Chesapeake Quarterly

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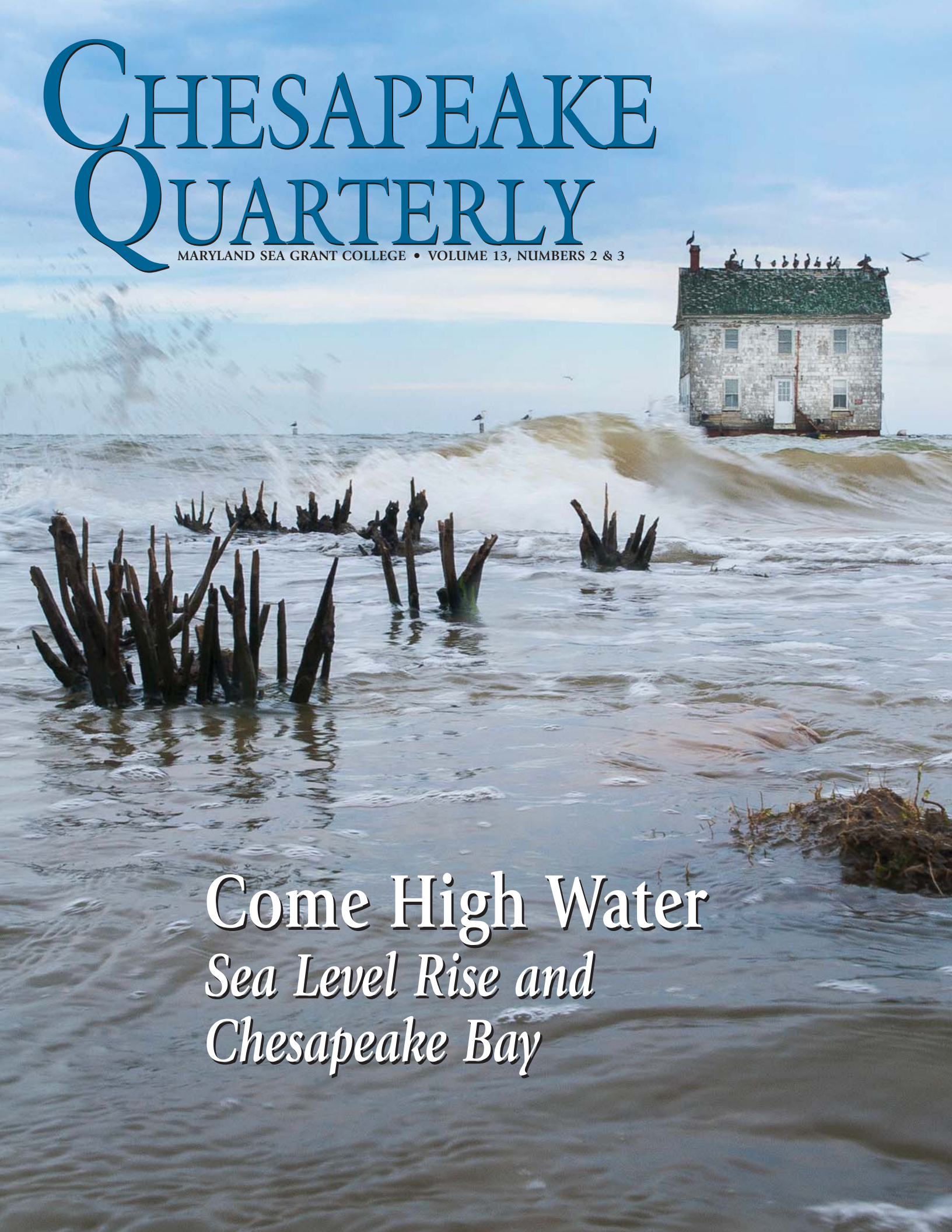

Come High Water

Sea Level Rise and Chesapeake Bay

contents

Volume 13, Numbers 2 & 3

More Stories and Information Online

The web version of this special issue of our magazine has a number of online-only stories about sea level rise in the Chesapeake Bay region. You can read summaries of these articles on pages 9, 17, and 27. To read the entire issue online, scan the QR code at right or visit www.chesapeakequarterly.net/sealevel

Chesapeake Quarterly

October 2014

Chesapeake Quarterly explores scientific, environmental, and cultural issues relevant to the Chesapeake Bay and its watershed. The magazine is produced and funded by the Maryland Sea Grant College.

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Cover photo: *This house on Holland Island in the Chesapeake Bay stood for more than a century. But the estuary's water level rose, the island eroded, and the inhabitants left. In 2010, the house — the last one left on the island — was swept into the Bay by encroaching waves.* ***Pages 2 and 3:*** *Maryland is experiencing one of the fastest rates of sea level rise in the nation. It also has some of the lowest-lying land, like this part of Dorchester County where Maple Dam Road has been flooded during high tides.* PHOTOS, DAVID HARP

Reckoning

Seas are rising in the issue of our magazine

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

with the Rising

Chesapeake region, flooding Bay shores. This special examines by how much, and what we can do.

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* teamed up with the *Bay Journal* newspaper to produce the articles in this special issue of our magazine. 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?

Additional articles and expanded information on the subject of sea level rise are available on a special website. To check them out, scan the QR code on the opposite page, or visit the web at: www.chesapeakequarterly.net/sealevel.

— *The Editors*

The Rising: *Why Sea Level Is Increasing*

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?

PHOTO, DAVID HARP

The Antarctic Connection

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

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 physi-

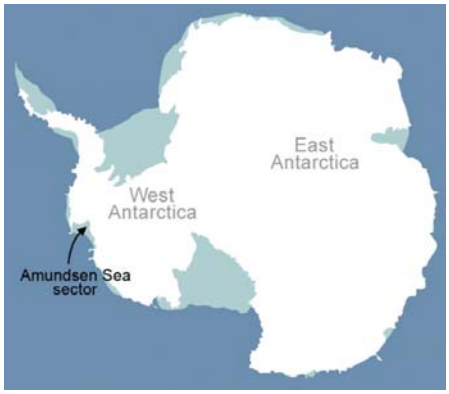
***Ice loss proceeds** at a staggering rate along the front of Thwaites Glacier (pictured here in 2012), part of the rapidly melting Amundsen Sea sector of Antarctica (map below). Ron Anderson (below, left) of Oxford, Maryland, has seen the toll of these global changes on the state's coast.*
CREDITS: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

cal 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 manmade 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. 8).

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.

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.

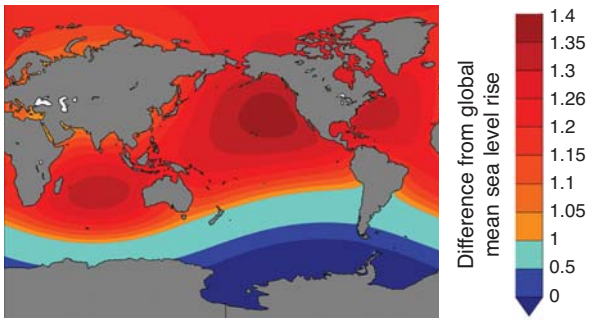
The geoscientist grew up in the Philadelphia area and spent family vacations in his grandparents' cabin on the

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

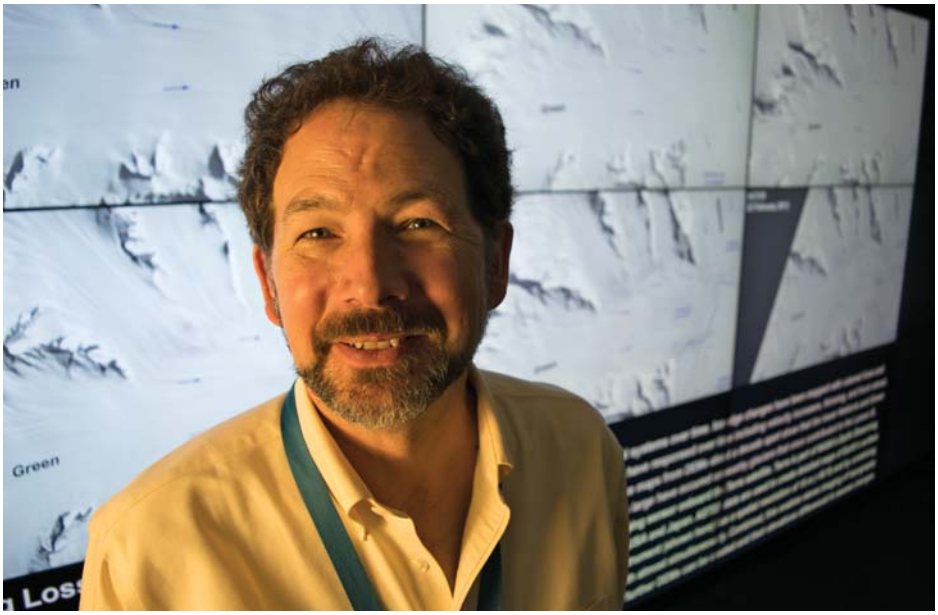
Note: Subtotals are rounded and so may not sum to total.



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



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 FINCHAM

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 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 of 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."

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As the Land Sinks

Daniel Strain

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

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.

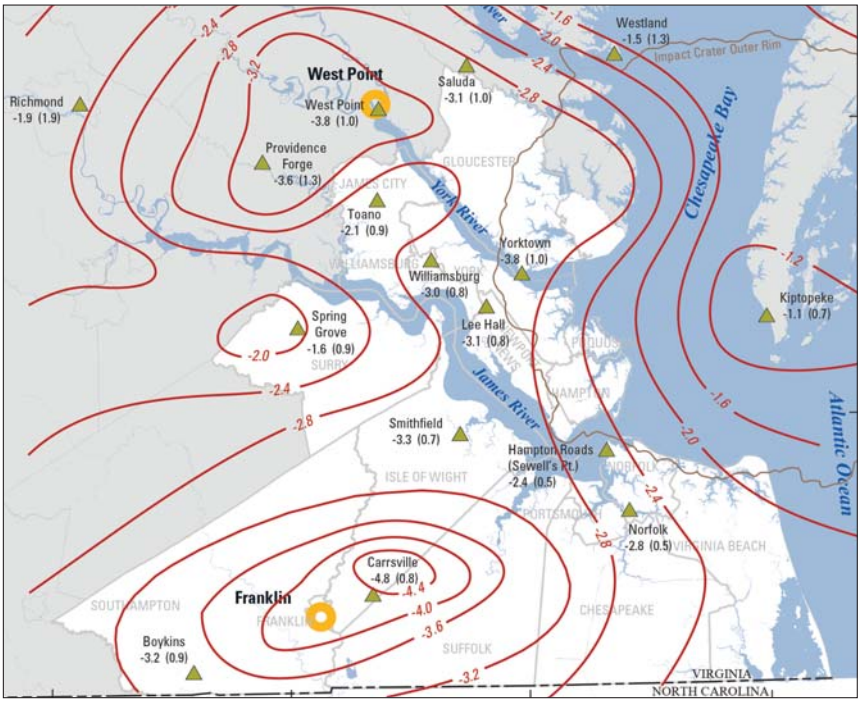
"This question kept coming up of what was causing this land subsidence," says Whitney Katchmark. She heads up the Water Resources Department in the Hampton Roads Planning District Commission, which advises towns in the region.

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

To understand why, think of a jelly doughnut. Like 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 sup-



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, DAVID HARP; MAP, U.S. GEOLOGICAL SURVEY

port 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 the next year or so. 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."

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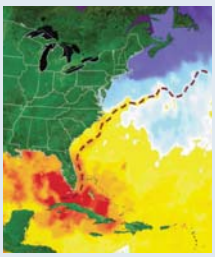
Online Features: www.chesapeakequarterly.net/sealevel

The Gulf Stream's Pull



NASA

Scientists have long suspected that climate change could force the Gulf Stream, a massive current in the Atlantic Ocean, to slow down. Recent research suggests that this shift may already be underway, and it could be helping to drive up water levels across the Mid-Atlantic coastline — causing an acceleration in sea level rise not seen anywhere else in North America. Many researchers, however, are still skeptical.

Storm Surge: Blowing Baltimore Away

Michael Kearney

The biggest threat to Baltimore is not the perfect storm — it's the perfect storm surge. Big winds drive a bulge of water up the Chesapeake Bay just as other bulges are also barging north: the long wave of a full-moon tide, the big slosh from an oscillating seiche event, the dome of water beneath a low-pressure storm center. Add in sea level rise, the physics of friction, the geometry of the Bay, and you've got faster, taller waves headed for Fells Point.

THE COSTS: *Effects on People and the Land*

PHOTO, 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

Rona Kobell, *Bay Journal*

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

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's 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.

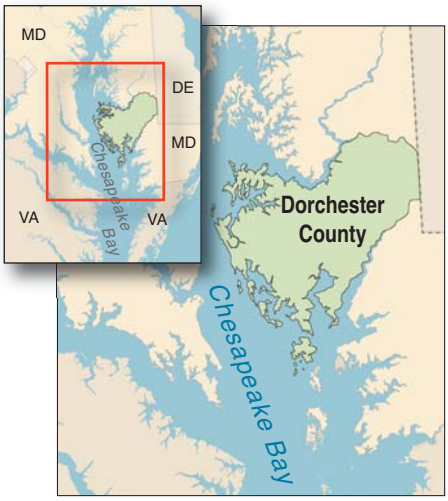
And more high water is coming. A scientific panel concluded in 2013 that sea level on Maryland's coasts is likely to rise over the next century by 3.7 feet and as much as 5.7 feet. The current rate of increase is about twice the national average. Dorchester is especially vulnerable to higher waters because it is the second-lowest-lying county in Maryland (after neighboring Somerset County) and one of the lowest in the United States.

Growing up in Dorchester County, *James Adkins (above), 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

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.

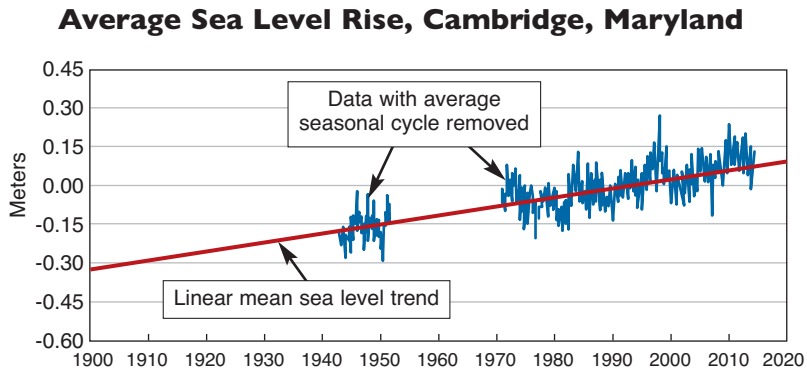
Jay Newcomb understands this problem all too well. He's the president of the Dorchester County Council, the manager of Old Salty's, a popular Hooper's Island restaurant, and a longtime school bus driver in a place where buses never last long because of saltwater damage. Rare among his neighbors, Newcomb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



One day last year, 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.



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

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 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 home-

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

owners 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 of 2014, which President Obama signed into law in June, authorizes the work. 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. 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

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

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.

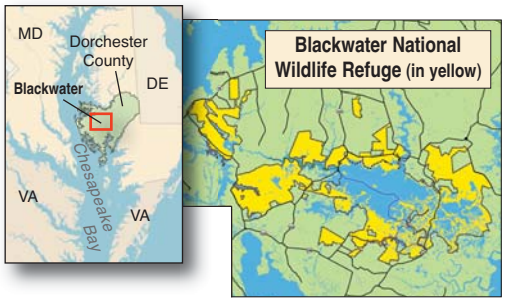
Whitbeck is a wildlife biologist at the Blackwater refuge, which occupies around 28,000 acres of forests, marshes, and water in Dorchester County on the Eastern Shore of Maryland. Today, he's interested in the transitions that are occurring across this landscape. Over the decades, Lake Blackwater — which 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.

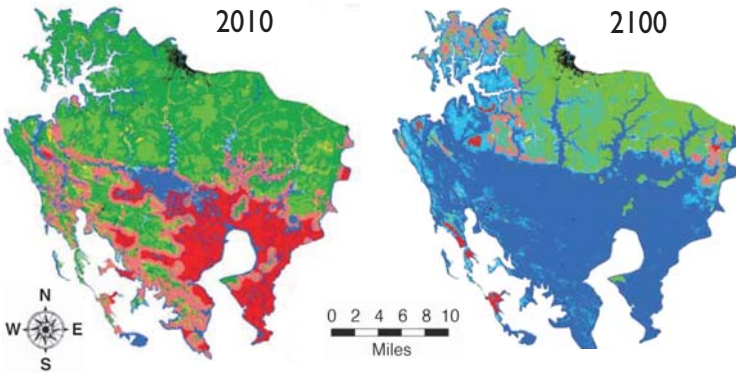
"You can see, essentially, the habitat transition in action. I mean, you can see that line of dying trees. You can see the marsh encroaching," Whitbeck says. "It's happening in front of our eyes."

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 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.



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, BLACKWATER 2100 TEAM

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.

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 (opposite page), 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.* PHOTO ABOVE, DAVID HARP; PHOTO OPPOSITE PAGE, DANIEL STRAIN

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.

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 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."

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Online Features: www.chesapeakequarterly.net/sealevel

Low-Lying Communities of Color at Risk

Emily Will, MDS

Sea level rise places an added burden on many African-American communities in the Chesapeake Bay region — areas that lie lower in both elevation and income than do some of their affluent neighbors. Many of these towns are unincorporated, limiting their access to resources like grants for shoreline stabilization.

Disappeared Islands

Courtesy, Hanks family

In times gone by, people called these watery places home — Parker's, Little Watts, Sharps. These once-inhabited islands in the Chesapeake Bay have disappeared beneath the waves, victims of erosion, a natural force that is strengthened by the estuary's rising water. Dozens of small islands like these were recorded in colonial times but do not appear on maps today.

THE RESPONSE: *How People Are Adapting*

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.

PHOTO, DAVID HARP

The Storm over Surges

When Sandy Came to Crisfield

Michael W. Fincham

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 on 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 jaw line, 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 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 river bank. 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,

John Barnette (red jacket) leads *the Somerset County Swift Water Rescue Team into the flooded streets of Crisfield 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 OF CRISFIELD, COURTESY OF SALISBURY NEWS, SBYNEWS.COM; INSET PHOTO, COURTESY OF THE SOMERSET COUNTY SWIFT WATER RESCUE TEAM

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 not 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 pressure, 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.

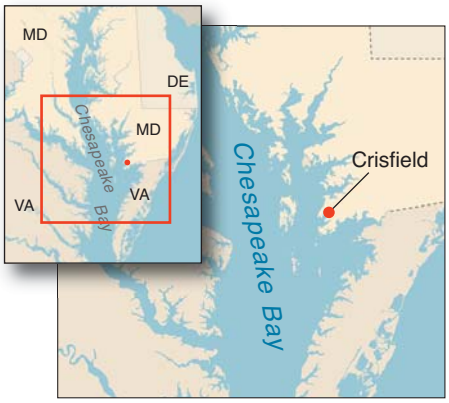
The results, however, have been uneven. In their post-storm review, the National Weather Service found that the storm surge from Isabel in 2003 ran one to three feet higher in the Chesapeake than the forecast, especially in the northern Bay. Its forecasts for Irene and Sandy were off even more. They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

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; MAP BELOW, ISTOCKPHOTO.COM/UNIVERSITY OF TEXAS MAP LIBRARY

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.

"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 spring tide, a collusion that helped create huge storm tides and surges and extensive flooding. Isabel, however, entered the Bay region on a much weaker neap 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."

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. 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.

"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

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. The bottom curve of Sandy's cyclone sent northwest winds blowing straight down the long reach of the Potomac River. Those winds pushed water out of the river, shoving it eastward across the Bay towards 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 flood waters. 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.

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.

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 Zodiacs, new dry suits and additional training.* PHOTO, COURTESY OF THE SOMERSET COUNTY SWIFT WATER RESCUE TEAM

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 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.

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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

A Flood Wall against the Future

If Katrina Came to Washington

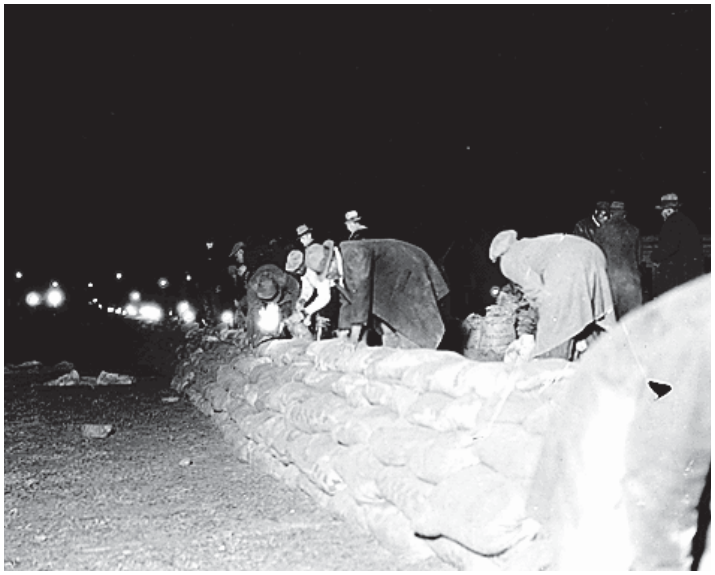
Michael W. Fincham

As dawn broke in Washington, D.C., a large tractor-trailer groaned to a stop on 17th Street just below the Washington Monument, a looming orange pillar in the early morning light. Men in green work vests and white hard hats began setting up red cones and waving traffic around the truck. On its long, open flatbed sat an odd new monument for the National Mall: a flood wall that is supposed to protect the nation's capital from the fiercer floods the future may bring.

The nation's capital is not New Orleans, but the hurricane that overwhelmed that Gulf Coast city raised alarms in Washington, D.C., and in many other riverside and coastal cities. When Katrina hit New Orleans, its storm surge broke through weak points in the city's elaborate levee system, letting rivers of sea water 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 level, more intense hurricanes along the North Atlantic, and stronger storm surges, a trifecta that carries expensive penalties for

poorly prepared communities. Downtown Washington, D.C., could be vulnerable to major flooding from the Potomac River.

With Katrina invading New Orleans in 2005 and Sandy surging into New York City in 2012, American planners are looking at engineering solutions that once seemed too far-fetched, too expensive, too European. The Brits had built floodgates across the Thames River in hopes of protecting London. And the Dutch had 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. In New York, planners are now discussing a surge barrier across the Verrazano Narrows. And in Virginia, scientists recently began running computer modeling studies to test the pros and cons of a giant floodgate across the mouth of the Chesapeake Bay.



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

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 runs along the north flank of the Reflecting Pool. Those who do know about the levee also know that it has a major gap: the busy 17th Street roadway that crosses the Mall just west of the Washington Monument. That gap gives morning rush hour traffic a shortcut across the Mall and an entryway into downtown D.C. It also gives flood waters from the Potomac a gateway into the city.

To test out a stopgap, the white hard hats began unloading the flood wall, piece by piece, working with a cranelike forklift. None of the Saturday morning joggers or bus tours stopped to watch, but a number of engineers were paying close attention. They were working for the U.S. Army Corps of Engineers, for Akima Construction, the general contractor, and for Waynesboro Alloy Works, one of the chief subcontractors.

Everybody had good reason to be attentive: the new flood wall, in its final form, would include 35 very heavy pieces of metal. As the engineers checked their clipboards, a work crew began hooking and swinging and lowering onto the street some large, carefully numbered metal posts and panels. The entire wall would include eight metal posts weighing in at 1,200 pounds each, and 27 aluminum panels tipping the scales at 800 pounds each.

All the parts were numbered because they had to be plugged together 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 magnify the process by several orders of magnitude. Heavy manhole covers had to be lifted off the roadway, metal posts had to be lowered down those manholes sockets, aluminum panels had to be slotted between the posts.

It's been called a flood wall, a floodgate, a post-and-panel wall, but the technical term for the design would be "a stop-log closure structure," says Tony Vidal, chief engineer for the project for the Corps. Between the posts, panels will be slotted on top of each other log-cabin style, raising a barrier that was supposed to stand three panels high and nine feet tall and stretch across the street and both its sidewalks. The 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 ground, each wall ends abruptly in mid-air, looking like a misplaced ski jump. The walls will connect the street-level barrier into the higher ground, tying this whole exotic structure into the familiar landscape of the National Mall.

Today would be a test fitting for just the ground-level panels, the sections that have to fit the curve of the street and the angle of the sidewalks. If this daytime fitting doesn't go well, the panels will go back to the shop, and the next test, a full test, will probably happen at night. "It's probably a good time to install it in the middle of the night," says Vidal, "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," says Amy Tarce of the National Capital Planning Commission. "If you google 'floods in D.C.,' 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 1936 flood that gave birth to the idea of a levee along the National Mall. "The Great Spring Flood" 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 between the high ground of the Lincoln Memorial and the higher ground of the

An artist's sketch shows an early version *of the 17th-Street flood wall (left). The photo above shows an example of how a "post-and-panel" flood wall would be erected. The Washington wall will have nine posts and 27 panels, all of them stored off-site. When a major flood event threatens the city, they would be trucked to 17th Street and craned into place.* DRAWING AND PHOTO, COURTESY OF THE U.S. ARMY CORPS OF ENGINEERS

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 word they used was 'unacceptable,' " says Tarce. "That's their technical term for saying the levee doesn't meet their criteria for a 100-year event."

The gap at 17th Street, under this once-in-a-100-year-flood scenario, would let river waters 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 national 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," says Tarce of the National Capital Planning Commission. The city government asked FEMA to postpone issuing the map, and FEMA agreed, exacting a promise that the city would fix the levee 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. Then 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., according to Ed Link, a senior research engineer at the University of Maryland who used to work for the Corps as "chief geek" or director of research. When many agencies are in charge, no one is in charge.

Another, more sobering, 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 Link and his colleague George Galloway, a research engineer from the University of Maryland who collaborated on studies of 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: rainstorm flood waters rushing downriver out of

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. A plaque on the structure reads: "Here the tide is ruled by the wind, the moon, and us (the Dutch)."* PHOTO, VLADIMIR ŠIMAN

the Potomac watershed and a hurricane storm surge driving upriver on a high tide. 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," says 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. "We have these stereotypical conceptualizations of storms," says 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," says Link. "It was this hybrid, it didn't behave like a hurricane, it didn't behave like a nor'easter, it behaved like a monster."

How do we do forecasts for these hybrid monsters? And how do we plan for them, especially in an era of rising sea level? "Statistically we are in Never-Never Land," says 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 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 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 City, 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 Bay.

Prepare for the predictable or for the nightmare monster? "I'll give you what my Dutch friends say," says 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. 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," says Galloway.

How does a city prepare for a disaster it can't define simply or predict? 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," says 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, says Link, is to apply certain key principles, and one of them is ongoing adaptation. "Everything has to be built to allow additional options," he says. "Every time you take step 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."

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," says Galloway, who 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 says, "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, unexpected floods.

"In D.C. we are plugging up the big

holes and we are paying attention to the things that are most obvious and near-term important," says Link, who collaborates closely with Galloway as part of an informal group of engineering researchers from three area universities. The group's job, however, is to look beyond the near term, to identify long-range risk, and to figure out adaptation strategies for the city for the next three or four decades. On the other hand, the Dutch, according to Galloway, are working on their 10,000-year plan.

By early afternoon, the test was finished. The crew slid all the clanging manhole covers back into place and fork-lifted all the posts and panels back on the truck. The street was clear, open once again to traffic and to flooding. And the panels were headed back to Waynesboro, Virginia, for yet more tweaking.

The wall could pass its final test sometime late this year. Then all its moveable pieces will be trucked off to storage, waiting for years, even decades, 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 block off 17th Street, the National Park Service will haul the wall out of storage, big trucks will rumble down Constitution Avenue, the forklift crane will swing into action again.

And some people will hold their breath. There's Murphy's Law to worry about, says Galloway. Some cities have misplaced their flood barriers. 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, says Galloway, but it may not be enough for an era when sea level is rising. "We've been lulled into this false sense of security that if you have a 100-year flood protection, then okay, we're safe," he says. "The Dutch just laugh at us when we say that."

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Online Features: www. chesapeakequarterly.net/sealevel

Are New Policies Needed to Meet the Challenge?

Governments at all levels — federal, state, and local — should provide more effective and coordinated leadership to address the risks of increased coastal flooding worsened by sea level rise, experts say. Municipalities now compete in a free-for-all for limited federal funding to harden coastlines. Some policy makers want to reduce existing incentives, like the federal flood insurance program, that encourage private landowners and municipalities to build near the water's edge.

Early Warnings from Smith and Tangier Islands

Sea level rise may seem like a distant prospect, but an alarm has been sounding in two small, historic communities sitting miles out in the Chesapeake, surrounded by water. Smith Island in Maryland and Tangier Island in Virginia have endured heavy flooding from storms and lost land and population as their shorelines have steadily eroded. Both communities have desperately searched for engineering solutions and funding to keep their localities from being drowned.

Norfolk at the Leading Edge

The Norfolk, Virginia, metropolitan area is another place in the Chesapeake region where coastal flooding exacerbated by sea level rise is increasingly common and too obvious for city leaders and residents to ignore. To cope with the rising water, the city developed a $300-million list of projects to fortify seawalls, replenish beaches, and create natural shoreline buffers. The U.S. Navy is also taking steps to adapt its base at Norfolk, the world's largest naval headquarters.

Living Shorelines: An Alternative to Armor

As rising seas increase erosion along Maryland's coasts, the traditional response has been to harden them with steel and rock. Now the state is requiring waterfront property owners to consider a natural alternative — constructing "living shorelines" of wetland plants that attenuate wave energy. The success of these shorelines depends on proper siting and design. And questions remain about whether these engineered projects will perform effectively over the long term.

Bringing Sand to the Beach

The risk of increased coastal flooding means that beach replenishment projects may become more important to seaside communities. Ocean City, Maryland, and Virginia Beach already rely on these projects to sustain their tourism-driven economies. But as supplies of offshore sand used for these projects become scarcer, and competition for federal funding increases, will there come a point when rebuilding beaches becomes untenable economically and politically?

PHOTOS ABOVE, DAVID HARP

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For More Information on Sea Level Rise

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://dnr.maryland.gov/ccs/coastalatlas/shorelines.asp – This site provides multiple layers of information about coastal hazards suitable for planning purposes. These include 100-year flood plains and areas suitable for building living shorelines to reduce erosion.