publications and maybe even get it out to a wider audience.

"The people," she said, "have such rich stories to share."

Vanished Chesapeake Islands

Dozens of islands listed in historical records have disappeared — washed away by erosion and sea level rise

Annalise Kenney and Jeffrey Brainard, *Chesapeake Quarterly*

When the Chesapeake Bay was settled in the 1600s, colonists began to record in county land records the names of hundreds of islands, some of which they would farm and call home. Islands called Turtle Egg Island, and Sharps Island, and Parker's Island.

But today, more than 400 of those islands in Maryland and Virginia cannot be found on modern navigational maps of the Bay, wrote William Cronin in his 2005 book, *Disappearing Islands of the Chesapeake Bay*. The islands apparently were eroded away, a process accelerated by storms and sea level rise.

In this photograph, the last house on Holland Island *was still standing — in 2010 it collapsed into the Chesapeake Bay, a victim of sea level rise and erosion.* PHOTO, DAVID HARP

A few of these islands contained active settlements of watermen and other workers, although it's difficult to pin down in historical records how many. Some of the islands were only farmed. Archives of historical societies around the Bay do offer stories and records describing the rugged people who lived and worked on tenuous specks of land — like those on Maryland's Holland Island. Residents were forced to abandon the eroding island in the early 1900s. Before they left, many families disassembled their houses and barged them to the mainland of the Eastern Shore, where some of these structures still stand today. (Additional examples of disappeared islands appear below.)

Holland and some other islands in the Chesapeake persisted well into the 19th and 20th century, only to shrink relatively quickly over a period spanning only a few decades. Why did they fade away so quickly? Two scientists at the University of Maryland, Michael Kearney and Court Stevenson, offered some insights in a study published during the 1990s in the *Journal of Coastal Research* — an analysis that Stevenson says he thinks still holds up today.

Rapid Decline after 1850

The scientists studied long-term patterns of sea level rise in the Chesapeake Bay. They wanted to study a period of time longer than the one covered by tide gauges, which were first deployed in late 1800s to record water levels in the Bay and elsewhere. Using various methods, Kearney and Stevenson were able to estimate the rate of sea level rise in the Chesapeake going back to the start of colonial settlement in the 1600s. To do this, the scientists studied the rate of vertical growth of marshes, which they used as an indicator

This 1877 map shows Holland Island *(identified as "Hollands Island") to the southwest of Bloodsworth Island, in Dorchester County, Maryland. Holland Island once supported 360 people and 60 homes, but most of the population moved off by 1918 as the island eroded away.* CHESAPEAKE BAY MAP, ISTOCKPHOTO.COM/UNIVERSITY OF TEXAS MAP LIBRARY; HOLLAND ISLAND MAP, JSCHOLARSHIP IMAGE FROM AN ILLUSTRATED ATLAS OF TALBOT AND DORCHESTER COUNTIES, MARYLAND, 1877, USED COURTESY OF SHERIDAN LIBRARIES OF JOHNS HOPKINS UNIVERSITY

of the rate of rise of the surrounding sea level. The scientists also analyzed old maps to estimate historic rates of land loss on Bay islands.

Kearney and Stevenson concluded that sea level in the Chesapeake rose relatively slowly from the 1600s until about 1850. After that, the rate increased sharply and more than doubled after about 1930. The Bay's sea level has risen about a foot over the past century.

The scientists noted that the acceleration was sudden enough that residents fled eroding and submerged land after having built houses and stores only a decade earlier.

Why did sea level accelerate so substantially in the Chesapeake after 1850? Kearney and Stevenson cited a general warming in global temperatures since that year as the Industrial Age unfolded. Emissions of greenhouse gases by industry eventually helped cause warming temperatures worldwide; the results included warmer oceans and rising sea levels globally. Additional factors particular to the Chesapeake added to the increase in sea level here, Kearney and Stevenson wrote. For example, groundwater withdrawals may have increased the rate at which the Bay's land was sinking, exposing more of the islands to the rising sea.

Small islands, and those at low elevation, would have been the most vulnerable to erosion. According to the land records described in Cronin's book, about one third of the 400 islands measured 10 acres or fewer.

Four hundred islands seem like a lot of lost land and memories. However, that number may have been inflated by a lack of precision in the old land records. Some of the 400 islands may have been recorded more than once in property records under more than one name.

Here are snapshots of six vanished islands that were known to have existed and that left behind a legacy beyond the land records — stories of persistence and work and roots that are now gone.

Holland Island: Picking Up and Moving Away

Holland Island, off Dorchester County, Maryland, was home to watermen who dredged oysters in the heyday of the Chesapeake's oyster fishery in the 1800s. By 1910 the island held nearly 360 people, 60 homes, seven stores, a church, and a two-room schoolhouse, according to records. But as the 20th century began, westerly waves in the Bay were edging closer to the islanders' wooden clapboard homes.

The families noticed, and began moving away. The late I.T. Todd, Jr., an early owner of the MeTompkin Bay Oyster Co. of Crisfield, Maryland, was one year old when his family left the island in 1918. Today, his son, Casey, owns the MeTompkin company and tells stories about when and why the family left.

"My grandmother knew it was time to go when she could throw her dishwater in the Bay," Casey Todd says. "The year before they left the island, their house was on the edge of the higher side of the island. The water had come right to their doorstep."

Board by board, the islanders tore down their school, church, houses, and stores and rebuilt them in the nearby fishing towns of Crisfield and Cambridge. "[Watermen are] working people," Todd says. A small remnant of Holland Island remains today, but the last remaining house, long abandoned, crumbled into the Chesapeake in 2010.

Today, erosion continues to eat away at other remaining, inhabited Bay communities, like Maryland's Smith Island.

"People talk about sea level rise, but for us, living

here for generations, this is nothing new," Todd says. "We've had erosion and sea level rise for 200 years. The seaside communities have been dealing with it. … We can literally watch it."

Sharps Island: Vacancy in a Hotel

Sharps Island, off Talbot County, Maryland, was once home to a three-story, Victorian-era hotel, according to William Cronin's book.

Built in the late 1800s by Miller R. Creighton, a shoe manufacturer from Baltimore, the hotel had a long boardwalk and steamboat pier. By the early 1900s, erosion had claimed enough of the island that it was closed and torn down. Its lumber was carried off to build houses on nearby Tilghman Island. By 1963, the island had vanished.

In 1950, a group of people, *dressed in attire from the early 20th century, posed for a photo on a small speck of land, all that remained of Sharps Island. It once measured as much as 700 acres and was home to a hotel and farms.* PHOTO, COURTESY OF THE HANKS FAMILY

Turtle Egg Island: Pirates of the Chesapeake

Some now-vanished islands, like Turtle Egg Island in Dorchester County, provided hideouts for pirates who plagued the Chesapeake region in the 1600s.

One infamous pirate named Roger Makeele appears in Maryland records in January 1685. Makeele and his crew of nearly 20 men and women plundered Chesapeake Bay vessels, towns, and Native American settlements from Tangier Sound in Virginia to the Choptank River in Maryland and reportedly some western shore homes in Maryland. When the Maryland Council issued a warrant for Makeele, the pirate fled the region for the sounds in North Carolina, another haven for pirates of the time.

"Swan Isle" and "Puddiford's Chance": Rewards for Servants

Small islands in the Chesapeake were bequeathed to indentured servants as early as the 1670s, William Cronin wrote. These servants were an important part of the colonial community. People who could not afford to travel to the New World had the option of signing themselves into servitude for a designated period of time. When their indentured time ended, the servants were given land, clothing, and farming supplies in order to establish themselves as free men.

In 1670, land records indicate that a man named Thomas Hooten received "Swan Isle" at the end of his period of servitude. Another servant, David Puddiford, was given "Puddiford's Chance" in 1672. The islands provided in those gifts are now gone. Swan Isle was located off Hooper's Island; the location of Puddiford's Chance is unknown.

Parker's Island: Newcomers Arrive, then Move Again

Erosion has led to high rates of erosion on the Eastern Shore of Maryland and Virginia because prevailing westerly winds push water southeast across the Bay. However, some of the disappeared islands were on the Bay's western shore.

In the 1850s, ten Eastern Shore watermen moved their families across the Chesapeake in search of new oyster grounds. They had discovered the Bay Shore Bar, a huge natural oyster reef off Anne Arundel County. To fish it, the families settled on Parker's Island, likely named for William Parker, a prominent Anne Arundel County settler.

But soon after the Eastern Shore settlers arrived, they realized their island was eroding away. The settlers relocated to the mainland, founding the small waterfront community of Deale, Maryland.

Sources of information about these islands: Holland Island, interview with Casey Todd and Dorchester County Historical Society; Sharps Island, Swan Isle, and Puddiford's Chance, Disappearing Islands of the Chesapeake Bay, William Cronin, Johns Hopkins University Press; Parker's Island, Anne Arundel County Historical Society.

Annalise Kenney was a Maryland Sea Grant communications intern in summer 2014.

Rising Sea Level Swallowing Red Knot's Migration Stopovers

Shorebird is first bird to gain Endangered Species Act protection primarily because of climate change

Karl Blankenship, *Bay Journal*

When it comes to endurance athletes, few can match the performance of the rufa red knot. The 5-ounce shorebird may fly 19,000 miles annually from its wintering grounds at the southern tip of South America to its summer breeding grounds in the Canadian Arctic and back again.

The red knot often flies nonstop for thousands of miles before landing on narrow sandy beaches where it forages for mussels and clams or, in Delaware Bay, feasts on recently buried horseshoe crab eggs, sometimes doubling its weight in a matter of days.

That migration has gone on for thousands of years, but its future is uncertain. Red knot populations have plummeted 75 percent since the 1980s, leading the U.S. Fish and Wildlife Service (USFWS) in December 2014 to list it as "threatened" under the Endangered Species Act. That designation means it could become

endangered — threatened with extinction — within the foreseeable future.

The knots' long migration puts them at various risks all along their route. The birds are threatened by coastal development; shoreline stabilization, that reduces beach area; invasive vegetation; aquaculture; and other activities that take place along the coasts. In some cases, the introduction of peregrine falcons may be taking a toll on migrating birds. During migration, they are also hunted at some stopover sites, including some Caribbean Islands.

The red knot may fly 19,000 miles annually *between its wintering grounds at the southern tip of South America and its summer breeding grounds in the Canadian Arctic. During its stopover in the Chesapeake Bay region, the bird feeds on horseshoe crab eggs (above).*

PHOTOS OF THE RED KNOT (OPPOSITE PAGE AND ABOVE), GREG BREESE, U.S. FISH AND WILDLIFE SERVICE

But the red knots' biggest challenge, according to the USFWS, is climate change. Warming temperatures will affect breeding and wintering grounds, along with some food supplies, while rising sea levels in coastal areas — including the Mid-Atlantic — will squeeze beach habitats during migration.

It is the first bird to gain Endangered Species Act protection primarily because of climate change. The birds' migration is so strenuous that their leg muscles, gizzard, stomach, intestines and liver all decrease in size in preparation for migration, while their pectoral muscles and heart increase in size. Because it takes days for the birds' digestive system to regenerate, foods consumed during stopovers need to be calorie-rich and easily digested.

The birds do the trip repeatedly: One bird, banded in Argentina in 1995 was nicknamed Moonbird because it logged enough miles to fly to the moon and at least halfway back during 21 years of migration. But the strenuous journey takes a toll, and human activities all along the way add to the difficulties. For the largest group of migrating birds, the ideal stopover historically was Delaware Bay, where they gorged on the eggs of horseshoe crabs, which are laid on the beach just as the red knots arrive during spring migration. But the overharvesting of horseshoe crabs greatly diminished that food supply, and the number of red knots stopping at Delaware Bay fell from 60,000 annually in the early 1980s to fewer than 20,000 in recent years, according to the USFWS.

The USFWS credited the Atlantic States Marine Fisheries Commission for recent actions aimed at curbing horseshoe crab harvests, though it said it was difficult to say whether those actions would lead to a rebound in red knots. And, a number of environmental groups that have long sought Endangered Species Act protection for the birds contend that the ASMFC's actions still fall short of what's needed to protect the bird.

"Now that they've been listed as threatened, it's time to make serious changes to horseshoe crab management and put a halt to their decline," said Jason Rylander, senior attorney for Defenders of Wildlife. "We've waited far too long for this decision, and red knots are paying the price."

Delaware Bay is not the only migration stopover, nor the only one where red knots face a challenge. Virginia's barrier islands are the second most important stopping point in the region, hosting about a third of the migrating red knot population. While the number of red knots at Delaware Bay declined sharply over the last 30 years, the numbers using Virginia's barrier islands had remained steady — until recently.

Results of an annual red knot barrier island survey conducted by the College of William and Mary Center for Conservation Biology and The Nature Conservancy is showing a decline along Virginia's coast as well. Bryan Watts, director of the Center for Conservation Biology, said that could reflect the rufa subspecies' broader population decline, but it's also possible that the barrier islands are facing their own food problem.

The islands were never an important area for horseshoe crabs, but as the islands migrate toward land,

marshes behind the islands retreat, exposing a rich layer of peat during low tides which provide an abundance of mussels and clams for the birds. The red knots' preferred food in that area is the blue mussel, but Watts said that species has undergone a dramatic decline because of climate change. It is extremely sensitive to warm temperatures, and the blue mussel's range is retreating northward at a rate of 7.5 kilometers per year. Virginia is now at the southern edge of its range.

"If that continues, it is like pulling the rug out from under the knots," Watts said. "They will get here, but the blue mussels won't be here to feed on anymore."

In addition to altering the available food supplies along the migration route, the changing temperatures are also affecting the northern breeding grounds, according to the USFWS. The breeding grounds are getting more dry, and their vegetation is changing. Some also believe that predation is increasing.

Changing temperatures also threaten to create "timing mismatches," in the food supply where the arrival of food sources — such as the deposit of horseshoe crab eggs — no longer coincides with the arrival of migrating birds.

The potential stopover habitat for red knots once ranged from North Carolina to New Jersey, but beaches are being lost to coastal development. "The places that they had available to them for foraging 50 to 100 years ago were much greater," Watts said. "Now they are being squeezed into smaller and smaller places, and they are having to do the best they can in what's left, basically."

The Virginia barrier islands are unique because they are mostly owned by The Nature Conservancy, USFWS, and the state of Virginia. "The barriers are only two percent developed," Watts said. "If you go up to the Jersey shore, it is 45 percent."

If that stretch of good, but contracted, habitat suffers from a food shortage because of the decline of blue mussels, it could cause problems similar to what the birds encountered in Delaware Bay with the horseshoe crab. "It's a concern that we have only recently identified, but it is looming," Watts said.

Sea level rise from climate change may further constrict the beach habitats available for red knots, though its impacts will be felt over a longer period of time. Data in the USFWS listing decision showed the mid-Atlantic region suffering from some of the greatest rates of sea level rise in the red knot's range.

Beaches may be inundated faster than they can regenerate as they migrate inland. Barrier islands are also at risk. They naturally migrate toward the mainland, but faced with the combination of more rapid sea level rise with more frequent severe storms, the islands "may disintegrate rather than migrate, representing a net loss of red knot habitat," the USFWS said.

Another concern, according to the service, is the rapid increase in the hardening of shorelines that typically accompanies development. Constructed bulkheads aimed at protecting land from being eroded by rising water levels also lead to a loss of beach habitats. About 40 percent of the coastline within the red knot's range is already developed, and much of that is already stabilized through bulkheads, levees, breakwaters or other structures that reduce or eliminate beach habitats, the service said. "The quantity of red knot habitat would be markedly decreased by a proliferation of hard structures," according to the USFWS.

While red knots, like most shorebirds, are typically associated with the Atlantic Coast, some also venture into the Chesapeake where they use sandy habitats, but they have never been surveyed or studied as much as those along the coast, Watts said.

"They do use the Bay even though it is not flatly recognized as supporting red knots," he said. "They come through here every year. Obviously it is not at the scale of Delaware Bay."

Watts considers the Mid-Atlantic to be a "neighborhood of staging areas" where red knots stop and refuel before continuing north, but where Delaware Bay has been dominant. But the Chesapeake could become more important to the birds if populations in Delaware do not recover, and those on Virginia's barrier islands continue to decline.

The birds are capable of sampling food supplies in different places and making adjustments in where they go, Watts said. "That is how they survived for thousands of years." It could result, he said, in neighborhoods like the Bay becoming more important over time — if its beach habitats keep pace with sea level rise.

The Response:
How People Are Adapting

DAVID HARP

For those who live in low-lying areas, sea level rise doesn't leave a lot of options: abandon the land or adapt to higher waters. Families deserted Holland Island and Sharps Island and dozens of other islands that now live on only in memories and on old maps. For those who would stay, there are some options: better storm forecasts, better flood preparation, and various old and new forms of flood control engineering.

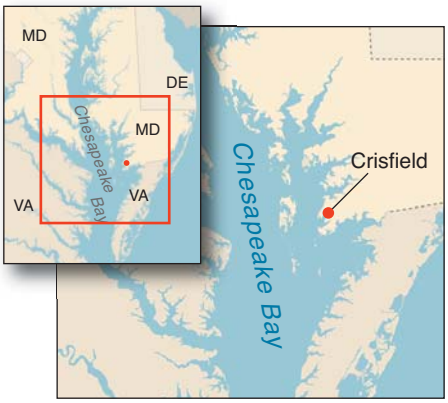
The Storm over Surges

When Sandy Came to Crisfield

Michael W. Fincham, ***Chesapeake Quarterly***

Every September John Barnette starts lifting all his crab traps out of the wide lower reaches of the Wicomico River. He motors up to a series of wire cages designed to catch summertime peeler crabs. Each cage is tall enough to stick up out of the water, and raising them out of the river, an annual autumn ritual, is hard work, best done when the temperatures are cooling and the Chesapeake Bay is beginning to turn clear and the blue crabs are heading south. The white haze of summer is gone and so are most of the late-day thunderstorms, but in 2012 he was keeping close track of weather forecasts. Autumn can bring large, late-season storms to the Chesapeake.

A waterman all his working life, Barnette is a lean man in his mid 50s, who has close-cropped hair, a strong jawline, and strong opinions about water safety. When he's not catching peeler crabs and working his oyster leases, Barnette heads up his county's Swift Water Rescue Team, a group of volunteers who try to save people from drowning, especially during storms and floods. One of his opinions is that even a small hurricane could easily submerge the lower third of his home county. Another is that sea level is rising and hurricanes may soon do even more damage around here. A largely flat, somewhat marshy slice of Maryland's lower Eastern Shore, Somerset County is bracketed by water on three sides: the



John Barnette (red jacket) leads *the Somerset County Swift Water Rescue Team into the flooded streets of Crisfield (opposite page) during Superstorm Sandy in 2012. Working with a small jon boat and the big trucks of the Maryland National Guard, the team brought out residents trapped by the floods unleashed by the storm surge.* PHOTO (ABOVE), COURTESY OF THE SOMERSET COUNTY SWIFT WATER RESCUE TEAM; PHOTO (OPPOSITE PAGE), COURTESY OF SALISBURY NEWS, SBYNEWS.COM; CHESAPEAKE BAY MAP, ISTOCKPHOTO.COM/ UNIVERSITY OF TEXAS MAP LIBRARY

Wicomico River on the north, the Pocomoke on the south, and the Chesapeake Bay on the west. Nine years earlier, he saw waters rise six feet on a Tropical Storm Isabel storm tide and submerge much of Dorchester County just north of here.

At each of his traps, Barnette has to winch an empty cage up onto his small boat and begin dismantling the nets and the net poles that run between the cage and the riverbank. Shouldering the poles, he slogs back into the marshes where he stands his poles up and leans them together. As he glides away from each site, he can see the tops of his net poles sticking up out of the tall marshes like tentless teepees.

By October, Barnette was dredging oysters and checking in with members of his rescue team. A tropical depression in the Caribbean was turning into a tropical storm named Sandy. By the time it hit Jamaica, Sandy was a Category 1 hurricane, by the time it hit Cuba and Haiti, it was a Category 2. As it moved north up the Atlantic coast, NOAA meteorologists tried to define the structure of the storm: Was it a hurricane? A tropical storm? A post-tropical depression? A wintertime low-pressure area? Or perhaps all of the above.

By the time Sandy reached the Chesapeake region, Barnette and his rescue team had reason to relax. The storm was running north along the ocean side, staying well east of the Chesapeake Bay, a track that usually drives water out of the Bay. The Eastern Shore, it seemed, faced little threat from a storm surge.

Sandy, of course, quickly became famous as a superstorm when it moved ashore up north in New Jersey. On October 29, it began pushing a historic storm surge through the state's seashore towns and pouring water into the streets and subways and suburbs of New York City. Down south in tiny Mount Vernon, Maryland, an unexpected phone call came in to the volunteer fire department. Could Barnette bring his Swift Water Rescue Team down to Crisfield, Maryland? "We've got people who need to be rescued," said the caller. "We've got flooding like we've never seen before."

It's not been the best of times for scientists trying to predict the worst of times. Around the Chesapeake Bay the worst of times are usually brought on by hurricanes, tropical storms, and nor'easters. They bring high winds, power outages, and flooding — much of it from storm surges and storm tides, both of which will come in stronger and higher as a result of rising sea level. Over the last 20 years, scientists with the National Weather Service (NWS) have sharpened their predictions for hurricane tracks but they have not made as much progress on their forecasts for hurricane intensity, says John Billet, science officer for the NWS Wakefield office. For storm surges, a spinoff of storm intensity, their forecast models have missed the mark during three recent hurricanes: Isabel in 2003, Irene in 2011, and Sandy in 2012.

What's missing from their models? To predict the risk and reach of hurricane storm surges, research scientists test out various experimental models and federal forecasters run operational models, dozens of models every day, using supercomputers to crunch data — a lot of data. The numbers come from buoys and balloons and aircraft, from ships and satellites, and they record air pres-

Better forecasts for hurricane storm intensity *is the focus for Bill Boicourt, an oceanographer with the University of Maryland Center for Environmental Science.* PHOTO, DAVID HARP

sure, wind fields, wave actions, tidal levels, and temperature swings in both the atmosphere and the ocean. Stuffed with data and interlaced with equations, the models are supposed to suggest where storm surges will hit and how bad the flooding will be.

The results, however, have been uneven. In their post-storm review, the National Weather Service found that the storm surge from Isabel in 2003 ran one to three feet higher in the Chesapeake than NWS predicted, especially in the northern Bay. Its forecasts for Irene and Sandy were off even more. They overpredicted the surge for Irene, and for Sandy they underpredicted how much water would sweep into Crisfield.

The science community learned a lot from those storms, says Bill Boicourt, a physical oceanographer with the University of Maryland Center for Environmental Science who works closely with forecasters with the National Weather Service. "That's another way of saying we blew the forecasts."

Predictions about storm surges in the Chesapeake usually begin with some basic physics about hurricanes and some basic geography about the Bay: hurricanes are tropical cyclones, large low-pressure systems that spin with a counterclockwise rotation, creating high winds and carrying heavy rains; the Bay is a long, narrow line of water running north and south. Hurricanes moving up along the east side of the Chesapeake usually drive water southwards down the Bay. Storms moving along the west side drive water northwards up the Bay. West-side hurricanes are much less frequent than east-side storms, but they do much more damage. As the Bay narrows to the north, it creates a natural funnel that squeezes incoming storm surges, raises water levels and expands the reach of surge-related flooding. The same funnels are found in each major river. During Isabel, water levels in Washington, D.C., were higher than they were at the mouth of the Potomac River.

"Isabel was a surprise," says Boicourt, in part because it was the first major storm in decades that tracked to the west of the Bay. It arrived in 2003, 70 years after the great August Hurricane of 1933, and it nearly matched the damage done by this legendary storm of the century. The 1933 hurricane entered the Chesapeake during the high point of a strong high tide, a collusion that helped create huge storm tides and surges and extensive flooding. Isabel, however, entered the Bay region on a much weaker high tide, but it still managed to hit many of the high-water marks from 1933. Sea level, as measured at Hampton Roads, had risen 1.35 feet in the region in 70 years. Isabel's storm surge flooded large tracts of Maryland's Eastern Shore and drove waist-high water into the downtown streets of Annapolis, Baltimore, Alexandria, and Washington, D.C.

Both Irene in 2011 and Sandy in 2012, on the other hand, were east-side storms. That's usually a less damaging storm pattern, but forecasts for their storm surges also proved problematic. The storm surge height during Irene fell 50 percent *below* model predictions, says Boicourt — but the storm surge during Sandy swept in at 15 percent *above* predictions. Storms passing to the east usually drive water down the Bay, and Sandy seemed no exception — at first. As Sandy passed by Maryland, water levels began dropping in Baltimore and Annapolis and along the western shore of the Bay. But unexpectedly they began rising along the lower Eastern Shore, especially in Crisfield.

It was an embarrassing moment for forecasters. The National Weather Service was predicting a two-to-four-foot surge for the lower Chesapeake but a five-foot surge was rolling into Crisfield. "We didn't expect that much to come across [the Bay]," says Billet, the NWS meteorologist. As the storm approached, Boicourt, the academic oceanographer, was getting questions about possible flooding. "I told people not

to worry about Sandy," says Boicourt. "I was wrong."

"Sandy was a watershed event," *says crabber and oysterman John Barnette, who headed up the Somerset County rescue team that responded to the flooding of Crisfield in 2012.* PHOTO, MICHAEL W. FINCHAM

John Barnette was not feeling well prepared about Crisfield. When the call for help came in, he met up with three team members of the Swift Water Rescue Team down at the Mount Vernon Fire Department. They hooked the 15-foot jon boat to the back of the big Chevrolet SUV and set off under low, wet clouds for the windy 25-mile drive down rain-slick roads.

His team, in his opinion, was well trained but poorly equipped. He'd run regular practice sessions during the year and had his team work with the University of Maryland Fire and Rescue Institute. It was that little flat-bottomed jon boat that bugged Barnette. Some inflatable Zodiacs, big, buoyant, and better balanced would be helpful. When a county official, nervous about the approach of Sandy, asked what gear he needed, Barnette told him, "It's too late, we can't go to Walmart and get it."

Driving into Crisfield, his team saw trees down, power lines down, a cemetery buried in gray water, its white gravestones sticking up in the flood like soldiers standing at attention. Water in the streets: ankle deep in places, knee deep, waist deep. Cars with water over their hoods, homes turned into islands. They found other rescue teams already working the flood: one group drove all night from South Carolina, hauling Zodiacs and a trailer full of extra equipment; the state police and the marine police were there, and the Maryland National Guard had rumbled into town with Humvees and trucks, most of them big, five-tonners. A city official gave Barnette and his team a list of names and addresses, people to be rescued. The list was two pages long.

Barnette drove into the flood as far he could, then launched the jon boat and tied it behind a big five-ton National Guard truck. Wading down Somerset Avenue, Barnette and his team began working the list, sloshing up to doorways and porches, loading people into the boat and ferrying them two at a time back to the Guard's big truck. With a Zodiac, Barnette thought, they could be ferrying six adults each run. When the rising water reached the truck's exhaust pipe, the driver put on the brakes, turning the big brown truck into another island in the stream. The rescue team kept wading through the streets in their bright yellow rain suits, ferrying people through the darkening water as the wet gray light began to wane.

Six months after Sandy, the question came politely to Bill Boicourt: "Am I right in saying that the models for Superstorm Sandy in the Chesapeake failed to predict the inundation of Crisfield?"

The occasion was a day-long conference. Eleven scientists from five states were camped around a quadrangle of long tables, settled behind their laptops, trying to come up with new projections for future sea level rise. There were PowerPoint presentations, and catered lunches, and for the oceanographers in the room, there were those questions about Crisfield. With sea level rising, accuracy in storm-surge forecasting was going to become even more critical in the near future.

The answer also came politely. "I'm going to be very careful about this," said Boicourt. In the days after Sandy had finished with Crisfield, he had gone back through the data and the storm surge models. With water levels dropping on the western shore, why did a five-foot storm surge roll east through Crisfield? It's an important question in an era of rising sea level: this historic fishing town, once the second largest city in Maryland, sits at the narrow end of a skinny peninsula surrounded by water on three sides. With many of its streets sitting less than three feet above current sea level, the place barely sticks above the waters of the Bay.

In his search through the storm data, Boicourt found what he was looking for: an explanation for an unexpected eastward surge of water. The prime mover, Boicourt said, was "the wrap-around wind" from Sandy. When the eye of the storm moved ashore in New Jersey, the size of its rotating cyclone was so large that the winds circling along its outer rim reached south all the way down to Maryland. In the western end of the state, those winds met a winter storm from the Midwest and started a blizzard, dropping two feet of snow in the mountains of Western Maryland.

There's hope that more accurate forecasts will help communities prepare for the stronger storm surges that can come in the near future.

Farther east, the bottom curve of Sandy's cyclone sent winds blowing out of the northwest and straight down the long reach of the Potomac River. Those winds pushed water out of the river, shoving it eastward across the Bay toward Crisfield.

The result, said Boicourt, was a "cross-bay setup," a slope in water levels with the high side on the eastern side of the Bay. This kind of setup was unusual, but it was probably not a one-time event. When Boicourt went further back, looking at the data and models for Hurricane Irene, a much smaller, east-side storm that hit a year earlier, he got another surprise: "Sure enough," he says, "there was a bulge on the eastern side of the Bay for that hurricane also." A small bulge that was easy to overlook — for a small storm.

It sounds like a simple answer, almost too simple: wind drove the surge across the Bay. But getting good data on wind energy, understanding its effect on water energy, and getting the data into models are not simple tasks. "We don't know how to translate accurately the wind-as-measured-over-water into actual stress delivered to the wavy surface," said Boicourt. "That's still a fuzzy thing."

Working the flooded streets of Crisfield in the fading light, John Barnette watched a National Guard truck back up and impale itself atop a fire hydrant hidden below the floodwaters. The broken hydrant began draining the town water supply, the Guard began sending other trucks to offload the evacuees from the truck, and Barnette kept his rescue team working. They turned the static, stuck truck into another island, a relay station where they could bring evacuees to wait under cover for the next pickup.

With winds gusting to 90 miles per hour, with trees still falling, with the light finally gone, all the teams were called in by 7:30. Barnette's group, by his estimate, brought out almost 40 people. More than 200 people had been carried out in all. They were trucked to a Red Cross shelter 20 miles up the road in Princess Anne. By the end of the day the shelter held 500 people, most of them driven out of their homes by power outages and by a storm surge that ran stronger than anyone expected.

Were there lessons from Sandy? When predictive models fall short in their forecasts about storm intensity, communities like Crisfield have to scramble to find help and evacuate people. And scientists have to scramble to answer questions. What data were missing from their models?

Nearly two years after Sandy, Bill Boicourt was trying to line up small boats during the summer of 2014, hoping for some hurricane action along the Mid-Atlantic. He wanted to measure water temperatures in the ocean in the middle of a hurricane. Boats in the 25-to-40-foot range might do the job: they were small enough to rent cheaply, big enough to carry some expensive research gear, fast enough to get back to port in a hurry.

Some of the missing data were real-time temperatures from real-world hurricanes: the right numbers for water temperatures, numbers taken at different levels, both surface and subsurface, and at different times during a storm's progress. According to an analysis published by 48 researchers, the NWS forecasts for Irene and Sandy did not include the right data about a subsurface layer of cold water. The shifts in that cold-water pool, they said, played a role in weakening Irene and strengthening Sandy. When scientists went back later and inserted the right numbers in the widely used Weather Research and Forecasting Model (WRF), the model suddenly clicked: it accurately described the storm surges from Irene and Sandy.

How do you get water temperatures during hurricanes? Boicourt and his collaborators have a plan: when a hurricane arrival is seven days away from the Mid-Atlantic, they will go into heavy watch mode. At

The flooding of Crisfield highlighted the need *for well-trained and well-equipped first responders based in Somerset County. The work of the county's swift water rescue team led to fast funding for two large new Zodiac boats, new dry suits, and additional training.* PHOTO, COURTESY OF THE SOMERSET COUNTY SWIFT WATER RESCUE TEAM

four days out, Boicourt and his crews will load their boats, then head out of Ocean City, Wachapreague, and Virginia Beach. Four to five miles offshore, they'll unload into the water a "light buoy," a 300-pounder that can measure temperature, salinity, and wave action and radio the data back to shore during the storm's passage. In one site, probably Wachapreague, they'll also launch an underwater glider, a torpedo-shaped tube that can capture subsurface temperatures as it goes. "Then we'll get the hell out of there," says Boicourt.

Other oceanographers will be unloading buoys and launching gliders in Massachusetts and along the south Jersey shore. Like most contemporary oceanography, this is a collaborative project with researchers working at the University of Maine, the Woods Hole Oceanographic Institution, Rutgers University, and the University of Maryland.

There's excitement about the project, at least among oceanographers. And there is faith, the faith of the scientist: dig up some more data, the right data taken at the right time, feed it into their models, and this time they can get everything right. They can churn out more accurate forecasts for storm intensity and storm surges.

There's also hope, hope that more accurate forecasts will help communities prepare for the stronger storm surges that can come in the near future. Crisfield is still there at the end of a skinny peninsula, and it still sits barely above sea level. And sea level keeps rising.

There were also lessons learned at the local level. Two months after the Crisfield flood, John Barnette got new boats for the rescue team, two Zodiacs big enough to carry eight people at a time. The funding started with an unexpected call, this one from the Maryland Emergency Management Agency. What did the water rescue team need? The team got new boats, new training, new members, and new, bright-red dry suits for all the volunteers.

"It's inevitable it's going to repeat itself," says Barnette, still a man with strong opinions about the Crisfield flood. "The sea level is rising here at a rate faster than it is anywhere else in the world, it seems. And the intensity of the storms will only get worse. But the biggest tragedy of all will be if we fail to learn from it."

In November he motored out on the Wicomico, headed out to dredge oysters, and found the tall green marshes lying flat along both sides of the river, as flat and bald as his backyard after the snow melts. There weren't enough trees or bushes left for a bird to perch on. And his net poles were gone, his tepees washed away in the flood. Sometime later he'd have to tramp into the winter woods and cut new poles. He'd need them come spring to get ready for his summertime crabbing.

A Flood Wall against the Future

If Katrina Came to Washington

Michael W. Fincham, ***Chesapeake Quarterly***

Engineers test out a new, *removable flood wall designed to protect downtown Washington, D.C., from waters unleashed by a once-in-a-100-year storm event. The post-and-panel structure will go up on 17th Street whenever a major flood threatens and come down when the threat subsides.* PHOTO, MICHAEL W. FINCHAM

Rush-hour commuters come barreling into Washington D.C. every workday, but on Halloween morning in 2014 they got an unwanted surprise: they found one of their most popular routes blocked off by yellow police tape.

It seemed an odd place for a crime scene investigation. The 17th Street shortcut across the National Mall is popular because it offers a scenic gateway into the city center, cutting between the towering Washington Monument and the Lincoln Memorial with its long, sky-colored reflecting pool.

This shortcut had once been a crime scene of sorts back on a stormy St. Patrick's Day in 1936 when the Potomac River staged a major breaking-and-entering episode, shoving floodwaters into the city through this same roadway.

What commuters could see behind the yellow tape this Halloween morning was not a crime scene, but a work scene. Three forklifts shuttled back and forth unloading two flatbed trucks stacked with bright aluminum panels and rust-colored steel posts, the metal pieces for an odd new monument for the Mall. Call it a crime prevention scene: three dozen workers in hard hats and neon-green vests were trying to set up a flood wall that, in theory, would block off this gateway and guard the city from future break-ins by the nearby Potomac.

When Hurricane Katrina overwhelmed New

Orleans in 2005, that crisis raised alarms in coastal and riverside cities around the country, including Washington, D.C. That hurricane sent a storm surge toward New Orleans that broke through weak points in an elaborate but ancient levee system, letting rivers of seawater pour through the gaps and inundate streets and neighborhoods, homes and businesses. The result was a civic catastrophe — and a signal. According to recent forecasts for global warming, the future will bring rising sea levels, more ferocious storms, and stronger storm surges, a trifecta that carries expensive penalties for poorly prepared communities. Downtown Washington, D.C. under some scenarios is vulnerable to major flooding from the tidal waters of the Potomac River.

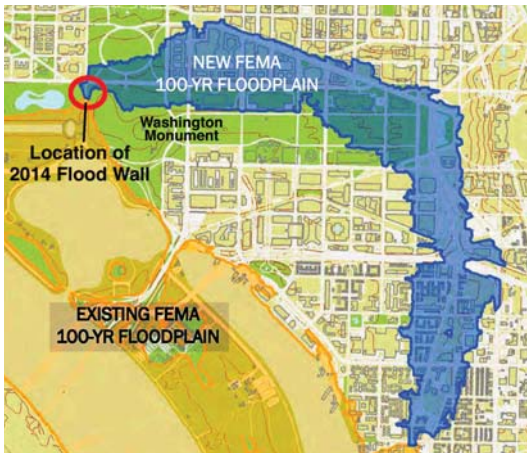
With Katrina invading New Orleans and Sandy surging into New York City in 2012, American planners are now looking more seriously at engineering solutions that once seemed too far-fetched, too expensive, too European. The British now have floodgates across the Thames River in hopes of protecting London. And the Dutch spent several decades building the massive Deltaworks project, a series of dams, dykes, locks, and levees that stretched across the mouths of several estuaries in the Netherlands. On this side of the Atlantic, planners in New York are now discussing the idea of building a surge barrier across the Hudson River at the Verrazano Narrows. And in Virginia, scientists recently began running computer modeling studies to test the pros and cons of building a giant floodgate across the mouth of Chesapeake Bay.

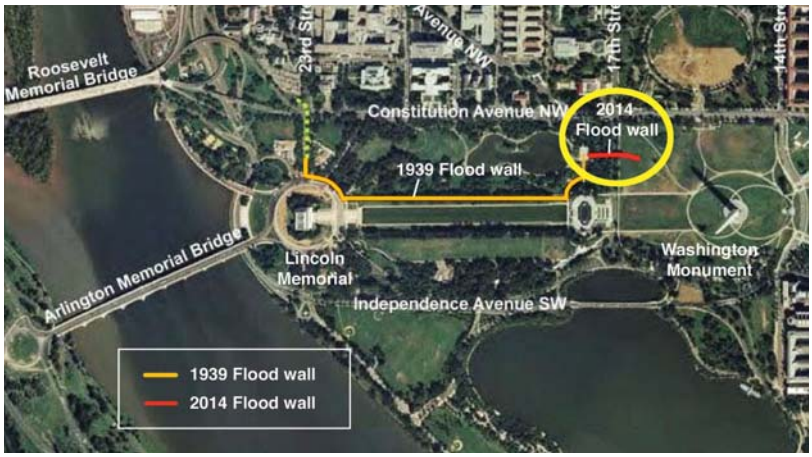
Rolando Sanidad, project manager *for the U.S. Army Corps of Engineers (top), stands by the east stone wall, one of two permanent pieces of the flood wall to block off 17th Street during major flood events. The removable panels of the flood wall connect to the west stone wall on the other side of the street. With posts and panels finally in place, the removable flood wall puts a nine-foot barrier between downtown D.C. and the Potomac River (bottom).* PHOTOS, MICHAEL W. FINCHAM

Along the banks of the tidal Potomac, planning agencies took one clear lesson from Katrina: look to your levees. Most visitors to Washington D.C. — and most natives — don't know the National Mall already has a flood-control levee, a low-lying, park-like ridge that was built along the north flank of the Lincoln Memorial Reflecting Pool. It was supposed to connect to the high ground near the Washington Monument. Those who do know about the levee also know that it has a major gap: that busy 17th Street shortcut across the Mall.

To plug this historic gap, the U.S. Army Corps of Engineers designed a moveable flood wall that could go up before the floodwaters arrived and come down once they subsided. That was the theory, and testing that theory was the goal that gathered all those trucks and forklifts and people on the Mall early on Halloween morning. Most of the workers came from the National Park Service, the agency that would take control of the wall and carry responsibility for erecting it well in advance of any future floods.

"The Park Service is going to have to do this install every year," said Rolando Sanidad, the project manager





FEMA's new floodplain map *(above left) led to the decision to build the flood wall. Finished in 2014, the wall closes a gap in the flood control levee built in 1939 (orange line, map above right). The old plan to fill the gap with sandbags was deemed inadequate after Hurricane Katrina.* MAPS, NATIONAL CAPITAL PLANNING COMMISSION

for the Corps and the man responsible for getting all the posts and panels and people together at the right place and the right time. "That's why you see such a heavy Park Service presence today," he said sweeping his arm toward all those workers in neon-green jackets. "They are actually doing hands-on training getting this stuff installed."

Some slightly nervous engineers were also doing eyes-on monitoring, checking the schematics on their clipboards as forklifts began swinging the posts and panels off the trucks. The new flood wall would have to be assembled from 35 very heavy pieces of metal. The eight metal posts weighed in at 1,200 pounds each. And the 27 aluminum panels tipped the scales at 800 pounds each.

All those posts and panels were numbered and lettered so they could be hooked up in the right order and in the right place. Think of putting together Ikea's largest wall cabinet or the world's largest Lego toy — then amplify the process by several orders of magnitude. Heavy manhole covers had to be lifted off the roadway, long metal posts had to be plugged into the manholes, aluminum panels had to be slotted in between the posts.

"During a normal operation, what we'll do is come in and put in all the posts, working from the east side to the west," said Sanidad, pointing to workers carefully lining a post above a manhole. Each post had to drop into a slot in a steel beam buried beneath the street. That beam in turn was sitting atop three concrete pillars that reach 30 feet down to connect with the ancient bedrock below the Mall. Each of these unseen pillars is embedded in a five-foot socket drilled into rock.

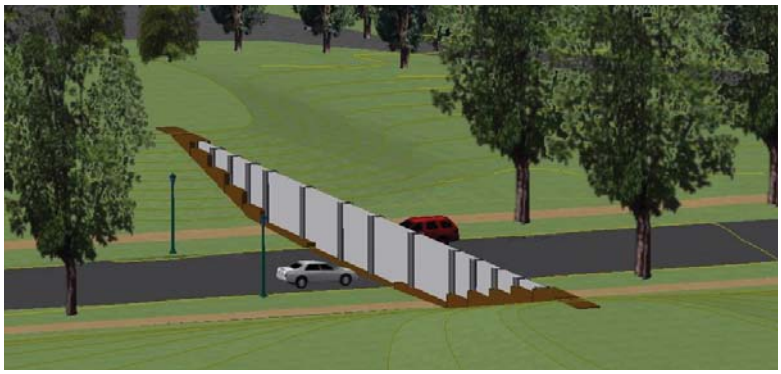
With the posts in place, the forklifts motored up, swinging heavy panels high in the air. With some yelling and a lot of back-and-forth maneuvering by the forklifts, workers lined up the panels and slid each one slowly down between two slotted posts. The bottom panels sat atop rubber gaskets, creating a tight seal with the street. Atop each bottom panel sat two other panels. The end result was supposed to be a metal wall nearly nine feet high stretching across the old 17th Street roadway gap.

The metal barrier also had to connect with two new concrete walls: one on the east side of the street, one on the west. Curving gracefully out of the nearby high ground, each wall ends abruptly in mid-air, looking like some kind of a misplaced ski jump. Clad with gray stone typical of many federal monuments, the stone walls connect the metal street-level wall with the high ground, tying this whole exotic structure into the familiar landscape of the National Mall.

Once the crew got the flood wall up, their job would be halfway finished. This Halloween event was only a test run for a future crisis, so the crew would have to take the wall apart and clear the street.

Even if this test went well, there would be other test runs, annual practice sessions to keep Park Service crews trained and ready. Perhaps some nighttime training, said Tony Vidal, chief engineer for the project for the Corps. "It's probably a good time to install it in the middle of the night," Vidal said, "because floods always happen right in the middle of the night, when you can't see, and it's cold and wet."

How was the 17th Street gap closed during past floods? "Sandbags," said Amy Tarce of the National Capital Planning Commission. "If you google 'floods in D.C.,'



An artist's sketch shows an early version *of the 17th-Street flood wall (top). The photo below shows the "post-and-panel" flood wall with labeled panels in place during the test assembly on Halloween 2014. The Washington wall has nine posts and 27 panels, all of them stored off-site. When a major flood event threatens the city, they will be trucked to 17th Street and craned into place.* DRAWING, COURTESY OF THE U.S. ARMY CORPS OF ENGINEERS; PHOTO, MICHAEL W. FINCHAM

you'll see historic photos of people in the middle of the night stacking sandbags." They were the solution du jour during three great floods of the 20th century: 1936, 1942, and 1972.

It was that "St. Patrick's Day Flood" of 1936 that gave birth to the idea of a levee along the National Mall. Also known as "The Great Spring Flood," this historic event not only inundated low-lying sections of the city, it also inspired Congress to order the Corps of Engineers into action. The engineers quickly built a new levee, a concrete wall that ran ruler-straight from the high ground of the Lincoln Memorial toward the higher ground of the Washington Monument. The engineers finished the wall by 1939, and in later years tore parts of it down and replaced it with the long, grassy embankment that now flanks the Reflecting Pool. According to Vidal, parts of the old wall are buried under the grass. The gap at 17th Street, however, was left as a permanent roadway, a breach to be sandbagged during flood times.

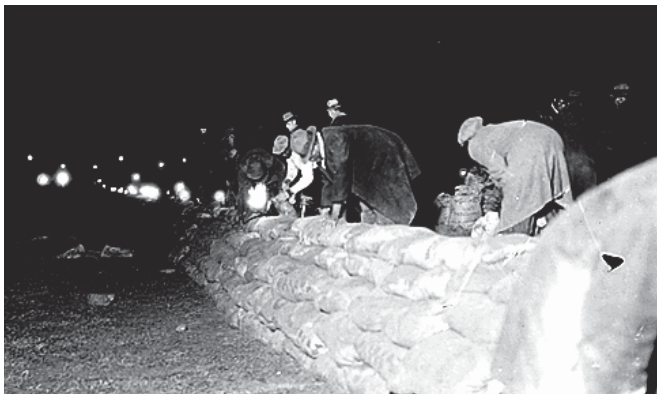
It was Katrina that killed off the sandbag solution. After the failures in New Orleans, the Federal Emergency Administration (FEMA) ordered the Corps to re-evaluate levees around the country, and the National Mall levee got a failing grade. There was that large gap at 17th Street and a low point at 23rd Street near the Lincoln Memorial. Sandbags would no longer suffice: they could topple during a big storm.

The gap at 17th Street, during a once-in-a-100-year storm, would let floodwaters from the Potomac surge up the road, take a right turn just past the Washington Monument and flow east down Constitution Avenue, spreading out to swamp an impressive list of federal buildings. At risk under various high-water scenarios would be the Justice Department, the Commerce Department, the IRS headquarters, the Smithsonian's Museums of Natural History and American History, the National Archives, even the National Gallery of Art. River waters could also pour down vents and stairs and escalators to disable the city's subway system. The city needed a better stopgap than sandbags.

When the Corps failed the levee, FEMA unleashed a storm of its own. It drew up a new map for the 100-year floodplain, labeling many dry land areas as floodable areas and automatically raising the threat of higher insurance rates under the rules of the National Flood Insurance Program. "There was a big uproar from the District," said Tarce at the National Capital Planning Commission. FEMA then exacted a promise that the city would fix the levees by November 2009.

It would, however, take six years to fix a levee that was originally built in two. Five options for the wall were designed and debated, and all of them had to work their way through 11 city and federal departments, including agencies as diverse as the U.S. Commission on Fine Arts and the D.C. Historic Preservation Office. More delays ensued when the principal contractor had to be fired, and another had to be hired. According to Vidal, "The only thing that really got this thing finally built, I hate to say, was Katrina."

There's a lesson there about the problem of flood control in Washington, D.C., said one engineer. When many agencies are in charge, no one is in charge.



Workmen from the Works Progress Administration (WPA) *use sandbags to build an emergency levee against the Great Spring Flood of 1936 in Washington, D.C., the event that led Congress to order the building of a permanent levee along the National Mall.* PHOTO, DEPARTMENT OF THE INTERIOR

Another lesson: Washington's new stopgap wall, when finally in place on 17th Street, cannot be a final solution to flood risks facing the nation's capital. That lesson comes from Gerry Galloway, a research engineer from the University of Maryland who collaborated on studies of Hurricanes Katrina and Sandy.

A nine-foot flood wall designed for a 100-year storm may not be enough to hold back future floods. According to Galloway, Washington, D.C., could be walloped by a one-two punch: rain-storm floodwaters rushing downriver out of the Potomac watershed and a hurricane storm surge driving upriver on a high tide from the Chesapeake Bay. The result could be a 500-year flood that would turn Constitution Avenue into a river running 10 to 12 feet deep. An even larger storm could do worse. "A Category 4 storm being pushed up the river at a time when the river is high would be a disaster," said Galloway. According to his calculations, flood levels would run 16 feet along the avenue.

High waters could also be coming from bizarre storms, odd events that don't fit our conventional definitions, said Ed Link, a senior research engineer at the University of Maryland who said he used to work for the Corps as "chief geek" or director of research. "We have these stereotypical conceptualizations of storms," said Link. "They are based on homogenous databases of hurricanes and river storms and nor'easters." But not all storms fit these categories. "Sandy was an aberration," he said. "It was this hybrid, it didn't behave like a hurricane, it didn't behave like a nor'easter, it behaved like a monster."

That leads to another, even more sobering lesson. There's a gap that may never be closed: the gap between our hopes to control flood risks and our limited abilities to predict them. How do we forecast these hybrid monsters? And how do we plan for them, especially in an era of rising sea levels. "Statistically we are in Never-Never Land," said Link. "We don't have good statistics for those kinds of weird things — and those weird things are the ones that cause the most problems."

You see the dilemma: does a city like Washington protect itself against the storm we think we can predict, the 100-year, or the 500-year event? Or does it plan something more ambitious, an engineering solution that protects against the weird monster that may never arrive?

It's sort of an existential dilemma for planning officials all along the Mid-Atlantic, whether they are debating a flood wall for Washington, D.C., a giant surge barrier across the harbor of New York, a giant barrier across the mouth of the Chesapeake Bay, or seawalls for small endangered islands like Smith and Tangier that are now slowly dwindling away in the middle of the Chesapeake.

Prepare for the predictable or for the nightmare monster? "I'll give you what my Dutch friends say," said Galloway. "It is much better for us as a nation to prepare for the totally giant event than it is to try and recover in our country from a flood." The United States, of course, is not the Netherlands, where the government has built dams and dikes and barriers across the mouths of several estuaries and is already preparing for rising sea levels by budgeting additions and repairs that stretch nearly two hundred years into the future. In the Netherlands, a giant storm surge out of the North Sea could inundate half the country. "They say they cannot afford to let it happen," said Galloway.

The key question in planning for flood control: "What is the risk you are willing to accept?" How do you answer that for Washington, D.C., where the threat is to symbolic structures rather than national survival? "In the iconic capital of the most powerful nation in the world," asks Galloway, "do we want to have a picture of downtown Washington underwater?"

How does a city prepare for a disaster it can't define simply or predict accurately? How does a state? A country? By a planning approach that recognizes the limits of planning. By predictions that recognize the limits of predictions. Those paradoxes lie at the heart of what

Link and Galloway are preaching as a result of their analyses of Katrina and Sandy and other great flood disasters. "I need to be worried about these uncertainties," said Link, "about these things that I don't know I don't know." Flood control engineers talk like philosophers because they don't want to look like generals who keep preparing to fight the last war rather than the next one.

The answer, said Link, is to apply certain key principles, and one of them is ongoing adaptation. "Everything has to be built to allow additional options," said Link. "Every time you take steps one and two, you are anticipating needing to take steps three and four." You may not know yet what those next steps would be, but "you make sure that step two isn't the last thing you can do."

The disastrous North Sea Flood of 1953 *spurred the government of the Netherlands to start work on the Deltaworks Project, a series of dams, dikes, sluices, locks, and levees to protect against another catastrophic storm surge. The Oosterscheldekering storm surge barrier (shown above) is the largest structure in the system, stretching nine kilometers and including sluice gates that are only closed during flood threats.* PHOTO, VLADIMIR ŠIMAN

A taller flood wall at 17th Street, for example, shouldn't be the last step in protecting Washington. "I am not suggesting that we need a 20-foot wall or a 30-foot wall surrounding downtown Washington," said Galloway. He points to other options. Structures in the flood zone could be individually prepped: subway vents can be shielded, generators and electrical boxes can be moved to the upper floors of buildings. "You might have mud," he said, "but you can still operate the buildings a day and a half later. It's flood-risk reduction, not flood prevention." Prepping infrastructure and training staff could reduce the impact of large, poorly predicted flood events.

Well before noon, the wall was up, and Washington, D.C. had a nine-foot barrier in place if Katrina came surging up the Potomac. The engineers checked out all the joints and fittings and slots. The work crew gathered in front of the wall for photographs "This is a historic day for the city," said a Park Service engineer. "The water can come," said Sanidad with a smile.

Then everybody went back to work. This Halloween event was only a test run for a future crisis, so the crew began taking the wall apart to clear the street. No flood was coming today, but the afternoon rush hour was, and it was only hours away.

The workers craned all the posts and panels back onto the trucks and slid the clanging manholes back into place. By mid-afternoon the yellow tape was down, the tractor-trailers were rumbling away, and the Washington flood wall was headed back to storage.

Test runs and training could be the key to flood control for the Nation's capital. Otherwise that moveable wall and all its moveable pieces could sit in storage for years, even decades, waiting for the next great spring flood or hurricane storm surge or hybrid storm event.

When one of those monsters arrives, police cars with whirling red and blue flashers will pull up, officers will string their yellow tape, the National Park Service will haul the wall out of storage, the big trucks will rumble down Constitution Avenue, the forklifts and cranes will swing into action again.

And some people will hold their breath. "There's Murphy's Law to worry about," said Galloway. Some cities have misplaced their flood barriers, he explained. Others have not gotten them up in time. Let's hope the guys who know where the pieces are stored are not on leave and the guys who remember how the pieces go together are not retired.

The new flood barrier is essential, but it may not be enough. "We've been lulled into this false sense of security that if you have a 100-year flood protection, then okay, we're safe," said Galloway. "The Dutch just laugh at us when we say that."

Armor, Adapt, or Avoid?

Policy experts consider the challenges ahead in preparing coastlines and communities for the effects of sea level rise

Rona Kobell, *Bay Journal*

When Superstorm Sandy devastated the New Jersey shore and flooded lower Manhattan two years ago, it illustrated some tough and surprising truths about how we prepare for — or ignore — the risks posed by coastal flooding in the Chesapeake Bay region.

People in New Jersey and New York never expected the scale of damages from Sandy, and here in the Chesapeake Bay, a big storm could give us a similar nasty shock. Rising sea level is projected to increase flooding and worsen the effect of storm surges in this region — not only in small waterfront communities but also in larger cities like Annapolis, Baltimore, and Norfolk. And, scientists say, the incremental rise of sea level here could bring a slow-motion increase in flooding that nevertheless will bring expensive and disruptive consequences.

This flooded street in Cambridge, Maryland, *is appropriately named Water Street. It floods routinely during abnormally high tides from the adjacent Choptank River and the city is forced to close it to traffic.* PHOTO, DAVID HARP

History has shown that Americans and their leaders have tended to react to coastal-flooding disasters rather than prepare for them. Sandy also highlighted that under current government policies, it can be difficult to mandate that counties and municipalities stop building in areas vulnerable to coastal flooding and sea level rise.

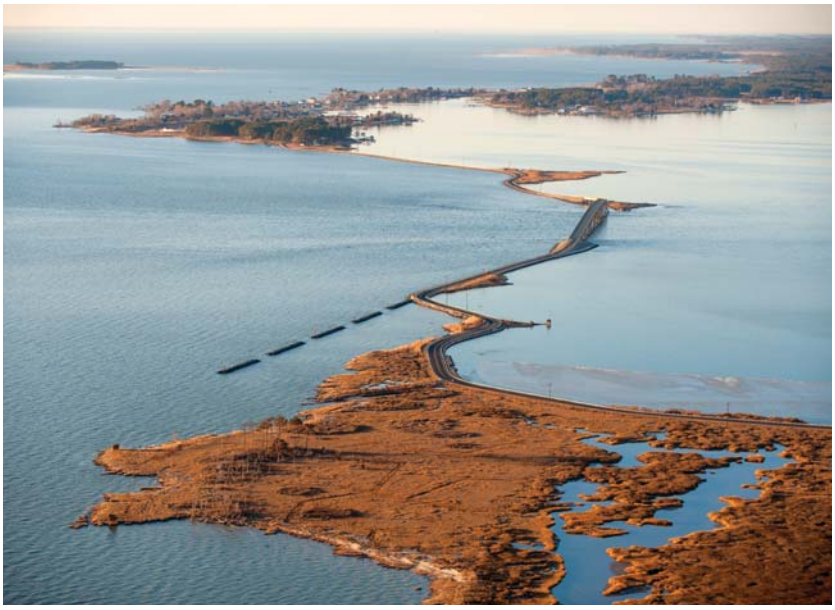
Nevertheless, the massive storm helped to focus the attention of officials and residents in Maryland and Virginia on the need to reduce these risks, and some progress is being made. Inevitably, the fixes needed are expensive, and funding to pay for them limited, raising questions of fairness about what areas to protect first. To change the status quo, experts say, governments will need to provide focused leadership and craft better policies — in areas like federal flood insurance and seawall construction — that better balance the risks and benefits of coastal development.

The Chesapeake's Special Risks

The risks of coastal flooding and sea level rise are especially great in the Chesapeake Bay region. Its land elevation is one of the lowest in the United States, and sea level here is rising faster than the global average. In Maryland, scientists' best estimate is an increase of more than 3 feet by 2100. In Virginia, scientists estimated the rise by then will be 1.5 to 7.5 feet.

The effects of sea level rise today are becoming harder to ignore. Recent science-based reports have described how streets and waterfront neighborhoods in Annapolis, Baltimore, and Norfolk have become flooded for more and more days each year, and those trends are likely to continue.

Residents will bear the costs of coastal flooding through expensive repairs to homes, loss of their cars,



Sea level rise could reshape coastlines *across the Bay, including along the narrow spit of land that makes up Hooper's Island in Maryland. The island loses about 24 acres each year to erosion.* PHOTO, DAVID HARP

and lost time at work. In all, the Delmarva Peninsula of Delaware, Maryland, and Virginia contains 183,000 residents, 116,000 homes, and $42 billion in property value located less than five feet above the local high tide line, according to Climate Central, a nonprofit organization based at Princeton University. Even people who don't live on the coast will have to pay, one way or another, for the effects of the flooding through public expenditures for disaster relief and to raise and replace flood-prone roads and other public infrastructure.

The Push for Policy

For many Americans, it may be all too easy to ignore or deny projections of future sea level rise. The occasional big storm illustrates the problem, but between storms, sea level rise in the Chesapeake Bay and elsewhere is so gradual that it is easy not to think about.

You can see this resistance to change in other parts of the country. Three hundred years ago in Louisiana, early settlers built homes on stilts above marshes and boated from place to place; but by the 1940s, bayou residents wanted their homes to look like other neighborhoods. Katrina deluged those low-sitting homes and the roads leading to them. And in 2008, when Hurricane Ike tore through the Bolivar Peninsula next to Galveston, Texas, the force of the storm killed 15 people and destroyed many small fishing cottages. But in both Louisiana and Texas, houses have been rebuilt without regard to whether they can withstand future flooding.

In 2014, the National Research Council, one of America's top scientific organizations, issued a report expressing serious concern about our nation's lack of coordination and preparedness for the coming sea level rise. The report, which the council wrote at the request of the U.S. Army Corps of Engineers, urged federal officials to work with the states to develop a national policy sooner rather than later.

"Living in these areas in a sustainable manner necessitates that we move away from the current disjointed and largely reactive approach to dealing with coastal natural hazards and instead develop a more systematic, proactive approach to managing the risk associated with living in coastal areas," said Richard A. Luettich, Jr., the report's lead author and a professor of marine sciences at the University of North Carolina, Chapel Hill.

A national policy would consider where the risks of coastal disasters and economic losses are highest, the report says. Such a plan should provide incentives to local and state governments to protect vulnerable areas before disasters hit.

The report acknowledges that not everyone will welcome a national policy on sea level rise. Among those who won't: limited-government advocates, developers, and local government officials who seek to grow their tax bases through waterfront development. But without a national approach to sea level rise, the report argues, "different federal agencies and regional and local jurisdictions plan for and invest in risk reduction in ways that are often inconsistent, leading to inefficient and, too often, inadequate outcomes."

Hans-Peter Plag agrees. The German-born director of the Climate Change and Sea-Level Rise Initiative at Old Dominion University in Norfolk has watched the Netherlands take a national approach to disaster planning while the United States has not. After Hurricane Katrina flooded New Orleans, people considered the storm a Louisiana problem. The lack of the big picture, Plag said, will cost Americans dearly.

"We are making decisions now that are harmful for our children," he said. "Because we are afraid of doing what is really necessary."

Acceptable Strategies of Risk

To do what is necessary to protect against coastal flooding and the effects of sea level rise, there are basically three options. One is armoring: property owners and governments can protect shorelines with hardened structures like stone jetties and seawalls. Another option is adaptation: governments can require that homes be raised, and property owners can do so voluntarily. A third option is retreat: moving way from places that people have called home. Some governments have offered to buy out homeowners in low-lying, flood-prone areas, like Somerset County did on Maryland's Smith Island in 2013. (Residents rejected the offer.)

Retreat is not a popular option, although in some places in the Chesapeake region, nature has imposed it through the steady processes of sea level rise and erosion. Old maps of the Chesapeake Bay bear witness to that — they list the names of many islands that have been submerged. In Maryland's Dorchester County, there's a road named for Punch Island. But there's no more island at the road's end.

More common responses to sea level rise involve adaptation and armoring. Recently, the Union of Concerned Scientists identified many cities, including Annapolis, Baltimore, D.C., and Norfolk, at increased risk from tidal flooding, and for these and other large cities abandonment seems implausible.

Critics complained that Norfolk was slow to acknowledge its flooding problems. But four years ago when the city decided to adapt, it did so with gusto. The city embarked on a new readiness plan for flooding. Millions of dollars are pouring into Norfolk and Hampton Roads — from the federal government, state government, and private foundations — to make the city more resilient. All over the city, you can see homes in various stages of being lifted and other projects to protect shorelines from flooding. Norfolk is on the radar screen of the region, the nation, and even the world. Recently, city officials went to Europe to discuss their policies.

Not all communities have the means to follow Norfolk's lead. Adaptation and armoring require not only determination but money, which Norfolk has — but which many smaller communities in the Chesapeake region don't.

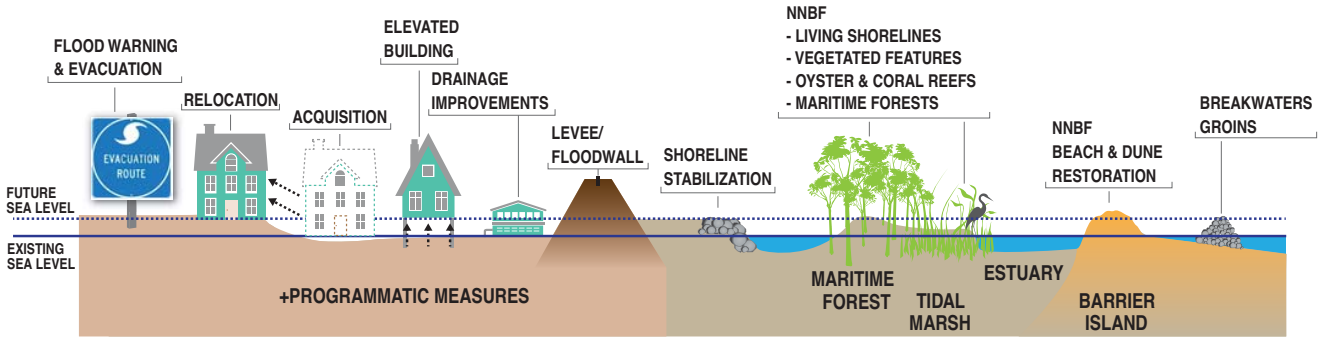
For example, Saxis, on Virginia's Eastern Shore — year-round population, 242 — is struggling to find about $1.6 million for its share of a project to install eight breakwaters. Superstorm Sandy knocked the town to its knees, flooding about half of the more than 200 homes there. Had the breakwaters been in place prior to Sandy, town officials believe the damage would not have been as extensive.

"We're sitting here, every storm, and we're losing land," said Saxis Mayor Denise Drewer. "And people are getting more concerned, because it's getting closer and closer to their back doors."

Saxis is not the only such community. Tangier Island tried, starting in the early 1990s, to secure funding for a promised jetty. The funds for that work were finally approved two years ago, and work is finally beginning.

Looking for Help

Such delays are common because these small communities wait in line with many others — including coastal cities like Norfolk, New Orleans, and Miami — for funding from the U.S. Army Corps of Engineers for

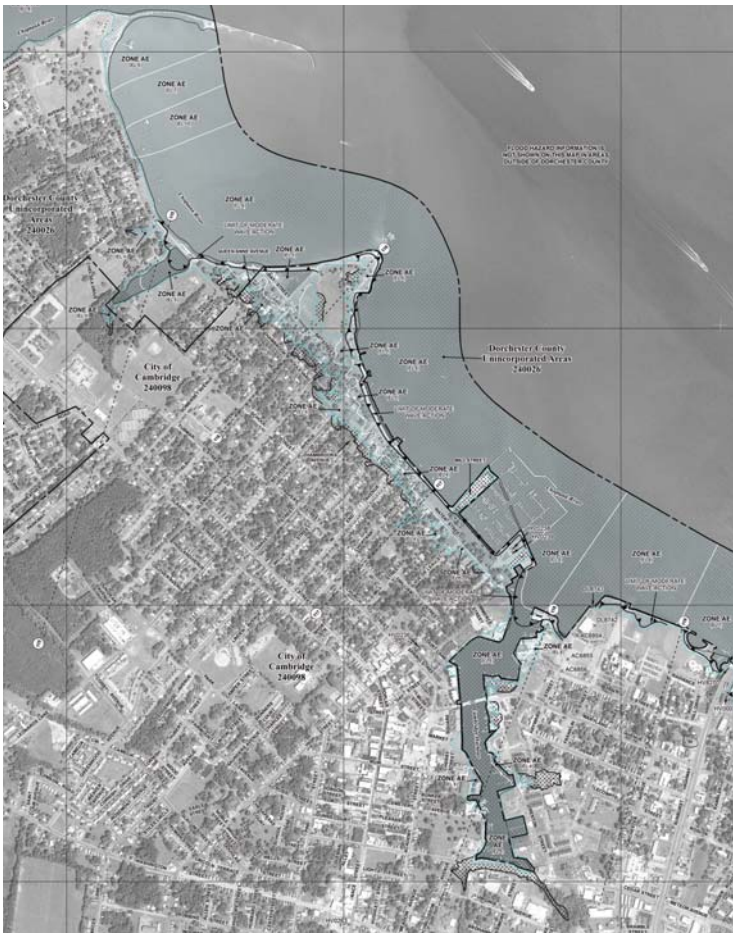


A combination of strategies have been developed *to help manage the risks of coastal flooding. Some, like elevating buildings, are structural. Others, like "living shorelines," are nonstructural and rely on natural resources (marked in the drawing above as NNBF, for natural and nature-based features). A number of experts have urged federal and state governments to devise a national, coordinated plan to manage flooding risks using a variety of methods.* ILLUSTRATION, U.S. ARMY CORPS OF ENGINEERS

their construction projects. The Corps currently has an enormous backlog of such projects nationwide, amounting to about $60 billion. But Congress allocates only about $2 billion per year for these projects and others to improve waterways and harbors. Adding to that backlog, most of the funding for these projects comes from the Water Resources Development Act, which Congress declined to reauthorize for seven years, from 2007 until 2014. (It finally did so in May 2014.)

For a community to receive priority on the Corps project list, it helps to be represented by a powerful member of Congress who can push the project in federal legislation. Otherwise, many communities that line up for this money will end up continuing to wait.

"I could name a dozen communities in Virginia that are all facing the same problem," says Skip Stiles, executive director of Wetlands Watch, a nonprofit organization in Norfolk. "I can't tell you who is more deserving of a $4-million breakwater. How do you choose?"



This Digital Flood Insurance Rate Map (DFIRM) *published by the Federal Emergency Management Agency (FEMA) in 2015, shows downtown Cambridge, Maryland. Owners of homes within certain areas on the map are required to buy federal flood insurance to qualify for a mortgage. The fairness and financing of the federal program have been debated in recent years following Hurricane Sandy. FEMA recently rolled out revised rate maps for Maryland (including this one in Dorchester County) and other states that it says are more accurate.* MAP, FEDERAL EMERGENCY MANAGEMENT AGENCY

Flood Insurance Follies

In addition to the Army Corps of Engineers projects, changes have been proposed for a federal program affected by coastal flooding and sea level rise: the National Flood Insurance Program. But it remains to be seen if the proposed changes will be enough to promote the program's survival.

In many coastal areas, lenders require flood insurance as a condition of a mortgage. For many borrowers, the federal flood insurance program is the only place to obtain an affordable policy. Under the program, private insurers sell policies, but FEMA sets the rates and pays for the claims. The program gives discounts to residents of towns that implement flood-control measures. These include up-to-date emergency-management plans, evacuation routes, and zoning that restricts building in floodplains. In Maryland and Virginia, state planners work closely with the local governments to institute these measures to qualify for the discounts.

But the rates do not fully cover the risks or the program's costs. After Hurricane Katrina, the flood insurance program was about $25 billion in debt — a tab that all American taxpayers may ultimately have to pick up. Sandy made that debt even larger, re-igniting cries for reform. The program has paid claims for "repetitive losses," effectively subsidizing the risks of individuals who chose to continue living in flood-prone areas after sustaining damage from multiple storms.

In 2012, Congress passed a law, signed by President Obama, to fix that disparity. The Biggert-Waters Flood Insurance Reform Act would have ended subsidies for homes built in flood-prone areas, and it adjusted future insurance premiums to reflect the true cost of coverage. It also phased out funds for repetitive losses, ending the practice of rebuilding in the same flood-prone area over and over again.

The outcry was fast and swift — from coastal homeowners, municipalities, and developers. Under pressure from constituents, Congress passed another law, the

Homeowner Flood Insurance Affordability Act of 2014, which rolled back many of those provisions. It did phase in over two years a rate hike of up to 18 percent for primary homes and up to 25 percent for secondary ones and homes that flood frequently.

The federal government has also rolled out a related effort to improve another aspect of coastal protection: new maps of flood plains. These maps show areas that every year have a one percent chance of being inundated by floods — that is, these areas will likely be flooded at least once every 100 years, on average. Home buyers within these designated flood plains typically are required to buy the federal flood insurance to qualify for a mortgage. Previous flood maps were considered outdated.

The revised maps, which should be final by 2015 and 2016 in most coastal counties in the region, will bring significant changes. For example, the historic district of Cape Charles on Virginia's Eastern Shore used to be in an at-risk zone for flooding; now, it isn't. The town greeted the news with joy — it was a testament to the flood control measures they'd undertaken, including breakwaters and dunes, and it would mean significantly lower rates of insurance.

Neighboring Saxis, on the other hand, is not so lucky. The new maps put 37 more homes in the flood zone, for a total of 220 — the great majority of the town.

States Set the Example

In the absence of a national policy to prepare for sea level rise, states have taken on the job of crafting their own solutions. State leaders decide which parcels of land to preserve through conservation easements and which roads to elevate. Through partnerships with federal agencies, state officials can coax and encourage development into areas where it is suitable and away from places where it floods.

This approach may not be comprehensive, but it's the way it's always been, said Bob Perciasepe, a former deputy administrator for the Environmental Protection Agency.

"How states will make this happen is how Congress will set policy for the entire country. They'll have to see it working on the state level," said Perciasepe, who is now president of the Center for Climate and Energy Solutions, a nonpartisan organization based in Arlington, Virginia.

Perciasepe and others think that Maryland is well poised to be a model. Under former Gov. Martin O'Malley, the state enacted its own plan for adapting to climate change. The Maryland Commission on Climate Change issued several recommendations in 2008, and its leaders have been "deep into implementation," according to Zoe Johnson of the Maryland Department of Natural Resources. Now, all state-funded infrastructure must factor both sea level rise and flooding into construction and design. Structures must be two feet above base flood elevation. (The base flood elevation is the level at which water is expected to rise during a typical flood, and is generally set by the federal government; states and counties follow that recommendation.) Nearly 40 communities have decided to adopt the two-foot rule in their own ordinances, and Johnson said more will follow suit as the planning continues.

"We do have control over projects that the state invests in, if it receives any state funding," Johnson said. "And we are starting to condition our funding that these issues be addressed."

While Maryland has been planning for sea level rise for nearly a decade, Virginia is not as far along. The previous governor, Republican Bob McDonnell, all but disbanded the state's climate commission. The current governor, Democrat Terry McAuliffe, brought it back.

One of the panel's members is Ann Swanson, executive director of the Chesapeake Bay Commission, and she said that states can make a difference in environmental outcomes like coastal flooding. She noted that California was the first state to require lower emissions of greenhouse gases; eventually, other states followed, and the EPA set a national policy. Similarly, she said, it was the states, including Maryland, that banned phosphates in detergent. Eventually, the federal government did the same, resulting in huge improvements in the country's waterways.

"When this country has a large issue to tackle, it's the states and the local governments who tend to tackle it first, and they set the course," she said. "With the Chesapeake region being so forward-thinking, it seems fitting that we could go first."

Early Warnings from Smith and Tangier Islands

Historic communities seek engineering projects, funding to survive flooding and rising water

Rona Kobell, *Bay Journal*

The Chesapeake Bay was once home to more than a dozen offshore island communities — tight-knit villages with enough land for baseball diamonds and marshes thick with crabs and fish.

James, Barren, Punch, Holland. One by one, they faded away. Erosion battered their shorelines. Rising waters submerged their soils. Islanders with means packed up their bags and tore down their homes, barged them to the mainland, and reconstructed them on higher ground in Crisfield and around Cambridge. The structures too battered to make the trip stayed, along with the gravestones, and eventually slipped into the sea.

These houses on Virginia's Tangier Island *sit just adjacent to acres of marsh grasses and, not far beyond, the open waters of the Chesapeake Bay. Low-lying island communities are especially vulnerable to sea level rise.* PHOTO, DAVID HARP; CHESAPEAKE BAY MAP (OPPOSITE PAGE), ISTOCKPHOTO.COM/UNIVERSITY OF TEXAS MAP LIBRARY

But 400 years after the first English settlers arrived, two offshore islands with villages remain. Smith Island, a marshy expanse of three towns 12 miles into the Chesapeake Bay in Maryland, is home to about 250 residents. Tangier Island, just a few miles south in Virginia, has more people — about 450 — but less land, with all of its inhabitants concentrated in a central area.

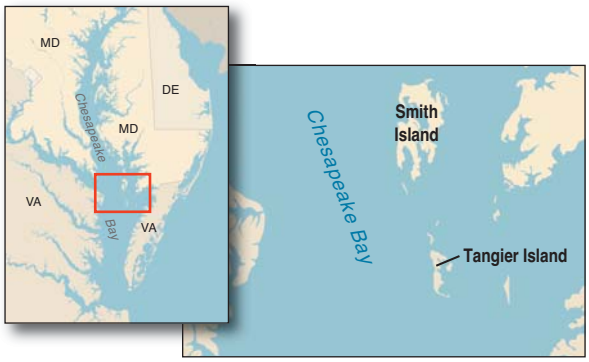
Both islands have lost land and population. Residents of both have clamored for government projects — seawalls, jetties, revetments — to protect what remains. And both communities have battled the perception that their survival is not worth the effort, that the millions of dollars in taxpayer money needed to protect so few people could be better spent.

Yet, the islands lodge themselves into a special place in the hearts of visitors and natives. Their fragility makes the attachment all the stronger. It's perhaps not surprising that first-time visitors have purchased homes within hours of disembarking the ferry.

"They are pretty much, to me, the intersection of the Chesapeake Bay and people," said author Tom Horton. He lived on Smith Island from 1987 to 1989 and later published a book about his experiences, *An Island Out of Time: A Memoir of Smith Island in the Chesapeake.* "I realize at some point there might be limits to what we can do to save them, but I'm hoping we can get a few more decades with them, or even more…. There's nothing

else like them, not just in Maryland and Virginia, but in the entire United States."

As much as Smith and Tangier islands might seem like places apart, it was not always so. The islands formed thousands of years ago, when the Susquehanna River valley flooded and became the Chesapeake Bay. The islands were the tops of ridges. Before the Bay's water rose to its current level, the islands were all connected to the mainland. The Indians didn't canoe to these islands, according to Smith Island resident and artifact expert Tim Marshall. They walked.



ISTOCKPHOTO.COM/UNIVERSITY OF TEXAS MAP LIBRARY

Tangier: Tight-knit on Loose Land

No one's sure of the origin of the name Tangier, but historians know how it was settled. In 1707, a man named Post traded an Indian chief two overcoats for the island. Post brought over three families from England to farm. They stayed. Today, the Parks, Pruitt, and Crockett families make up about half of Tangier's population.

Once, Tangier had eight ridges, with distinct towns on each. More than 2,000 people lived and worked here, farming or fishing or working at the clothing factory. For entertainment, there was an opera house. For history buffs, there was the famous military fort where Joshua Thomas, the parson of the islands, warned British troops they were going to get walloped in Baltimore during the War of 1812. It seemed improbable, but history proved Thomas right, and the wounded British returned to Tangier to tell him so.

But with every heavy storm, the once-sturdy island lost more ground. By the 1930s, only three communities remained — all on ridges separated by bridges over marsh. Main Ridge is the central one, near the bustling harbor ringed with shanties. West Ridge stretches to the left and includes Tangier's small airstrip as well as its waste-disposal facility. Canton Ridge, the Crocketts' original home, sits on the smallest piece of land, its shore jutting into Mailboat Harbor like an arrowhead. All over the island are signs of its precariousness — water in yards at high tide, jagged cuts where land used to be, crosses once erected on high ground that are now nearly submerged.

For decades, islanders pleaded for federal and state help to stabilize the shoreline. In the 1990s, the U.S. Army Corps of Engineers built a seawall on the west side. Without it, residents say, they would have lost the airstrip. The Corps also planned to construct a jetty and seawall that would protect the harbor's entrance channel and keep the waters navigable. In the process, it would also safeguard Tangier's east side. The Corps got the authorization in 1996.

But the Corps never got the money. Tangier residents lobbied every governor, senator, and representative they could. The $4.2-million project remained on the books, but that was the only place it lived.

The inaction angered Tangier Mayor James "Ooker" Eskridge, a deeply religious man who traces his Tangier heritage back 200 years. Several young island men had served their country in Afghanistan and Iraq, building millions of dollars worth of infrastructure there, only to find their own yards awash when they returned.

"We're only a few miles from Washington, D.C., and we would like some help," Eskridge said as he steered his boat, the Sree-Davi, through the sound's broken lands. "If we could just get some stone for Tangier, we would be here until the Lord decides to come back, until the last days."

Eskridge may have his prayers answered, finally. In the fall of 2012, just weeks after Superstorm Sandy destroyed many crab shanties on the island and flooded several homes, the Army Corps of Engineers announced it was going ahead with building the jetty and seawall. The federal government kicked in $3.2 million; Virginia is picking up the rest of the tab. Work should begin this fall.

But while the project will help stabilize the shoreline and gird the island against the punishing waves, it will likely not stop the island's persistent flooding from storms and high tides. And Corps officials said the project won't necessarily give the island more time, as islands are dynamic. Inlets open and close, shorelines erode and accrete. The Corps is also investigating a project that will build breakwaters on the western side and further protect the habitat of the Uppards, a marshy mudflat that was once home to the island's highest ground and its main town. Today, all that remains is a dilapidated hunting shack. That project would offer

some more shoreline protection, but again it's not certain how much or for how long.

Earlier this year, Hampton Roads *Virginian-Pilot* columnist Roger Chesley suggested the jetty project was a waste of taxpayers' money. He suggested the government divide the money by the number of residents and give each resident there about $8,400 to leave. Islanders were irate, especially since Chesley acknowledged he'd never been there.

But the beleaguered community does seem to have a friend in a high place that can help secure its future: Col. Paul Olsen, commander of the Army Corps of Engineers' Norfolk District. For Olsen, the loss of Holland and the islands before it remains a cautionary tale of a people who could not adapt. Tangier must adapt, he said, because the Chesapeake's future is one of more Tangiers: islands unto themselves. Tangier will go first in trying solutions, Olsen said, so it can show communities in the water-prone Hampton Roads area the way forward.

"The only way Tangier would be untenable is if we take our eyes off Tangier and we don't study it and don't pay attention to it," Olsen said. "Tangier is a cultural jewel. It's historic. It's a slice of Americana. And it needs to be watched very closely."

Smith: Uniting at Last

Smith Island seems less fragile than Tangier, less vulnerable to the effects of the rising sea. Nearly 7,000 acres of tidal marsh protect the people of Smith from storms and provide the Chesapeake Bay with one of its finest crab nurseries. The island has three towns. One, Tylerton, has a 20-year-old seawall. It is separated by a channel from another part of the island that includes the main town, Ewell, and a smaller village, Rhodes Point. Martin National Wildlife Refuge occupies the island's northern half.

In 2003, Smith was barely touched by Tropical Storm Isabel, which devastated Tangier, tore apart Hooper's Island, and flooded Annapolis. In 2012 Superstorm Sandy again battered Tangier, but Smith Islanders had minimal damage. Old-timers say the last truly devastating storms were a half century ago: Hurricane Hazel, in 1954, and the unnamed storm of 1962.

On Smith, the greatest threat to survival came in the form of a buyout offer from the state of Maryland following Sandy. The government was offering a $2 million pot of money for residents who wanted to leave. The money came courtesy of the federal government, which has a policy not to fund rebuilding of houses in places that are likely to flood again. If Smith Islanders took the buyout, they would receive the highest appraised value for their land — but in exchange, the land would become "dead," never to be built on again.

On an island already struggling, even a few departures could lead to restaurants and shops closing their doors. Sandy had damaged just a few homes, but those residents felt they were entitled to rebuilding money. Which the government wasn't offering.

To most islanders, the buyout offer was infuriating, and perplexing: why them and not Crisfield, where many homes and businesses flooded?

"Nobody lost their home just due to Superstorm Sandy," said the island's pastor, Rick Edmund. "We couldn't figure out why they wanted to buy out our property."

Islanders saw that their only choice was to fight the buyout and push for rebuilding funds. State Senator Jim Mathias and Somerset County officials called a meeting in Crisfield in May 2013 to discuss the buyout with islanders. One of the most vocal opponents was a retired Navy submarine officer named John Del Duco. A New York native, Del Duco had bought his property eight years ago after doing a google search for "cheap waterfront real estate." Smith Island was the second listing. He'd never heard of it.

Financially, the buyout deal would have been great. But Del Duco and his wife, Pam, wanted no part of it. Though they had only lived on the island full-time about a year, they had become part of the community. Pam worked at one restaurant; John volunteered at the other, often running his skiff to the mainland for supplies. Together, they helped manage one of Ewell's two bed and breakfasts.

Del Duco stood up at the meeting and advocated for his new community.

"I said, 'why are we condemning the property?'" he said. "The culture of this very special place needs to be preserved. We have people here who can go into a cemetery next to their homes and see the gravestones of their father, grandfather, great-grandfather, and great-great grandfather. Show me another place in the world where that is true… Smith Island is as much an important symbol of this country as the bald eagle."

As Del Duco was at the meeting, Eddie Somers was mulling his own course of action. Somers, who captains an icebreaker for the Maryland Department of Natural Resources, is genteel and reserved. He and his wife live

Flood waters overtop a sea wall *on Maryland's Smith Island in the Chesapeake Bay. Sea level rise is helping to make high water events like this one worse and more frequent on this fragile island.* PHOTO, DAVID HARP

full-time in Crisfield, but they're both native Smith Islanders. About a decade ago, they bought property in Rhodes Point and built their dream house, a skinny, three-story structure that resembles a city rowhouse, only with no attached neighbors.

Somers, too, was angry.

"What if they came in where you live and said, 'we're not fixing anything anymore. We gave you permits, we told you to do this and that, and now, we're done with you?'" Somers said. "You expect people to turn their backs on you. But you never expect that from your own government."

Somers had met Senator Mathias a year before and had his personal cell phone number. He decided to call. The senator told Somers to call Del Duco. The county, Mathias said, needed to hear their views — officials had already heard plenty from two vocal island residents who wanted the buyout.

Somers and Del Duco met, talked, and recruited more neighbors. On an island of independent watermen, they didn't expect it would be easy. Smith Island, unlike Tangier, has no formal government; the Methodist church holds the community together and organizes charity functions, while Somerset County provides emergency services.

But the islanders quickly formed an association, Smith Island United. They drafted an alternative to the buyout — a prioritized list of projects to shore up key areas of the island against erosion. Islanders voted nearly unanimously to reject the buyout. Two months after they offered the buyout deal, Somerset County officials took it off the table. Mathias watched on C-SPAN as the head of the Federal Emergency Management Agency committed to re-evaluate federal relief money for Somerset County.

In the end, Smith Island will receive $15 million in federal Sandy relief money, even though the storm barely touched them. About $9 million will finance a breakwater project on Martin National Wildlife Refuge. Close to $5 million will pay for a jetty to protect Rhodes Point, a project the Army Corps had hoped to complete years ago; ideally, the Corps will contribute an additional $2.8 million, but if it doesn't, the county will scale back the work and do it without a federal partner. Close to $1 million will be split between Ewell and Rhodes Point for fixing their county docks, which had fallen into disrepair over the years. And $90,000 will fund a "visioning" study to plan for the island's future. Like their Corps counterparts in Virginia, Maryland Corps officials can't say exactly how much time these projects will buy Smith. But islanders estimate another century, at least.

From his third-floor porch, Somers can look 10 miles northwest on a clear day and see one possible future for Smith Island: the remains of Holland Island and its surviving stand of hardwoods. But around him on Smith Island, he can see a different scene that represents an alternative future, if it can be preserved. He sees skimmers gliding through a serpentine belt of lush marsh. He sees tourists, clutching real-estate listings, mulling their own dreams. He sees a place with many more good years left.

"Why," he asked, "would anyone want to let it go?"

Norfolk: on the Leading Edge

Leslie Middleton, *Bay Journal*

Barely a month after Rear Admiral Dixon Smith took command of Navy Region Mid-Atlantic in Norfolk, a nor'easter blew through, showering the naval station here with what he thought was a fairly moderate amount of rain. "I was stunned at the localized flooding on the streets," he says, "and it wasn't even a hurricane."

Since then, heavy rains have repeatedly forced Smith to use his front door because his backyard is flooded. While he is stationed in Norfolk, Smith lives in an historic house on Admirals Row. Like much of Naval Station Norfolk, the homes in this part of the naval station are built upon former wetlands filled to make space for the 1907 Jamestown Exposition.

U.S. Navy Captain Bob Clark *looks out over Naval Station Norfolk, which he commands. This base, the largest naval facility in the world, is considering raising its piers so that rising waters do not disrupt its bustling operations.* PHOTO, DAVID HARP

Naval Station Norfolk is the world's largest naval base and home port to over 75 ships of the fleet that defends U.S. interests in the Atlantic Ocean, the Mediterranean Sea, and the Indian Ocean.

It is also one of the Navy's most vulnerable.

Norfolk and the surrounding Hampton Roads area, which is home to 28 other defense installations, is experiencing one of the fastest rates of sea level rise in the United States because of the combined influences of rising seas and subsiding land.

Most of the station lies 13 feet or less above mean sea level. Some scenarios project that waters around Norfolk will rise by six feet or more in the next 100 years, and studies by the U.S. Army Corps of Engineers show that 60 to 80 percent of the station could be flooded during storms the size of Hurricane Isabel in 2003.

But while numerous studies have shown that a smaller rise in sea level will inundate major portions of the naval base and other installations, the Navy has yet to make a comprehensive plan — nationally or locally — to deal with the challenge.

But not for want of critical attention.

The last two Defense Quadrennial Reviews (an in-depth examination of strategy) have pointed to the mounting threats to national security, abroad and in the United States, from the effects of climate change. The Navy has formed a climate change task force and is in the process, along with the other armed services, of evaluating the operational and installation vulnerabilities of facilities around the world. The Army Corps of Engineers' research arm developed sophisticated models for predicting sea level rise impacts, first looking at different scenarios at the Norfolk base and now using these methods at other defense installations.

All of this planning is intended one day to help naval leaders like Captain Bob Clark, commanding officer of Naval Station Norfolk. From the sixth story of the Ops Tower, he has a panoramic view of the Navy's 13 piers and the rest of the base. On the waterfront below him, the flow of fuel, aircraft, munitions, and housekeeping services is a highly orchestrated logistics exercise that is performed round the clock, in almost any kind of weather. Under stormy skies, a phalanx of tugboats tends to the amphibious landing craft USS Iwo Jima, while delivery and maintenance vehicles navigate between and around steam pipes, overhead cranes, and pedestrians.

Sea level rise and storm surges could disrupt this steady flow of activity in several ways, Clark says. When the water rises with a storm surge, port operations shut off steam and electric power to the ships docked alongside the piers, forcing them on to ship power, which is less efficient and more costly than shore services.

"We have close to 54,000 people who work here," Clark says, "with an average of 40,000 coming in and going out every day." But flooding during rainstorms on Hampton Boulevard outside the station regularly impedes the flow of traffic to and from the station. And requires port ops to move scores of cars from a parking lot near the airfield that regularly floods.

"It's a readiness issue," says Clark, whose many responsibilities often leave little time for thinking about a future of rising sea levels.

"We have a lot of aging infrastructure," Clark says, adding there are no projects in the works at Naval Station Norfolk to address sea level rise but noting he expects that it will be considered when the Navy replaces the piers.

Right now, the only specific project the Navy can point to that has planned for sea level rise in the Norfolk area are two oil-tanker piers the Navy is building across the Elizabeth River at a separate facility on Craney Island. These will be three feet higher than the piers being replaced, raised to protect the utilities from wave damage and flooding. The height increase was limited by the operational limits of current ships and equipment, said Beth Baker, a spokesperson for the Navy.

Defense Department guidance currently specifies only that the effects of climate change be "considered" in planning efforts, says Captain Pat Rios, the Navy's lead engineer for the Mid-Atlantic region.

But the interface between facilities and operational planning is complex and requires evaluating many needs and tradeoffs, Rios says. "I'm clocking through 10 different things that are considerations as I go through the day." What are the support requirements for the aircraft, the ships? Where to buy fuel? What's the best crane for an operation? "There are just hundreds of considerations, not just sea level rise."

There are signs that the naval station and the community that surrounds it are gaining some traction in planning for sea level rise by working together.

In 2014 the White House announced that planning already underway between local governments and federal facilities in the region would serve as a model for other communities seeking to deal with sea level rise. The collaboration was officially named the Hampton Roads Mitigation and Adaptation Pilot Project and was kicked off at a conference in Norfolk in 2014 organized by Old Dominion University. The event brought together Navy personnel, scientists, academics, industry, regional planners, and local government officials.

Many of the presentations focused on the need to develop a common set of data about impacts of sea level rise across multiple agencies and institutions so that regional decision making starts from a common baseline.

It's an approach born of necessity and mutual dependence, Admiral Smith says. The Norfolk region relies on the Navy and other Defense Department installations for almost half of its economic activity. The base relies on local utilities for power and water, and the transportation infrastructure connects the base by land to the rest of the region.

"If we do something and [the city of] Norfolk doesn't do anything, but Virginia Beach does, are we getting where we need to be? I think not," says Smith, who serves as the Navy's representative on the coordinating body for the planning project. "So we've got to work together."

But the planning effort is constrained by the fact that neither the Navy — nor the region — has yet to settle on a specific projected rate of sea level rise for the Norfolk region, a number that would in turn drive its decisions about how to adapt.

Whether to allocate federal dollars toward sea level rise adaptations at Naval Station Norfolk is a decision for Congress and should be part of a national policy on sea level rise, Smith says. "It's something we have to do as a society," says Smith, who commands the Navy's shore-based activities from Maine to Virginia. "You may have to retreat a little bit. Who knows, maybe 30 years from now there may be a part of this base we're not using anymore."

In the meantime, Smith says, the Navy has a huge investment in infrastructure not only in Norfolk but also all over the world, and Navy managers have to balance the current needs to fix leaking roofs and repair roadways with planning for future operational capabilities. The Navy, says Captain Rios, strives to meet these needs "just in time" — not too soon, not too late, balancing a future of unknowns against today's resources.

Only time will tell whether the Navy's planning efforts — along with efforts by the rest of Hampton Roads — will be implemented "just in time."

Living Shorelines Meet Rising Seas

Leslie Middleton, ***Bay Journal***

Most of the shoreline along the Chesapeake Bay's tidal reaches is composed of highly erodible soils — and it's also mostly privately owned.

The question of what to do about the effects of sea level rise hits many waterfront property owners right in their own backyards as valuable real estate is lost to higher tides and storm surges are amplified by rising seas and a changing climate.

Until recently, the options for homeowners were limited — and decidedly of the brute force variety. Steel vertical bulkheads and stone riprap have been the choice of thousands who wanted immediate control of erosion.

Volunteers plant marsh grasses *along a "living shoreline" on the South River in Anne Arundel County, Maryland. This native vegetation can protect shores from erosion and wave damage and create habitat for wildlife.* PHOTO, DAVID HARP

But these days, some homeowners are choosing "living shorelines," using a suite of techniques that employ strategically placed plantings and rock sills that attenuate wave energy while at the same time allowing the building — or rebuilding — of plant communities that resemble fresh or saltwater tidal wetlands. The states of Maryland and Virginia and other organizations have backed this approach.

But, in the face of uncertain rates of sea level rise, are living shorelines a stopgap measure, or are they a good investment for property owners?

The answer is: it depends.

It depends on the site's conditions and how the project is designed. For many properties, the space available for building a living shoreline is constrained by existing structures and neighboring properties. And questions remain about whether these engineered living shorelines will perform effectively over the long term.

"Some sites are better suited to living shorelines than others," says Scott Hardaway of the Virginia Institute of Marine Sciences (VIMS).

Hardaway has been designing living shorelines for three decades. As a coastal manager, he says, he's been dealing with sea level rise the whole time. The formation and destruction of coastlines and beaches is a continual — and natural — process, and understanding these processes is key to evaluating sites and developing designs that can adapt to rising sea level.

"It's all about the energy coming at the shore — how much, from what direction, with how much

fetch?" Hardaway says. In most locations, the installation of a living shoreline requires moving some earth to change the slope of the beach to allow a sufficient width of constructed shoreline so that the sand, rocks, and plants attenuate the wave energy.

One Family's Living Shoreline

John and Ruth Martin's home in Norfolk backs up to a stretch of the Lafayette River that is flanked by waterfront homes. Their backyard is a small peninsula dotted with live oaks and Virginia pines that provide welcome shade and native habitat for birds and wildlife.

In 2006, when the Martins returned from living overseas for seven years, they were shocked to see how much of the marsh that had flanked their property on three sides had disappeared. Aerial photos from earlier decades confirmed the loss. That persuaded the Martins it was time to take action — to build a living shoreline.

They brought in 400 tons of rock, 600 cubic yards of sand, and 5,000 plugs of panic grass and smooth cordgrass. Today, healthy stands of marsh grasses grow behind short sections of rock structures, or revetments. They were designed as the living shoreline's first line of defense from waves generated by powerboat wakes and storms. The revetments were also intended to help maintain the remaining wetlands that existed on the Martins' property before they began the project.

The total cost ran in the tens of thousands of dollars, driven up by the need to deliver the sand and rock by barge. The Martins also invested a considerable amount of sweat equity.

"To begin with, we decided upon a living shoreline for the erosion control," Ruth Martin explained. But as she and her husband explored alternative designs, they realized that they could build the revetments high enough to provide protection from sea level rise as well, at least for a time.

Because living shorelines are designed for specific sites, it can be difficult to compare costs between these more natural systems and other erosion control methods like bulkheads and riprap. And finding an experienced marine contractor to do the work is still a challenge, though efforts to expand the knowledge base are bearing fruit as more property owners ask for alternatives to traditional hardening of shorelines.

"I think we're going to see living shorelines really take off once we figure out the nexus between all the requirements local governments have to protect water quality and address the impacts of sea level rise."

A Movement toward Living Shorelines?

Interest in living shorelines has grown. The state of Maryland has been encouraging living shorelines for three decades, and enacted legislation in 2008 requiring homeowners to use living shorelines to protect waterfront property. Homeowners can get a waiver allowing them to use alternate erosion protection if a living shoreline is not feasible. (Maryland will consider whether the area is subject to excessive erosion or heavy tides or the surrounding waterway is too narrow.)

Virginia, too, has legislatively stated a preference for living shorelines and worked to create a general permit designed to streamline the process of obtaining necessary permission from local wetlands boards and state agencies.

The Chesapeake Bay Trust has funded numerous public demonstration projects around the Bay that include living shorelines — some of which have been around for almost 30 years. These projects have been very resilient in storms, says Jen Wijetunga, a civil engineer with the Trust. And an increasing number of designs accommodate sea level rise in the choice and placement of plants.

In addition to buffering against sea level rise, living shorelines offer other advantages to homeowners and their communities. The plants help to improve water quality by taking up excess nutrients and trapping sediment. Because of their effectiveness in doing that, living shorelines can now be counted as a BMP — or best management practice — under the Chesapeake Bay TMDL cleanup plan.

"I think we're going to see living shorelines really take off once we figure out the nexus between all the requirements local governments have to protect water quality and address the impacts of sea level rise," says Kevin DuBois, an ecologist with the City of Norfolk and a strong proponent of living shorelines.

The marsh vegetation in a living shoreline also can provide nursery grounds for fish and habitat for other wildlife. Darcy and Brooks Stephan installed a 300-foot-

long living shoreline by their house on the Lynnhaven River in Virginia Beach two years ago. "It has improved the habitat immensely," says Darcy, saying that her shoreline now teems with life. "We have raccoons, opossums, muskrats." And, of course, the herons: great blue, common egret, green night heron.

Keeping Pace with the Water

Evidence suggests that living shorelines do accomplish their intended purpose of controlling shoreline erosion. For a report published in 2006, Hardaway and colleagues at VIMS surveyed 36 living shorelines installed at various locations in the Virginia portion of the Bay between 1984 and 2003. The team found little to no signs of erosion in the upland areas behind all but five of these sites. (Some of those had rock sills sticking up less than one foot above mean high tide, leaving those shorelines exposed to large waves.)

In coming years, an important question will be whether these living shorelines can keep pace with the rising tides in a region that many call "ground zero" for sea level rise.

Patrick Megonigal from the Smithsonian Environmental Research Center and Matt Kirwin of VIMS have studied this question and concluded that the tidal marshes that defend a coastline's integrity can keep pace with rising seas, if they remain healthy and nourished with enough sediment to allow them to build upwards as sea levels rise. In any given area, Kirwan and Megonigal said in a study published in 2013, total wetland area may stay the same, even as portions of the marsh lose ground or are destroyed.

Several design factors influence whether a living shoreline can survive over time, says Pam Mason, a coastal resource specialist at VIMS. One is whether it can move or "migrate" inland as tides reach higher and higher. Another consideration, she says, is the length of restoration along a reach (or segment) of shoreline. Coastal processes are dynamic and specific to the topography — a living shoreline built between sections of shoreline protected by bulkheads may not be effective due to currents generated by the hardened sections.

Choosing and planting vegetation according to salt tolerance is another strategy to help keep pace with rising water levels. "We take this into account when we design living shorelines," says Sarah Picking, a landscape architect in Norfolk who has guided clients through the decision-making process. "We make sure that the more salt-tolerant species are planted in the tidal zone, the less salt-tolerant species are planted in the upland regions," to mimic how they are found in nature.

However, sea level rise and climate change are expected to change the Bay's salinity over time, and it is unclear by how much in particular locations.

Another strategy for building a living shoreline that persists is to build its rock sill higher than necessary in anticipation of future sea level rise. The additional cost is not always one that homeowners are willing to bear.

And some restoration professionals wonder what will happen to those rock sills during the high tides of the future. In 50 or 75 years, the living shoreline's vegetation may be inundated and die because of rising sea levels, says Joe Fehrer, who works with The Nature Conservancy in Virginia and Maryland. What if all that's left is an underwater pile of stones, he wonders?

Other people advocate augmenting the living shoreline's first line of defense using another kind of natural tool. They want to develop oyster reefs on top of the rock sills by setting spat or by relying on nearby oyster beds to help populate new habitat there.

Researchers have studied the vertical reef growth of oyster reefs in high salinity environments in North Carolina's coastal bays, and the results are promising. In April 2014, Antonio Rodrieguez from the University of North Carolina reported that accretion rates of intertidal oyster reefs have the potential to surpass all other coastal ecosystem engineers and to keep up with rising sea levels as they grow ever taller — and wider. Like marsh vegetation, oyster reefs also help to improve the Bay's water quality.

Although questions remain about their effectiveness, living shorelines may offer one creative solution for protecting shorelines from erosion while maintaining, restoring, and even enhancing the natural habitat, at least in the short term.

Nourishing Our Coastal Beaches

Adaptive Strategy or Fiscal Sand Trap?

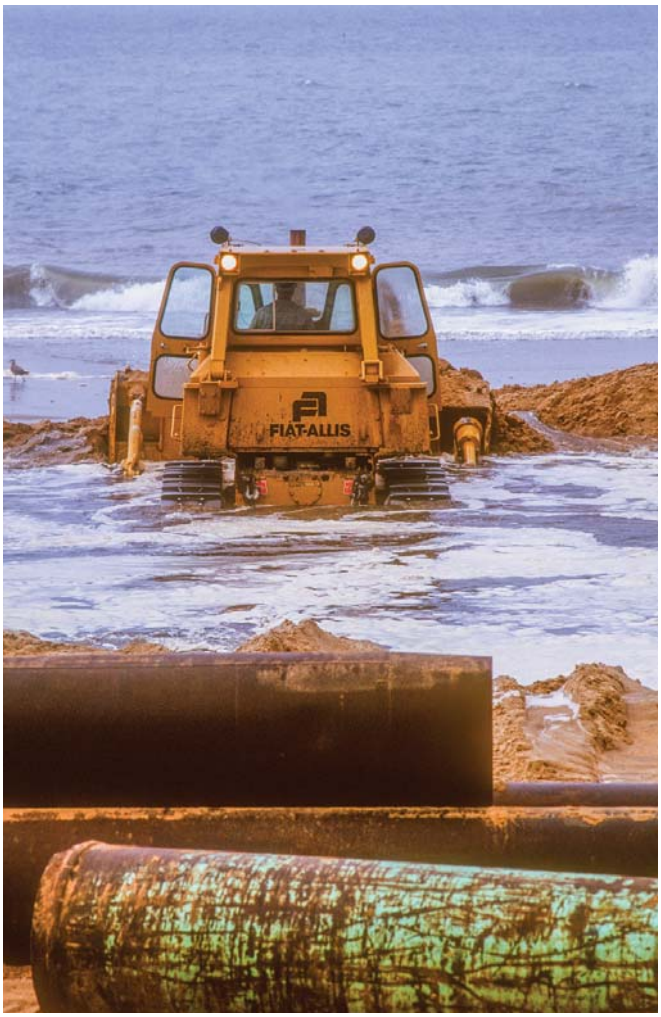
Leslie Middleton, *Bay Journal*

Visitors to seaside resorts like Ocean City, Maryland, and Virginia Beach come for sun, surf, and sand. But the sand would not be there if it weren't for multi-million-dollar, long-term beach replenishment projects that protect the physical and economic foundations of these beach communities from damaging storms.

Virginia Beach taxpayers invest between $2 and $3 million annually to preserve this beachfront that draws a much larger amount of tourism dollars to this community, says Phillip Roehrs, Virginia Beach's water resources engineer. "There's one thing we can do quite easily to address sea level rise," Roehrs says, "and that is to build the beaches higher."

Terry McGean, city engineer for Ocean City, also thinks that for large oceanfront communities, beach replenishment provides flexibility in the face of the uncertainty of how high — and fast — sea level will rise. "The beauty of a beach replenishment project is that you can adjust it in the face of what sea level rise actually is."

The risk of increased coastal flooding means that beach replenishment projects may become more important to seaside communities. But as supplies of offshore sand used for these projects become more scarce, and competition increases for federal funding to rebuild after larger, more damaging storms, will there come a point when building beaches higher becomes untenable economically and politically?



A bulldozer arranges sand in Ocean City, *Maryland, as part of a long-running beach replenishment project there. Ocean City is one of many coastal towns that use sand dredged offshore to rebuild beaches that are steadily eroded by the ocean. Sea level rise will likely increase the rate of erosion.*
PHOTO, DAVID HARP

Building on Shifting Sands

Ocean-facing beaches gain and lose sand through the seasons and over time as a result of natural processes.

Currents that run along the shore move sand along the coast, while other forces continually move sand and other sediments between the beach and offshore sandbars through cycles of erosion and accretion.

Undeveloped beaches, such as those on Virginia's barrier islands, migrate over time, eroding in some places while elsewhere building vast sandy peninsulas like the tip of Assateague Island. Left alone, inlets fill in, and heavy storms cut new channels across islands.

But increasingly since the early 1900s, people have built hardened structures like jetties and seawalls to interrupt the dynamic equilibrium between sand and sea and to protect against the relentless forces of ocean and wind. As high tides and damaging storms threatened nearby hotels, houses, and businesses, an array of shoreline protection measures have been employed to protect life and property. Before those measures became available, retreating was the only option for many homeowners. In the 1920s, the 300 residents of Wash Woods, a community south of Virginia Beach, started to leave, weary of repeated inundations from the sea washing over the dunes. All that remains today is the Methodist Church steeple.

Summer visitors enjoying a day on the beach *in Ocean City, Maryland, (above) aren't thinking about the price of upkeep for their vacation spot. That sum is significant — costs for beach improvement in the town have topped $115 million since 1998. But Terry McGean, the city engineer, says that these efforts have prevented $717 million worth of damage.* PHOTO, MICHAEL W. FINCHAM

Today there are also what engineers call the "softer" structural options — like beach replenishment, where stretches of beach are rebuilt to resist erosion. Tons of sand are sculpted into a profile designed to provide protection to the hotels and boardwalks that anchor a way of life for many beachfront communities.

These engineered beaches must be replenished every few years or after especially damaging storms through fresh infusions of sand obtained from some other location. The larger projects, like those at Virginia Beach and Ocean City, are built by the U.S. Army Corps of Engineers and have multi-decade project timelines. John Headland, a private engineering consultant involved with coastal projects for over 30 years, says, "You have to replace pavement on streets, and likewise you have to replace sand on beaches."

The Balance Sheet: Sand, Dollars, and Time

The first designed beach "renourishment" project was constructed in 1922 at Coney Island, followed in the next 80 years by 333 engineered projects — and 517 million cubic yards of sand — along the Atlantic and Gulf coasts.

The Army Corps of Engineers advised the early projects and since the 1950s has managed all federally funded beach renourishment projects, expanding its traditional role in improving flood protection, harbors, and waterways. The beach sand projects are selected and funded based on "federal interest." This means they must meet a threshold where the cost of preventing storm-related damage to public infrastructure and private homes is significantly lower than the costs likely to be incurred as a result of significant storm damage.

In Maryland, combined costs for the Ocean City beach project have topped $115 million since 1998. But McGean says the latest estimate is that $717 million of damage has been prevented by these beach improvements.

For the Ocean City project — a nine-mile stretch of beach partly buttressed by a sea wall that protects the boardwalk — the federal government provides 53 percent of the cost. The remaining 47 percent is split evenly

in two parts, one paid by Maryland and the other paid by the city of Ocean City and the surrounding county.

All parties share in the costs because all derive some benefits. For the Corps, the spending reduces the federal government's costs for disaster relief, insurance programs, and subsidies for rebuilding damaged structures.

Local communities share in the costs because they depend upon the beaches to generate the tax revenues that flow from homeowners and tourism. In Virginia Beach, the cost of periodic replenishment represents about 10 percent of tax revenue from oceanfront tourism, Roehrs says. For communities like Virginia Beach and its waterfront strand to the south, Sandbridge, the sand is, quite simply, why these communities exist.

The projects in Virginia Beach and Ocean City were designed before Hurricane Sandy demolished homes, hotels, and holiday dreams worth billions of dollars in New Jersey and New York coastal communities — and before billions of "hurricane relief dollars" were spent for rebuilding beaches in many Mid-Atlantic communities.

Some critics think that large federal subsidies for beach replenishment are unfair because they are funded by many taxpayers living away from coasts to help support the beach-side homes of a wealthy few. The federal funding formula and Corps rules for replenishment projects give more weight to communities with expensive homes than to locales with less valuable real estate.

Behind the Sea Wall

In 2008, the Corps of Engineers policy stated that all its projects must "incorporate" sea level rise in designs.

Justin Callahan, coastal engineer with the Corps' Baltimore District, explained that beach replenishment projects are more at risk from increases in storm surges — a function of sea level rise and the intensity, direction, and duration of repeated storms — than from sea level rise alone.

In the face of more sophisticated data analysis on sea level rise trends, the Corps is now reviewing design criteria for all its coastal protection projects. Accommodating changing conditions and new data are part of the ongoing review process for long-term beach renourishment projects, says Jen Armstrong, a Corps project manager in the Norfolk district office. "We have a mechanism to go back and re-evaluate our projects based on changing conditions."

This kind of adaptive management, Headland says, offers a conservative approach for coastal communities to meet the challenges of accelerating coastal erosion resulting from rising seas. A beach replenishment project designed to a certain width and elevation geometry can provide protection today and be adjusted periodically to increasingly higher elevations, as needed. "This gives you a lot of flexibility," Headland says, over the planned project period, which can span up to 50 years.

But beach replenishment alone isn't sufficient to protect important infrastructure located "off the beach" like roadways, electrical power, and stormwater collection systems. All are increasingly vulnerable to damage from floodwaters associated with longer and more intense storms. Ocean City's stormwater system has limited ability to drain streets during flooding. During Hurricane Sandy, Ocean City's engineered beach survived mostly intact. But, McGean says, "All our flooding — and property damage — was from the Bay side."

Borrowing Sand from Offshore Deposits

The nine-mile strand of clean sand along Virginia Beach's boardwalk and shorefront neighborhoods is neither natural nor cheap.

Spikes in sand prices, resulting from demand from communities ravaged by hurricanes and nor'easters, make project costs unpredictable for the feds and their local partners. "The most we've paid is a little over eight dollars a cubic yard," Roehrs says, "but if we'd had to buy sand after Hurricane Sandy, we would have paid as much as 15 dollars a cubic yard."

Supplies of sand can also be uncertain. The sand comes primarily from offshore sandbars, most of which have formed over millennia from erosional processes that have transformed upland rocks and sediment to sandy ocean bottom.

As the demand for beach-rebuilding sand has escalated, more Mid-Atlantic states are reaching beyond the three-mile state limit into federal waters to obtain it. The federal Bureau of Ocean Energy and Mining and the U.S. Geological Survey are studying these offshore resources on behalf of the states.

But coastal sand mining is not without ecological impacts. "Coastal sand mining disrupts the near-shore ocean food web by removing bottom-dwelling organisms," says Gwynn Crichton, senior scientist for The Nature Conservancy, "and this can disturb shoal areas where marine life congregates."

Using sand from other sources to rebuild beaches is fraught with other problems. Although benthic organisms in the surf zone can rebound with time, the composition and abundance of species there change when

incoming sand grain characteristics are not closely matched with those of the replacement sand, according to Crichton. Migrating shorebirds, crabs, and fish depend on these organisms, like the millions of coquina clams that ascend through the sand after every receding wave.

And while beach replenishment projects are seasonally restricted to limit impacts on nesting sea turtles, changes in beach-face geometry can prevent females' access to safe nesting sites — and the composition of the sand itself may negatively impact sea turtle incubation rates.

We say we are "nourishing" the beach. But the sand that is "borrowed" from offshore sites generally does not return to these same sites — and the overall health of the ecosystem has been compromised.

Ironically, the language used to describe the process suggests an improvement in beach health — we say we are "nourishing" the beach. But the sand that is "borrowed" from offshore sites generally does not return to these same sites — and the overall health of the ecosystem has been compromised.

Castles in the Sand

It's easy to forget that beaches are dynamic geologic structures, built up over millennia, constantly changing with seasonal cycles of wind, weather, and tides. But this is exactly what attracts us to them, as expressed in a traditional nursery rhyme.

> Down at the seashore, isn't it grand?
> Wiggling my toes in the soft warm sand
> Building a tall sand castle, where the king and queen stay
> When the tide comes rushing in they will have to
> move away

The words capture the lure and the dangers of building on oceanfront property — and an alternative to beach replenishment that no one is willing yet to address seriously, says geologist Robert S. Young, director of the Program for the Study of Developed Shorelines at Western Carolina University. That alternative: moving away from the beach.

Young says that "refreshing" damaged beaches is simply not a long-term fix for a serious and rising problem. In an August 14, 2014, *New York Times* op-ed, he wrote that spending post-Hurricane Sandy federal dollars to rebuild costal communities — including dunes and beaches — is leading to the waste of millions of dollars in the absence of a national plan for coastal adaptation. For Young, these strategies need to include "managed retreat," a politically unpalatable option, but one that increasingly crosses the minds of policy makers and local managers.

Virginia Beach is poised to commission a study on the cumulative impacts of sea level rise on the city and other strategies for adaptation in addition to beach replenishment.

As hard as it is to contemplate how large, beach-dependent communities might "move away" like the king and queen in the nursery rhyme, engineers like Phillip Roehrs of Virginia Beach admit that "what keeps us up at night is knowing that there can always be a [flooding] event that is bigger than the one you've been able to prepare for."

Or, afford.

"If we evaluated sea level rise and did the straight-line math," says Roehrs, to estimate what it would take to adequately protect the shorelines and inland infrastructure, "we'd find out that it would take some ungodly amount, and we'd throw our hands up in despair."

In the meantime, communities like Virginia Beach and Ocean City will continue to maintain — and nourish — their beaches while planning for the future.

More Information and Resources

Studying the Causes of Sea Level Rise and Projected Increases

- **Updating Maryland's Sea-Level Rise Projections,** Scientific and Technical Working Group, Maryland Climate Change Commission, http://ian.umces.edu/pdfs/ian_report_413.pdf – This 2013 report describes causes and projections of sea level rise in the Chesapeake Bay through 2100. See a video and article summarizing this study: http://www.mdsg.umd.edu/news/scientists-unveil-new-projections-sea-level-rise-maryland
- **Recurrent Flooding Study for Tidewater Virginia,** Virginia Institute of Marine Science, http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_Study_web.pdf

Planning for Sea Level Rise

- **CoastSmart Communities,** Maryland Department of Natural Resources, http://dnr.maryland.gov/CoastSmart/resourcecenter.asp – This state program works to help homeowners and coastal communities plan for coastal flooding and sea level rise. The website includes, for example, a fact sheet about elevating houses to avoid flooding and lower flood insurance premiums.
- **Climate Change in Maryland,** Maryland Department of Natural Resources, http://www.dnr.state.md.us/climatechange/ – Learn about other ways that the state of Maryland is working to adapt to the effects of sea level rise and other aspects of climate change. Provides links to tips on how people can help in their everyday lives, like conserving electricity and water.

Floodplain Maps and Federal Flood Insurance

- **Maryland Digital Flood Insurance Rate Maps (DFIRM),** http://mdfloodmaps.com – Coastal flooding, which is worsened by sea level rise, has led the federal government to update floodplain maps in Maryland and other states. The redrawn maps have included some homeowners within floodplains who previously were outside — and as a result, may be required to purchase flood insurance for the first time. However, property owners may be eligible to save money on premiums through the National Flood Insurance Program if they obtain policies through the program before new floodplain maps take effect. This website has an online tool that allows users to understand their flood risk and choices.

Sea Level Rise Viewers

Several websites allow users to see for themselves the simulated effects of differing amounts of sea level rise at the neighborhood level around the Chesapeake Bay. Here are some of these viewers and their features:

- **Climate Central: Surging Seas,** http://sealevel.climatecentral.org/ssrf/maryland – Pick a level of sea level rise (up to 10 feet), and you can see the numbers of people, houses, and acres in towns and cities that would be inundated. This viewer also plots the locations of schools and hospitals; identifies the income and ethnic makeup of people in the areas affected; and shows ranges of property value (by acre), among other information.
- **NOAA Viewer,** http://coast.noaa.gov/digitalcoast/tools/slr – See photos of various landmarks as they would look under higher water. The simulation illustrates the loss of marshes as they are flooded.
- **Coastal Atlas, Maryland Department of Natural Resources,** http://gisapps.dnr.state.md.us/coastalatlas/iMap-master/basicviewer/index.html – Part of the Coastal Atlas, this interactive map shows multiple layers of information about coastal hazards suitable for planning purposes. The layers include sea level rise, flood plains, and areas suitable for building living shorelines to reduce erosion. More information about the map and the Coastal Atlas is available at http://dnr.maryland.gov/ccs/coastalatlas/index.asp

Acknowledgments

About This Special Report

Chesapeake Quarterly magazine and *Bay Journal* newspaper jointly produced the content in *Come High Water: Sea Level Rise and Chesapeake Bay*, a special report about how sea level rise presents challenges for the people, communities, and ecology of the Bay region.

Staff members from both publications authored articles and other material in the report. Selected articles from this package appeared in print in the two publications. This comprehensive print report includes articles that appeared in print and those that appeared only online. The report includes two articles that did not appear in the package originally published in 2014 and a third article that was revised. Two articles (Loss of Coastal Marshes to Sea Level Rise Often Goes Unnoticed, p. 28, and Rising Sea Level Swallowing Red Knot's Migration Stopovers, p. 36) were written and published by *Bay Journal* in 2015. In addition, A Flood Wall against the Future (p. 46) was revised to include information and photographs not available at the time of publication.

Staff members from both publications who were involved in creating the articles and other content in this report were:

Chesapeake Quarterly — Michael W. Fincham, Daniel Strain, Sandy Rodgers, and Jeffrey Brainard

Bay Journal — Rona Kobell, Leslie Middleton, Karl Blankenship, David Harp, and Michael Shultz

In addition to the print version of *Chesapeake Quarterly*, Maryland Sea Grant created a web microsite that contains articles in this package by both publications as well as interactive tools, a photo gallery, and video interviews. Staff who created the microsite included: Dan Jacobs, Amit Janbandhu, Sandy Rodgers, Michael W. Fincham, Daniel Strain, and Jeffrey Brainard. You can visit the microsite at:

http://www.chesapeakequarterly.net/sealevel/

About *Chesapeake Quarterly* and *Bay Journal*

Chesapeake Quarterly is the magazine of Maryland Sea Grant College at the University of Maryland. Subscriptions are free. You may sign up for a print and/or electronic subscription at:

http://www.chesapeakequarterly.net/subscribe/

Maryland Sea Grant receives funding from the National Oceanic and Atmospheric Administration and the state of Maryland. Our program works to apply science to protect and restore the Chesapeake Bay and Maryland's coastal resources. We fund and explain scientific research to help leaders and communities deal with our state's major environmental challenges. We promote a sustainable coastal economy. Learn more about Maryland Sea Grant's work and accomplishments at:

http://www.mdsg.umd.edu/welcome-and-mission

Bay Journal is a newspaper that publishes 10 issues a year covering the Chesapeake Bay region. Publication is made possible through grants from the EPA Chesapeake Bay Program Office, the Campbell Foundation, the Town Creek Foundation, National Oceanic and Atmospheric Administration Chesapeake Bay Office, the Rauch Foundation, the Brendsel Family Foundation, the Sumner T. McKnight Foundation, the Shared Earth Foundation, the Virginia Environmental Endowment, the Abel Foundation, and reader donations. For more information about *Bay Journal* or to subscribe, visit them at:

http://www.bayjournal.com/

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Cover photo: Photographer David Harp took this shot of the last house on Holland Island in 2009. In October 2010, it collapsed and was swept into the Bay. For more about the island and its inhabitants, watch this *Chesapeake Quarterly* video on YouTube:

https://www.youtube.com/watch?v=H46Pb8pEMfM

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Maryland Sea Grant is non-profit and has limited funding. Please consider making a financial contribution to support publications like this and future issues of *Chesapeake Quarterly* magazine at:

http://www.mdsg.umd.edu/donate

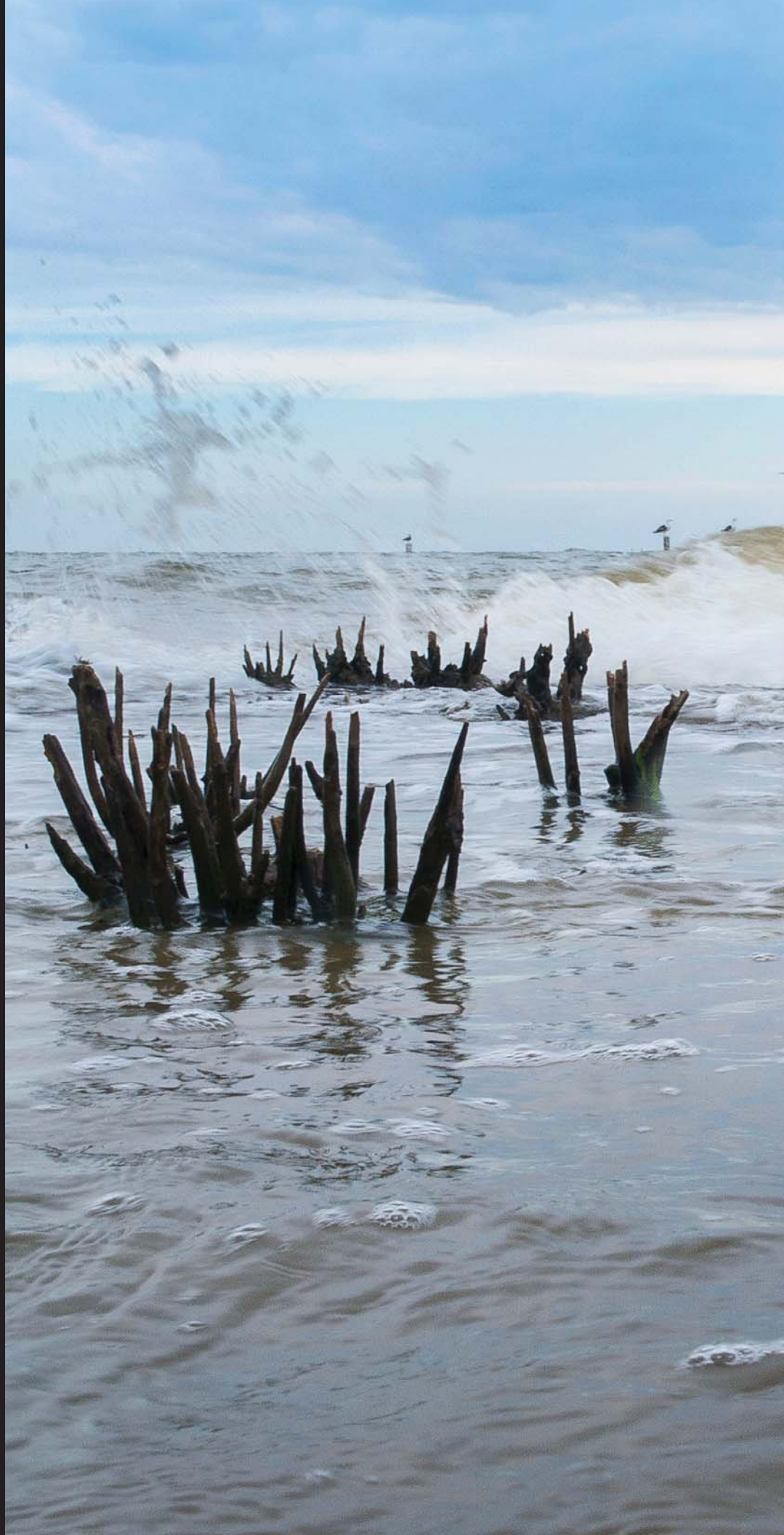
COME HIGH WATER

Sea Level Rise and Chesapeake Bay

From the Foreword

The articles in this special report go well beyond sea level rise projections to illuminate how sea level rise increases the risks posed by tidal extremes and storm surges; the consequences for the Chesapeake Bay region's coastal landscapes, biota, and human communities; and how we can become more resilient in the face of rising Bay levels. I strongly recommend that you read it cover to cover and put it on your coffee table for the enrichment of your family members and guests.

— Donald Boesch
President, University of Maryland Center for Environmental Science



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