

# Rising Tides, Sinking Coast

How Virginia's coastal communities  
can adapt to surging sea levels

By Carl Hershner  
and Molly Mitchell

**Sea level rise in Virginia is a documented fact. Water levels in Hampton Roads have risen more than one foot over the past 80 years.<sup>1</sup> The causes of this rise are well understood, and current analyses suggest the rate of rise is increasing.<sup>2,3</sup> The consequences of higher sea level are evident in the increased frequency of significant flooding events in coastal Virginia communities. In the face of increasing risks, adaptation is essential, and the need to act is immediate.**

The sea level along Virginia's coast is affected by three general factors: the volume of water in the ocean, the elevation of the Virginia shoreline, and the movement of water in the ocean. All three things have been changing in recent times. The result for coastal Virginia has been a long-term and recently accelerating rise in the level of tidal waters in the commonwealth.

The first factor—the volume of water in the ocean—is simple to understand. Increasing the volume of water in the ocean will unavoidably raise the water level at the shoreline. Two things are currently causing the volume of ocean water to increase: Glaciers, ice caps, and ice sheets in Greenland and Antarctica are melting, adding water that was stored on land surfaces to the ocean basins; and, at the same time, the water in the oceans is warming, causing it to expand. Taken together, these processes are believed to have added more than half a foot to ocean levels in the past century. Both of these processes have increased recently, and now are adding to the oceans' volume at about twice the former rate.<sup>4</sup> Moreover, rates are anticipated to increase even further, depending on how much the Earth's atmosphere warms.

The second factor—the elevation of Virginia's shoreline—is surprising for many people living in the commonwealth. It turns out that Virginia's coast is sinking. Again, there are a number of contributing factors. The primary cause is the continuing adjustment of the Earth's crust to the melting of glaciers from the last ice

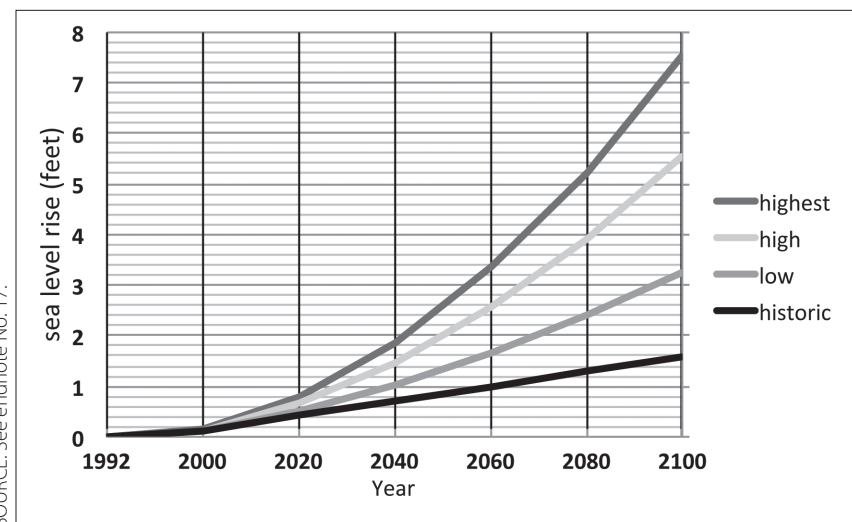
age. About 25,000 years ago, huge ice sheets extended from the North Pole south to what is now northern Pennsylvania and New Jersey. These ice sheets were estimated to be more than a mile thick, exerting tremendous pressure on the Earth's crust, actually causing it to bulge up in the region of Virginia. As the ice sheets melted and retreated northward, that pressure was released, and the Earth's crust has been slowly readjusting ever since. The result is a slow sinking of the mid-Atlantic coastal region.<sup>5</sup>

In addition to the general subsidence of the region, there are two other more local processes that are adding to the general sinking of land area. The first is the

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**Figure 1:**  
Southeast Virginia sea level rise scenarios



the globe. Some are driven by winds, others are driven by the cooling of sea water near the poles. Just as warming sea water causes it to expand, cooling sea water causes it to contract and become denser. When surface waters near the poles are cooled, they tend to sink and flow south, being replaced by warmer waters from the tropics that are drawn north to replace the sinking polar waters. In the north Atlantic, this process drives a major circulation pattern scientists call the Atlantic Meridional Overturning Circulation (AMOC). The Gulf Stream is a part

of this larger circulation. Studying the world's oceans, one of the things we have learned is that moving water is affected by the earth's rotation. Thus, in the Northern Hemisphere, water is diverted slightly to the right, a fact that causes the typical counterclockwise spiral of water moving down a drain. At the very large scale of the Atlantic Ocean, the northward flow of the AMOC tends to move water away from the U.S. coast (to the right of the northward-flowing surface water). Some of the recent rapid rise in local sea levels may be explained by a slowing of the AMOC as the polar region warms. Slower moving water means less pressure to move water away from the coast, and the result is higher water levels on the mid-Atlantic coast.

Looking forward, sea level rise is anticipated to continue. We do not expect that the subsidence rate for the Virginia coastal region will change, so its contribution to rising sea level should remain constant. Current understandings of global atmospheric processes indicate that temperatures will continue to rise for at least the rest of the century, although it is uncertain how high they may go.<sup>8</sup> At a minimum, rising temperatures will sustain current trends in glacier and ice cap melting, as well as thermal expansion of ocean water. Indeed, several recent independent analyses have detected acceleration in the rate of sea level rise from the mid-Atlantic to New England.<sup>2,3,9</sup> This means that we will see higher sea levels in

continuing compaction of the materials that were blasted apart when a meteor struck the area near Cape Charles about 35 million years ago.<sup>6</sup> Materials in the impact crater, which extends from the mouth of the Rappahannock River to Virginia Beach, continue to settle and compact to this day (see Figure 2, opposite page).

The other process is even more localized, but adds significantly to the slow sinking of land in a number of areas: the removal of large volumes of deep groundwater (see Figure 3, opposite page). Two examples of the impact can be found in West Point and Franklin, where paper mills extract groundwater as part of their manufacturing process. Much like the pumping of oil along the Gulf Coast, removal of liquids from deep in the earth causes the overlying areas to settle as sediments compress.<sup>7</sup>

Together, the land's responses to the retreat of the glaciers, the meteor impact, and groundwater pumping have caused subsidence in our region that almost doubles the effect of increasing ocean volume. At present, sea level in southeastern Virginia is rising at a rate slightly greater than 1.5 feet per century, and it appears to be accelerating.<sup>2,3</sup>

The third factor—the movement of water in the ocean—may explain some of the increasing rate of rise. As anyone who has spent time at sea knows, there are many large currents that circulate ocean waters around

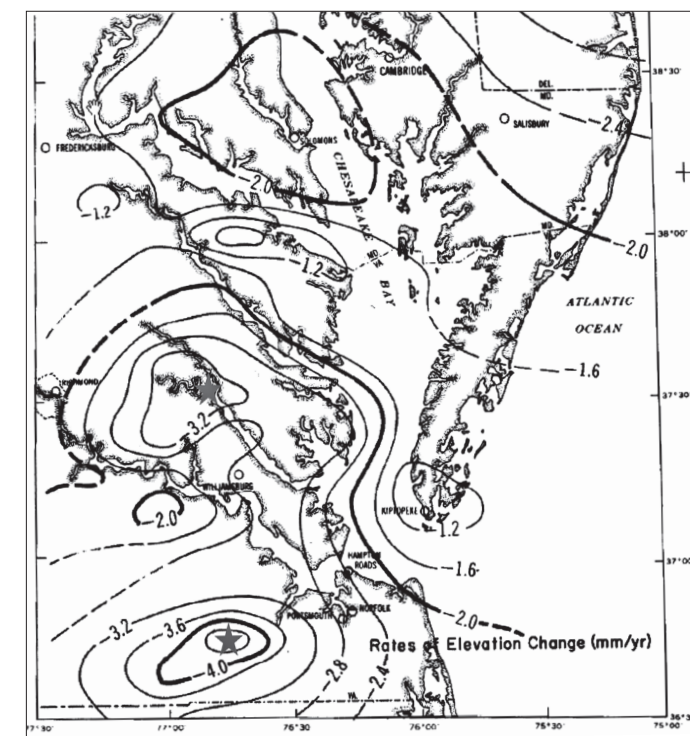
the future, and they will probably rise more rapidly than they have in the last century.

The long-range, end-of-the-century forecasts have significant uncertainty, with projections for the region's sea level to rise anywhere between 1.5 and 7.5 feet. These projections are based on the National Climate Assessment, a report from the U.S. Global Change Research Program that has projected four scenarios of global sea level rise for its 2013 report to Congress.<sup>10</sup> By adding what we know about land subsidence in the Virginia coastal region, we are able to develop regional scenarios to inform planning and adaptation efforts. The scenarios are shown in Figure 1 (opposite page). They all begin with the documented sea levels in 1992. The lowest curve (labeled "historic") represents a simple extrapolation of the historic average rate of rise. The top curve (labeled "highest") represents the physically possible circumstance that would occur with rapid melting of all the Earth's glaciers and ice caps—essentially, a worst-case scenario. The middle two curves are based on models of the global system's response to either significant efforts by the world's nations to reduce greenhouse gases (the "low" curve) or business as usual (the "high" curve). Recent trends in Virginia sea levels suggest that we are on the "high" curve. Whether this rate of increase will be sustained is uncertain, but it does inform thinking about the commonwealth's future.

Given what is currently known, it seems reasonable to anticipate that, sometime in the next 30 to 50 years, sea level in Virginia will be 1.5 feet higher than it is presently. This timeframe makes the consideration of potential impacts relevant for home mortgages and most public infrastructure (e.g., roads, schools, fire stations).

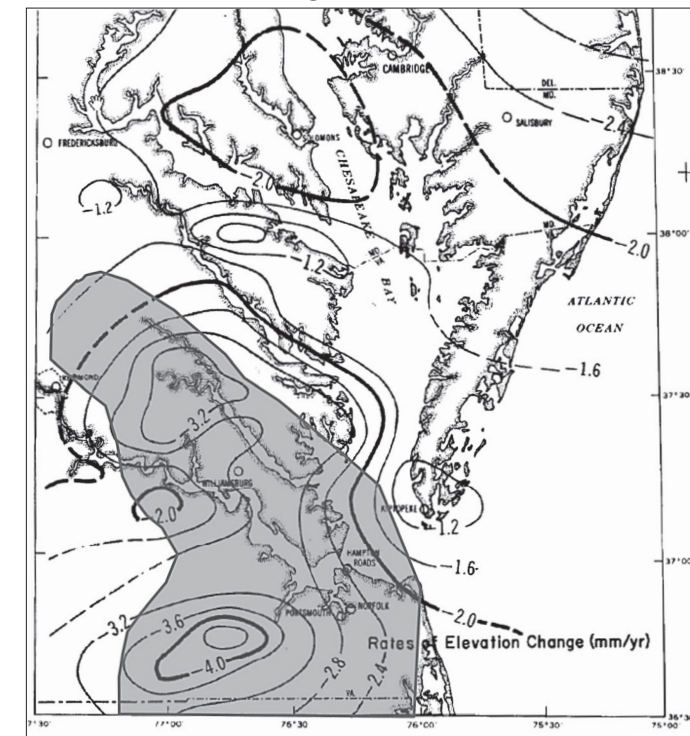
Southeastern Virginia is particularly susceptible to the risks attendant to sea level rise. Most of the densely populated land around Hampton Roads is low-lying and subject to extensive flooding when major storms pass through the region. The Hampton Roads Planning District Commission undertook an analysis of lands and infrastructure at risk as part of a climate change study for the region.<sup>11</sup> The commission concluded that, given

**Figure 2:**  
Rate of vertical land surface movement (millimeters/year) from 1942 to 1971



The image represents the cumulative subsidence occurring in the region due to glacial isostasy, groundwater withdrawal, and meteor breccia contraction. Negative values indicate downward movement. From Holdahl and Morrison, 1974; see endnote No. 18.

**Figure 3:**  
Land subsidence due to groundwater withdrawal



The shaded area highlights the region in which groundwater withdrawal is a significant element in the total subsidence value. After Pope and Burbey, 2004; see endnote No. 19.

the low relief of the area and the patterns of development, there were nearly 60,000 parcels that could be permanently or regularly inundated by tidal waters by the end of the century. These properties represent investments that total more than \$20 billion. The commission's staff examined another metric of risk, transportation infrastructure in the region, and concluded there were approximately 500 miles of roads that could be regularly flooded under future sea level conditions.

Local governments are already keenly aware of the problems frequent flooding creates. Beyond the safety risks during storm events, tidal flooding damages seawalls, sewers, drainage systems, and wastewater treatment plants. The cities of Norfolk and Hampton have each undertaken local studies to assess the extent of the flooding problems and to begin identifying options.

### Adaption strategies

There are three main categories of sea level rise adaptation strategies: management/retreat, accommodation, and protection.

Management/retreat actions include zoning policies aimed at preventing development in high-risk areas, policies aimed at discouraging rebuilding in high-risk areas, and the reclamation or abandonment of highly flood-prone lands. While risk avoidance seems entirely reasonable, the challenge with accelerating sea level rise is that risk areas are no longer static. Potentially, the population affected by management/retreat policies can be constantly changing and expanding.

Accommodation actions are currently the most common in Virginia's coastal plain. Such actions include raising buildings and roads above flood levels, establishing evacuation routes and warning systems, and creating or enhancing stormwater system capacity. None of these options are truly inexpensive. Elevating a home above flood levels can be very expensive. The Federal Emergency Management Agency recently gave Gloucester County \$1 million to raise 11 homes damaged by floodwaters.<sup>12</sup> But elevating homes still leaves cars, septic

tanks, and landscaping at risk from floodwaters. Elevating roads is also enormously expensive and can sometimes aggravate flooding issues on adjacent properties.

Protection measures typically involve some form of engineering to protect existing land uses. Hard engineering solutions, such as levees and storm surge barriers, are probably the best known. These structures tend to be very expensive to construct and maintain, and they only work in settings where the topography and development patterns make them possible. The City of Norfolk conducted some preliminary investigations of protection measures for two of its most flood-prone neighborhoods. In both cases, the potential projects would cost millions of dollars, and only ultimately protect a small proportion of the city.<sup>13</sup> Virginia Beach already uses a strategy of rebuilding its oceanfront beaches to maintain a level of storm protection.<sup>14</sup> As evidenced by the impacts of Hurricane Sandy on the New Jersey coast, beaches—even large, well-nourished beaches—cannot provide complete protection.

The most appropriate strategy for an area depends on existing infrastructure and uses, population size, economic conditions, projected growth, and surrounding land use. Protection measures are not likely to be a practical option in some of Virginia's more rural coastal communities. The density of development is simply not great enough to justify investment in large engineered structures. Even in some of the most highly developed communities, topography and shoreline patterns make defensive structures impractical.

Accommodation is often a first-choice strategy, since it maintains current uses and development patterns. However, it is expensive and therefore not practical for all property owners. In fact, accommodation is so expensive that it is not likely to be a practical undertaking with public funding. Ultimately, accommodation can only buy time in many settings and can actually increase other risks by encouraging occupation of increasingly unsuitable sites.

Management/retreat is likely to be the most practical option for much of Virginia's coastal zone. It is not clear whether local governments in Virginia would require any additional tools or authorities to implement managed retreat, but it is clear that these strategies can be effective at minimizing public and private risks and costs.

In addition, what is abundantly clear from examination of policies and practices elsewhere in the country and around the world is that timely action is critical. Many of the strategies for dealing with sea level rise have proven to require long lead times for effective implementation. Typically, there is a need for planning studies that require years, even when undertaken expeditiously. And then the actual construction of larger solutions consumes considerable time. The floodgates on the Thames River in England are an example.<sup>15</sup> They were originally conceived in 1966, finally became operational in 1982, and are envisioned to provide protection for the London metropolitan area until about 2030. Virginia's coasts are already bearing a sea level at which even modest storms produce significant social and economic consequences.<sup>16</sup> For many coastal localities, current projections suggest that these consequences will become unsustainable within the next 30 years. **VIA**

### Endnotes

<sup>1</sup> The measurement is based on National Oceanic and Atmospheric Administration tide gauge records. More information can be found at <http://tidesandcurrents.noaa.gov/sltrends/msltrendstablefc.htm>.

<sup>2</sup> Boon, John D. "Evidence of sea-level acceleration at U.S. and Canadian tide stations, Atlantic coast of North America." *Journal of Coastal Research* 28.6 (2012).

<sup>3</sup> Ezer, Tal, and William Bryce Corlett. "Is sea level rise accelerating in the Chesapeake Bay? A demonstration of a novel new approach for analyzing sea level data." *Geophysical Research Letters* 39 (2012).

<sup>4</sup> Boon, John D., and John M. Brubaker and David R. Forrest. "Chesapeake Bay land subsidence and sea level change: An evaluation of past and present trends and future outlook." Special Report No. 425 in *Applied Marine Science and Ocean Engineering*. Virginia Institute of Marine Science, 2010.

<sup>5</sup> Sella, Giovanni F., and Seth Stein, Timothy H. Dixon, Michael Craymer, Thomas S. James, Stephane Mazzotti, and Roy K. Dokka. "Observation of glacial isostatic adjustments in 'stable' North America with GPS." *Geophysical Research Letters*, 34 (2007).

<sup>6</sup> Additional information on the meteor impact can be found at <http://woodshole.er.usgs.gov/epubs/bolide/>.

<sup>7</sup> Further reading on land subsidence is available at <http://ga.water.usgs.gov/edu/earthgwlandsubside.html>.

<sup>8</sup> The most recent information is in the Southeast Region Technical Report to the National Climate Assessment, available online at [http://downloads.usgcrp.gov/NCA/Activities/NCA\\_SE\\_Technical\\_Report\\_FINAL\\_7-23-12.pdf](http://downloads.usgcrp.gov/NCA/Activities/NCA_SE_Technical_Report_FINAL_7-23-12.pdf).

<sup>9</sup> Sallenger Jr., Asbury H., and Kara S. Doran and Peter A. Howd. "Hotspot of accelerated sea-level rise on the Atlantic coast of North America." *Nature Climate Change*. 24 June 2012. Web.

<sup>10</sup> As of press time, this report was not yet released to the public.

<sup>11</sup> Hampton Roads Planning District Commission. "Climate Change in Hampton Roads, Phase III: Sea Level Rise in Hampton Roads, Virginia." July 2012. Web. 14 Nov. 2012.

<sup>12</sup> Sabo, Matt. "Gloucester receives \$1 million to elevate flood-prone homes." *Daily Press*. 29 Feb. 2012. Web.

<sup>13</sup> A description of potential projects can be seen at [www.norfolk.gov/publicworks/SW/pdf/FUGROCityWideFloodStudy.pdf](http://www.norfolk.gov/publicworks/SW/pdf/FUGROCityWideFloodStudy.pdf).

<sup>14</sup> See the 2002 "Virginia Beach Beach Management Plan" at [www.vb.gov.com/government/departments/planning/areaplans/Documents/Oceanfront/beach\\_management\\_plan.pdf](http://www.vb.gov.com/government/departments/planning/areaplans/Documents/Oceanfront/beach_management_plan.pdf).

<sup>15</sup> For more information on the Thames Barrier, see the Environment Agency website at [www.environment-agency.gov.uk/static/documents/Leisure/Thames\\_Barrier\\_Project\\_pack\\_2012.pdf](http://www.environment-agency.gov.uk/static/documents/Leisure/Thames_Barrier_Project_pack_2012.pdf).

<sup>16</sup> For more information on consequences, see the Virginia Department of Emergency Management website on hurricane history in the region: [www.vaemergency.gov/readyvirginia/stay-informed/hurricanes/hurricane-history](http://www.vaemergency.gov/readyvirginia/stay-informed/hurricanes/hurricane-history).

<sup>17</sup> In order to generate the curves for the Virginia coastal zone, the authors added regional subsidence values to the equations used by the forthcoming National Climate Assessment report.

<sup>18</sup> Holdahl, S.R., and N.L. Morrison. "Regional investigations of vertical crustal movements in the U.S., using precise leveling and mareograph data." *Technophysics* 23 (1974): 373-90.

<sup>19</sup> Pope, Jason P., and Thomas J. Burbey. "Multiple-Aquifer Characterization from Single Borehole Extensometer Records." *Ground Water* 42.1 (January-February 2004): 45-58.