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The Impact of Climate Change on Virginia's Coastal Areas

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THE IMPACT OF CLIMATE CHANGE ON VIRGINIA'S COASTAL AREAS

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VASEM VIRGINIA ACADEMY OF SCIENCE, ENGINEERING, AND MEDICINE

Virginia Academy of Science, Engineering, and Medicine

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Front cover: A few people brave the rain and walk the boardwalk as Hurricane Earl moves over Virginia Beach, Virginia, on September 3, 2010. (UPI/Alexis C. Glenn)

Back cover: Tidal waters flood yards in Tangier Island on September 16, 2016. (U.S. Army/Patrick Bloodgood)

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EXECUTIVE SUMMARY

As part of HJ47/SJ47 (2020), the Virginia General Assembly directed the Joint Commission on Technology and Science (JCOTS) to study the "safety, quality of life, and economic consequences of weather and climate-related events on coastal areas in Virginia." In pursuit of this goal, the commission was to "accept any scientific and technical assistance provided by the nonpartisan, volunteer Virginia Academy of Science, Engineering, and Medicine (VASEM)" (see *Appendix A*). VASEM convened an expert study board with representation from the Office of the Governor, planning district commissions in coastal Virginia, The Port of Virginia, the Virginia Economic Development Partnership, state universities, private industry, and law firms (see *Appendix B*). In producing the report, the board followed methods similar to those used by the National Academies of Science, Engineering, and Medicine by convening an expert committee tasked with studying and reporting on the topic. As a result, the report represents the views and perspectives of the study board members but was not submitted for public review or comment.

This report is the product of those efforts. It finds that climate change will have an increasingly disruptive effect on people living in Virginia's coastal areas during the 21st century — and that these disruptions will have repercussions across the Commonwealth. It includes an explanation of the physical forces driving climate change, an analysis of the current and projected effects of climate change on the Commonwealth, perspectives that legislators might consider as they face these challenges, and recommendations that could help Virginia implement more productive and effective strategies to address them.

The Elements of Climate Change

The key to grasping the impacts of climate change is a basic understanding of the mechanisms that set it in motion. Small recalibrations of the greenhouse gases in the Earth's atmosphere can have enormous implications for the solar energy the Earth retains. This surplus of energy, mostly in the form of heat, has set in motion the changes that will define the century.

For most of the past 800,000 years, the concentration of greenhouse gases in the atmosphere has been between about 200 and 280 parts per million. In the past century, that concentration has jumped to more than 400 parts per million, increased by human activities

such as burning fossil fuels and deforestation. (The sources for information in the executive summary can be found in the notes at the end of each chapter.)

The result has been that the Earth has absorbed an enormous amount of energy, which is expected by 2050 to raise the average land and surface water temperatures 2.7°F above the level at the start of the Industrial Revolution. For most of human history, this temperature has been relatively stable, fluctuating no more than a few tenths of a degree each year — and very gradually declining over most of the last 7,000 years. As a result of human intervention, however, climate has altered at rates that, according to the United Nations Intergovernmental Panel on Climate Change (IPCC), "far exceed the rates of change driven by geophysical or biosphere forces that have altered the Earth System trajectory in the past."

For Virginians living on the coast, the immediate consequences will be rising sea levels, more intense and frequent storms, and warmer and more variable local temperatures. These primary drivers translate into recurrent flooding, saltwater intrusion into drinking water, inundation of septic systems, and threats to public health, among other issues.

- The most obvious immediate consequence of climate change for coastal Virginians is sea-level rise, fueled by melting ice sheets and glaciers and by thermal expansion of water, compounded in Virginia by land subsidence and the slowing of the Gulf Stream. The rate of relative sea-level rise in coastal Virginia, which combines both sea-level rise and land subsidence, is among the highest rates in the United States.
- The additional energy trapped by greenhouse gases manifests itself in more frequent and intense weather events characterized by extreme rainfall and extreme winds. Between 1980 and 2020, Virginia was affected by 17 tropical cyclones, 30 severe storms, and 15 winter storms that *each* caused more than a billion dollars in damage across the United States.
- The third consequence of a warmer atmosphere is increased variability in seasonal temperatures. Both maximum and minimum winter temperatures, especially in coastal regions, were higher in the period between 1986 and 2015 compared to a baseline average established between 1895 and 2000. This increased variability can have important consequences for agriculture and growing seasons, civil infrastructure lifespans, and human health, particularly for physically vulnerable populations and those who work in outside occupations such as landscaping and construction.

Over the last half century, scientists have created progressively more detailed and accurate climate models that project these changes into the future. Modeling groups are constantly refining their simulations to incorporate additional Earth system processes, take advantage of new datasets, and leverage new high-performance computing resources.

As an ensemble, current models show that changes in climate processes affecting Virginia's coast will accelerate as the century progresses.

- Under the Intermediate-High Sea-Level Rise projection developed by the National Oceanic and Atmospheric Administration and adopted by the Commonwealth for planning purposes, there could be as much as 6.69 feet of relative sea-level rise at Sewells Point in Norfolk between 2000 and 2100.
- Modelers have shown nearly a doubling of the frequency of Category 4 and 5 storms by the end of the 21st century. The largest increase is projected to occur in the Western Atlantic, north of 20°N, which crosses the Eastern Seaboard just south of Florida.
- Even under optimistic projections about our ability in coming years to reduce greenhouse gas emissions, historically unprecedented temperature increases and heat waves are projected for Virginia by the end of the 21st century.

Current Impacts on Virginia

The Virginia coast is already feeling the costly consequences of sea-level rise in a number of ways. They range from compromised stormwater infrastructure in Norfolk, which has lost 50 percent of its design capacity due to rising sea levels, to recurrent flooding in Virginia Beach, which costs the city $26 million a year.

Storm intensity has also increased in recent years. Using Norfolk Airport rain-gauge records dating back to the early 1900s, the City of Virginia Beach determined that heavy-precipitation events increased at a rate of about 3 percent per decade until 1950, when the frequency accelerated to approximately 7 percent per decade.

This situation is exacerbated when the rainfall associated with more intense storms is combined with high winds and storm surges. Like rainfall, storm surge from tropical cyclones and extratropical storms (nor'easters) has worsened in Virginia: six of the 10 most extreme storm surges recorded at Sewells Point over the last century have occurred in the last 20 years, with the surge from Hurricane Isabel (2003) reaching over 1.5 meters (4.9 feet) above normal tide levels.

Other effects of climate change on the natural world are particularly clear in the Chesapeake Bay area, where they affect local fisheries, agriculture, and the health of the region's inhabitants. For instance, warmer water temperatures have stressed the seagrass and other submerged aquatic vegetation that is fundamental to the health of the bay. Such vegetation provides habitat for waterfowl, fish, and other marine creatures, filters nutrients from the water, and is an important source of dissolved oxygen. Rising water temperatures have also increased the concentration of *Vibrio* bacteria in the Chesapeake Bay and the Atlantic Ocean, increasing the likelihood of infection from contaminated fish or shellfish.

Coastal Virginia localities have spent millions of dollars to counter the effects of sea-level rise and coastal flooding. A number of these mitigation efforts have involved infrastructure improvements. In 2013, for instance, Norfolk elevated approximately 1,500 feet of Brambleton and Colley Avenues that were flooded between 200 to 300 hours annually due to high tides and storms. Hampton announced in 2020 that it will spend $12 million on three major

flood-reduction projects. They include a green infrastructure project that will store and slow water through the redesign of existing waterways to reduce flooding.

Large-scale planning efforts that account for sea-level rise and climate change are also occurring across the Commonwealth. *Norfolk Vision 2100* and Virginia Beach's *Sea Level Wise* initiative are two examples. Other communities have launched initiatives that will secondarily mitigate some of the consequences of climate change. For instance, SWIFT (the Sustainable Water Initiative for Tomorrow) is a water-treatment initiative created by the Hampton Roads Sanitation District (HRSD) to ensure a sustainable source of groundwater while addressing water quality issues in the Chesapeake Bay. As it injects treated water into the aquifer, SWIFT may slow the subsidence that contributes to relative sea-level rise and flooding and increase the volume and pressure in the aquifer, reducing its vulnerability to saltwater intrusion.

Future Impacts on Coastal Urban Areas

While many impacts will be shared across urban and rural coastal areas in coming decades, they will have different consequences in different locations. For example, under NOAA's intermediate-high scenario, which has been adopted by Virginia for planning purposes, the impact on urban infrastructure will be substantial. Many major transportation arteries — highways as well as rail lines — will be periodically or permanently inundated by flood waters.

Scientific studies predict the following scenarios:

- There will be an increase in average cyclone intensity, precipitation rates, and number of very intense Category 4 and 5 storms. In Hampton Roads, flood damage from a 100-year storm — that is, a storm with a 1 percent chance of occurring in any given year — would cause the regional economy to shrink by $611 million the following year.
- Hotter, more frequent heat waves could lead to an annual average of 170 excess deaths on dangerously hot days by the 2040s. A hotter, wetter climate can also affect public health by creating favorable conditions for vectors of infectious disease, which can be particularly challenging in densely populated regions.
- Racial and ethnic minorities, the poor, the elderly, renters, non-native English speakers, and those with mobility challenges will be disproportionately affected by recurrent flooding and heat waves. For instance, many households, particularly in urban communities, may be unable to afford life-saving air-conditioning or lack access to official cooling centers.

Since 2015, the Code of Virginia has required localities included in the Hampton Roads Planning District Commission to incorporate strategies to combat sea-level rise and recurrent flooding in their comprehensive plans. Additionally, increasingly more reliable future climate change and flooding projections have spurred urban localities across coastal Virginia to

develop plans to counter these effects. *The Virginia Coastal Resilience Master Planning Framework* provides a comprehensive survey of these efforts. A sampling of these includes the following:

- The Northern Virginia Resiliency Roadmap developed by the Northern Virginia Resiliency Planning Work Group in conjunction with the Virginia Coastal Zone Management Program
- *Resilient Hampton*, *Vision 2100* in Norfolk, and Virginia Beach's *Sea Level Wise*, all in the Hampton Roads area
- The Multi-Regional Hazard Mitigation Plan developed by PlanRVA and Crater PDC for their 26 combined localities.

The *Virginia Coastal Resilience Master Planning Framework* is a first step toward a state master plan that acknowledges the science of climate change, the complexity of the challenges facing Virginia, and the limits of available fiscal resources while prioritizing resilience projects in accordance with state guidelines and local and regional needs.

Future Impacts on Coastal Rural Areas

Rural coastal communities in Virginia are also sensitive to the effects of climate change but often lack the financial resources of urban regions to address the challenges. Rural coastal communities face many of the same challenges as their urban counterparts, but the consequences can differ substantially. For instance, urban roadways inundated by recurrent flooding affect a large number of people, but city-dwellers are less likely to be completely cut off than those who live in sparsely populated rural areas often serviced by only a single road.

The impacts on rural coastal communities in Virginia will be varied:

- The effects on agriculture include water-logged soils in flood-prone areas, an increase in soil salinity due to saltwater intrusion, more variable temperatures affecting seed germination, and an increase in agricultural pests and diseases.
- A Virginia Coastal Zone Management (CZM) Program-funded study found that 209 miles, or 13.8 percent, of the state-maintained roadways on the Eastern Shore face permanent inundation with three feet of sea-level rise — possibly as early as 2060.
- Because rural communities mostly rely on septic systems, sea-level rise and recurrent flooding can negatively affect public health by causing septic systems to fail or by reducing their longevity.
- Saltwater intrusion into groundwater will affect wells in rural areas. Because of the low recharge rate of the underlying Yorktown-Eastover aquifer, the Eastern Shore is far more susceptible to saltwater intrusion than areas to the west of the Chesapeake Bay.

- Climate change will affect the levels of plankton, which form the basis of the food web in the Chesapeake Bay, and will increase the prevalence of noxious organisms like algae and jellyfish.
- Because of zoning classifications, working waterfront businesses may be unable to retreat from their current locations as waters rise.
- Important cultural resources in urban areas as well as rural ones — including archaeological sites on Jamestown Island — will likely be lost to rising waters.

Planning for climate change in rural coastal Virginia necessarily differs from the approaches favored in more densely developed and populated areas like Hampton Roads or Northern Virginia. With more land to protect and few resources at their disposal, communities in rural areas are turning primarily to green initiatives like strategic land conservation, wetland restoration, and living shorelines.

Perspectives for Decision-Makers

The need to respond to climate change becomes more pressing with every passing year, but developing coherent strategies to mitigate, adapt to, and remediate its effects is a daunting challenge. Funding is finite, a fact that the authors of the *Virginia Coastal Resilience Master Planning Framework* state in no uncertain terms: "There is not, nor will there ever be, enough funding to protect all homes, businesses, infrastructure, and other coastal assets where they currently exist." Faced with limited resources, legislators, policy-makers, and planners must weigh costs and benefits, a consideration that is easily stated but that entails grappling with such vexing dilemmas as *costs and benefits to whom?, over what period of time?,* and *on what geographic scale*?

Building consensus for these decisions is equally difficult because even solutions with minimal impact may ultimately entail some concession to the inevitability of disruption or loss. We can mitigate, forestall, and delay, but given recent events and projected trends, mere preservation of the status quo may not be feasible in many cases. For social, cultural, and economic reasons, this is a difficult truth for people to accept. Legislators, policy-makers, and planners must find ways to recognize, respect, and account for this reluctance in any solution they propose.

As mitigation and adaptation become more urgent, there will be a growing need for expertise and innovation as well as organizations with the capacity to complete large- and small-scale projects. As it grapples with these issues, Virginia has an opportunity to develop innovative and future-looking initiatives that can serve as an example for other coastal communities, initiatives that will benefit not only coastal Virginia but the entire Commonwealth.

If decision-makers are to address the opportunities as well as the risks presented by climate change, it is important for them to consider the following perspectives:

- **Taking a Statewide View**. The consequences of climate change in coastal Virginia will have repercussions throughout the state. Unless coastal challenges are treated as a state-wide issue, it will be difficult to muster the will and resources needed to address a challenge of this scale and complexity.
- **Responding in a Proactive, Coordinated Way**. Allowing market forces alone to determine the timetable and nature of the Commonwealth's response to climate change will likely prove disruptive. Proactive coordination, including with financial market stakeholders, will set the stage for a more rational response that accounts for the needs of disadvantaged communities.
- **Appreciating the Challenge for Localities**. Although climate change is a global challenge, individual jurisdictions will bear the brunt of the response and will do so in different ways depending on local conditions. Support from and collaboration with the Commonwealth, regional planning bodies, and the private sector will be necessary to maximize their efforts.
- **Addressing Inequality**. Climate change can be expected to exacerbate existing economic inequality and heighten challenges that disadvantaged communities already face in areas like healthcare and housing. However, with climate change placing pressure on government budgets, providing the financial assistance and incentives needed to offer equitable options to stakeholders in these communities will become increasingly difficult.
- **Adjusting to Intersecting Stakeholder Timeframes**. Almost every response to climate change will require public- and private-sector decision-makers to manage conflicting time frames. This is often a reflection of the nature of specific impacts, as some are more immediate or costly than others. However, these timeframes also reflect factors like budgeting cycles and grant deadlines, durability of different assets, and projected depreciation or lost value of assets. These timeframes are apt to differ from one group of stakeholders to another.
- **Understanding the Role of Flood Insurance.** Recent losses have caused the National Flood Insurance Program and private insurers to take a more stringent view of risks and to increase their pricing. The result is that more and more individuals and commercial enterprises lack adequate flood insurance, in some cases making it impossible for them to use these assets as collateral for loans.
- **Managing Mitigation, Remediation, and Relocation.** Mitigation, remediation, and relocation, individually and in combination, are likely to have their appropriate places in coastal Virginia's response to climate change. The scale and timing of their deployment will depend on factors specific to the community and region, but one fact is clear: mitigation measures (risk reduction, prevention and adaptation) are generally more cost-effective strategies to address climate change than after-the-fact remediation.
- **Engaging a Multiplicity of Funding Sources**. The multiple ways for the Commonwealth to fund and finance resilience projects include federal programs,

grants from nonprofit foundations and community development finance institutions, bonds, and various forms of revenue streams funded by special tax, fee, flood control, or improvement districts. However, the state will need to supplement these efforts with meaningful and sustained state funding.

- **Embracing and Encouraging Innovation**. Significant innovation will be required to avoid the worst impacts of climate change and to mitigate the impacts that coastal regions are already experiencing and are likely to experience in the future. Virginia could become a national center of expertise and innovation in this regard. However, some of the key tools and incentives to achieve leadership on an expedited basis are lacking, insufficient, or not well marketed to or coordinated with the private sector.

Recommendations

Taking these impacts and decision-making perspectives into account, the members of the study board offer the following recommendations. In formulating these four interlocking recommendations, study board members have drawn on their long history of working in coastal Virginia to assess the impact of climate change on the Commonwealth and to find ways to improve the state's response. Taken together, these recommendations provide an overarching framework that has the potential to help Virginia adjust to the changes that will occur in coming decades and reduce the disruption to its economy and the lives of its citizens.

The four recommendations are as follows:

Recommendation 1: *Establish a Structure for More Effective Collaboration and Coordination*

We recommend that the climate change program structure in Virginia should be headed by a statutorily created council modeled after the Council on Virginia's Future (2004–2017) and appropriately funded and staffed. Chaired by the Governor, that organization of legislative leaders and citizen members successfully created a statewide strategic plan focusing all 11 secretariats and 93 agencies on a specific set of goals. The advantage of this approach is that it builds upon existing governmental structures while enhancing the Commonwealth's capacity to plan and respond to the challenges of climate change. Furthermore, we recommend that this council plan not only for the resilience of Virginia's coast but also for the entire state. While climate change will manifest itself in distinct ways in different regions, it will have statewide implications.

Recommendation 2: *Address Gaps in Policy and Procedure*

We recommend that Virginia establish and optimize a substantive budgetary policy and procedure for climate impact review as part of relevant state agency planning that (i) provides equitable opportunity for all stakeholders, including members of underserved or disadvantaged communities, with consideration given to such concerns and impacts as transportation and

evacuation, sheltering, relocation, housing, etc., and (ii) incorporates and facilitates feasible resilience strategies. Such policy and procedure will also need to ensure compliance with the Virginia Environmental Justice Act, as applicable.

Recommendation 3: *Create a Body to Coordinate and Support Critical Data Collection and Technology Transfer Across the Commonwealth*

We recommend that the Commonwealth create, fund, and staff a Climate Change and Resilience Resource Center for Virginia, with a board of directors drawn from planning district commissions and other entities representing local governments, the Commonwealth's universities and research institutions, nonprofits, and private firms specializing in environmental mitigation and adaptation. This entity would be charged with synthesizing research and development efforts for Virginia's climate response to maximize benefits for the state's citizens and promote collaboration. It would also assist entities applying for funding from federal, state, and local sources by identifying needed research priorities and would provide seed money to entities engaged in or fostering promising research and development.

Recommendation 4: *Provide Meaningful Economic Innovation and Incentives to Build a Resilience Economy in Virginia*

We recommend that the General Assembly provide incentives for businesses to develop innovative resilience-enhancing products, technologies, designs, and services, to partner with universities to capitalize on their expertise, and to foster workforce development in building and implementing resilience solutions. These incentives could include such nonfinancial measures as expedited permitting so that innovative solutions like green infrastructure can be rapidly implemented. However, funded incentives — including tax breaks for related R&D and capital investment as well as grants and low-interest financing — will also be important.

U.S. AIR FORCE/AIRMAN 1ST CLASS SARAH DOWE

Water rises during Hurricane Dorian at Joint Base Langley Eustis, Virginia, September 6, 2019.
Many planes and personnel were evacuated in preparation for the hurricane.

CHAPTER 1

The Elements of Climate Change

The recently published *Virginia Coastal Resilience Master Planning Framework* is the latest in a series of studies that document the intensifying impact of climate change on Virginia's coast. The authors state unequivocally, "Climate change is real, and has real consequences for all of us — particularly people living in coastal areas."[1]

The researchers who produced the Fourth National Climate Assessment for an interagency U.S. government taskforce emphasize this point: "There is high confidence in our understanding of the greenhouse effect and the knowledge that human activities are changing the climate in unprecedented ways. There is enough information to make decisions based on that understanding."[2]

Multiple studies published in peer-reviewed scientific journals show that 97 percent or more of actively publishing climate scientists agree with these conclusions, as has every major American scientific association as well as the National Academy of Sciences.[3]

The Energy Budget

Simply put, human activity has altered the energy budget of the Earth. Solar energy absorbed by the Earth's surface is radiated back into the atmosphere as heat. The amount of energy that ultimately escapes into space is determined by the presence of greenhouse gases such as carbon dioxide, methane, nitrous oxide, fluorinated gases, and water vapor that can readily absorb this heat.

Although greenhouse gases make up slightly less than 0.1 percent of the atmosphere, infinitesimal changes can have outsized impacts. For most of the past 800,000 years, the concentration of greenhouse gases in our atmosphere has ranged between about 200 and 280 parts per million. In the past century, that concentration has jumped to more than 400 parts per million, increased by human activities such as burning fossil fuels and deforestation.[4] Carbon dioxide levels are now higher than at any time in the last 3.6 million years.[5]

The impact has been dramatic. Every four years, the Intergovernmental Panel on Climate Change (IPCC) a group of 1,300 independent scientific experts from the United States and

other countries, issues an assessment report. In 2018, the panel stated, "Human activities are estimated to have caused approximately 1.0°C [1.8°F] of global warming above pre-industrial levels, with a *likely* range of 0.8°C [1.4°F] to 1.2°C [2.2°F]."[6] These temperature figures do not refer to the temperature at a specific location, but rather reflect the vast quantity of energy required to boost average air and surface water temperatures across the entire globe.

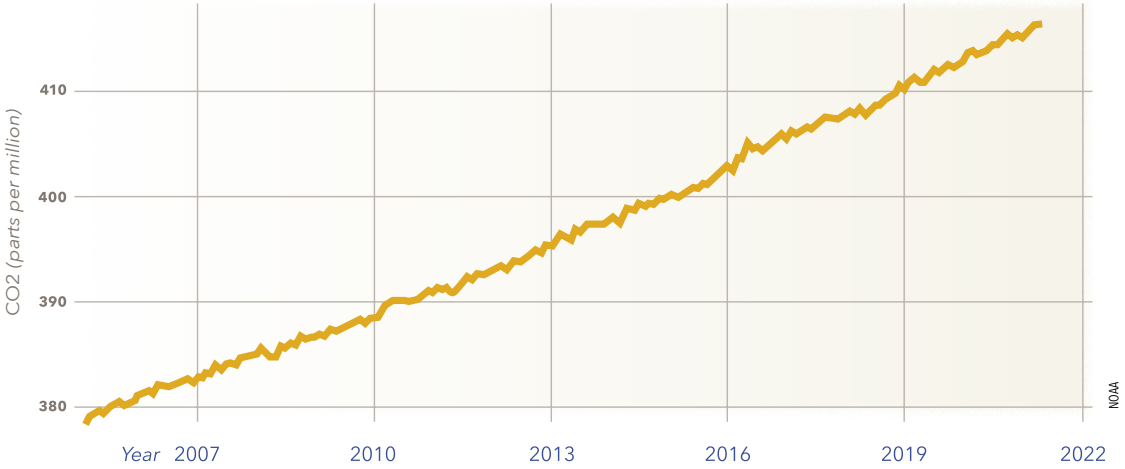
This rapid change in the Earth's energy budget is unusual — and it is accelerating. While the global average of air and sea surface temperatures fluctuates from year to year, in preindustrial periods this fluctuation was no more than a few tenths of a degree. In fact, the global average temperature has been slowly declining over the last 7,000 years at a baseline rate of 0.02°F per century. Since 1970, however, the global average temperature has been rising at a rate of 3.0°F per century — and this rate is increasing. According to the IPCC, the global temperature is expected to jump almost a full degree Fahrenheit between 2020 and 2050 at the latest.

For most of human history, our climate has been relatively stable. As a result of human intervention, however, it has altered at rates that, according to the IPCC, "far exceed the rates of change driven by geophysical or biosphere forces that have altered the Earth System trajectory in the past." The consequences will be far-reaching.

This chapter focuses on the immediate consequences of climate change rather than its secondary effects — for instance, recurrent flooding or saltwater intrusion. For Virginians, this translates into rising sea levels, more intense storms with more precipitation, and warmer and more variable local temperatures.

In the following chapters, we document the challenges that these three consequences pose for individuals, communities, government agencies, and businesses in Virginia. We look at impacts we have already observed and those that we can expect in the future, both in rural and urban areas.

ATMOSPHERIC CARBON DIOXIDE, 2005 TO PRESENT[7]



The Mechanisms of Climate Change in Coastal Virginia

The impacts of global warming vary from place to place. High temperature extremes and heavy precipitation events are increasing. Growing seasons are lengthening, and wildfires are on the rise. Glaciers and snow cover are shrinking, and sea ice is retreating. Seas are warming, rising, and becoming acidic. Each area of the United States faces a unique combination of challenges.

Sea-Level Rise

The most obvious immediate consequence of climate change for coastal Virginians is sea-level rise driven by melting ice sheets and glaciers — there is simply more water — and by thermal expansion. As seawater warms, it takes up more space. Thermal expansion accounts for roughly one-third of global sea-level rise observed by satellite altimeters since 2004,[8] while the bulk of the remainder is caused by melting ice. Changes in ocean surface elevation related to ocean circulation dynamics and weakening of the Gulf Stream also play a role.[9]

Other forces can influence sea-level rise in the short-term. These include fluctuations in temperature of offshore waters, changes in atmospheric conditions that can affect the overall weight of the atmosphere, and variations in wind conditions that can pile up or push ocean water away from the coast.[10]

Sea-level rise is occurring at an accelerating rate. Global mean sea level has risen 8 to 9 inches since 1880, with about a third of that in just the last two and a half decades. In October 2020, global mean sea level was 3.8 inches (96.3 millimeters) above the 1993 average. From 2018 to 2019, in two years, global sea level rose 0.24 inches (6.1 millimeters).[11]

SEA-LEVEL RISE, 1995 TO PRESENT [12]

Sea-level rise in coastal Virginia is exacerbated by land subsidence, much of which is driven by long-term, isostatic geologic processes. During the last ice age, the weight of the Laurentide ice sheet covering Canada and the northern United States pushed Earth's underlying crust downward, which forced the crust to the south to bulge upward. Now that the sheet has long melted, the crust in Virginia is returning to its previous position. Extensive groundwater pumping is also playing a role in subsidence.[13] Across the Hampton Roads region, total subsidence is estimated to average 3.1 mm/year (the equivalent of an inch every eight years).[14] Recent studies using satellite data have shown this rate of subsidence varies considerably from point to point across the region.[15]

As a result of this combination of conditions, *i.e.*, sea-level rise compounded by land subsidence, ***the rate of relative sea-level rise in coastal Virginia is among the highest in the United States***.[16] Using the National Oceanic and Atmospheric Administration's (NOAA) Sewells Point tide gauge in Norfolk as the primary tidal data reference (it has been in operation longer than any other Virginia tide gauge), Virginia has experienced more than 18 inches of relative sea-level rise in the past 100 years.[17] The impact is dramatic. Since the mid-1800s, an estimated 400-square kilometers (approximately 100,000 acres) of uplands in the Chesapeake Bay region have converted to tidal marsh.[18]

Extreme Weather

The additional energy trapped by rising levels of greenhouse gases also manifests itself in an ***increase in frequency and intensity of weather events characterized by extreme rainfall and extreme winds.*** Between 1980 and 2020, Virginia experienced 17 tropical cyclones, 30 severe storms, and 15 winter storms that each caused more than a billion dollars in damages across the United States. Wind, precipitation, and storm surge-related damage from tropical cyclones alone made up nearly half of weather-related damage in Virginia during this period.[19]

Since 1990, the number of extreme precipitation events with more than two inches of precipitation has steadily increased. Tropical Storm Lee in 2011, for instance, resulted in total damages of $3 billion, with Washington Dulles International Airport receiving a total of 8.74 inches of rainfall from the storm, approximately 20 percent of the total annual precipitation for the year (46.2 inches).[20] Indeed, the contribution of tropical cyclones to overall extreme precipitation has been increasing by approximately 5 to 10 percent per decade in the southeastern Atlantic coastal states. These storms are wetter and more frequent than in the past.[21]

At the same time, the intensity of seemingly ordinary weather events has increased. On July 8, 2019, isolated portions of Northern Virginia experienced localized flooding that demonstrated the principle that it is often not the total amount of rainfall, but how fast it falls, that is significant. Total rainfall measured at Reagan National Airport for the July 8 storm was 3.3 inches. Other local gauges exceeded 4 inches. Rainfall rates, however, reached the equivalent of 7 to 9 inches per hour. As a result, Four Mile Run in Arlington County rose 11 feet in an hour. This storm was considered a 150-year storm based on the airport's rainfall intensity data, which means it had less than a 1 percent chance of occurring in any given year. Damage estimates were placed at approximately $3.5 million from this one event.[22]

Reston Park and Ride in Fairfax County floods during Tropical Storm Lee in September 2011.

Shifting Seasonal Temperatures

The third consequence of a warmer atmosphere is shifting seasonal temperatures. Over time, the entire earth is expected to warm, but temperatures will not rise evenly. Since 2000, for example, Arctic regions have warmed at more than twice the rate of the globe as a whole.[23]

In Virginia, the seasons have grown warmer. According to NOAA's National Centers for Environmental Information, the average annual temperature has increased in Virginia by 1.5°F since the beginning of the 20th century. In particular, Virginia has seen average summer temperatures hit record highs and very cold nights dramatically decrease.[24] Both maximum and minimum winter temperatures, especially in coastal regions, were higher in the period between 1986 and 2015 compared to a baseline average established between 1895 and 2000.[25]

The Models behind the Projections

While changes in sea level, weather patterns, and temperature seasonality can be observed in historical records, scientists simulate the future by developing climate models that can be run under different greenhouse gas emission scenarios. Building and running these models requires the ability to represent Earth system processes with mathematical equations, describe initial conditions and projected changes in greenhouse gas emissions, and use powerful supercomputers to simulate possible climate futures.

Once a climate model has been created, it is tested using hindcasting. In hindcasting, the model is run over historical periods so that the results can be compared with the observed records to see how well they match. With each run, scientists successively refine their model

One phenomenon that all climate models account for is the positive feedback loops that a warming planet generates. In effect, climate change causes a cascade of effects that can dramatically amplify climate change.

assumptions to replicate the past more accurately. This process of model calibration increases confidence in the model and its predictions for the future.

Researchers have been creating climate models of increasing sophistication since 1970, providing enough time to test their accuracy. A study of 17 models of global average temperature developed between 1970 and 2007, for instance, found that 14 of them accurately tracked rising temperatures.[26] The Sixth Assessment Report, to be issued by IPCC in 2021, will feature runs from 100 state-of-the-art models produced by 49 different modeling groups. These modeling groups are constantly refining their simulations to incorporate additional Earth system processes, take advantage of new datasets, and leverage new-high performance computing resources.

One phenomenon that all climate models account for is the positive feedback loops that a warming planet generates. In effect, climate change causes a cascade of effects that can dramatically amplify climate change.

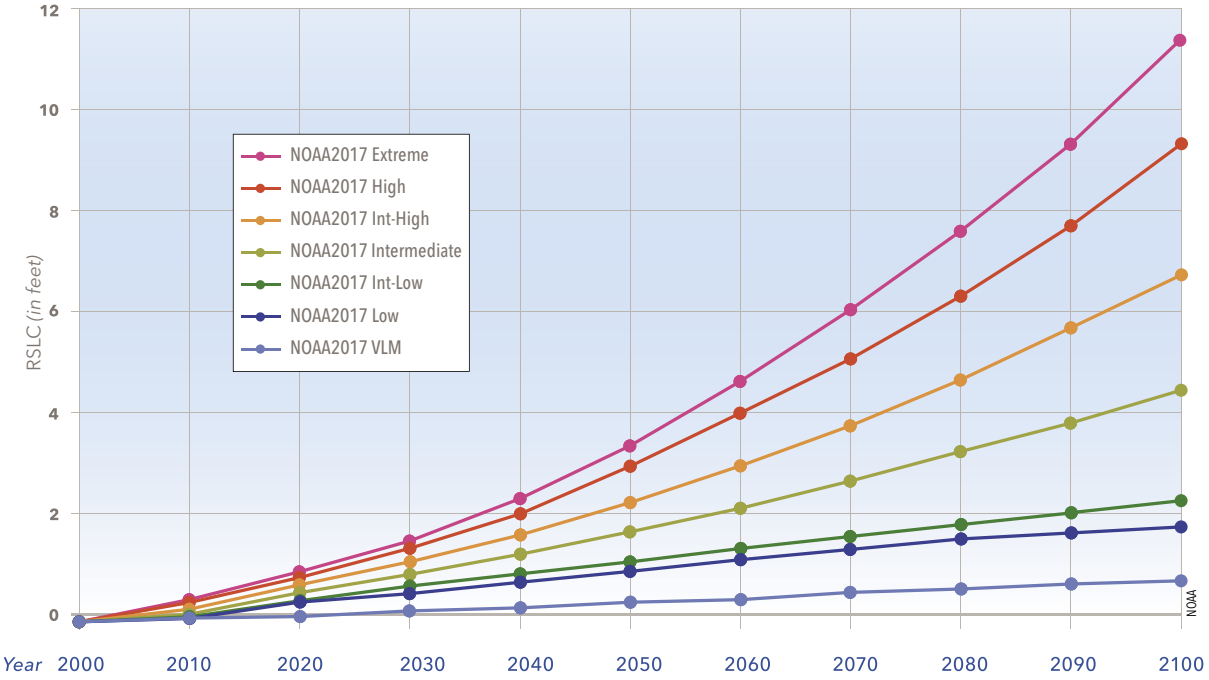
For instance, the permafrost — the layer of frozen soil that blankets the Arctic — contains huge amounts of carbon, equivalent to more than twice the amount of greenhouse gases currently in the atmosphere.[27] As the permafrost thaws, it releases its stored carbon in the form of methane and carbon dioxide. These additional greenhouse gases, in turn, make the planet warmer, which increases the pace of thawing and causes additional greenhouse gas emissions. The danger of these positive feedback loops is not simply that they will accelerate climate change — for instance, sea levels will rise that much faster — but also that they will lead to a tipping point, at which climate change not only accelerates but becomes irreversible.

Projected Sea-Level Rise

The models show that changes in climate processes affecting Virginia's coast will accelerate as the century progresses. In 2012, at the request of the U.S. Climate Change Science Program, NOAA reviewed the research on global sea-level rise projections. The agency revised its findings in 2017 following a review by the U.S. Interagency Sea-Level Rise Taskforce. It posited six scenarios based on increasing amounts of greenhouse gas emissions. These range from the low-emission estimate of sea-level rise of at least 12 inches (0.3 meters) above 2000 levels in Virginia by 2100, to as much as 8.2 feet (2.5 meters) under the extreme emissions scenario.[28]

As part of Executive Order 45, signed by Governor Ralph Northam in November 2019, the Commonwealth adopted the NOAA Intermediate-High Sea-Level Rise projection as the planning standard for Virginia state-owned buildings. **Using that scenario, there could be as much as 6.69 feet of relative sea-level rise at Sewells Point between 2000 and 2100.** [29]

RELATIVE SEA-LEVEL CHANGE SCENARIOS FOR SEWELLS POINT, VIRGINIA (feet)



Areas far from the coast will also be affected. Approximately 200 acres of Ronald Reagan Washington National Airport are within the 100-year floodplain, which is 11.4 feet above mean sea level. The IPCC has also issued projections. Under its high emissions growth scenario, permanent inundation of portions of Reagan's taxiways and access roadways is possible.[30]

Projected Extreme Rainfall Events and Intense Storms

Although there is still uncertainty about the impact of global warming on the frequency of intense storms, recent studies suggest that the average intensity of tropical cyclones (including hurricanes in the North Atlantic) is projected to rise. Both theory and numerical modeling simulations generally indicate an increase in tropical cyclone intensity in a warmer world, and the models generally show an increase in the number of very intense tropical storms.[31] **Modelers have shown nearly a doubling of the frequency of Category 4 and 5 storms by the end of the 21st century. The largest increase is projected to occur in the Western Atlantic, north of 20°N.**[32] These storms will also be characterized by higher precipitation rates.[33] One reason for this is that as atmospheric temperature rises, atmospheric water vapor content rises as well.[34]

The Port of Virginia's Norfolk International Terminals.

Projected Higher Temperatures

Even under optimistic projections about greenhouse gas emissions, **historically unprecedented temperature increases and heat waves are projected for Virginia by the end of the 21st century.** Average annual temperatures are expected to exceed historic record levels in just 30 years, by 2050. Future heat waves are likely to be more intense, and so are naturally occurring droughts. Even if overall precipitation increases, higher temperatures will increase the rate of loss of soil moisture during dry spells.[35]

The Stakes for Virginians

Climate change and its impacts — including sea-level rise and changing storm patterns — are already affecting Virginia. Model projections of the future show these impacts are only beginning and will intensify in the future.

The *Virginia Coastal Resilience Master Planning Framework* does an excellent job of gathering a variety of sources to explain why climate change matters.[36] It defines coastal Virginia as lands east of the fall line separating the Piedmont from the coastal plain, a line that runs roughly along the route of Interstate 95. Coastal Virginia represents almost one quarter of the Commonwealth's land area, approximately 8,950 square miles, and has more than 10,000 miles of tidally influenced shoreline.[37,38]

ZOONAR/ALEX GRICHENKO/ALAMY

Generally speaking, the closer a location is to this shoreline, the more vulnerable it is to rising sea level and flooding. Recent estimates show that 250,000 acres of land, 1,469 miles of roads, and property valued at $17.4 billion lie less than five feet above the high-tide line in Virginia. These figures jump to 490,000 acres, 4,500 road miles, and $54.8 billion within nine feet of high tide.[39]

The economic activity generated by coastal Virginia is significant:

- The Department of Defense and its contractors collectively employ 252,187 people and, in 2017, spent more than $46.2 billion in Virginia. The Hampton Roads region alone is home to 139,000 military personnel and contractors.[40,41]
- The Port of Virginia is the third-highest-ranked port by volume on the East Coast and seventh nationally by tonnage in the United States,[42] and port-related industries support 397,000 jobs. It accounted for 7.5 percent of Virginia's 2018 gross state product and 7.0 percent of total employment compensation.[43]
- Direct expenditures associated with coastal tourism in Virginia exceed $5.2 billion annually.[44]
- Commercial and recreational fisheries and aquaculture support nearly 15,000 jobs and $1 billion in sales in Virginia.[45]

Climate change, of course, does not simply affect businesses and government agencies. It has an impact on individuals and the communities in which they live. Coastal Virginia is home to more than 70 percent of the state's population.[46] Climate change affects human health and wellbeing in a variety of ways that include damaging and decreasing the value of homes, overwhelming stormwater, sewer, and septic systems, extending the range of disease-carrying vectors like mosquitoes, and diminishing water quality.[47] It will also strain the budgets of many localities and disproportionately affect poor residents. People who are already vulnerable, including lower-income and other marginalized communities, have diminished capacity to prepare for and cope with extreme weather and climate-related events.[48]

The following chapters explore the specific impact of climate change on coastal Virginia in more detail. Chapter 2 provides an overview of current impacts facing the Commonwealth, offering clear evidence that climate change is not only a *future* problem but also a *current* problem for many Virginians. Chapters 3 and 4 present the best understanding of future impacts for Virginians, focusing on urban (Chapter 3) and rural (Chapter 4) areas separately because of their unique but related characteristics.

Climate change presents many complex problems for decision-makers, and Chapter 5 highlights some of the issues they will face, providing context and discussion for each. Finally, Chapter 6 offers recommendations for key steps Virginia can take to promote resilience and identify opportunities as it faces the climate change challenge.

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A pier that was destroyed in Colonial Beach, Virginia, in Hurricane Isabel on September 16, 2003.

CHAPTER 2

Current Impacts on Virginia

Compared to the impact that climate change is expected to have on coastal Virginia in the last half of the 21st century, the consequences to date have been relatively mild and manageable. Nonetheless, they are an indicator of the challenges Virginia will face in the future — and, as such, they have prompted a number of jurisdictions to begin planning for the new climate.

Enumerating the possible cascading consequences of climate change is a complex process that varies by locale. Global warming and the resulting sea-level rise and changing weather patterns affect the environment singly and in combination. Take flooding as an example. Sea-level rise by itself will lead to more frequent high-tide flooding, but it will also amplify the flooding caused by more intense and frequent storms. These consequences, in turn, will interact with a host of other natural, economic, and demographic factors. For instance, in Virginia Beach, each of its four major watersheds poses distinct flooding challenges, which are influenced not simply by flood pathways but also by land use and development.[1]

The impacts of climate change — and their costs — are already with us. In this chapter, we look at instances in coastal Virginia in which climate change already has had a measurable impact. In addition to enumerating consequences of climate change that are already being felt, this chapter highlights some of the efforts under way to address climate change's impacts, efforts that represent significant investments within the region.

Recurrent Flooding

The Virginia coast is already feeling the costly consequences of sea-level rise in a number of ways. A system of sensors installed in Norfolk's stormwater infrastructure has revealed that, due to rising sea levels, there is always standing water in parts of the system. As a result, the system's ability to drain streets after a rainfall has been curtailed by as much as 50 percent in some areas. This has led to more frequent road closures and exposes infrastructure not designed for frequent inundation to general deterioration and corrosion.[2]

Many low-lying coastal areas and those with strong prevailing winds experience recurrent flooding during 4 percent of high tides, even on sunny days.

Even in the absence of rainfall, tidal flooding is now routine in some areas. In 1960, there were 1.7 days of recurrent tidal flooding in Hampton Roads. By 2014, this figure had risen to 7.3 days.[3] The City of Virginia Beach reports that many low-lying coastal areas and those with strong prevailing winds experience recurrent flooding during 4 percent of high tides, even on sunny days.[4]

The economic consequences of recurrent flooding are considerable, including the need to replace and upgrade infrastructure, loss of property and declining business values, and loss of tax revenue. Currently, the average annualized losses from coastal flooding in Virginia Beach are estimated to be $26 million a year, a number that is expected to triple in 20 years. At the same time, coastal flooding can erode a municipality's ability to raise the capital to offset these losses. Credit agencies now take into consideration a municipality's vulnerability to flooding in determining its credit rating. In 2014, the credit-rating agency Moody's Investors Service Inc. sent a questionnaire to the City of Virginia Beach asking about the City's sea-level rise vulnerabilities, expenses, and plans to address future impacts.[5]

Changing Storms

Increased precipitation adds to the likelihood of flooding, and heavy-rain events are on the rise. Virginia Beach has found that heavy-rain events, where two or three inches of rainfall in a short period of time, are becoming more frequent. Using the Norfolk Airport rain gauge records, which date back to the early 1900s, the city determined that heavy-precipitation events had been increasing at a rate of about 3 percent per decade until 1950, when frequency accelerated to approximately 7 percent per decade. To make matters worse, when the city compared more than 60 years of historical rainfall records against maximum tide levels, it found that over 50 percent of the rainfall events occurred while the water level was higher than average daily high tide.[6]

At the same time, storm surge from tropical cyclones and extratropical storms (nor'easters) has worsened in Virginia: Six of the 10 most extreme storm surges recorded at Sewells Point over the last century have occurred in the last 20 years, with Hurricane Isabel (2003) reaching over 1.5 m (4.9 ft) above normal tide levels.[7] As sea levels continue to rise, storm surges will be able to reach even farther inland.

Remarkably, none of the extreme surges in the last 20 years were the result of a direct hurricane hit, thus far sparing Virginia from the kind of devastation seen, for example, in New Jersey in 2012 when Hurricane Sandy brought in surges that were 2.7 m (8.9 ft) above normal tide levels at Sandy Hook, New Jersey.[8] The Army Corps of Engineers estimates the odds of a tropical cyclone surge in Hampton Roads exceeding 2.0 m (6.6 ft) above normal tide levels in a 10-year period are currently about 1 in 5.[9]

A recent study published by the Commonwealth Center for Recurrent Flooding Resiliency highlights the potentially catastrophic impact of such storms. The total impact of a hurricane similar to Florence (2018) or Katrina (2005) striking Hampton Roads today could approach, if not exceed, $40 billion during the first year after landfall. This would equate to approximately 40 percent of the Hampton Roads region's Gross Domestic Product (GDP) and approach 10 percent of the Commonwealth's GDP.

Direct damage by wind and water alone would likely exceed $17 billion. A storm of this magnitude would destroy about 38,000 residential, business, and other structures. In addition, more than 175,000 people could lose their jobs. With output, sales, and compensation all declining, the economic impact of such a storm would amount to an additional $23 million — and the disruption caused by this decline would linger for years. Although Hampton Roads has not been hit by a storm of this magnitude in recent decades, the historical record shows that the area has been struck by comparable storms several times in the past.[10]

The situation is exacerbated when extreme rainfall coincides with extreme storm surge. Such poorly characterized and understudied compound events can have unforeseen and catastrophic impacts.

While extreme precipitation events and storm surge events individually present a flood threat, the situation is exacerbated when extreme rainfall coincides with extreme storm surge. Such poorly characterized and understudied compound events can have unforeseen and catastrophic impacts, such as recently occurred in Houston-Galveston, Texas, in 2017 during Hurricane Harvey.

Ecosystem Health

The effects of climate change on ecosystems in Virginia have also begun to be apparent. In 2017, managers, researchers, and educators from the National Oceanic and Atmospheric Administration, the University of Maryland Center for Environmental Science, the Chesapeake Bay National Estuarine Research Reserves of Maryland and Virginia, and Chesapeake Environmental Communications identified a number of climate-related changes that have already affected the Chesapeake Bay.[11] These changes directly affect the ecology of the bay and, by extension, local fisheries, agriculture, and the region's inhabitants.

Using climate data from Chesapeake Bay National Estuarine Research Reserve system (NERRs) locations and information from the National Climatic Data Center (NCDC) going back to the year 1900, they documented the effects of rising temperatures and increased precipitation on this ecosystem and identified the following trends over the past century:

The Armistead Avenue road-raising and green infrastructure project, funded by a City of Hampton environmental impact bond, will eliminate chronic flooding on a major thoroughfare and evacuation route.

- The length of the growing season has increased by more than 30 days, starting earlier and ending later than in the past. This increase is greater in the Chesapeake Bay region than anywhere else on the East Coast.
- There are 30 fewer frost days per year, which may prevent agricultural pests from dying off in winter.
- There are 30 more warm summer nights with temperatures at or above 68°F (20°C) each year now. These warm nights affect human health, especially in urban areas, and also lower crop yields.
- The Chesapeake Bay region receives about 4.5 more inches of rain per year than it did a century ago, an increase of 12 percent. Increased precipitation may lead to increased nutrients and sediments washing into the bay.

These trends have already begun to alter the bay's ecology. Hotter atmospheric temperatures have translated into hotter water temperatures. Warmer water holds less dissolved oxygen than colder water, thereby making estuarine ecosystems experiencing eutrophication

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or algal blooms more likely to become dead zones. Over the last three decades, the bay's water temperature rose 1.5°C, cancelling out — or largely compensating for — potential benefits of nutrient management over the past three decades.[12]

Warmer water temperatures have also stressed seagrass and other submerged aquatic vegetation fundamental to the health of the bay. This vegetation provides habitat for waterfowl, fish, and other marine creatures, filters nutrients from the water, and is an important source of dissolved oxygen. In 2005 and 2010, the two most recent years of significant die-off, water temperatures exceeding 86°F occurred for more than a quarter of the summer. These warm-water events are becoming more frequent, with 10 warm-water events since 1900. Six of them occurred in the last 15 years.

The longer growing season, particularly the later onset of fall, has posed problems for some migratory species in the bay. Warmer temperatures encourage them to delay migration, leaving them vulnerable to cold snaps. In 2014, warmer water temperatures enticed speckled trout to overwinter in the Rappahannock River and tributaries of Mobjack Bay. Thousands were killed during a February cold snap. Similar circumstances in 2011 led to the death of 2 million juvenile spot.

Tidal marshes provide important ecosystem services. However, when inorganic sediment inputs are too small to enable marshes to keep abreast of rising sea levels, they begin to deteriorate. Analyses conducted almost 20 years ago, using aerial and satellite data, found that more than 50 percent of Chesapeake Bay marshes were degraded.[13] The loss of the marshes has set off a cascading series of events. Increased water turbidity leads to a reduction of submerged aquatic vegetation, increasing the prospects for eutrophication.

Human Health

The impact of rising sea levels, increased precipitation, and higher temperatures on human health in coastal Virginia has so far been subtle, but the mechanisms are already in place for it to have serious consequences. For instance, increased flooding has made it more difficult to access medical care. Southern Virginia Beach has a dearth of potential evacuation routes, and hospitals and emergency shelters are already difficult to access during recurrent flooding and storm surges.[14]

Rising water temperatures increase the concentration of Vibrio *bacteria in the Chesapeake Bay and the Atlantic Ocean, making infection from contaminated fish or shellfish more likely.*

Rising water temperatures increase the concentration of *Vibrio* bacteria in the Chesapeake Bay and the Atlantic Ocean, making infection from contaminated fish or shellfish more likely.[15] *Vibrio vulnificus* bacteria can cause symptoms like bloody diarrhea and vomiting, while *V. parahaemolyticus,* found in oysters, can produce deadly bloodstream infections. In response, NOAA released a new forecast tool in 2019 that shows public health officials in Maryland and Virginia when and where the pathogenic *Vibrio vulnificus* bacteria is most likely to be found in the Chesapeake Bay. The April to November seasonal forecast provides up to a two-day early warning of the probability of occurrence in bay waters. NOAA also has produced a tool to assess danger from *V. parahaemolyticus.*

Other potential impacts of climate change on human health include the introduction of vector-borne diseases, higher levels of heat-related illnesses and deaths, increases in cases of asthma and allergies, and groundwater pollution that leads to contaminated drinking water. These, however, have not yet been extensively documented.

Current Responses

Localities throughout coastal Virginia have already spent millions of dollars to counter the effects of sea-level rise and coastal flooding. A number of these have involved infrastructure improvements. In 2013, for instance, Norfolk elevated approximately 1,500 feet of Brambleton

and Colley Avenues that were flooded between 200 to 300 hours annually as a result of high tides and storms, events that caused major traffic jams, affected access to a medical center, and threatened a regional light rail project. Norfolk raised the roadway 2.5 feet at a cost of $2.4 million.[16] Three years later, flooding caused by Hurricane Matthew closed a different section of Brambleton Avenue for two months.[17]

Norfolk has been a pioneer in planning for sea-level rise, detailing long-term strategies to address the risk of sea-level rise in *Vision 2100*.[18] Norfolk also adopted an innovative and nationally unique re-write of its zoning ordinance to direct new and more intense development to higher ground.[19]

Another example of an innovative local government response is Hampton's announcement in 2020 that it will spend $12 million on three major flood reduction projects. They include a green infrastructure project that will slow and store water through the redesign of existing waterways in order to reduce flooding upstream and downstream in Newmarket Creek; improvements to North Armistead Avenue that combine road-raising with green infrastructure; and the transformation of a detention pond into a stormwater park with enhanced storage capacity. It is funding the project through an environmental impact bond[20] — the first of its kind to be used by a community in Virginia.

Another ambitious effort is Virginia Beach's *Sea Level Wise Adaptation Plan*. In 2020, the Virginia Beach City Council approved a sea-level rise plan to address flooding, which includes multi-billion-dollar infrastructure projects, development restrictions in some parts of the city, and a program of purchasing properties in danger of flooding. It requires developers to adhere to strict requirements to manage stormwater and flooding.[21]

Other communities have launched initiatives that will, as a secondary impact, mitigate some of the consequences of climate change. For instance, SWIFT (the Sustainable Water Initiative for Tomorrow), a water-treatment initiative created by the Hampton Roads Sanitation District (HRSD), is designed to ensure a sustainable source of groundwater while addressing water quality issues in the Chesapeake Bay. This initiative will take already highly treated wastewater through additional advanced water treatment to produce drinking-quality water, treat it to match the existing groundwater chemistry, and add it to the Potomac Aquifer, the primary source of groundwater throughout eastern Virginia. In the process, HSRD also hopes to reduce some of the subsidence that contributes to relative sea-level rise and flooding, and increase the volume and pressure in the aquifer, reducing its vulnerability to saltwater intrusion.[22]

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CHAPTER 3

Future Impacts on Coastal Urban Areas

By 2040, Virginia is expected to leapfrog New Jersey and Michigan and become the nation's 10th most populous state, with more than 10 million people, according to recent projections from the Demographics Research Group at UVA's Weldon Cooper Center.[1] The population is not only growing, but also shifting. The share of Virginia's population living in many of its largest urban areas is expected to rise, while most rural Virginia counties are likely to experience slower growth or more population decline than in the past.

Alexandria and Arlington County are expected to grow between 17 and 18 percent by 2040, but there are exceptions to this trend of urban growth. The populations of Hampton, Portsmouth, and Newport News are all expected to decline, and Norfolk and Virginia Beach to grow by less than 3 percent.

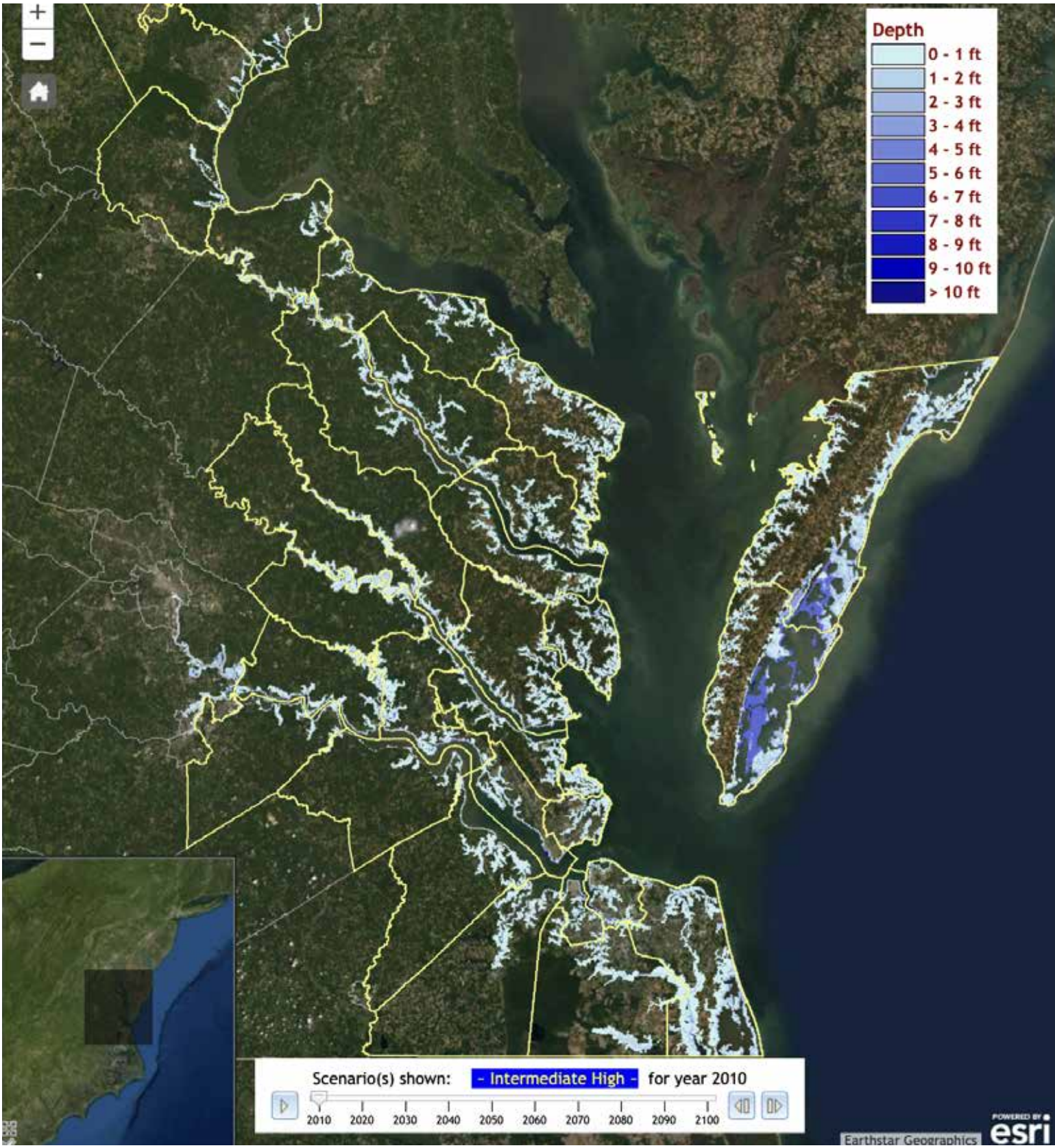
The center's analysis does not take into account the impact of climate change on these coastal urban areas. Given the disruption climate change is expected to cause, it could negatively affect population growth. In other words, if this crisis grows without an adequate response, it could limit the ability of coastal municipalities to address its consequences by reducing their tax base.

An Accelerating Challenge

Sea-level rise provides a baseline for estimating damage caused by recurrent flooding and storm surges. The rate of sea-level rise at the Sewells Point monitoring station in Norfolk, for instance, has been accelerating, reaching almost a quarter inch in 2020.[2] As a result, it is likely that the disruption caused by recurrent flooding and storm surges to Virginia's urban coastal communities — measured in geographic, economic, and social terms — will also grow worse as the century progresses.

This expectation is evident in the estimates of predicted sea-level rise at Sewells Point:

INUNDATION BY 2100 UNDER NOAA INTERMEDIATE-HIGH SCENARIO



SOURCE: VIMS

- The intermediate sea-level rise projection created by the U.S. Army Corps of Engineers, the most optimistic of the group, shows sea levels increasing more than 60 percent faster between 2090 and 2100 than between 2020 and 2030.[3]
- The VIMS Norfolk Sea-Level Report Card shows that coastal waters will rise twice as fast between 2040 and 2050 (the last year in its estimate) as between 2020 and 2030.[4]
- NOAA's intermediate-high scenario (adopted by the Commonwealth for planning purposes) also shows sea level rising twice as fast, this time comparing the period between 2090 and 2100 to that between 2020 and 2030.[5]

VIMS maintains an interactive sea-level rise projection map showing inundation under various scenarios.[6] Under NOAA's intermediate-high scenario, the map shows significant portions of Norfolk and Virginia Beach under water by 2100, and major transportation arteries — highways as well as rail lines — severed.

Recurrent Flooding

Researchers at Old Dominion University and the Commonwealth Center for Recurrent Flooding Resiliency have developed a model that combines the sea-level rise curve chosen by the Commonwealth for planning purposes (again, NOAA's intermediate-high projection) with Commonwealth LiDAR elevation data, estimates of subsidence, building site locations, road overlays, and other data to illustrate the way progressive sea-level rise will exacerbate flooding in the region.[7]

The projected consequences are alarming:

- In 2040, the area in coastal Virginia potentially affected by relative sea-level rise and minor tidal flooding, also known as nuisance flooding, is estimated to be 568 square miles (424 due to sea-level rise, 144 due to minor tidal flooding)
- In 2060, it will extend to 656 square miles (534 due to sea-level rise, 122 due to minor tidal flooding)
- In 2080, it will reach 784 square miles (649 due to sea-level rise, 135 due to minor flooding). *(The study includes a* webmap *that enables viewers to track this progressive inundation).*

The economic disruption caused by the combination of relative sea-level rise and tidal flooding can be inferred from the damage to infrastructure. The total length of roadway potentially affected provides an idea of the extent of the damage:

- In 2040, 545 miles will be affected (165 miles due to sea-level rise, 380 miles due to minor tidal flooding)
- In 2060, 972 miles will be affected (439 miles due to sea-level rise, 534 miles due to minor tidal flooding)

- In 2080, 1,762 miles will be affected (952 miles due to sea-level rise, 810 miles due to minor tidal flooding).

Building damage follows a similar progression:

- In 2040, 30,795 buildings will be affected (6,204 due to sea-level rise, 24,591 due to minor tidal flooding)
- In 2060, 57,740 buildings will be affected (23,433 due to sea-level rise, 34,307 due to minor tidal flooding)
- In 2080, 111,545 buildings will be affected (56,178 due to sea-level rise, 55,367 due to minor tidal flooding).

Hampton Roads, the Eastern Shore, and the Middle Peninsula will be the most severely and critically affected. The actual impact of recurrent tidal flooding will also depend on the frequency and duration of flooding. In addition, these figures do not include the consequences of tidal flooding combined with extreme rainfall events, whose frequency and intensity are expected to increase in Virginia with climate change.[8,9]

Changing Storms

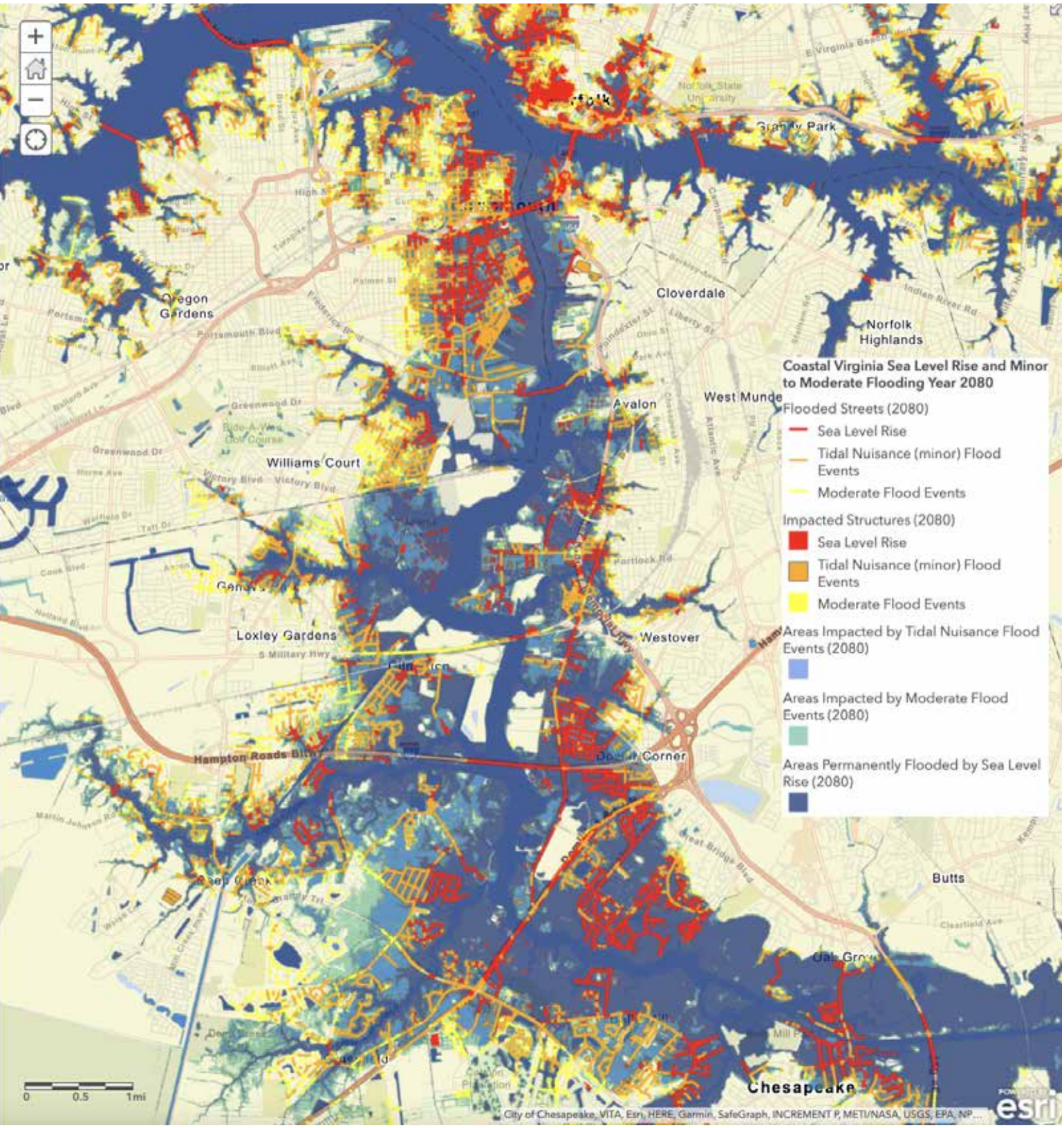
There are conflicting research findings about the impact of climate change on the frequency of Atlantic Coast hurricanes during the rest of this century. Some models show them to be decreasing while others show them on the rise.[10,11] Frequency, however, is a metric dominated by weak storms, though we have seen in recent years the extensive damage that very large, slow-moving Category 2 hurricanes like Sandy and Ike can do.

There is a strong consensus, however, that there will be an increase in average cyclone intensity, precipitation rates, and the number of very intense Category 4 and 5 storms. Estimates range from an 11 percent to a 42 percent increase in intense storms in the Atlantic Basin by the late 21st century. However, when Category 5 storms are isolated, this number increases to 136 percent.[12]

Intensity is important. The damage caused by the weakest Category 5 hurricanes, with wind speeds of 160 mph, is 429 times that of the weakest Category 1 hurricane, with wind speeds of 75 mph.[13] In addition, there is evidence that hurricanes will intensify more rapidly in the future, catching people in the affected areas off guard. A storm that intensifies by 70 mph in the 24 hours just before landfall occurred on average once per 100 years in the late 20th century. By the end of the 21st century, it may occur every five to 10 years.[14]

The way accelerating sea-level rise magnifies the economic impact of hurricanes is captured in a study commissioned by the Virginia Coastal Policy Center at the College of William & Mary Law School. Flood damage from a 100-year storm surge in Hampton Roads would cause the regional economy to shrink by $611 million the following year. These impacts

ELIZABETH RIVER SEA-LEVEL RISE AND FLOODING UNDER NOAA INTERMEDIATE-HIGH SCENARIO IN 2080[10]



SOURCE: OLD DOMINION UNIVERSITY

would increase to $1.239 billion with a sea-level rise of 0.5 meters (predicted by the year 2040) and to $2.180 billion with a sea-level rise of 0.75 meters (predicted by 2060).

This economic contraction would also reduce federal, state, and local tax revenues. Again, these revenues would decrease exponentially with sea-level rise. At current sea level, tax collections in Hampton Roads would fall by $27 million. Under the 0.5-meter and 0.75-meter sea-level rise scenarios, tax collection would fall by $95 million and $309 million, respectively. In other words, sea-level rise in the event of a 100-year storm would lead to tax collection shortfalls three to 10 times higher than would occur without sea-level rise.[15]

Human Health

As the climate grows hotter and wetter, human health will suffer. Heat alone is a cause for concern, especially in cities, where the heat island effect magnifies the consequences of heat waves. For example, from 1975 to 2010, the Virginia Beach metropolitan area experienced an average of approximately 20 excess deaths per year (deaths above the daily summertime average) on dangerously hot summer days. Hotter, more frequent heat waves could lead to an increase to an annual average of 170 excess deaths on dangerously hot days by the 2040s.[16]

Rising atmospheric temperature and more intense rainfall create a favorable environment for mosquitoes. The *Aedes aegypti* mosquito, which carries dengue, chikungunya, Zika, and yellow fever viruses, is projected to spread throughout the Southeast by mid-century.

Many of the James River watershed's census tracts that are among the most socially vulnerable to disaster are located within metropolitan Richmond and Hampton Roads.

Low-Income Communities

In urban as well as rural areas, the harmful effects of climate change will fall most heavily on Virginia's low-income communities. Flooding is one instance. A recent study by the National Academy of Sciences concluded that the poor along with racial and ethnic minorities, the elderly, renters, non-native English speakers, and those with mobility challenges were disproportionately affected by recurrent flooding.[17]

Many low-income neighborhoods are concentrated in areas with poorly insulated buildings and heat-absorbing surfaces.[18] These households may be unable to afford life-saving air-conditioning and lack access to official cooling centers and thus will be disproportionately affected by heat waves.[19, 20]

Another climate-change-related health risk that affects low-income and minority groups is exposure to toxic and hazardous substances. In the tidal region of the James River — from Richmond to Hampton Roads — 234 facilities regulated for toxic and hazardous substances are located in the highest quartile of CDC Social Vulnerability Index (SVI) tracts likely to be flooded

by one to five feet of sea-level rise. Of these facilities, 91 will be flooded when seas rise just one foot, which most climate scientists expect to occur in Virginia by 2050, less than 30 years from now. When flooding and storm surge are added, the number of affected facilities rises to 1,095.

Many of the James River watershed's census tracts that are among the most socially vulnerable to disaster are located within metropolitan Richmond and Hampton Roads, such as Petersburg, Hopewell, Norfolk, Newport News, Hampton, and Chesapeake. One of these highest-quartile SVI tracts, in Norfolk, contains 164 flood-exposed industrial facilities and a population of more than 3,600 residents within one square mile. On average, these highest-quartile SVI communities in the James River watershed each contain 25 flood-exposed facilities regulated for toxic and hazardous chemicals.[21]

Long-Term Planning

Since 2015, the Code of Virginia has required localities included in the Hampton Roads Planning District Commission to incorporate in their comprehensive plans strategies to combat sea-level rise and recurrent flooding.[22] The *Virginia Coastal Resilience Master Planning Framework* provides a comprehensive survey of these efforts.

In Northern Virginia, they include the efforts of the Northern Virginia Resiliency Planning Work Group, which has partnered with the Virginia Coastal Zone Management Program to create the *Northern Virginia Resiliency Roadmap*. The roadmap is designed to promote the inclusion of climate change considerations in local policy and planning, to foster the development of methods and techniques to assess and manage climate change-associated risks, and to encourage collaboration among stakeholders on developing a response to these risks in the region.[23]

In the Hampton Roads area, these efforts include the *Resilient Hampton* planning strategy,[24] *Vision* 2100,[25] and Virginia Beach *Sea Level Wise*.[26] The four planning district commissions east of the fall line have also launched a series of initiatives, ranging from the Multi-Regional Hazard Mitigation Plan developed by PlanRVA and Crater PDC for their 26 combined localities[27] to the Hampton Roads Planning District Commission's decision in 2018 to adopt unified sea-level rise predictions that member localities should use in planning and engineering decisions. They closely align with the NOAA Intermediate-High curve that the Commonwealth has chosen for this framework and the Virginia Flood Risk Management Standard, the first such standard in the nation that incorporates sea-level rise projections in the siting of new state buildings.[28]

The framework also enumerates the many state efforts to address climate change, beginning with the creation of the Governor's Commission on Climate Change, which produced the Climate Change Action Plan in 2008,[29] as well as dozens of core state agency programs and initiatives. The framework in itself is an acknowledgment that immediate action is imperative. It sets the stage for developing a Virginia Coastal Resilience Master Plan that recognizes the science of climate change, the complexity of the challenges facing Virginia, and the limits of available fiscal resources while prioritizing projects in accordance with state guidelines and local and regional needs.

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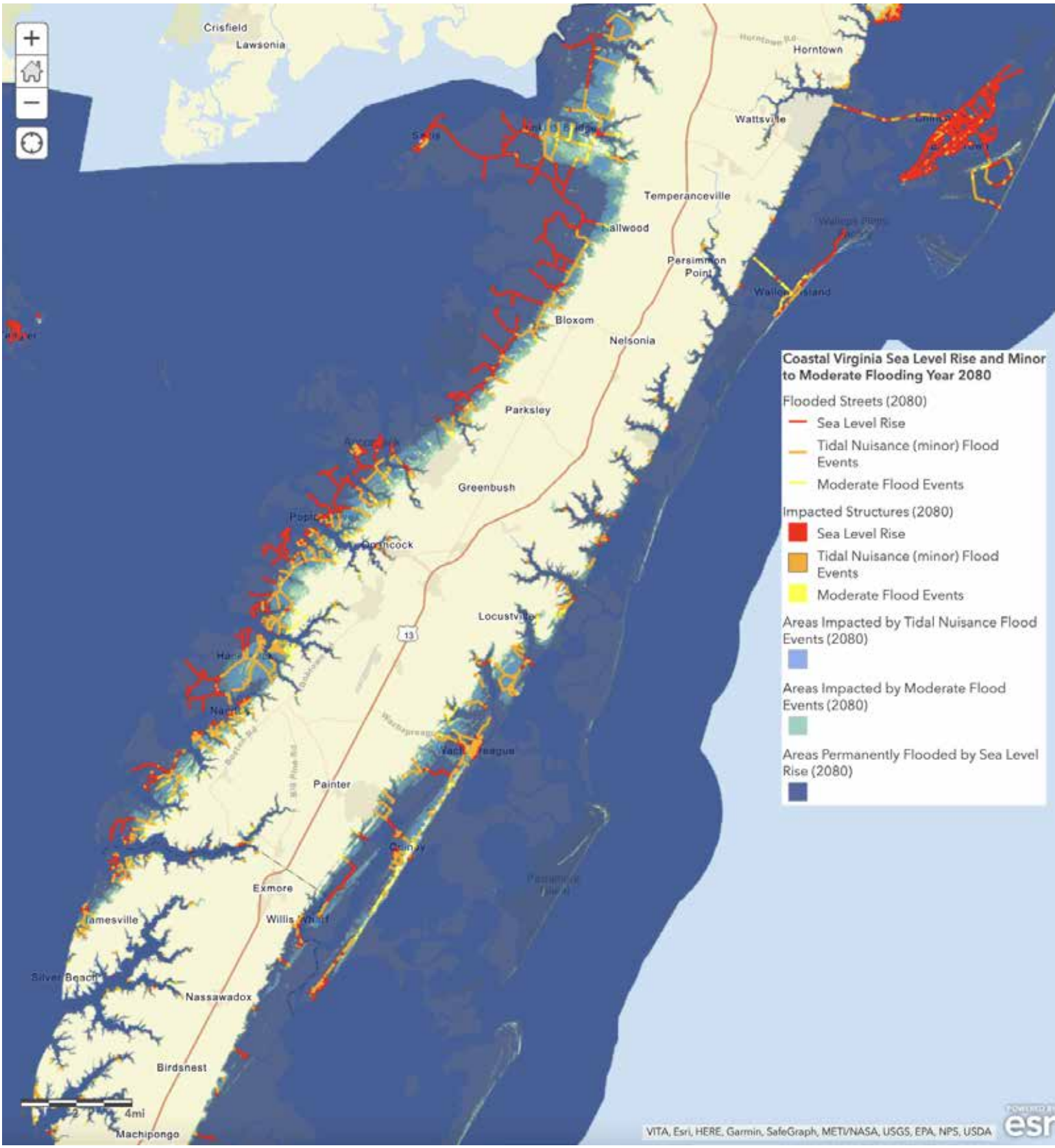
EASTERN SHORE SEA-LEVEL RISE AND FLOODING UNDER NOAA INTERMEDIATE-HIGH SCENARIO IN 2080[6]



SOURCE: OLD DOMINION UNIVERSITY

CHAPTER 4

Future Impacts on Coastal Rural Areas

Rural coastal communities in Virginia are susceptible to the effects of climate change but often lack the resources many more populated regions can bring to bear on the problem. Although these counties are faring better economically than many in Southside or Southwest Virginia, none of the 12 counties in the three rural planning districts in coastal Virginia — Accomack-Northampton, Middle Peninsula, and Northern Neck — has a median income that equals or exceeds the 2018 Virginia median household income of $71,564. The median income in Accomack and Northampton Counties is in the $43,000 range.[1]

Several counties in the region exhibit high social vulnerability, characterized by older and minority populations living in flood-prone areas.[2] In Northampton, Accomack, Essex, and Richmond counties, minorities make up more than 35 percent of the population. Inhabitants are also aging.[3] In Lancaster County, for instance, 36.3 percent of the population is in the 65+ age group, making it the oldest county in Virginia, and in Northumberland County the proportion is 32.8 percent. By 2040, Northampton and Mathews counties are expected to join them as counties with an elderly population of over 30 percent.[4]

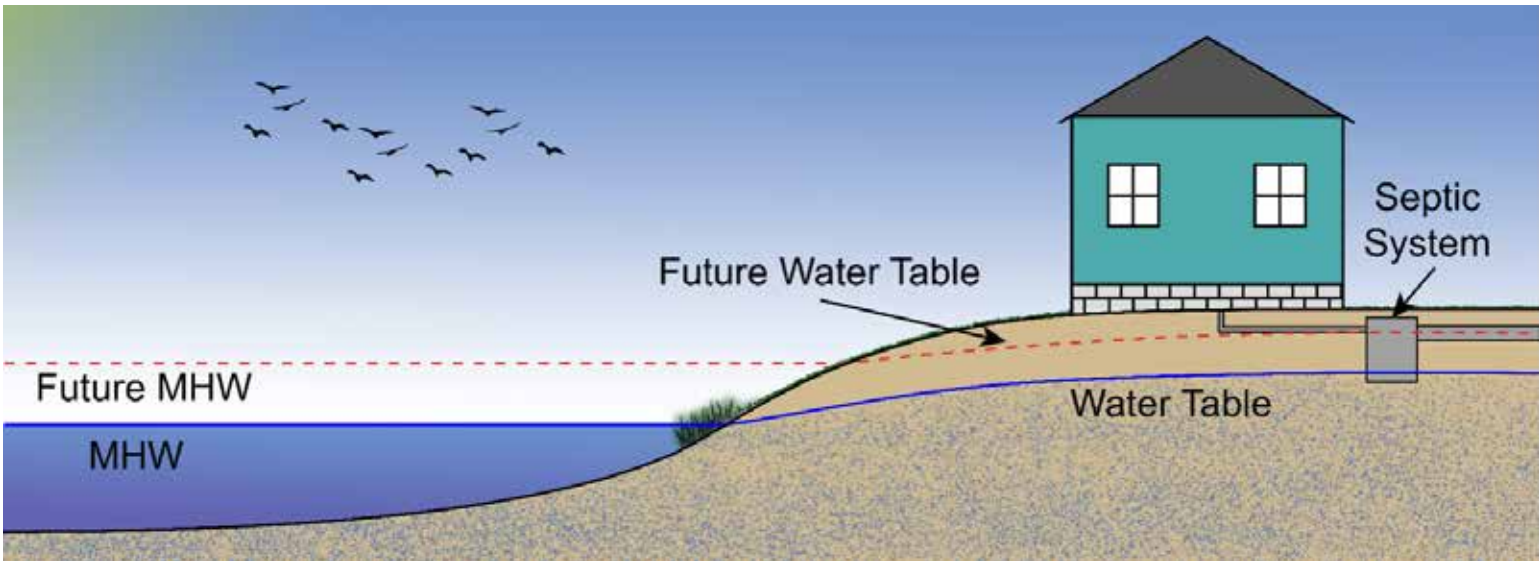
Several counties in the region exhibit high social vulnerability.

In addition, the population in many of these rural counties is already shrinking, and many are projected to decline further by 2040. Accomack County, for instance, is expected to lose 22 percent of its population, according to UVA's Weldon Cooper Center, and Northumberland County's population will drop 16.9 percent.

Furthermore, throughout rural coastal Virginia, property taxes account for upwards of 90 percent of government revenue. This presents a clear and significant fiscal challenge to local governments, as many valuable waterfront properties are exposed to sea-level rise.

The implications of a shrinking, vulnerable, aging population are not hard to imagine. They increase the likelihood of economic decline, a diminishing tax base, and faltering community life just as the need to address the impacts of climate change become more pressing.

IMPACT OF RISING MEAN HIGH-WATER LEVELS ON SHORELINE SEPTIC SYSTEMS



CENTER FOR COASTAL RESOURCE MANAGEMENT

Recurrent Flooding

Rural coastal communities face many of the same challenges as their urban counterparts, but their consequences can differ substantially. In a city, roadways inundated by recurrent flooding affect more people, but city-dwellers are less likely to be completely cut off than those who live in sparsely populated rural areas. In these cases, a flooded road might mean community members cannot get to work, travel for healthcare, or evacuate in the event of an emergency. A Virginia Coastal Zone Management (CZM) Program-funded study found that 209 miles, or 13.8 percent, of the state-maintained roadways on the Eastern Shore face permanent inundation with three feet of sea-level rise — possibly as early as 2060.[5,6]

Some issues, however, are distinct to rural areas. Because rural communities are more reliant on septic systems, sea-level rise and recurrent flooding can negatively affect public health by causing septic systems to fail or by reducing their longevity. In addition, flooding can cause on-site systems to overload, which can impede or stop treatment. This in turn can cause on-site systems to back up, particularly if their drain fields become clogged.[7,8]

This problem is particularly acute in the Middle Peninsula, Northern Neck, and Eastern Shore, where areas with a high degree of reliance on septic systems frequently coincide with low-income and historically disenfranchised communities. Known as "wastewater islands," these communities have no access to centralized public sewer systems and typically have poor soils that are not compatible with conventional septic systems.[9]

With climate change, an increase in failing septic systems poses multiple threats to communities. When released into the soil and water, bacteria and parasites from human waste can cause outbreaks of dysentery, hepatitis, typhoid, and hookworm. Human waste also carries nitrogen, the primary pollutant in the Chesapeake Bay, which produces algae blooms and dead zones. The Virginia Department of Health estimated in 2011 that on-site sewage systems contribute about 4 percent of the nitrogen that flows into the bay annually, with more than half a million systems in Virginia contributing 2.9 million pounds of nitrogen to the bay every year.[10] Over the last decade, these numbers are likely to have increased as more septic systems have failed. Recurrent flooding of septic systems and the resultant pollution of local waterways also can contribute to closure of shellfish harvesting areas by the Virginia Department of Health, negatively affecting the state's aquaculture industry and recreational oyster growers.

With climate change, an increase in failing septic systems poses multiple threats to communities.

There are a few potential solutions to this challenge, but none will be easy to achieve. The most obvious yet most controversial is for a community to prohibit new development in low-lying areas that recurrently flood and are not connected to a sewer system, and/or incentivize development away from those areas to higher ground in the jurisdiction. The Center for Coastal Resource Management at VIMS has been working with the state Health Department to predict where septic failures are likely to occur, but its work has been hampered by the need to digitize records from health departments that predate the establishment of the statewide database in 2003.

Another possible solution would be to install elevated engineered septic systems. In 2021, the Virginia legislature authorized and funded a multiyear pilot project for the Middle Peninsula Planning District Commission to test such systems.[11] Finally, flooding septic systems in an area can be addressed by installation of a community wastewater treatment system on higher ground. However, that requires an appropriate available site, a funding source, and enough residents of the area concurrently agreeing to switch from their septic systems to wastewater treatment that requires monthly payments.

Another existing challenge facing rural communities in coastal Virginia that is exacerbated by climate change is the extensive system of ditches that collect runoff from roads and fields. In low-lying coastal areas, drainage is difficult even when ditches are properly maintained. But long stretches are often neglected because ownership is not clear or maintenance is not a priority or is unaffordable. Poor drainage results in flooding after storms, separating residents and businesses from county and emergency services, and rising sea levels have already exacerbated this problem.[12] Furthermore, water can stagnate and become a breeding ground for mosquitoes. Rising sea levels and more frequent intense storms will magnify the problem.[13]

Saltwater Intrusion

Saltwater intrusion into aquifers, caused in part by sea-level rise, is another issue that affects urban and rural regions differently. In cities, water authorities serving millions of people have the resources and the economies of scale to launch innovative programs such as SWIFT that enable them to recharge aquifers and potentially limit intrusion. Because rural areas depend on individual wells, community members have no ready mechanism to combat the intrusion that will come with rising seas.

Susceptibility to intrusion is not well understood, but vulnerabilities are not evenly distributed across the Virginia coast. Because of the low recharge rate of the underlying Yorktown-Eastover Aquifer, the Eastern Shore is far more susceptible to saltwater intrusion than is the coastal plain west of the Chesapeake Bay. The extent of this vulnerability is unknown, however, because the model that could be used to predict regional impacts has not been calibrated for this use, and relevant data is scarce.[14] The U.S. Geological Survey undertook a study in cooperation with the Virginia Department of Environmental Quality between 2016 and 2019 to develop a hydrogeologic framework for the groundwater system on the Eastern Shore, but an active monitoring system has yet to be put in place.[15]

Agriculture

On the Eastern Shore, low-lying fields flooded at high tide are being abandoned, and ghost forests of dead trees proliferate.

As the century progresses, farmers will increasingly have to deal with the more intense precipitation, longer periods of drought, and increasing temperature and temperature variability caused by climate change. An overall increase in precipitation may increase water availability, but it also creates greater flood potential and water-logged soils, which can reduce crop production. Higher temperatures will dry soils more rapidly, reduce organic carbon levels in the soil, and affect seed germination. Reduced frost risk and warmer winters may allow earlier planting but could also expand the range of agricultural pests and diseases. The effects are expected to become increasingly pronounced as the century progresses, especially for crops located near the warm end of their suitable temperature range.[16]

Rising sea-levels — leading to more frequent flooding and accelerated saltwater intrusion — can also damage coastal agriculture and ecosystems by increasing soil salinity. On the Eastern Shore, low-lying fields flooded at high tide are being abandoned,[17] and ghost forests of dead trees proliferate. Ultimately, these areas will be replaced by saltwater marshes, a transformation that may increase the rate of subsidence of these lands, accelerating this process. As part of a recent National Science Foundation grant, researchers at VIMS Coastal Geomorphology and Ecology Laboratory will be investigating whether this transformation contributes to higher relative sea-level rise.[18]

KEVIN LAMARQUE/REUTERS/ALAMY

Rising sea levels have created a ghost forest on Assateague Island.

Aquaculture and Fisheries

Virginia is the nation's third-largest producer of marine products, with total landings in 2019 of 393 million pounds, outpaced only by Alaska and Louisiana. The dockside value to watermen was $184,270,303.[19] Virginia was also the largest seafood production state on the East Coast. As of 2018, Reedville was the fifth-largest U.S. fishing port based on landings, and Hampton Roads was the nineteenth-wealthiest seafood port in the nation.

The effects of climate change will place these fisheries in jeopardy, but the complex ecology of the Chesapeake Bay watershed and Virginia's offshore waters makes the exact extent and sequence of events difficult to predict. The fate of plankton, which form the base of the estuarine and coastal food web, is a good example. Plankton respond quickly to changes in their habitat — on time scales of days to weeks — and are often the first to feel the impact of changes in their environment. Fluctuations in such variables as nutrient levels, temperature, salinity, and carbon dioxide concentrations associated with climate change can alter the abundance and

growth rates of plankton species and shift the type of species present. These changes, in turn, can affect the economically important species that feed on them.

Additionally, climate change may promote the growth of noxious organisms like algae and jellyfish that can harm human beings.[20] It may also facilitate the spread of known diseases to previously unaffected fish and shellfish populations, exacerbate disease where it already exists, and result in the emergence of novel pathogens. For instance, oysters and clams are both ecologically and economically important but are harmed by several destructive protozoan parasites. A warming climate may exacerbate at least one of these parasitic diseases. Range expansion northward of oyster parasites and lethal dermo disease agent *Perkinsus marinus* has already been attributed to elevated water temperatures, particularly during winter months.[21]

At the same time, climate change is likely to increase the prevalence of *Vibrio* bacteria in the waters of the Chesapeake Bay. As noted earlier, *Vibrio* can cause illness in people who eat contaminated seafood or are exposed to contaminated water. Although *Vibrio* species occur naturally in the Chesapeake Bay, their abundance varies with water temperature, salinity, and other factors. It is estimated that there are more than 34,000 cases of *V. parahaemolyticus* infection each year, with about $40 million in associated economic costs. *V. vulnificus* infections are much rarer but are more likely to lead to hospitalization and serious illness, with mortality rates of 30 to 40 percent and $320 million in economic costs.

As waters rise over time, existing waterfront businesses will need to retreat upland.

Using a number of climate change models for the rest of the century, researchers found that the probability of deadly *V. vulnificus* occurrence is likely to increase markedly across the bay during the peak summer season, and the overall area of high probability will expand. Similarly, the mean predicted concentration of *V. parahaemolyticus* in oysters rose throughout much of the bay. These findings have obvious implications for recreational use as well as for commercial fishing.[22]

A related challenge posed by sea-level rise is its potential impact on working waterfront areas in the Commonwealth. As waters rise over time, existing waterfront businesses such as marinas, ports, marine railways, and crab and shellfish processing operations will need to retreat upland. These businesses, however, may find their ability to move upland constrained where surrounding areas have been rezoned for residential use or where there is a dearth of appropriate property immediately up-gradient for relocation. Already, many of these companies lack sufficient access for bringing aquacultural gear ashore.[23]

Cultural Resources

Because of their long history of settlement, another risk posed by sea-level rise to Virginia coastal rural areas is the inundation of historic sites, which include Revolutionary War and Civil War battlefields, historic homes, and places of worship as well as sites prized by

Native Americans. Colonial Jamestown epitomizes this vulnerability.[24] Jamestown's elevation is just three to seven feet above sea level. A reconnaissance survey conducted in 2016 of archaeological sites on Jamestown Island revealed that two known sites have already been lost to coastal erosion, 24 are in the process of being eroded or submerged, and by 2065, only two archaeological sites on Jamestown Island will remain entirely above water.[25] Today, organizations including the Union of Concerned Scientists, the National Park Service, and the National Trust for Historic Preservation, as well as other community, local, state, and private partners use the threats to Jamestown, the "birthplace of America," to emphasize the scale and scope of climate change and generate attention and support for the preservation of historic structures and archaeological sites.[26]

Long-Term Planning

Planning for climate change in rural coastal Virginia necessarily differs from the approaches favored in more densely developed and populated areas like Hampton Roads or Northern Virginia. With more land to protect and few resources to do so, communities in rural areas are turning primarily to green initiatives like strategic land conservation, wetland restoration, and living shorelines.[27]

For instance, the Middle Peninsula Planning District Commission (MPPDC) manages a living shoreline incentive program (LSIP). Legislation approved during the 2015 General Assembly allowed the Department of Environmental Quality to provide funding for living shorelines via revolving loan funds through the Virginia Clean Water Revolving Loan Program. Building on this project, the MPPDC has debuted "Fight the Flood," an online business-to-consumer marketplace, where property owners can find contractors and businesses specializing in flood mitigation and receive their professional services at a discounted rate. Residents who participate in the new program will also receive further discounted loan rates through LSIP.[28]

On the Eastern Shore, The Nature Conservancy, which protects the 14 undeveloped barrier and marsh islands that compose the Virginia Coast Reserve, has partnered with VIMS and the Coastal Zone Management Program-funded Seaside Heritage Program to establish the world's largest seagrass restoration project and to build oyster reefs for shoreline protection.[29]

In addition, officials in a number of rural coastal communities — including Accomack and Northampton Counties as well as the Towns of Chincoteague and Wachapreague[30,31,32,33] — have added resilience to sea-level rise in their comprehensive plans and are working to collect the baseline data needed to manage it more effectively. The Accomack-Northampton Planning District Commission, for instance, has sponsored a Transportation Infrastructure Inundation Vulnerability Assessment to determine the extent of transportation infrastructure on the Eastern Shore at risk of inundation from rising sea levels and to determine when permanent inundation is likely to occur.[34]

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Shops and restaurants in Alexandria prepare for Hurricane Sandy, October 29, 2012.

CHAPTER 5

Perspectives for Decision-Makers

The need to respond to climate change becomes more pressing with every passing year, but developing coherent strategies to mitigate or adapt to its effects is a daunting challenge. Funding is finite, a fact that the authors of the *Virginia Coastal Resilience Master Planning Framework* state in no uncertain terms: "There is not, nor will there ever be, enough funding to protect all homes, businesses, infrastructure, and other coastal assets where they currently exist." Faced with limited resources, legislators, policymakers, and planners must weigh costs and benefits, a consideration that is easily stated but that entails grappling with such vexed cost-and-benefit dilemmas as *to whom? over what period of time?* and *on what geographic scale*? There are no easy answers.

Building consensus for these decisions is equally difficult because even solutions with minimal impact entail some concession to the inevitability of disruption and loss. We can mitigate, forestall, and delay, but given the forces that have been put into play, it is beyond our power to preserve. For social, cultural, and economic reasons, this is a difficult truth for people to accept. Legislators, policymakers, and planners must find ways to recognize and respect this reluctance in any solution they propose.

As mitigation and adaptation become more urgent, there will be a growing need for expertise and innovation as well as organizations with the capacity to complete large- and small-scale projects. As it addresses these issues, Virginia has an opportunity to develop innovative and forward-looking initiatives that can serve as examples for other coastal communities, initiatives that will benefit not only coastal Virginia but the entire Commonwealth.

In this chapter, we take a closer look at some important perspectives for decision-makers to consider as they grapple with responses to climate change.

Taking a Statewide View

The impact of climate change on coastal Virginia will not be confined to the coast. The economy of the entire state, for instance, is dependent on services delivered by The Port of Virginia and such coastal enterprises as shipbuilding, fisheries, and the military. The latest

The port is responsible for nearly one of every 10 jobs in Virginia.

study by the Raymond A. Mason School of Business at the College of William & Mary shows the port is responsible for nearly one of every 10 jobs in Virginia. These jobs extend outside the gates of the port's terminals to the thousands of businesses across the state that rely on the port as their gateway to the global market.[1] Millions of people across the state will be indirectly affected by economic losses and displacement in the coastal area. This situation provides an opportunity to think holistically about economic development across the Commonwealth.

Responding in a Coordinated, Proactive Way

Taking a coordinated, proactive response is important for many reasons. If the Commonwealth fails to take the lead, we can expect a fragmented, inefficient response, driven in part by market forces. For instance, with sea-level rise, banks and insurance companies will be unwilling to support investment in coastal property and infrastructure. In fact, we are already seeing this start to happen. Research by the Commonwealth Center for Recurrent Flooding Resilience, Wharton Risk Center, and First Street Foundation shows that property held by coastal property owners, and in particular by low-income property owners, is already losing value.[2,3,4]

One school of thought holds that we should let market forces drive the transition. However, it is likely that when they do, the changes they cause will be disruptive and the economic impact significant and uneven, creating "have and have-not" communities.

The state has an opportunity to play a critical role in coordinating actions across coastal communities, regions, and planning districts to incentivize collaborative action, but first it will have to accept its position as a leader. At present, the Commonwealth has no single entity planning for climate change. It also has no planning entity focused solely on planning for budget and financial matters related to climate change. All land-use planning has been pushed to the localities. For an effective set of cohesive strategies to be developed, the state might take a more proactive role in coordinating and facilitating climate resiliency planning even as localities retain their primary role in land use planning.

Further, there is a lack of legislated interagency coordination for climate or environmental resilience and sustainability. Until the most recent Virginia coastal resilience master planning effort, the program that has come closest to achieving this level of coordination is the Virginia Coastal Zone Management Program, which was funded exclusively by NOAA. The last formal Commonwealth-wide interagency coordination effort was the establishment of the Council on the Environment, which was absorbed into what is now the Department of Environmental Quality.

As interest in climate adaptation and mitigation takes shape at the federal level, states that have strategies and plans in place will be better prepared to take advantage of changes in policy, grants, and other federal funding opportunities. They will be able to show that through their aligned resilience planning and implementation efforts, they are making a difference in a quantifiable way, developing and putting into practice strategies to deal with climate impacts.

Appreciating the Challenge for Localities

Although climate change is a global challenge, individual jurisdictions will bear the brunt of the response and will do so in different ways depending on local conditions and priorities. Local jurisdictions and supporting regional planning districts in Virginia have already begun to respond in their own ways. Though data gaps persist, these entities are gradually developing tools to model the scope, scale, and timing of these impacts and to determine how they will prioritize, invest, and deploy their limited resources over time to address the risks.

Nonetheless, the breadth of activities they need to undertake is daunting, as is the extent of the resources they must commit. The response includes a variety of core local government functions such as land-use planning, building code revision, building permit review and enforcement, economic development, and housing, to name just a few. Communities must engage private utility companies and other businesses that provide essential services as partners in these efforts. This includes organizations that supply electricity, telecommunications, healthcare, water, and wastewater and solid waste management, among others. Communities will also likely need to encourage private sector investment in resiliency as part of their overall strategy. Finally, localities need to plan their efforts and the timing of their implementation to optimize opportunities and minimize risks.

A coordinated and inclusive planning approach would maximize the effectiveness of such efforts, but this will require support from and collaboration with the Commonwealth, regional planning bodies, and the private sector. Such support will be especially important to smaller and rural communities. Not only are the challenges they face different in many respects from those faced by their larger urban counterparts, but they generally have less capacity to respond to the challenges. Regional planning entities are already assisting small rural communities meet these challenges, mainly with land use, demographic, and date-gathering expertise. In support of these local and regional efforts, state government can offer financial resources, regulatory program oversight and consistency, technical assistance, and incentives to the private sector.

Addressing Inequality

As this report has documented, climate change can be expected to exacerbate existing economic inequality and heighten challenges that disadvantaged communities already face in areas such as healthcare. Market forces and historic housing policies have meant that lower income or racially segregated neighborhoods are often located in lower-value land tracts, including floodplains or flood-prone areas. Today, residents and small businesses located in such areas are less likely to have the financial means to protect their properties or relocate to less vulnerable areas.

With climate change exerting pressure on government budgets, providing the financial assistance and incentives needed to offer equitable options to stakeholders in these

communities will become increasingly difficult. Certainly, relocation of one or more entire neighborhoods to preserve the integrity of a community will not typically be feasible, both for financial and land-use reasons. Communities will need to consider how to allocate resiliency resources in an equitable manner with appropriate stakeholder input to ensure that all neighborhoods are given due consideration and fair treatment.

There are also opportunities to make investments in disadvantaged communities to increase their resiliency to flooding. The private sector can play a role via HUD financing. Examples include the Ohio Creek Watershed Project in Norfolk,[5] the Region Greenhouse Gas Initiative (RGGI) energy efficiency fund, and the Community Flood Preparedness Fund (funded by RGGI auction proceeds). This requires that no less than 25 percent of the moneys disbursed from the fund each year be used for projects in low-income geographic areas.[6]

Adjusting to Intersecting Stakeholder Timeframes

Almost every response to climate change will require public- and private-sector decision-makers to manage conflicting time frames. This is often a reflection of the nature of specific impacts, as some are more immediate or costly than others. However, these timeframes also reflect factors like budgeting cycles and grant deadlines, durability of different assets, and projected depreciation or lost value of assets. These timeframes are apt to differ from one group of stakeholders to another.

For instance, the planning horizon for community infrastructure and assets is often 30-to-50 years, based on expected serviceable lifespan and the term of public debt (bond) service. Large-scale infrastructure projects as well as related utility services and land-use planning will consequently require a long perspective that accounts for projected changes over that time. Failure to address these factors can threaten a locality's economic and social sustainability. This, in turn, can affect its credit rating, and thus its ability to borrow funds and remain viable over time.

Most retail and commercial businesses have a planning horizon of five-to-seven years due to relatively short financing cycles and shifting market forces, whereas heavier industries with significant capital investment (manufacturers, energy producers, logistical and distribution centers, and terminals and ports) may have longer planning cycles linked to the useful life and depreciation of their assets.

Finally, individuals facing flooding risks have various planning horizons, most often tied to the level of investment in and value of their homes, the vulnerability of their property, and the financial resources they have available to address the most immediate threats.

If the options made available to stakeholders to address climate risks and recurrent flooding do not match a stakeholder's planning timeframe, these provisions will seem irrelevant at best or even inimical to the stakeholder's interests. Therefore, state and local agencies must craft incentives that fit the timescale and priorities of stakeholders to achieve greater resiliency.

ROBERTO WESTBROOK / ALAMY

Insurance adjuster examining flooding damage to house in Norfolk in 2015

Understanding the Role of Flood Insurance

The National Flood Insurance Program, administered by the Federal Emergency Management Agency (FEMA), is $20 billion in debt, having drained its reserves reimbursing homeowners for losses caused by storms whose intensity can, in part, be attributed to climate change. In response, it has adopted a more actuarial, market-oriented approach to assessing and pricing risk of loss and setting coverage rates. This has caused the cost of homeowner's flood insurance to rise significantly over recent years. At the same time, private flood insurers are either leaving the market or similarly raising their rates based on the latest market risk analysis. Their actions affect businesses as well as private property owners.

The result is that more and more individuals and commercial enterprises lack adequate flood insurance. In these instances, lenders and banks will no longer issue mortgages to homeowners for coastal properties and will be reluctant to lend to underinsured commercial and industrial facilities located along the shoreline or in flood-prone areas. If they do, it will be at higher interest rates to offset their higher loan risks. Without access to affordable insurance and lending markets, homeowners and business will not be able to invest in at-risk properties. In essence, the financial markets will affect, if not begin to drive, homeowner and business decision-making regarding whether to stay or go or whether to invest further in their current locations.

By acting early, however, local jurisdictions and the Commonwealth can encourage individuals and businesses to move to safer locations within their boundaries, sparing these governments the expense of purchasing or condemning low-lying properties and removing the property owners from their tax base. Norfolk's comprehensive plan and zoning ordinance are already encouraging movement to higher ground. The transfer of development rights (TDRs), authorized under state law since 2006, may also offer financial incentives for shifting land use consistent with resiliency goals.[7,8]

Managing Mitigation, Remediation, and Relocation

Mitigation, remediation, and relocation, individually and in combination, are likely to have their appropriate places in coastal Virginia's response to climate change. The scale and timing of their deployment will depend on factors specific to the community and region. One fact is clear: Mitigation measures (risk reduction, prevention, and adaptation) are generally more cost-effective strategies to address climate change than after-the-fact remediation. Indeed, the cost of mitigation is generally one-sixth the cost of recovery.[9] The best way to manage the risks is to stay ahead of them where possible, as delay increases the costs of mitigation and diminishes its potential value and cost-effectiveness.

Mitigation measures are generally more cost-effective strategies to address climate change than after-the-fact remediation.

There are practical and fiscal limits to the utility of mitigation, however. Other options, such as planned relocation and remediation, may be the most appropriate measures in certain situations to limit unreasonable risk of exposure or to address the risks of impacts that are not reasonably avoidable.

The government's ability to take (or impose) mitigation measures or, as needed, to encourage (or impose) relocation, either through incentives or eminent domain, is restricted in many respects by economics and legal limitations. Localities must also evaluate several issues related to how their policies and actions may affect private property, steps that may in turn affect local economic development and the tax base or create legal liabilities for localities:

- Some residents or small businesses may not have the financial resources to relocate within the community or elsewhere, or they may have strong family, cultural, or business ties to the neighborhood that they do not want to disrupt or abandon.
- Localities will need to consider which incentives (chiefly financial) could be feasibly and lawfully used to encourage property owners to adopt or accept mitigation and relocation options, e.g., lower or deferred property-tax rates or rebates, or lower local utility fees.

- Most of Virginia's coastal areas are privately owned, and waterfront properties are often of higher value than other property and therefore generate relatively greater property-tax revenues.
- Generally, private landowners must be compensated for loss of their property (actual possession or loss of value) resulting from government actions or regulations that serve a public purpose or use.

Localities need to balance the potential loss to their tax base from declining property values caused by flooding against the potential loss of tax base associated with mitigation measures limiting property use or relocation.

Engaging a Multiplicity of Funding Sources

The resilience projects undertaken by the state may range from building seawalls as protection for natural or manmade infrastructure to creating wetlands and other nature-based features to act as flooding buffers. In each case, the state will need to determine the best approach to pay for each project based on location, type, purpose, and available funding programs and partnerships. Funding options include the following:

- Federal grants for resilience planning, projects, and academic research
- Congressional appropriations for United States Army Corps of Engineers' projects
- Grants from nonprofit foundations.

Special tax, fee, flood control, or improvement districts also can provide a source of revenue to local governments for specific purposes. Some examples of other financing options are these:

- Traditional municipal bonds
- Innovative bonds such as resilience and catastrophe bonds and environmental-impact bonds, including bonds funding green infrastructure in the City of Hampton, discussed above
- Revolving loan funds administered by the state or a planning district commission.

Community development institutions, whose goal is to promote economic revitalization and community development in low-income communities through mission-driven, locally informed investments, are another source of finance. In the case of disasters caused by climate change, parametric insurance may also play a role. Parametric insurance pays out when a disaster meets specified parameters such as wind speed or flood depth. Banks may also be a source of assistance. To meet their Community Reinvestment Act requirements, banks can

play a role, not just in the recovery and rebuilding of a low-income community that has been designated a disaster area, but also in strengthening the community's resilience.

In many cases, jurisdictions will have to draw on a combination of sources — a capital stack — to finance resiliency and adaptation.

To date, groups in the state have used a number of creative solutions to secure funding and direct it to offset or adjust to the impacts of climate change such as the following:

- Commercial Property Assessed Clean Energy (C-PACE) ordinances, which pave the way for private-sector financing of clean energy and resiliency projects for commercial, family, and nonprofit buildings. The 2020 General Assembly passed legislation allowing Virginia to offer a statewide C-PACE program. Fairfax, Loudon, and Arlington Counties as well as Norfolk, Alexandria, Richmond, and Dumfries all have C-PACE ordinances.[10]
- GO Virginia is a bipartisan, business-led economic development initiative established to change the way Virginia's diverse regions collaborate on economic and workforce development activities. It funded the Coastal Resilience and Adaptation Economy Region 6 Action Plan, issued in March 2021, a joint effort of Sea Grant Virginia, the Middle Peninsula Planning District Commission, and the Middle Peninsula Alliance.[11]

Given the scope of the challenge, the state will need to supplement these efforts with meaningful and sustained state funding for coordination and implementation of any plans.

Embracing and Encouraging Innovation

Significant innovation will be required to avoid the worst impacts of climate change and to mitigate the impacts that coastal regions are experiencing now and are likely to experience in the future. Innovation is also critically important because it holds the promise of addressing the climate challenge without compromising economic growth. The right framework and investment for climate-related innovation will accelerate the development of high-impact technological breakthroughs while driving down the costs of existing options.

Virginia has an opportunity to leverage breakthrough technologies that would not only cut emissions and mitigate climate-related impacts but also boost the state's economy and position the Commonwealth at the forefront of this technological and industrial marketplace.

To accomplish these goals, Virginia should consider embracing market-based policies as the most effective and efficient way to effect emissions reductions across the economy, deploy energy-saving innovations, and mitigate current and future impacts. The state's approach might include both high-tech and low-tech green approaches as well as economic incentives that encourage efficient, low-cost, and environmentally compatible methods of addressing impacts.

There are a number of core principles that Virginia could follow for effectively harnessing the power of innovation:

- First, government can provide predictable and long-term policy signals to give potential innovators and adopters of climate-friendly technologies the confidence to undertake necessary investments.
- Second, government can craft policy measures so that they are flexible enough to give potential innovators incentives to identify the best ways to meet climate objectives and to avoid locking in technologies that may be less attractive or even obsolete in the future.
- Third, government can focus on solutions designed to leverage private capital as much as possible and avoid crowding out private investment.
- Fourth, government can coordinate its approach across agencies and programs at multiple levels as well as with the private and philanthropic organizations to harmonize and streamline its climate-related activities and maximize their impact. Government should consider ways to integrate currently isolated efforts around Virginia (e.g., buffer zones around military bases and other federal facilities) into coordinated statewide frameworks.
- Fifth, government can be receptive to bold ideas and willing to reimagine what its coastal communities might look like in the future (e.g., floating cities, much greater reliance on wind energy).
- Finally, government can track the performance of all initiatives in order to evaluate effectiveness and continuously improve based on lessons learned.

A number of programs in Virginia are already funding innovation:

- The Virginia Innovation Partnership Authority (VIPA) was established in 2020 to support the life cycle of innovation, from translational research and entrepreneurship to pre-seed and seed-stage funding as well as acceleration, growth, and commercialization, resulting in the creation of new jobs and new company formation.[12]
- RISE, a nonprofit economic development organization, is dedicated to accelerating innovation and business growth in coastal communities. It has helped coastal communities adapt to flooding, storm surge, and other climate change challenges, and has deployed $4 million in financial support and services to 27 businesses developing new, scalable solutions for such problems.[13]

Chapter 5 Endnotes

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STEVEN JONES/ALAMY

Virginia's wetlands may not be able to keep pace with rising sea level.

CHAPTER 6

Recommendations

The Virginia Academy recruited an expert study board to produce this report. Members include engineers and scientists, representatives of local planning district commissions, veterans of state government and the Office of the Governor, members of the legal community, and specialists in economic development, among others (see *Appendix B*). All have a long history of working in Virginia to assess the impact of climate change on the Commonwealth and to find ways to improve the state's response. Their expertise and insight have been critical to chapters summarizing the fundamental science, describing the near-term and long-term impacts of climate change on Virginia's coasts, and enumerating perspectives that decision-makers should consider as they prepare for the future.

In producing the report, the board used methods similar to the National Academies of Science, Engineering, and Medicine, which rely on expert perspectives of commission members. Consequently, the expertise and experience of its members are most clearly reflected in the four interlocking recommendations that conclude the report. Taken together, these recommendations provide an overarching framework that has the potential to help Virginia adjust to the changes in coming decades that are inevitable and to do so with less disruption to its economy and the lives of its citizens.

Recommendation 1:
Establish a Structure for More Effective Collaboration and Coordination

As this report demonstrates, the impacts of climate change will be far-reaching and will necessitate an equally far-reaching response. They will require a comprehensive system of coordination that focuses expertise across government, business, and academia on the intersecting challenges of climate change.

We recommend that the climate change program structure in Virginia be headed by a statutorily created council modeled after the Council on Virginia's Future (2004–2017) and appropriately funded and staffed. Chaired by the Governor, that organization of legislative leaders and citizen members successfully created a statewide strategic plan focusing all 11 secretariats and 93 agencies on a specific set of goals. The advantage of this approach is that it builds upon existing governmental structure while enhancing the Commonwealth's capacity to plan and respond to the challenges of climate change. Furthermore, we recommend that this council plan not only for the resilience of Virginia's coast but also for the entire state. While climate change will manifest itself in distinct ways in different regions, it will have statewide implications.

The newly created council could be staffed by Virginia's chief resilience officer,[1] who should be empowered to address resilience issues among all secretariats and agencies of the Commonwealth. It could likewise be staffed by the special assistant to the governor for coastal adaptation and protection, who should be a member regardless of its composition. In either case, it should be appropriately funded to accomplish the task. Again, the Council on Virginia's Future serves as a model that demonstrates how a small staff in a coordinating role with an appropriate budget can have a large impact if that staff enjoys the backing of the Governor's Office. The secretariats and agencies can accomplish much in such an arrangement if given clear, thoughtful direction.

We believe this structure will create a sense of urgency, while at the same time producing results not seen before. This structure would also create a sustainable framework that, like the Council on Virginia's Future, is capable of withstanding the transition to a new governor every four years.

Background

Although climate change is a challenge rooted in the natural world, it has consequences for every aspect of life. Among those covered in this study are its impacts on health, transportation, ports, agriculture, inland fisheries, historic resources, emergency response, and housing. These areas are the purview of individual cabinet members and fall under the jurisdiction of separate and often multiple state agencies.

Because the impacts of climate change do not easily conform to the structure of the Commonwealth's administrative branch, Virginia is limited in its ability to address them in a

coordinated and coherent way. Even in cases like wetlands management, where the effects in question are confined to a natural area, different state agencies — in this case the Department of Environmental Quality and the Virginia Marine Resources Commission — are responsible for separate parts of the landscape. This arrangement inhibits the flow of information from one department to another and jeopardizes the Commonwealth's ability to understand the consequences and optimize its response.

There have been a number of efforts to develop a comprehensive approach. In 2007, Governor Tim Kaine created the Governor's Commission on Climate Change, which produced a Climate Change Action Plan, released in 2008.[2] In 2011, the General Assembly advanced important legislation to facilitate the adoption of living shorelines,[3] and in 2012 directed VIMS to study strategies for adaptation to prevent recurrent flooding in Tidewater and Eastern Shore localities.[4] The resulting VIMS report, *Recurrent Flooding Study for Tidewater Virginia*,[5] led the General Assembly to establish what is now known as the Joint Sub-Committee on Coastal Flooding to review flood preparedness options.[6]

In 2014, Governor Terry McAuliffe convened the Climate Change and Resiliency Update Commission, which produced a final report in December 2015.[7] Also in 2014, based in part on the anticipated Climate Change and Resiliency Update Commission report, the General Assembly passed legislation creating the Secure and Resilient Commonwealth Panel, chaired by the secretary of public safety and homeland security, to advise the Governor on emergency management. That panel in turn created a Recurrent Flooding Subcommittee.[8] Governor McAuliffe also appointed the secretary of public safety as the Commonwealth's first chief resilience officer in 2014.[9] In 2016, the General Assembly created (but did not capitalize) the Virginia Shoreline Resiliency Fund, a revolving loan fund to help localities increase their resilience to coastal flooding, and established CCRFR, which includes VIMS, Virginia Coastal Policy Center (VCPC) at William & Mary Law School, and Old Dominion University (ODU).[10]

Most of these actions produced useful information and encouraged continued dialogue about climate change impacts and the need for coastal adaptation and protection in the Commonwealth. But so far, they have failed to produce a coordinated plan to mitigate flooding and other coastal hazards.

In 2018, the General Assembly created and funded the position of special assistant to the governor for coastal adaptation and protection to ensure a more permanent focus on addressing coastal hazards.[11] In addition to filling the special assistant position, Governor Ralph Northam has issued two executive orders intended to foster consistent and sustainable long-term action on climate change mitigation, including coastal resilience. In Executive Order 24 (2018), he appointed the secretary of natural resources as the Commonwealth's chief resilience officer, a decision affirmed by the General Assembly in 2021.[12,13] In addition, the *Virginia Coastal Resilience Master Planning Framework* was published in October 2020, laying out a path for Virginia's first coastal resilience master planning effort, now in progress.[14]

Among other directives, the framework created a Technical Advisory Committee, established by Executive Order 71, bringing together planning district and regional commissions, state agencies, and other key federal and academic partners.[15] The framework

further directed the Virginia Coastal Zone Management Program to report directly to the secretary of natural resources, codified by Executive Directive 13.[16]

While these actions create additional capacity and information exchange relative to coastal adaptation planning, they are limited to the eight coastal planning districts. Much broader coordination is needed to address resilience across the Commonwealth. In addition, Recommendation 1 would help to reconcile the roles of the chief resilience officer and the special assistant to the governor for coastal adaptation and protection.

Recommendation 2
Address Gaps in Policy and Procedure

We recommend that Virginia establish and optimize a substantive budgetary policy and procedure for climate impact review as part of relevant state agency planning that (i) provides equitable opportunity for all stakeholders, including members of underserved or disadvantaged communities, to have consideration given to such concerns and impacts as transportation and evacuation, sheltering, relocation, housing, etc., and (ii) incorporates and facilitates feasible resilience strategies. Such policy and procedure will also need to ensure compliance with the Virginia Environmental Justice Act, as applicable.

This might include action in a number of areas:

Floodplain Management and Risk

- Determine state guidance on acceptable levels of risk for public infrastructure (water, wastewater, transportation, solid waste management).
- Extend the statute that requires HRPDC localities to incorporate sea-level rise into their comprehensive plans to more coastal localities.
- Promote and facilitate acquisition, conservation, and protection of land in floodplains.
- Encourage localities to restrict or discourage development in floodplains, clearly authorizing localities to adopt more stringent resilience requirements than those set forth in the Uniform Statewide Building Code for development in flood-prone areas outside of Special Flood Hazard Areas on FEMA flood insurance rate maps.
- Encourage broader adoption of flood insurance.
- Limit installation of new septic systems in regularly flooded areas and encourage the installation of community wastewater systems to serve multiple properties in low-lying areas.

Resilience

- Identify and create resilience strategies for roads, bridges, and roadside ditches that experience or are expected to experience frequent flooding and review design standards for roads and related stormwater management in coastal areas to ensure that they incorporate adequate resilience measures.
- Require minimum resilience measures for all capital projects and infrastructure receiving state funding.
- Establish a comprehensive post-disaster damage assessment process (essential for securing federal funds).
- Ensure military access to critical transportation routes during natural hazards and post-hazard recovery.

Outreach and Equity

- Develop and implement a state climate outreach and engagement plan targeted at citizens and local governments.
- Ensure disadvantaged populations are equitably represented and served as resilience plans and strategies are developed.
- Provide training and education for relevant staff (local, regional, and state government) regarding coastal management and resilience.

Background

While significant strides have been made since 2018 by both the current administration and the General Assembly in aligning agency actions to promote a resilient Virginia, there is no comprehensive requirement for climate risk to be incorporated into agency action.

Executive Order No. 24 (2018) and the *Virginia Coastal Resilience Master Planning Framework* it created set in motion an assessment of agency actions with regard to floodplain management and resilience. The forthcoming Coastal Resilience Master Plan will likely further advance the alignment across executive agencies on floodplain management and resilience.

Executive Order No. 45 (2019), *Floodplain Management Requirements and Planning Standards for State Agencies, Institutions, and Property*, establishes new freeboard requirements for state-owned properties in flood-prone areas and requires the convening of a state-wide workgroup establishing NFIP-compliant requirements for all development activities on state-owned property. In addition, the General Assembly has required incorporation of sea-level rise and climate risk into certain environmental laws like the Tidal Wetlands Act and the Chesapeake Bay Preservation Act. However, none of these actions requires a climate impact review as part of relevant state agency planning.

Recommendation 3

Create a Body to Coordinate and Support Critical Data Collection and Technology Transfer Across the Commonwealth

We recommend that the Commonwealth create, fund, and staff a Climate Change and Resilience Resource Center for Virginia, with a board of directors drawn from planning district commissions and other entities representing local governments, the Commonwealth's universities and research institutions, nonprofits, and private firms specializing in environmental mitigation and adaptation. This entity would be charged with synthesizing research and development efforts for Virginia's climate response to maximize benefits for the state's citizens and promote collaboration. It would also assist entities applying for funding from federal, state, and local sources by identifying needed research priorities and would provide seed money to entities engaged in or fostering promising research and development.

Background

Although a great deal of research has been conducted, gaps in fundamental information about the impacts of climate change are limiting decision-makers' ability to take effective action to mitigate or adapt to the consequences of climate change. As climate change accelerates, the need for this information becomes only more pressing. The examples cited below are appropriate for a report on coastal issues, but similar deficits can be found in efforts to track the impacts of climate change in other parts of the state. This is why we believe this center should have a Commonwealth-wide mandate.

This report has highlighted data gaps in the coastal region. For instance, only preliminary data exists on saltwater intrusion in the Eastern Shore aquifer. While work has advanced as part of a partnership between NASA Joint Propulsion Laboratory and ODU addressing localized subsidence in the Hampton Roads area, the data is not easily accessible. Our understanding of sea-level rise has similar gaps. Although localities, RISE Resilience (initially funded with support from the Commonwealth's HUD National Disaster Resilience Competition award), VIMS, the Hampton Roads Planning District Commission, and others have developed a network of tide gauges, a more comprehensive network — or at least better coordination and integration of data from current gauging networks — could yield an open, detailed, easily accessible information source for understanding trends in sea-level rise, groundwater levels, and rainfall.

Collecting a complete, appropriate, observation-sensing network, in itself, is not sufficient. Also needed is a way to transform the data into models and maps that can help decision-makers with varying technical capacity better understand the impact of climate-related changes on people and infrastructure and use data to catalyze commercialization and business opportunities in Virginia. Progress in this area has been catalogued in the *Virginia Coastal Resilience Master Planning Framework*:

- ODU and CCRFR developed an updated Coastal Virginia Sea-Level Rise and Recurrent Flooding Predictive Inundation Model, which generates maps showing regional and local comparisons of impact and which provides local planners with a tool to support risk assessment and flood preparedness efforts.
- The Virginia Department of Emergency Management (VDEM), working with the Federal Emergency Management Agency (FEMA) and NOAA's National Hurricane Center, maintains interactive maps of potential storm-surge hazards for Virginia using the new SLOSH MEOW (Sea, Lake, and Overland Surges from Hurricanes, Maximum Envelope of Water) model.
- VIMS has developed a state-of-the-art model, SCHISM (Semi-implicit Cross Scale Hydroscience Integrated System Model), which simulates general circulation from oceanic to tidal-creek scales and predicts storm-surge inundation with high resolution and precision.

VIMS also maintains a Shoreline Management Model (SMM), a decision-support tool that includes a database of shoreline conditions, established as a geographic information system (GIS) model, that helps recommend best management practices for shorelines, using data and decision-tree logic to assess potential conditions.

Additional tools would be useful. The Commonwealth, for instance, lacks a statewide predictive floodplain mapping program. Tools that would reveal the susceptibility of state roadways to coastal effects and measure the long-term vulnerability of critical evacuation routes would also be useful. Creating these more complex models in some instances requires integration of various assumptions and distinct methodologies. For example, a large disciplinary disconnect exists in the methodologies used for hazard characterization in inland and coastal areas.

Moving forward, new technologies will present opportunities to better monitor and mitigate climate change in coastal communities. For example, 5G technology will increase our ability to track the changing environment. Cloud-computing will allow for more complex and real-time decision-support systems. Internet of Things (IoT) and cyber-physical systems technologies offer the opportunity for real-time coordination of stormwater and transportation infrastructure systems in response to changing environmental conditions. These technologic innovations are not limited to digital tools. For instance, decision-makers require design guidance for nature-based mitigations that would characterize their reliability in the face of considerable uncertainty. If we are to minimize the disruption of climate change, decision-makers will require more options and a better sense of what works best in different situations. We need to coordinate these efforts and create clear pathways for bringing research to practice.

Addressing these opportunities to translate research and development to into practical solutions with the urgency they deserve requires coordination and resources. Currently, many groups — state agencies, localities, regional organizations, and universities and research institutions — are working diligently to fill the gaps. Recommendation 3 will help ensure that the impact and scope of their work is maximized by providing a mechanism to enhance their collaboration, focus their work on top-priority knowledge gaps, build their capacity through

collaboration with industry and government, and enable them to work in larger teams to tackle ambitious, real-world projects. Finally, when new breakthroughs are identified in research, the pathway to adoption should be as friction-free as possible so that new technologies can make their way to the marketplace, a topic addressed in Recommendation 4.

Recommendation 4
Provide Meaningful Economic Innovation and Incentives to Build a Resilience Economy in Virginia

The scale of impacts on coastal Virginia and across the state provides an opportunity for the Commonwealth to be a global market leader in solutions that enhance resilience. We recommend that the General Assembly provide incentives for businesses to develop innovative resilience-enhancing products, technologies, designs, and services, to partner with universities to capitalize on their expertise, and to foster workforce development in building and implementing resilience solutions. These incentives could include such nonfinancial measures as expedited permitting so that innovative solutions like green infrastructure can be rapidly implemented. However, funded incentives — including tax breaks for related R&D and capital investment as well as grants and low-interest financing — will also be important.

As part of this effort, we recommend that the Commonwealth continue to support economic development investments in Virginia's resilience and adaptation economy, such as the recent GO Virginia grant to foster coastal resilience and an adaptation economy.[17] We further recommend that the state explore making financial and nonfinancial incentives available to smaller local jurisdictions to increase their ability to support business activities that further resilience and enable them to address impacts such as overburdened septic systems and ditch networks that affect water quality.

Background

Engaging with the Virginia Economic Development Partnership is the logical first step for developing a resilience and sustainability ecosystem in the Commonwealth. But the Commonwealth should go further, incentivizing efforts to expand collaboration among the Virginia Economic Development Partnership, local economic development organizations, universities, and resilience businesses to expand innovation, grow resilience economic clusters in rural, suburban, and urban areas across the Commonwealth, and brand Virginia as a leader in resilience solutions. These efforts would build on the considerable strengths we have, such as the Commonwealth Center for Advanced Manufacturing. These efforts might focus on the following market opportunities:

- Using advanced data analytics, technologies, data management, and communication systems to enable rapid adaptation in the face of natural hazards.
- Introducing living-with-water strategies and retrofitting as an alternative to razing waterfront homes and properties.
- Developing and integrating hybrid blue-green-gray infrastructure with living shorelines, creating a comprehensive solution across marine-tidal landscapes.
- Creating innovative flood management and infrastructure tailored to rural, suburban, and urban settings.

Part of resiliency is knowing how to minimize or avoid economic loss. The following could be done in this area:

- Assess and share the economic impact of resiliency planning and project implementation, and research the economic cost of flooding.
- Assess the vulnerability of coastal Virginia's business sector to future flood risk.
- Advance policies and strategies that can reduce flood insurance premiums and increase localities' FEMA NFIP Community Rating System (CRS) credits.
- Require sellers to disclose a property's location in a floodplain and its flood history.
- Acquire and protect land in floodplains.
- Develop programs to purchase and transfer development rights where economically feasible to encourage the movement of development from low-lying areas.
- Encourage landowners to convert hardened shorelines into living shorelines and support measures required for successful implementation.

A number of initiatives have created a foundation for economic development. In addition to the Coastal Resilience and Adaptation Economy project funded by GO Virginia, organizations like RISE Resilience — initially funded with support from the Commonwealth's HUD National Disaster Resilience Competition award — are actively accelerating business growth and innovation around solutions to coastal resilience challenges in Hampton Roads. Another effort is the Open Seas Technology Innovation Hub, which ODU is leading with support from the U.S. Economic Development Administration. Its goal is to determine difficult maritime and coastal challenges, identify innovative solutions for these problems, and work with individuals and companies to grow these solutions into businesses. The Commonwealth has an interest in encouraging these activities, incentivizing additional initiatives, and playing an active role in coordinating them.

Chapter 6 Endnotes

1 HB1313 (Chapter 493 of the 2020 Acts of Assembly) directed the Governor to designate a chief resilience officer to serve as the primary coordinator of resilience and adaptation initiatives in Virginia and as the primary point of contact regarding issues related to resilience and recurrent flooding. The legislation also directs the director of the Department of Conservation and Recreation and "either the Special Assistant to the Governor for Coastal Adaptation and Protection or the Chief Resilience Officer" to jointly hold meetings of representatives of various state programs, entities, and localities in order to determine, coordinate, and prioritize the Commonwealth's efforts and expenditures to increase flooding resilience.

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16 Commonwealth of Virginia, Office of Governor. (2018). Executive Directive Number Thirteen, Directing the Virginia Coastal Zone Management Program Regarding Responsibility and Reporting to the Commonwealth Chief Resilience Officer, Retrieved from https://www.governor.virginia.gov/media/governorvirginiagov/executive-actions/ED-13-Directing-the-Virginia-Coastal-Zone-Management-Program-Regarding-Responsibility-and-Reporting-to-the-Commonwealths-Chief-Resilience-Officer.pdf.

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APPENDIX A

House and Senate Joint Resolution 47 (2020)

Directing the Joint Commission on Technology and Science to study the safety, quality of life, and economic consequences of weather and climate-related events on coastal areas in Virginia. Report.

Agreed to by the House of Delegates, February 7, 2020
Agreed to by the Senate, March 3, 2020

WHEREAS, the Commonwealth has thousands of miles of shoreline, including the tidal portions of the Chesapeake Bay and its tributaries, stretching 7,213 miles; and

WHEREAS, the sea level rose approximately six inches in the last 26 years or about an inch every four years when adjusting for the effect of ground subsidence; and

WHEREAS, state and local governments, the private sector, and individual citizens have spent or are planning to spend significant resources on projects related to sea-level rise and flooding; and

WHEREAS, the data that is required to inform and appropriately direct such spending is technically complex and liable to be accidentally or intentionally misinterpreted; now, therefore, be it

RESOLVED by the House of Delegates, the Senate concurring, That the Joint Commission on Technology and Science (the Commission) be directed to study the safety, quality of life, and economic consequences of weather and climate-related events on coastal areas in Virginia.

In conducting its study, the Commission shall examine (i) the negative impacts of weather, and geological and climate-related events, including displacement, economic loss, and damage to health or infrastructure; (ii) the area or areas and the number of citizens affected by such impacts; (iii) the frequency or probability and the time dimensions, including near-term,

medium-term, and long-term probabilities of such impacts; (iv) alternative actions available to remedy or mitigate such impacts and their expected cost; (v) the degree of certainty that each of these impacts and alternative actions may reliably be known; and (vi) the technical resources available, either in state or otherwise, to effect such alternative actions and improve our knowledge of their effectiveness and cost.

The Office of the Clerk of the House of Delegates shall provide administrative staff support. The Division of Legislative Services shall provide legal, research, policy analysis, and other services as requested by the Commission. Technical assistance shall be provided to the Commission by the Secretary of Natural Resources. The Commission shall accept any scientific and technical assistance provided by the nonpartisan, volunteer Virginia Academy of Science, Engineering, and Medicine. All agencies of the Commonwealth shall provide assistance to the Commission for this study, upon request.

The Commission shall complete its meetings by November 30, 2020, and the Chairman shall submit to the Division of Legislative Automated Systems an executive summary of its findings and recommendations no later than the first day of the 2021 Regular Session of the General Assembly. The executive summary shall state whether the Commission intends to submit to the General Assembly and the Governor a report of its findings and recommendations for publication as a House or Senate document. The executive summary and report shall be submitted as provided in the procedures of the Division of Legislative Automated Systems for the processing of legislative documents and reports and shall be posted on the General Assembly's website.

APPENDIX B

Committee Member and Staff Biographies

Study Board Leadership

Jonathan L. Goodall, Co-chair

Jonathan Goodall is a professor of civil engineering in the Department of Engineering Systems and Environment at the University of Virginia (UVA). He is trained as a water resources engineer and works to advance the field of hydroinformatics, where data and computational science are used to improve the understanding, forecasting, and management of water systems. Much of his current work focuses on adapting techniques from cyber-physical systems for real-time flood mitigation in coastal urban communities experiencing sea-level rise impacts. This research has focused on the Hampton Roads region of Virginia as a testbed and the City of Norfolk in particular.

Dr. Goodall is the associate director of the interdisciplinary Link Lab in UVA's Engineering School and leads its Smart Cities research area. He is a member of UVA's Pan-University Environmental Resilience Institute steering committee and is an affiliated faculty member of the Center for Transportation Studies. Dr. Goodall is a registered Professional Engineer and was elected a fellow of the American Society of Civil Engineers in 2018.

He holds a B.S. in civil engineering from the University of Virginia and an M.S. and Ph.D. in civil engineering from the University of Texas at Austin.

Antonio Elias, Co-chair

Antonio Elias retired from Orbital ATK, Inc. as executive vice president and chief technical officer. Prior to the merger of Orbital Sciences and ATK, he served as Orbital Sciences Corporation's chief technical officer, corporate senior vice president, and founder and general manager of its Advanced Programs Group. He was the lead architect of the Cygnus cargo resupply spacecraft and also led the technical team that designed and built the Pegasus air-launched booster. He headed the design teams of Orbital's APEX and Sea Star satellites and X-34 hypersonic research vehicle. Dr. Elias came to Orbital from the Massachusetts Institute of Technology, where he held teaching and research positions.

Dr. Elias is the current secretary-treasurer of the Virginia Academy of Science, Engineering and Medicine (VASEM). He is a fellow of the American Institute of Aeronautics and Astronautics (AIAA), the American Astronautical Society (AAS), and the International Academy of Astronautics. His awards include AIAA Engineer of the Year, the AIAA Aircraft Design Award, AIAA Von Karman lectureship, and the AAS Brouwer Award. He is a co-recipient of the National Medal of Technology and the National Air and Space Museum Trophy.

Dr. Elias holds B.S., M.S., E.A.A., and Ph.D. degrees from the Massachusetts Institute of Technology.

Study Board Members

Elizabeth Andrews

Elizabeth Andrews is professor of the practice at William & Mary Law School and director of the Law School's Virginia Coastal Policy Center. Under her leadership, the center produces research and white papers on various coastal policy issues and hosts annual conferences and webinars on climate change-related topics, including the region's first forum on innovative funding methods for resilience projects.

Ms. Andrews came to William & Mary Law School after serving as the water policy manager for the Virginia Department of Environmental Quality, where she worked closely with the legislature, the regulated community, and environmental organizations to address the water quality and quantity challenges facing Virginia. Prior to that, she was a senior assistant attorney general and chief of the Environmental Section of the Virginia Office of the Attorney General, where she oversaw a team of attorneys representing and providing counsel to the secretary of natural resources and the natural resources agencies of the Commonwealth. She also chaired the office's internal APA Committee and for many years served as an appointed member of the Virginia Code Commission's Administrative Law Advisory Committee due to her expertise in Virginia administrative law.

She serves as the Virginia representative to the Chesapeake Bay Program's Climate Resiliency Workgroup, as a member of the Virginia Land Conservation Foundation Board of Trustees, and as a member of the Board of Governors of the Virginia State Bar Environmental Law Section. In 2020, she was appointed by Governor Northam to the Technical Advisory Committee charged with developing Virginia's first coastal resilience master plan and serves as chair of its Finance Subcommittee.

Ms. Andrews is a graduate of William & Mary and received her Juris Doctor degree, *summa cum laude*, from the Washington College of Law at American University.

Christopher "Kit" Chope

Kit Chope is vice president, sustainability for The Port of Virginia. He joined the Virginia Port Authority in July 2015 after retiring from the United States Navy with 26 years of service. He was a tactical jet aviator: highlights of his career include command of Naval Air Station Oceana at Virginia Beach, Virginia, and Strike Fighter Squadron 22 in Lemoore, California.

In his capacity as vice president, sustainability, Capt. Chope leads and coordinates all internal and external engineering, environmental, and coastal resiliency activities to ensure The Port of Virginia operates and grows sustainably and innovatively.

Capt. Chope is actively involved in the local community: he is a member of several nonprofit boards and is a 2014 alumnus of the CIVIC Leadership Institute.

He holds a B.A. in international politics from The Citadel and an M.A. in national security and strategic studies from the U.S. Naval War College.

Senator John Cosgrove

A retired naval officer who has served many years in elected office, Senator John Cosgrove has spent his life in service to his community, state, and nation. Sen. Cosgrove was elected to the Virginia Senate in 2013, representing the 14th Senate District, which includes parts of Chesapeake, Virginia Beach, Suffolk, Portsmouth, Southampton County, Isle of Wight County, and Franklin. Previously, he served on the Chesapeake City Council and then as vice-mayor before being elected to the House of Delegates in 2001. He represented the citizens of the 78th House District for over 12 years.

In the Virginia Senate, Sen. Cosgrove serves on the Transportation Committee, the Education and Health Committee, and the Rehabilitation and Social Services Committee. In his 15 years as a state legislator, he has received numerous awards and accolades.

Sen. Cosgrove is a graduate of Tidewater Community College and Old Dominion University, where he received his B.S. in engineering.

Jason El Koubi

Jason El Koubi serves as executive vice president of the Virginia Economic Development Partnership (VEDP), leading the organization's strategy and operations in collaboration with the president and CEO and directly overseeing activities related to economic competitiveness, international trade, incentives, research, and operations.

Working with a wide variety of partners and stakeholders, Mr. El Koubi helps lead the development and implementation of a multiyear strategic plan for economic development of the Commonwealth that encompasses activities across state government. Among other transformational goals, the plan aims to position Virginia as an economic growth leader among U.S. states over the next 10 years while reversing negative growth trends in rural and other distressed areas.

Mr. El Koubi was previously president and CEO of One Acadiana (a regional economic development organization), assistant secretary of Louisiana Economic Development (LED), and policy director of the Baton Rouge Area Chamber. He began his career as an environmental engineering consultant.

Mr. El Koubi has lived, worked, or traveled in more than 40 countries, was selected for the French-American Foundation's Young Leaders program, is a fellow of the British-American Project, and is a term member of the Council on Foreign Relations.

Mr. El Koubi earned a B.S. in biological engineering from Louisiana State University, where he was elected speaker of the student senate. As a Rotary Foundation Ambassadorial Scholar, he earned an M.S. in public policy from the London School of Economics.

Jennifer Irish

Dr. Jennifer L. Irish is a professor of coastal engineering and associate director of the Center for Coastal Studies at Virginia Tech. Before joining academia in 2006, Dr. Irish served as regional technical specialist in coastal engineering for the U.S. Army Corps of Engineers.

Her scholarly contributions have advanced understanding in four areas within coastal engineering and science: airborne lidar bathymetry in the coastal zone, nature-based infrastructure for coastal hazard mitigation, physics of storm surge and related probabilistic surge hazard assessment, and impacts of sea-level rise at the coast.

Dr. Irish is a member of the Virginia Academy of Science, Engineering and Medicine, a member of the Coastal Engineering Research Council, and a fellow of the American Society of Civil Engineers. She serves on the editorial boards of *Coastal Engineering* and the *Journal of Waterway, Port, Coastal, and Ocean Engineering*.

Dr. Irish holds a B.S. and M.S. in civil engineering from Lehigh University and a Ph.D. in civil engineering from the University of Delaware.

Lewis L. Lawrence III

Lewis Lawrence serves as the executive director for the Middle Peninsula Planning District Commission (MPPDC) as well as secretary and lead planner for the Middle Peninsula Chesapeake Bay Public Access Authority (PAA). He grew up on the shores of the Chesapeake Bay in Virginia and is continuing his family's 150-plus year tradition of public service and protecting the bay's health. His entire professional career has focused on coastal zone management for the community his family has resided in for three centuries.

Recipient of numerous national and state awards for innovation in community planning and problem-solving at the local and regional level, Mr. Lawrence specializes in applied local and regional planning and policy development. Through his work with the Virginia legislature, shorelines owned by private homeowners and waterfront businesses can now access revolving loan funds to finance the construction of living shorelines. In addition, Mr. Lawrence oversaw the development of legislation that resulted in living shorelines no longer being taxed as improvements to real property.

Mr. Lawrence is now working towards blending resiliency and water quality to encourage homeowners to protect both buildings and shorelines with structures that are bigger, taller, and stronger to withstand storms of today and tomorrow through the development of the Fight the Flood Program. The program connects property owners with tools and funding to contract with specialized businesses that can help evaluate, design, and build solutions to address rising flood waters.

Mr. Lawrence holds a B.S. from Christopher Newport University and an M.C.R.P. from the University of Memphis.

Robert W. Lazaro, Jr.

Robert W. Lazaro, Jr. serves as executive director of the Northern Virginia Regional Commission (NVRC). Mr. Lazaro has a long history of public service in the community, having served eight years as mayor and two years as councilman in the Town of Purcellville, Virginia. During his service, the town was recognized for strong financial stewardship, environmental protection, and sustainability. Under Mr. Lazaro's leadership, Purcellville became the smallest town in Virginia to achieve a Triple A bond rating in its first foray into the bond market.

Mr. Lazaro has served in the leadership of statewide and regional organizations, including as current vice-chairman of the Virginia Land Conservation Foundation, former chairman and vice-chairman of the NVRC, and as an active participant in the Transatlantic Urban Climate Dialogue with colleagues from Germany and Canada.

Mr. Lazaro holds a degree in public administration from St. John's University.

William H. Leighty

William Leighty serves as a senior strategic advisor to the dean at the L. Douglas Wilder School of Government and Public Affairs at Virginia Commonwealth University. From January 2002 until September 2007, he was chief of staff to Governors Mark Warner and Tim Kaine, essentially serving as the chief operating officer of the Commonwealth. Mr. Leighty received a number of accolades for his work. In 2005 and again in 2007, *Governing* magazine named Virginia the "Best Managed State in the Nation," and in 2007, *Governing* magazine named Mr. Leighty one of nine "Public Officials of the Year" nationally. Before that, he was director of the Virginia Retirement System, where he led the agency to three consecutive U.S. Senate Productivity Awards. He joined state government after serving in the United States Marine Corps. In 2016, he was asked to co-chair the transition committee for the newly elected mayor of the City of Richmond.

Upon retirement Mr. Leighty joined DecideSmart LLC consulting. Among his assignments, he served as senior advisor to the Scottish Executive advising the government on how to design and implement Scotland Performs, a national performance management system; conducted a performance review of the United Nations Joint Staff Pension Fund, a $52 billion pension system; and led a five-person delegation to Nigeria to conduct a "new governors" seminar for the newly elected governors of Nigeria. He afterwards completed a manual for the Nigerian National Governors Association on how to make the transition to power.

Mr. Leighty graduated from Mary Washington College as a member of Phi Beta Kappa and holds an M.B.A. from Virginia Commonwealth University.

Mark W. Luckenbach

Mark Luckenbach is a professor of marine science and associate dean of research & advisory service in the School of Marine Science at the Virginia Institute of Marine Science (VIMS). As associate dean he provides oversight and strategic leadership of the research enterprise and state-mandated advisory programs at VIMS. He also serves as a co-director for the Commonwealth

Center for Recurrent Flooding Resiliency, a collaboration among VIMS, the Virginia Coastal Policy Center at the William & Mary Law School, and Old Dominion University. The center provides coordinated university-based assistance for addressing coastal and inland flooding resilience and adaptation.

Since joining the faculty at William & Mary's Virginia Institute of Marine Science in 1985, Dr. Luckenbach has conducted research on a wide range of topics in estuarine and coastal ecology in the U.S. and Asia, including restoration ecology of oyster reefs and seagrass meadows, shellfish aquaculture, invasive species, land-use practices, and water quality. Before becoming associate dean, he spent 20 years as the director of the VIMS Eastern Shore Laboratory, where he led the development of a resiliency master plan to transform that flood-prone campus.

Dr. Luckenbach holds a B.S. from the University of North Carolina and a Ph.D. from the University of South Carolina.

Elise Miller-Hooks

Dr. Elise Miller-Hooks holds the Bill and Eleanor Hazel Endowed Chair in Infrastructure Engineering in the Sid and Reva Dewberry Department of Civil, Environmental, and Infrastructure Engineering at George Mason University. She has also been a faculty member at the University of Maryland, Pennsylvania State University, and Duke University and served as a program officer and program director for the National Science Foundation.

Dr. Miller-Hooks has expertise in disaster planning and response; multi-hazard civil infrastructure resilience quantification; stochastic and dynamic network algorithms; mathematical modeling and optimization; transportation systems engineering; intermodal passenger and freight transport; real-time routing and fleet management; paratransit, ridesharing and bikeways; and collaborative and multi-objective decision-making.

Her research program has been funded by numerous agencies, including the NSF, European Commission, Federal Highway Administration, U.S. Department of Transportation, I-95 Corridor Coalition, Maryland State Highway Administration, Maryland Industrial Partnerships, and various other agencies and companies. She received an NSF CAREER award, the Charley Wootan Award for Best Ph.D. Dissertation from the Council of UTCs, and several other national awards related to her dissertation and ongoing research, including two best-paper awards.

Dr. Miller-Hooks has authored approximately 150 articles and reports and over 230 conference presentations and invited or keynote lectures. She serves on the editorial boards of *Transportation Science* (Associate Editor), *Operations Research* (Associate Editor - Policy Modeling and Public Sector OR Section), and *Journal of Intelligent Transportation Systems and Transportation Research Part B*. She is chair of the Transportation Research Board's (TRB's) Transportation Network Modeling Committee, founding co-chair of the TRB Task Force on Emergency Evacuation (now a full committee), and past president of the INFORMS (Institute for Operations Research and the Management Sciences) Transportation Science and Logistics Society (TSL) and the Women in OR/MS Forum (WORMS).

Dr. Miller-Hooks holds a B.S. in civil engineering from Lafayette College and an M.S. and Ph.D. in civil engineering from the University of Texas at Austin.

Ann C. Phillips

Rear Admiral Ann Phillips is the special assistant to the governor for coastal adaptation and protection for the Commonwealth of Virginia. Before joining the Northam administration, she worked to address sea-level rise and climate change impact on national security at the regional, national, and international level, and chaired the Infrastructure Working Group for the Old Dominion University-convened Hampton Roads Sea-Level Rise Preparedness and Resilience Intergovernmental Pilot Planning Project.

Before her work on climate-change impact and sea-level rise, Adm. Phillips served nearly 31 years on active duty in the United States Navy. She had the honor to commission and command the USS MUSTIN (DDG 89) and to command Destroyer Squadron 28. Her final flag command was as commander, Expeditionary Strike Group TWO, including all the Amphibious Expeditionary Forces on the East Coast of the United States.

Adm. Phillips holds a B.A. from the University of North Carolina and an M.B.A. from The College of William and Mary. In addition, she is a certified Chesapeake Bay Landscape Professional, Level 2 and is an alumna of CIVIC Hampton Roads (2015), and alumna and board member of Lead Virginia (2017).

Henry "Speaker" Pollard V

Henry Pollard is a partner with Williams Mullen, a Richmond-based law firm. With three decades of experience in environmental law, Mr. Pollard specializes in a broad range of environmental and regulatory issues, including those related to water quality, wastewater, sewage, stormwater management, wetlands, water rights, solid and hazardous waste, Superfund, petroleum and chemical storage, air pollution, cultural resources, and species protection at federal, state, and local levels.

Mr. Pollard has assisted his clients with a broad range of representation, including enforcement defense (administrative, civil, criminal), permitting, real estate and corporate transactions, due diligence investigations, financing risk management, litigated matters, and regulatory and legislative affairs. In particular, Mr. Pollard has responded to the mounting concerns associated with the greater frequency and severity of flooding in coastal communities and has increased his focus on coastal flooding and resiliency planning issues.

Mr. Pollard's clients have ranged from financial institutions to power plants, from the government to the private sector, as well as trade groups and individuals. He also has experience working for the Virginia Department of Waste Management/Environmental Quality as an enforcement specialist, where he led and coordinated statewide hazardous waste enforcement actions, developed administrative cases and conducted administrative enforcement proceedings, prepared enforcement policy and assisted with civil litigation and criminal enforcement and prosecution of environmental cases.

Mr. Pollard has been recognized as a leading environmental attorney in the U.S. by *Chambers USA* (2016-present). He is listed in *The Best Lawyers in America*© for Environmental Law (2018–present), and he has been named among Virginia's "Legal Elite" for Environmental Law by *Virginia Business* (2015–present).

He earned a B.S. in chemistry from Hampden-Sydney College and an M.B.A. and J.D. from the University of Richmond. He also participated in a summer studies program in marine policy at the Duke University Marine Lab.

Emily Steinhilber

Emily Steinhilber is director of Virginia coastal resilience for the Environmental Defense Fund (EDF). She joined EDF after serving as an assistant research professor in the Office of Research at Old Dominion University (ODU) where, in addition to other resilience initiatives, she coordinated the ODU arm of the Commonwealth Center for Recurrent Flooding Resiliency (CCRFR), a partnership of the Virginia Institute of Marine Science, William and Mary Law School's Virginia Coastal Policy Center, and ODU. Established by Virginia's General Assembly, the CCRFR launched in July of 2016 and provides coordinated and applied research and technical support for planners and decision-makers in Virginia.

Previously, Ms. Steinhilber served as the assistant director for Coastal Resilience Research at ODU and facilitated the Hampton Roads Sea-Level Rise Preparedness and Resilience Intergovernmental Planning Pilot Project. The pilot project sought to develop a "whole of government" and "whole of community" approach to sea-level rise preparedness and resilience in the region.

Ms. Steinhilber was the executive director of the Virginia Coastal Coalition, a nonprofit based in Virginia Beach dedicated to creating a collaborative forum for a solutions-based approach to sea-level rise planning and preparedness in Hampton Roads. The organization focused on leveraging the work of academia, nonprofits, and government to create a dialogue within the business community.

A member of the Virginia State Bar, Ms. Steinhilber is active within the Hampton Roads Community and serves on Virginia Beach's Green Ribbon Committee and the Virginia Beach Wetlands Board, the Lynnhaven River Now Board of Directors and the WHRO Public Media Governing Board.

Ms. Steinhilber holds a B.A. in economics and history from the University of Virginia and an M.S. in environmental law and policy and a Juris Doctor from the Vermont Law School.

Study Board Staff

Charles Feigenoff

Dr. Charles Feigenoff has been a freelance copywriter and marketing consultant for more than 30 years, specializing in annual reports, executive communication, and print and online marketing and advertising. Dr. Feigenoff has worked extensively with a variety of Fortune 500 companies such as Metropolitan Life, Marriott International, and Capital One; with international, national, and regional businesses including Sunrise Senior Living, Rosetta Stone, LexisNexis, Cadence Bank, and XO Communications; with government and nonprofit organizations such as the Kennedy Center, World Bank, USAID, and the National Academy of Engineering; and with academic institutions such as the University of Virginia, Washington and Lee University, and Georgetown University. Most recently, he authored UVA's strategic plan as well as its four-year financial plan.

During his career, Dr. Feigenoff has written more than 50 annual reports for organizations in a wide variety of sectors, including financial services, defense, education, healthcare, and commercial real estate. His reports have earned a Gold MarCom award, a Silver ARC award, and a best-of-the-year award from the Rocky Mountain Chapter of National Investor Relations Institute.

Dr. Feigenoff earned a B.A. in English from Cornell University, an M.A. in English from the University of Colorado, and a Ph.D. in English from the University of Virginia.

Jennifer Sayegh

Jennifer Sayegh is an assistant vice president in the McGuireWoods Consulting Virginia state government relations group. She assists clients with legislative monitoring and provides lobbying services in matters before the Virginia General Assembly and executive agencies. With a focus on education policy, Ms. Sayegh provides in-depth research and analysis on policy and legislative matters.

Prior to joining McGuireWoods Consulting, she served as the assistant director of appointments for the Secretary of the Commonwealth in the Office of Governor Terence R. McAuliffe. In that role, she was responsible for assisting the governor in the appointment of thousands of individuals to serve on state boards and commissions. Ms. Sayegh has experience working on boards under the following cabinet secretariats: Agriculture and Forestry, Commerce and Trade, Finance, Technology, Natural Resources, and Veterans and Defense Affairs.

She also worked as the executive assistant to the vice chancellor for institutional advancement for the Virginia Community College System, where she was involved in statewide initiatives, fundraising and development, prospect research, and special events.

Ms. Sayegh graduated from the University of North Carolina at Chapel Hill with highest honors and distinction. She is also an alumna of Lead Virginia, a statewide leadership program that connects professionals on issues that matter most to the Commonwealth.

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