AN ANALYSIS OF THE POTENTIAL COSTS AND CONSEQUENCES OF A HURRICANE IMPACTING THE VIRGINIA BEACH-NORFOLK-NEWPORT NEWS METROPOLITAN AREA



COMMONWEALTH CENTER FOR RECURRENT FLOODING RESILIENCY

PARTNERS -

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(İ) **OLD DOMINION** UNIVERSITY

CCRFR Report 9 May 2019

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EXECUTIVE SUMMARY

Hurricanes, by their very nature, are uncertain events. While no major (Category 3 or higher) hurricane has struck the Commonwealth since 1851, the hurricane of 1821 resulted in significant storm surge and wind damage in Hampton Roads. The demographic shifts over the last three decades have led to increased population density in Northern Virginia and many coastal counties and cities in the Hampton Roads region.

The total impact from such a hurricane could approach, if not exceed, \$40 billion in the first year after landfall. Increased population density in coastal areas directly correlates with increased property and lives at risk.

A hurricane similar to Florence (2018) or Katrina (2005) striking Hampton Roads would catastrophically impact the lives of Virginians and the economy of the region and the Commonwealth. The total impact from such a hurricane could approach, if not exceed, \$40 billion in 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.

Wind and water damage would likely exceed \$17 billion and possibly approach \$20 billion. Residential structures would bear the brunt of damage, with over 6,000 residences destroyed in the hurricane. In total, about 38,000 residential, business, and other structures would be damaged or destroyed during the hurricane. Wind damage would account for approximately \$4 billion of total physical damage, with water damage likely exceeding \$13 billion. The immediate physical damage to structures would lead to the short-term displacement of about 200,000 of the region's 1.7 million residents. Over 16,000 of these displaced individuals would seek public shelter, placing significant strain on public and private resources. With over 6,000 residences destroyed during the hurricane, a considerable number of individuals would be permanently displaced outside of Hampton Roads.

Over 175,000 individuals could possibly lose their jobs in the immediate aftermath of a catastrophic hurricane striking Hampton Roads. In the first year following the hurricane, we estimate that output and sales would decline by approximately \$17 billion, and compensation would decline by about \$6 billion, resulting in a total economic impact of approximately \$23 billion. When the estimated physical damages and economic impact are aggregated, the total damage from a major hurricane would approach, if not exceed, \$40 billion and potentially reduce economic growth in the region for years to come. Given the potential magnitude of losses from a major hurricane making landfall in the Hampton Roads region, planning and preparation for such an event is paramount. As sea temperatures rise, the number, magnitude, and track of hurricanes will shift, further increasing the importance of preparing for the 'big one.' Prior planning and preparation also generate positive spillovers by improving the region's capacity to respond to other large events, including severe weather, terrorism, or large-scale accidents. The region's preparation for such an event should not be altered by it's recent history of avoiding severe impacts from major hurricanes.

THE RESEARCH COLLABORATIVE

The Old Dominion University research collaborative has decades of experience with economic impact analysis, fiscal impact analysis, qualitative interviews, survey research, and consulting at all levels of government. The unique combination of experience and ability to convey complex topics to the public and policymakers ensures that our approach is technically rigorous, academically sound, and accessible to stakeholders.

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Old Dominion University (ODU):

Located in Norfolk, Virginia, ODU is one of the eight colleges and universities in Hampton Roads. It is an accredited research university offering 69 bachelor's degrees, 55 master's degrees, 41 doctoral degrees, and 2 educational specialist degrees. Currently, over 24,000 students are enrolled, including an international student population of 1,408 representing 130 countries.

Dragas Center for Economic Analysis and Policy (The Dragas Center):

The Dragas Center undertakes a wide range of socio-economic, demographic, transportation and defense-oriented studies. Since 1999, the Dragas Center has produced the influential *State of the Region Report* for Hampton Roads. In its 19th year, the *State of the Region Report* continues to stimulate thought and discussion that will ultimately make Hampton Roads an even better place to live. In 2015, the Dragas Center started producing the *State of the Commonwealth Report*. The report analyzes the Virginia economy and assesses its future progress, including detailed information regarding the Commonwealth's metropolitan areas. The faculty of the Dragas Center have provided advice and assistance to numerous clients on economic impact analyses, regional economic development, and a wide range of public policy issues, including the impact of the opioid crisis and the emergence of Airbnb.

Commonwealth Center for Recurrent Flooding Resiliency (CCRFR):

The CCRFR engages the expertise, resources, and intellectual vibrancy of the College of William & Mary (W&M) and ODU in support of building resilience to rising waters. The Center serves, advises, and supports Virginia by conducting interdisciplinary studies and by providing training, technical and non-technical services, and policy guidance in the area of recurrent flooding resilience to the Commonwealth and its local governments, state agencies, industries, and citizens.

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Faculty and Research Staff Biographies and Qualifications

Robert McNab, Principal Investigator, is the Director of the Dragas Center for Economic Analysis and Policy and a Professor in the Department of Economics in the Strome College of Business at Old Dominion University. Dr. McNab oversees the work of the Dragas Center. His research focuses on topics in public finance, defense economics, and fiscal decentralization. He is the editor of the annual State of the Region: Hampton Roads and State of the Commonwealth reports. Professor McNab is a member of the Joint Advisory Board of Economists of the Commonwealth of Virginia and a member of the Survey of Professional Forecasters of the Federal Reserve Bank of Philadelphia. He earned his PhD in Economics from the Andrew Young School of Policy Studies at Georgia State University. Dr. McNab may be reached at rmcnab@odu.edu.

Vinod Agarwal is the Director of the Economic Forecasting Project in the Dragas Center for Economic Analysis and Policy and a Professor in the Department of Economics in the Strome College of Business at Old Dominion University. His research interests are in applied economics. His articles have appeared in various journals such as Cornell Hotel and Restaurant Quarterly, Journal of Travel Research, Economic Development and Cultural Change, Eastern Economic Journal, Economics of Education Review, Growth and Change, Journal of the American Real Estate and Urban Economic Association, Social Science Quarterly and Southern Economic Journal. He earned his doctoral degree from the University of California at Santa Barbara. Dr. Agarwal may be reached at vagarwal@odu.edu.

Barbara Blake is the Chief Administrative Officer of the Dragas Center for Economic Analysis and Policy in the Strome College of Business at Old Dominion University. Her research interests include the Economics of Social Issues and Domestic and International Migration. She is a Quality Matters (QM) Certified Master Peer Reviewer and a QM Subject Matter Expert (SME) in Economics for a network of over 750 universities from 47 different US states and 6 countries. She is a Certified Microsoft Faculty Fellow and a Faculty Contributor in Economics to Macmillan Education Corporation. Dr. Blake earned her Doctorate in Higher Education Administration from The George Washington University, Washington, DC. Dr. Blake may be reached at bblakego@odu.edu.

Sheila Hutt serves as a Graduate Research Assistant in the Center for Geospatial Science, Education, and Analytics (GeoSEA) and is a graduate student in the Department of Ocean, Earth, and Atmospheric Sciences at Old Dominion University. She performs a variety of geospatial analysis and hazards modeling for the Center, while her academic research focuses on submarine groundwater transport into the Chesapeake Bay. In addition to her academic pursuits, Sheila is employed full-time as a Cartographer for Naval Facilities Command (NAVFAC) at Naval Station Norfolk.

Tim Komarek is an Assistant Professor in the Department of Economics and a Fellow in the Dragas Center for Economic Analysis and Policy in the Strome College of Business at Old Dominion University. Dr. Komarek is an urban and regional economist. His academic work has examined entrepreneurial attitudes, energy and economic development, and place-based policies, among other topics. His articles have appeared in various journals such as *Regional Science and Urban Economics, Economic Development Quarterly, Journal of Regional Science,* and *Journal of Regional Analysis and Policy*. He holds a Ph.D. from Michigan State University. Dr. Komarek may be reached at tkomarek@odu.edu; 757-683-4534 (office).

George McLeod is Senior Geospatial Fellow for the Commonwealth Center for Recurrent Flooding Resiliency (CCRFR), directs the Center for Geospatial Science, Education, and Analytics (GeoSEA), and is adjunct faculty in the Department of Political Science & Geography at Old Dominion University. His primary areas of research are in coastal and marine remote sensing, the application of geospatial technologies to problems related to coastal geomorphology, sea-level rise and flood hazard, and coastal land use policy. He has developed and taught courses in Geographic Information Systems (GIS), Remote Sensing, 3-dimensional GIS, Cartography, Geospatial Intelligence, Geospatial Field Techniques, and Public Health GIS. Mr. McLeod may be reached at gmcleod@odu.edu; 757-683-6752 (office).

Emily Steinhilber is an Assistant Research Professor in the Office of Research at Old Dominion University where, in addition to other resilience initiatives, she coordinates 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.

INTRODUCTION

On August 27th, 1668, a storm lashed the Chesapeake Bay with gale force winds and rain that, by some accounts, lasted for over twenty-four hours. When the rain and winds finally abated on August 28th, the scene was one of utter devastation.

In context, about 50 percent of annual rainfall fell within one month of Matthew's arrival and 25 percent of annual rainfall within a day of arrival. "Houses and barns were ruined, chimneys wrecked, fences flattened, tobacco in the fields cut to pieces. By the action of the gale and resulting high tide, the waters of Chesapeake Bay were driven into the rivers and creeks, so that rowboats and sailboats were left high and dry, and during the height of the storm, the rising tide overflowed banks and forced people to take refuge on rooftops."¹

For the Virginia Beach-Norfolk-Newport News Metropolitan Statistical Area (MSA) ("Hampton Roads"), the question is not if, but when a major tropical storm or hurricane will impact the region. Even a relatively weak storm can generate significant financial costs. Hurricane Matthew, for example, had weakened to a post-tropical cyclone by the time it entered Virginia in October 2016. Post-tropical cyclone Matthew did not directly impact Hampton Roads, skirting the coast before heading out to sea. Matthew's long duration bands of rain on the western side of the cyclone, however, still produced between 3 and 14 inches of rain within a 24-hour period. In context, about 50 percent of annual rainfall fell within one month of Matthew's arrival and 25 percent of annual rainfall within a day of arrival. The rain fell on an already saturated region, challenging and, in some cases, overwhelming drainage infrastructure. Flooding from rainfall was the primary cause of damage, followed by wind. There was not an appreciable storm surge to note, illustrating the weakness of Matthew and how a relatively benign storm can still result in significant damage to property. Figure 1 illustrates the areas affected by the remnants of Matthew.

The damage inflicted by post-tropical cyclone Matthew resulted in 2,661 approved applications for the Federal Emergency Management Agency (FEMA) Individuals and Household Program (IHP).² Of the \$10.20 million in approved applications, the majority (\$8.24 million) were for housing assistance. FEMA also obligated another \$15.86 million in public assistance grants, of which \$8.95 million were for emergency work, and \$6.42 million were for permanent work.

^{1.} Whichard, R. D. (1959). The History of Lower Tidewater Virginia. New York: Lewis Historical Publishing Company, Inc.

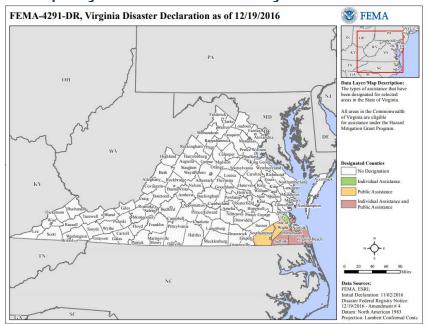
^{2.} FEMA's Individuals and Households Program (IHP) provides financial and direct services to eligible individuals and households affected by a disaster. For more information, see https://www.fema.gov/media-library-data/1528984381358-6f256cab09bfcbe67475 10c215445560/IndividualsHouseholdsPrograms.pdf

The National Flood Insurance Program (NFIP) also paid over \$10 million in claims. Many damaged residences were also not covered by flood insurance. Jeffrey D. Stern, state coordinator for the Virginia Department of Emergency Management, estimated that Matthew caused nearly \$500 million in damage.³

We must also recognize that the estimated costs do not include numerous volunteer agencies which provided financial assistance, cleanup, and remediation of damaged housing. In the immediate aftermath, calls for volunteers highlighted the need to gut damaged homes and clear debris.⁴ The Virginia Conference of the United Methodist Church, for example, reported several thousand volunteer hours in support of recovery efforts.⁵ Including these efforts would likely raise damage and recovery estimates by millions of dollars.

Aside from the physical damage from rain and wind, Matthew appears to have had a negligible impact on economic activity in Hampton Roads in October 2016. Seasonally-adjusted nonfarm payrolls increased by 0.36 percent year-on-year, in line with increases in previous months. Monthly retail sales also increased year-over-year, suggesting that while sales may have been displaced during the storm, the storm did not significantly impact sales over the entire month. Year-on-year growth in private sector payrolls slowed from 2.0 percent in October 2015 to 0.3 percent in October 2016, but this can be largely explained by the overall tepidness of the regional economy.

FIGURE 1



FEMA Map of Virginia's Disaster Declaration Following Hurricane Matthew

Source: Federal Emergency Management Agency (2016)

3. https://pilotonline.com/news/local/weather/storms/article_2bc3125c-0056-5def-af77-42d6ed7f6e43.html

^{4.} https://pilotonline.com/news/government/local/article_552b1f56-ec18-5245-84b9-b16da79f582d.html

^{5.} For an overview of the Virginia Conference of the United Methodist Church's Hurricane Matthew recovery efforts, see https://

www.facebook.com/vaumconf/videos/10155682528153533/?v=10155682528153533

The monthly data, however, may mask changes in the composition of spending. Evidence from Florida suggests that Hurricane Matthew depressed overall retail spending by 2.6 percent for October 2016.6 Spending at grocery stores increased significantly prior to Matthew's landfall, fell precipitously on the day of landfall, and recovered quickly. Restaurants and clothing stores saw net reductions in sales of 4.1 percent and 6.8 percent, respectively for the month. These results lend credence to the argument that forward-looking households adjust the timing of consumption purchases in the face of temporary shocks. In other words, in anticipation of a hurricane or other adverse weather event, households shift purchases forward (to prepare) and backward (to recover). There are also substitution effects as households that increase grocery spending will likely decrease restaurant spending after the event. A larger scale event, however, will have more noticeable micro and macroeconomic impacts. Superstorm Sandy, for example, had an estimated macroeconomic impact on the Northeastern United States four times that of Hurricane Matthew.

Undoubtedly, severe weather events can disrupt economic activity. Whether this disruption is temporary depends, in part, on the magnitude and type of weather event. A blizzard may temporarily disrupt consumer spending, business activity, and, in some cases, lead to the loss of life. Snow melts, however, and if flooding is not an issue, economic activity returns quickly to normal. Tropical storms and hurricanes, on the other hand, have the potential to not only disrupt economic activity in the short-term, but also create enough damage to residential and commercial infrastructure to lower potential economic activity for months, if not years. As the damage to public and private infrastructure increases, the impact of the hurricane may linger, leading to more deaths in the aftermath than during initial landfall. George Washington University estimated that the total excess mortality post-hurricane Maria was between 2,658 and 3,290 deaths for the period of September 2017 through February 2018 (Milken Institute School of Public Health, 2018). Every social and age group experienced increased mortality during this period. Individuals in lower socioeconomic development communities and males age 65 or greater experienced even higher rates of excess mortality. Partly as a result of the hurricane, the population of Puerto Rico declined by 4.3 percent from 2017 to 2018 (United States Census Bureau, 2018).

We should also recognize that the responsiveness of the federal government may be limited due to political factors. As of early May 2019, federal aid for the response to Hurricane Michael was embroiled in a political debate. The mayor of Mexico Beach, Florida observed that most of the 1,100 residents had some assistance from home insurance to offset the cost of repairs, the city relies on FEMA to fix damage to public infrastructure. One problem is that FEMA operates on a reimbursement basis, there are at least \$35 million in estimated damages, and the entire city budget is only \$3.5 million. The need outweighs the ability to pay.⁷

If past is prologue, however, then a significant storm striking Hampton Roads is an eventuality; merely a question of when and how prepared the region is for the resulting damages. While there is significant variation in damages from hurricanes and other weather events, we believe it is prudent to explore the economic impact of a hurricane making landfall in Hampton Roads.

^{6.} Aladangady, A., Aron-Dine, S., Dunn, W., Feiveson, L., Lengermann, P., & Sahm, C. (2016). The Effect of Hurricane Matthew on

Consumer Spending. FEDS Notes. https://doi.org/10.17016/2380-7172.1888

^{7.} http://fortune.com/2019/05/06/disaster-relief-bill-hurricane-maria/

Understanding the extent of the estimated physical and economic impacts will assist decision-makers in weighing the costs of planning and preparation with those of response. We must also recognize that even if a hurricane does not make landfall in Hampton Roads, the remnants of hurricanes often travel through the region. Improving the resiliency of the region to sea level rise and storms carrying more moisture is imperative given that improvements in one dimension provide capacity in the other.

FIGURE 2

Federal, State and Local Offices Tour Flooding Damage in Virginia Beach, 2016



Source: The Virginian Pilot (2016)

RECENT MAJOR STORMS AND HURRICANES IN THE UNITED STATES

To understand how a major storm (such as Superstorm Sandy in 2012) or hurricane (such as Hurricane Michael in 2018) could affect the Commonwealth of Virginia, we briefly review major storms and hurricanes that have impacted the United States over the last three decades. Advances in weather forecasting and surveillance have, in most cases, led to dramatic reductions in the loss of life from major tropic storms, cyclones, and hurricanes.

A reasonable conclusion is that the physical damage and economic impact from tropical storms, cyclones, and hurricanes is likely to increase, on average, over the coming decade. In terms of known fatalities, the 1900 Galveston Hurricane had estimated sustained winds greater than 120 miles per hour (mph), a storm surge of approximately 20 feet, and an estimated loss of life between 6,000 and 12,000 people. More recently, as illustrated in **TABLE 1**, Hurricane Maria struck Puerto Rico with maximum sustained winds of 175 mph and reported maximum storm surge of 3 to 5 feet.⁸ The damage to the island was undeniably catastrophic, with most of the electrical, sanitation, and communication infrastructure failing in the aftermath of the storm.

Why does it seem that major tropical storm, cyclone, or hurricane damage appears to be rising over time? Rising population in coastal areas is one of the primary drivers. Population density has increased at significantly higher rates for coastal counties over the last three decades relative to the remainder of the United States. From 1980 to 2017, the population density in shoreline counties along the Gulf Coast and East Coast rose by 160 people per square mile, compared with 26 people per square mile in the rest of the continental United States.⁹ Simply put, there are now more people, homes, and businesses at risk. A reasonable conclusion is that the physical damage and economic impact from tropical storms, cyclones, and hurricanes is likely to increase, on average, over the coming decade.

Another contributing factor is climate change. The preponderance of scientific evidence is that average global temperatures have risen and will continue to rise over the coming decades. The intensity and damage resulting from hurricanes in the North Atlantic basin appears to be positively correlated with the global average rise in sea level temperatures (Estrada, Botzen, & Tol, 2015). While projections on the number of tropical cyclones may be uncertain, the intensity and rainfall associated with these storms is expected to increase in the future. Coupled with sea level rise, these storms will likely have greater storm surge risk than historical storms (Walsh et al., 2016).

^{8.} https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf

^{9.} Dapena, K. (2018, September 29, 2018). The Rising Costs of Hurricanes. Wall Street Journal. Retrieved from https://www.wsj.com/ articles/the-rising-costs-of-hurricanes-1538222400

Hurricane Harvey is a recent example of the linkage between the average rise in ocean temperatures and rainfall after landfall. Prior to Harvey's formation and passage through the Gulf of Mexico in 2018, ocean heat content was the highest on record. After Harvey's passage, ocean heat content fell sharply. Harvey not only was 'fueled' by record ocean temperatures but also accumulated more moisture, which, in turn, increased rainfall and flooding after landfall (Trenberth, Cheng, Jacobs, Zhang, & Fasullo, 2018).

TABLE 1

| YEAR | NAME | CATEGORY | STATE | ESTIMATED DIRECT DAMAGES (Millions of 2018 Dollars) | estimated Fatalities |
|------|----------|----------|---------------------------|---|-------------------------|
| 1980 | Allen | 5 | ΤX | \$914 | 259 |
| 1983 | Alicia | 3 | TX | \$5,042 | 21 |
| 1984 | Diana | 2 | NC, SC | \$156 | 3 |
| 1985 | Elena | 3 | AL, MS, FL | \$2,917 | 4 |
| 1985 | Gloria | 3 | NJ, PA, RI, MD, VA, NY | \$2,100 | 8 |
| 1985 | Juan | 1 | LA, FL | \$3,500 | 12 |
| 1985 | Kate | 2 | FL, GA | \$700 | 5 |
| 1986 | Bonnie | 1 | TX, LA | \$96 | 3 |
| 1986 | Charley | 1 | NC | \$34 | 5 |
| 1988 | Florence | 1 | LA, MS, AL, FL | \$6 | 1 |
| 1989 | Chantel | 1 | TX | \$202 | 13 |
| 1989 | Hugo | 4 | NC, SC, PR, VI | \$14,175 | 56 |
| 1989 | Jerry | 1 | TX, Eastern U.S. | \$141 | 3 |
| 1991 | Bob | 3 | NC, NY, New England | \$2,765 | 17 |
| 1992 | Andrew | 5 | FL, LA | \$47,429 | 26 |
| 1995 | Erin | 2 | FL, AL, MS | \$1,153 | 6 |
| 1995 | Opal | 3 | FL | \$7,744 | 59 |
| 1996 | Bertha | 2 | NC, SC, VA | \$432 | 12 |
| 1996 | Fran | 3 | NC | \$8,002 | 34 |
| 1997 | Danny | 1 | LA, MS, AL, FL | \$156 | 5 |
| 1998 | Bonnie | 3 | NC, SC, VA | \$1,109 | 3 |
| 1998 | Earl | 2 | FL, GA, NC, SC | \$121 | 3 |

Damage Estimates from Selected Major Storms and Hurricanes, United States, 1980 - 2018

TABLE 1 (CONT'D)

Damage Estimates from Selected Major Storms and Hurricanes, United States, 1980 - 2018

| YEAR | NAME | CATEGORY | STATE | ESTIMATED DIRECT DAMAGES (Millions of 2018 Dollars) | estimated Fatalities |
|------|-----------|----------|---|---|-------------------------|
| 1998 | Georges | 2 | FL, MS, AL \$4,259 | | 602 |
| 1999 | Bret | 4 | ТХ | \$22 | 0 |
| 1999 | Floyd | 2 | Mid-Atlantic and NE U.S. | \$10,399 | 57 |
| 2002 | Lili | 1 | SC, LA | \$1,291 | 13 |
| 2003 | Claudette | 1 | TX | \$245 | 1 |
| 2003 | Isabel | 2 | Mid-Atlantic U.S. | \$7,328 | 17 |
| 2004 | Charley | 4 | FL | \$20,089 | 15 |
| 2004 | Frances | 2 | FL | \$12,637 | 8 |
| 2004 | lvan | 3 | AL, FL | \$25,017 | 92 |
| 2004 | Jeanne | 3 | FL | \$9,969 | 3000 |
| 2005 | Dennis | 3 | FL | \$3,272 | 42 |
| 2005 | Katrina | 3 | FL, LA, MS | FL, LA, MS \$138,861 | |
| 2005 | Rita | 3 | LA, TX | \$15,476 | 7 |
| 2005 | Wilma | 3 | FL | \$27,009 | 23 |
| 2007 | Humberto | 1 | TX, LA, MS, NC, SC | \$60 | 1 |
| 2008 | Dolly | 1 | TX | \$1,224 | 1 |
| 2008 | Gustav | 2 | LA, MS, AL, FL | \$5,385 | 112 |
| 2008 | lke | 2 | LA, TX | \$34,429 | 103 |
| 2011 | Irene | 1 | Mid-Atlantic and North-Eastern U.S. | \$15,070 | 58 |
| 2012 | Isaac | 1 | FL, LA, MS, AL | \$3,401 | 41 |
| 2016 | Matthew | 5 | FL, GA, NC, SC, VA | \$10,462 | 47 |
| 2017 | Harvey | 4 | TX, LA | \$128,053 | 107 |
| 2017 | Irma | 4 | FL | \$54,294 | 92 |
| 2017 | Maria | 5 | PR | \$93,222 | 3,057 |
| 2018 | Michael | 4 | FL, NC, SC, MD | \$15,000 | 60 |
| 2018 | Florence | 4 | FL, NC, SC, VA | \$17,900 | 55 |

Source: FEMA (2018), Commonwealth of Virginia (2018), NOAA (2018), and authors' calculations.

HURRICANES IN VIRGINIA AND HAMPTON ROADS

While historical records may not fully record major storms and hurricanes that made landfall in Virginia, the first recorded hurricane was August 24th, 1635. In September 1667, the Chesapeake Bay rose 12 feet, and a large number of homes were destroyed in Jamestown. Less than 100 years later, a hurricane caused the Chesapeake Bay to rise 15 feet and destroyed Fort George at Old Point Comfort. In September 1821, the eye of a hurricane passed near Norfolk, and the American Beacon newspaper reported that "So general and widespread is the devastation that it would be impossible to give a detail of its awful consequences...The ground stories of all warehouses on the wharves and as high up as Wide Water Street, were entirely overflowed."

It should be clear that Virginia has been significantly affected in the past by major storms.

TABLE 2 contains a listing of the major stormsand hurricanes from the 1600s to the early 2019.One should immediately recognize historicalrecords are incomplete and that the smallernumber of recorded storms in the 1600s and 1700sdoes not necessarily imply there were actually

fewer severe weather events. Regardless of the completeness of these records. It should be clear that Virginia has been significantly affected in the past by major storms. **We should avoid the implicit bias that our most recent data accurately reflects the historical likelihood of a major storm or hurricane striking Virginia.**

TABLE 2

Historical Major Storms and Hurricanes in the Commonwealth of Virginia

| PERIOD | YEAR OF MAJOR STORM OR HURRICANE |
|--------|---|
| 1600s | 1635, 1667, 1693 |
| 1700s | 1749, 1775, 1769, 1785 |
| 1800s | 1804, 1821, 1846, 1876, 1878, 1879, 1888, 1889, 1893, 1894, 1896 (2), 1897, 1899 |
| 1900s | 1903, 1924 (2), 1926 (2), 1928, 1932, 1933 (2), 1935, 1936, 1944, 1952, 1953, 1954, 1955, 1959 (2), 1960, 1964, 1969, 1971, 1972, 1979, 1985 (2), 1986, 1996 (2), 1997, 1998, 1999 (2) |
| 2000s | 2003, 2004 (3), 2006, 2009, 2011 (2), 2012, 2016 |

Source: Virginia Department of Emergency Management (2016). Official weather reporting began in Norfolk in 1871, however, early colonists and others recorded severe weather events

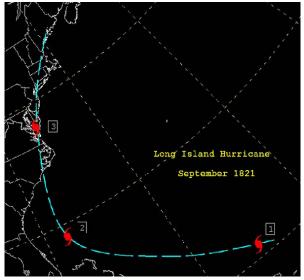
TABLE 3 illustrates the lives lost and direct damages for a select number of hurricanes that have passed by or through Virginia in the past 100 years. Hurricane Isabel in 2003 tops the list with an estimated 100 lives lost and approximately \$2.5 billion in estimated damages. Second is an unnamed hurricane in 1933 (often referred to as the 'Chesapeake-Potomac Hurricane') that resulted in an estimated 18 fatalities and \$1.2 billion in estimated damages in 2018 dollars. We must be careful to note that the damage estimates do not include economic impacts; that is, the estimated damages are for the destruction of property and loss of life. If we had accurate estimates of the economic impact of these storms, the consequences would be significantly higher than the reported damage estimates.

It is evident that violent, damaging storms have struck Virginia in the past. There were numerous severe weather events in the first 200 years of the Commonwealth that, according to historical records, resulted in the Chesapeake Bay rising by at least 10 feet. In several cases, the major cities in Hampton Roads at the time were completely flooded and suffered significant wind damage.

Yet, the most recent storms and hurricanes may be relatively mild in comparison with the Norfolk-Long Island Hurricane of 1821. To place this storm into context, only 136,000 people lived at the time in New York City and Washington, D.C., compared with almost 10 million in 2018. Weather observations reported gale-force winds in Norfolk on September 3, 1821, accompanied by a 10-foot storm surge. The storm continued onto the New York-New Jersey area without a significant loss of strength, with hurricane force winds and a storm surge up to 20 feet in Atlantic City.¹⁰ Figure 3 illustrates the estimated track of the 1821 hurricane.

FIGURE 3

Estimated Track of the 1821 Norfolk-Long Island Hurricane



Source: https://www.wpc.ncep.noaa.gov/research/roth/sp1821.gif

The damages in 1821 were limited, not because of the strength of the storm, but due to the nature of the economy at the time of landfall. Agriculture and light manufacturing were the dominant industries, and population density was relatively low compared to today. Public transportation infrastructure, sanitation, and water systems were limited, and written communication, while slow, did not require fixed infrastructure or electricity.

If a hurricane like that of 1821 struck today, however, direct damages would likely equal or exceed the most damaging hurricanes in recent memory. Such a hurricane would place millions of people and trillions of dollars of public and private assets at risk. A 2014 simulation by Swiss Re, an international reinsurance company, estimated that wind and storm surge damages for the U.S. would exceed \$40 billion and \$60 billion, respectively. The total economic impact would likely exceed \$150 billion dollars for the United States

^{10.} Linkin, M. (2014). The big one: The East Coast's USD 100 billion hurricane event.

(Linkin, 2014). Damages for the Commonwealth would be in the billions of dollars if a future hurricane followed a track similar to the 1821 storm.

Yet, we should be careful in assessing the reported magnitude of the tropical storm, cyclone, or hurricane. Hurricane Florence in 2018, for example, was a Category 1 hurricane when it made landfall in North Carolina.¹¹ Florence, however, caused extensive damage, primarily due to extensive rainfall in an already saturated area. Superstorm Sandy had been downgraded to an extratropical storm by the time it made landfall in 2012. Yet, because Sandy made landfall in densely populated areas of the Eastern Seaboard, it resulted in significant damage and continues to rank among the top-10 most expensive storms to strike the United States in the last three decades.

What does this mean for the Commonwealth and Hampton Roads? Northern Virginia and Hampton Roads are relatively densely populated areas of Virginia. A major storm such as Hurricane Michael (Florida, 2018), Florence, (North Carolina, 2018), Sandy (New York-New Jersey, 2012), or Katrina (Gulf Coast, 2005) would likely result in billions of dollars in damages as the result of storm surge and flooding. Wind damage would likely be in the billions of dollars. These are the direct consequences of these storms. If a future storm damaged infrastructure, housing, and businesses like Michael or Katrina, the economic impact would be greater than the direct damages of the storm. Simply put, a major storm or hurricane striking Hampton Roads or Northern Virginia could easily rank among the most costly storms in Commonwealth and U.S. history.

^{11.} Hurricanes are typically categorized along the Saffir-Simpson Hurricane Wind Scape. A Category 1 hurricane will produce very dangerous winds with some damage while a Category 3 hurricane (classified as a major hurricane) will result in devastating damage. For more information see: https://www.nhc.noaa.gov/aboutsshws.php

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Selected Recent Storms and Hurricanes Impacting the Commonwealth of Virginia

| DATE | EVENT | FATALITIES | Estimated Damages in 2018 Dollars | Homes Damaged and Destroyed | Businesses Damaged and Destroyed | Estimated Recovery Assistance | Estimated Public Assistance |
|------|---|------------|--------------------------------------|--------------------------------|-------------------------------------|----------------------------------|--------------------------------|
| 1993 | Unnamed Chesapeake- Potomac Hurricane | 18 | \$1.2 billion | | | | |
| 1969 | Hurricane Camille | 153 | \$4.0 billion | | | | |
| 1972 | Tropical Storm Agnes | 55 | \$578 billion | | | | |
| 1999 | Hurricane Floyd | 4 | \$367 million | | | | |
| 2003 | Hurricane Isabel | 100 | \$2.5 billion | 10,151 | 1,477 | \$149 million | \$270 million |
| 2004 | Hurricane Gaston | 9 | \$60 million | 5,798 | 97 | \$19.6 million | \$28 million |
| 2004 | Hurricane Jeane | 1 | \$4.6 million | 280 | 12 | \$3.2 million | |
| 2006 | Tropical Depression Ernesto | 7 | \$144 million | 609 | | Denied by FEMA ¹² | \$44.7 million |
| 2011 | Tropical Storm Lee | 2 | \$12.5 million | | | Denied by FEMA ¹³ | \$5.1 million |
| 2012 | Hurricane Sandy | 2 | \$17.8 million | 245 | | | \$10.5 million |
| 2016 | Hurricane Matthew | 2 | \$60.2 million | 2000+ | | \$10.2 million | \$15.9 million |

Note: Estimated damages do not include the economic impact of the storms. Then-year dollars have been converted to 2018 dollars using the Implicit Price Deflator for Gross Domestic Product from the Bureau of Economic Analysis. Historical data are often incomplete with regards to home and businesses damaged or destroyed as well as official assistance.

^{12.} http://www.vaemergency.gov/fema-denies-appeal-for-tropical-depression-ernesto-assistance/

^{13.} https://www.washingtonpost.com/blogs/virginia-politics/post/fema-denies-aid-to-help-northern-virginia-recover-from-tropical-storm-lee

THE CHANGING DEMOGRAPHICS OF VIRGINIA

Virginia is currently the 12th most populous state in the nation with a 2018 estimated population of 8,517,685 (United States Census Bureau, 2018). Virginia's population ranking in the U.S. has waxed and waned, in large part due to economic circumstance. In the 1870 census, Virginia ranked as the 10th most populous state. By 1930, however, the Commonwealth was the 20th most populous state in the nation. The advent of World War II and rapid expansion of the federal government led to an influx of people to the Commonwealth, increasing the population of Virginia at a much faster rate than many other states.

By 2040, our state will be home to more than 10 million people making it the 10th largest state. More recently, Virginia has continued to grow, albeit slowly. From 2010 to 2017, the population of Virginia has increased by 494,625 or about 6.1 percent. While this represents an absolute increase in the population, the annual rate of population growth has tapered off in the current decade to its slowest rate of increase since the 1920s (**FIGURE 4**). The Weldon Cooper Center Demographics Research Group at the University of Virginia estimates that Virginia will continue to grow steadily in coming years, and by 2030 will be the 11th largest state. By 2040, our state will be home to more than 10 million people—making it the 10th largest state.

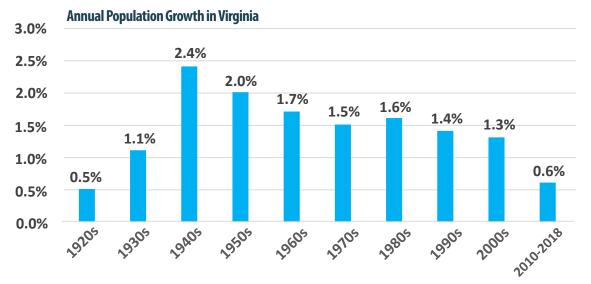


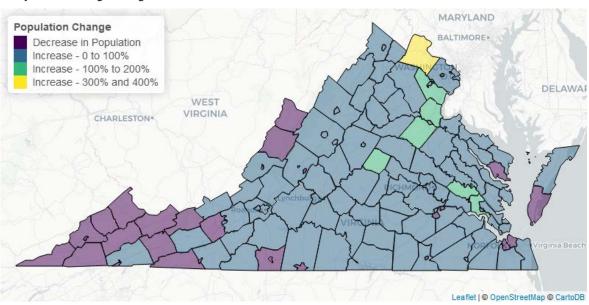
FIGURE 4

Source: Demographic Research Group, University of Virginia, Dragas Center for Economic Analysis and Policy, U.S. Census Estimates of the Components of Resident Population Change, April 1, 2010 to July 1, 2018 While Virginia's total population has grown, all areas of the Commonwealth have not grown equally, and some (mostly in the south and southwest areas of Virginia) have actually lost population. In the 2000s, 103 cities and countries increased in population while only 30 localities declined in size.¹⁴ Forty-nine localities in Virginia grew by 10 percent or more in the 2000s. This decade, however, 72 cities and counties have grown while 61 cities and counties have become smaller. Only 13 localities in the Commonwealth have grown by 10 percent or more this decade, a sign of slowing population growth.

The geographic center of Virginia's population shifted eastward from the 1940s to the 1970s, but then began a dramatic shift northward. This makes the scenario of a tropical storm, cyclone, or hurricane striking the Commonwealth concerning. The current population center resides just east of Spotsylvania County.¹⁵ By 2040, the geographic population center of the Commonwealth will be near Fredericksburg. By 2040, half the state's population will live in Northern Virginia, which we define as the area bordered on the south by Fredericksburg, on the north by the Potomac River, and on the west by the Shenandoah Valley. Additionally, more people are living closer to the water in the Commonwealth, increasing the potential for damage and loss of life if a tropical storm, cyclone, or hurricane came ashore in Virginia.

FIGURE 5 provides a visual picture of population growth rates from the 1990 Census to 2017. While several cities and counties lost population in Southwestern Virginia, population increased in many central and eastern Virginia cities and counties. Loudon County experienced the greatest increase in population from 1990 to 2017, increasing by 366 percent. This population growth has been uneven in the Chesapeake Bay area, with Norfolk, for example, losing 6.3 percent of its population while Chesapeake and Virginia Beach grew by 58 percent and 15 percent, respectively, over the period.

FIGURE 5



Population Change in Virginia, 1990-2017

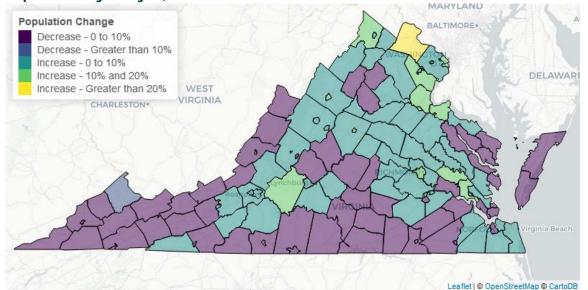
14. One locality, Newport News, remained essentially unchanged in population from the 2000 to 2010 Census. 15. U.S. Census (2018) and University of Virginia Weldon Cooper Center for Public Service, StatCh@t, June 26, 2017. From 2010 to 2017, population change has largely been in the 'urban crescent', with population increasing in most of Northern Virginia, Richmond, and Hampton Roads (**FIGURE 6**). There are notable exceptions, however, as Norfolk, Newport News, Portsmouth, and Poquoson have all lost population this decade. Overall, the Hampton Roads region has gained population this decade, led, in part, by Chesapeake.

perspective is that most of the tracts gaining the most population this decade border or are reasonably close to water and would likely be impacted by storm surge.

In **FIGURE 7**, we illustrate how population density has changed this decade in the Hampton Roads region.

FIGURE 6

Population Change in Virginia, 2010-2017



Source: U.S. Census Bureau, 2000 Decennial Census and 2017 Population Estimates and Dragas Center for Economic Analysis and Policy.

Population change at the Census tract level, however, reveals interesting information. Drawing into the Hampton Roads region, we present the ten largest population tracts in terms of population in 2017 in **TABLE 4**. First, seven of the top-10 tracks in terms of population gain were in Chesapeake and Virginia Beach, followed by James City County (2), and Norfolk (1). Census Tract 9.02 in Norfolk had the largest increase in population in Hampton Roads.

We note, however, Tracts 9.01 and 9.02 include large parts of Naval Station Norfolk. Another

Density increases in the census tracts bordering or near water of interest. The increasing density of these tracts provides a rationale for the increasing economic impact of a severe weather event striking Hampton Roads. The increasing density also illustrates the challenge of evacuating Hampton Roads. Increasing population density in Chesapeake and Virginia Beach requires longer evacuation lead times given the number of people and structures at risk from a tropical storm, cyclone, or hurricane.

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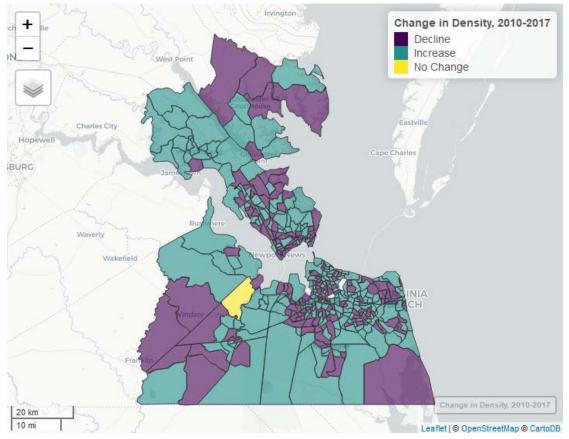
Population and Population Density Change, Ten Most Populous Tracts Hampton Roads, 2017

| NAME | 2010 Population | 2017 Population | 2010 Density | 2017 DENSITY | PERCENT CHANGE IN DENSITY |
|--|--------------------|--------------------|-----------------|-----------------|------------------------------|
| Census Tract 9.02 Norfolk | 3,541 | 15,271 | 506.56 | 2,184.61 | 331.26% |
| Census Tract 213.02 Chesapeake | 9,658 | 11,858 | 1,250.72 | 1,535.62 | 22.78% |
| Census Tract 215.01 Chesapeake | 10,150 | 10,950 | 1,333.61 | 1,438.72 | 7.88% |
| Census Tract 802.06 James City County | 9,721 | 10,768 | 1,354.41 | 1,500.28 | 10.77% |
| Census Tract 211.02 Chesapeake | 7,898 | 10,595 | 136.08 | 182.55 | 34.15% |
| Census Tract 454.17 Virginia Beach | 9,169 | 9,473 | 2,604.40 | 2,690.75 | 3.32% |
| Census Tract 454.23 Virginia Beach | 8,805 | 9,409 | 559.76 | 598.16 | 6.86% |
| Census Tract 454.06 Virginia Beach | 9,254 | 9,381 | 5,335.12 | 5,408.34 | 1.37% |
| Census Tract 803.01 James City County | 8,863 | 9,014 | 287.60 | 292.50 | 1.70% |

Source: U.S. Census Bureau, 2000 Decennial Census and 2017 Population Estimates and Dragas Center for Economic Analysis and Policy.

FIGURE 7

Change in Population Density, Hampton Roads 2010-2017



Source: U.S. Census Bureau, 2000 Decennial Census and 2017 Population Estimates and Dragas Center for Economic Analysis and Policy.

In summary, not only has the population of Virginia increased recently, the population center has moved towards the water. Increasing population density in proximity increases the probable damages from storm surge during a severe weather event. As tropical storms, cyclones, and hurricanes are typically most powerful at landfall, increasing population density increases the number of lives and structures at risk from wind damage. Simply put, there are more people, structures, and infrastructure in harm's way.

PHYSICAL DAMAGE

Estimating the physical damage from a tropical storm or hurricane is a journey in uncertainty. Every weather event is unique, and the estimates from any model are a product of the underlying assumptions.

Working on the assumption that a Florencetype hurricane made landfall in Hampton Roads, the HAZUS model estimates that 20,137 structures, or 3 percent of all the buildings in Hampton Roads would be at least moderately damaged. We use the HAZUS model to generate the damage estimates for a hurricane similar to Florence making landfall in Hampton Roads. The HAZUS model is a regional multi-hazard model designed to "assist in risk-informed decision-making efforts by estimating potential losses from earthquakes, floods, hurricanes, and tsunamis and visualizing the effects of such hazards."16 The Federal Emergency Management Agency (FEMA) developed HAZUS in concert with the National Institute of Building Sciences (NIBS). HAZUS estimates multi-hazard losses at a regional scale and is widely used by state, regional, and local officials in emergency preparedness. One way to think about HAZUS is that it employs data on structures and geographies to generate estimates of wind and water damage resulting from different types of hazards (hurricanes, floods, earthquakes).

Wind Damage

For the Hampton Roads region, HAZUS estimates that there are 580,120 buildings with an aggregate replacement value of \$209.4 billion in 2014 dollars. About 92 percent of the physical structures are residential, followed by commercial (5.1 percent), and industrial (1.3 percent). On a valuation basis, 83 percent of the value is residential, followed by commercial (11.3 percent), and industrial (2.4 percent). The valuation of building exposure by occupancy type is illustrated in **TABLE 5**. As winds may strike any part of the region, all the building stock in Hampton Roads is considered at risk.

Working on the assumption that a Florencetype hurricane made landfall in Hampton Roads, the HAZUS model estimates that 20,137 structures, or 3 percent of all the buildings in Hampton Roads would be at least moderately damaged. Approximately 1,388 buildings would be severely damaged while 1,114 buildings would be destroyed (TABLE 6).

The wind damage associated with a Florencetype hurricane will also generate debris. Such a hurricane would generate approximately 1.8 million tons of debris, the majority of which are tree debris (63 percent), followed by brick and wood debris. The hurricane would simply level many trees in Hampton Roads. It would require an estimated 15,252 truckloads to remove the wind-associated debris from the region.

^{16.} https://www.fema.gov/hazus

Of note, the destruction of property would displace 1,500 households and require shortterm shelter for 800 people. The loss of capital stock would be approximately \$4.1 billion for residential property, \$197 million for commercial property, and \$129 million for other types of property. In other words, the wind damage alone would be about \$4.5 billion.

TABLE 5

Building Exposure by Occupancy Type Wind Exposure

| OCCUPANCY TYPE | EXPOSURE (Thousands of Dollars) | Percent of Total |
|----------------|------------------------------------|------------------|
| Residential | \$173,813,656 | 83.0% |
| Commercial | \$23,656,194 | 11.3% |
| Industrial | 5,082,380 | 2.4% |
| Religious | \$2,954,001 | 1.4% |
| Education | \$2,264,787 | 1.1% |
| Government | \$1,147,721 | 0.6% |
| Agricultural | \$474,893 | 0.2% |
| Total | \$209,393,632 | |

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Source: HAZUS Estimates for Florence-Type Storm Impacting Hampton Roads (2019). Percentages rounded to nearest tenth and may not sum to 100 percent.

Expected Wind Damage by Occupancy Type Florence-Type Hurricane Impacting Hampton Roads

| OCCUPANCY | TOTAL | NO D | amage | MINOR DAMAGE | | MODERATE DAMAGE | | SEVERE DAMAGE | | DESTRUCTION | |
|-------------|--------------|--------------|----------------|--------------|---------|-----------------|---------|---------------|---------|--------------|---------|
| | <u>Count</u> | <u>Count</u> | <u>Percent</u> | <u>Count</u> | Percent | <u>Count</u> | Percent | <u>Count</u> | Percent | <u>Count</u> | Percent |
| Agriculture | 1,587 | 1,298 | 81.8% | 195 | 12.3% | 61 | 3.8% | 29 | 1.8% | 4 | 0.3% |
| Commercial | 29,561 | 24,649 | 83.4% | 3,471 | 11.7% | 1,241 | 4.2% | 199 | 0.7% | 1 | 0.0% |
| Education | 1,421 | 1,201 | 84.5% | 161 | 11.3% | 53 | 3.7% | 6 | 0.4% | 0 | 0.0% |
| Government | 1,128 | 964 | 85.5% | 121 | 10.7% | 39 | 3.4% | 4 | 0.4% | 0 | 0.0% |
| Industrial | 7,503 | 6,236 | 83.1% | 864 | 11.5% | 330 | 4.4% | 69 | 0.9% | 4 | 0.1% |
| Religion | 3,554 | 3,027 | 85.2% | 414 | 11.7% | 102 | 2.9% | 11 | 0.3% | 0 | 0.0% |
| Residence | 535,367 | 435,493 | 81.3% | 81,889 | 15.3% | 15,810 | 3.0% | 1,070 | 0.2% | 1,105 | 0.2% |
| Total | 580,120 | 472,869 | | 87,115 | | 17,634 | | 1,388 | | 1,114 | |

Source: HAZUS (2019). Numbers may not sum to totals due to rounding.

Water Damage

The number of buildings that may be affected by flooding is less than that possibly affected by significant winds. While wind damage may occur miles inland, water damage is primarily concentrated in areas close to the ocean, rivers, and low-lying areas prone to flooding. **TABLE 7** illustrates the valuation of building stock at risk from flooding. Of the \$209.4 billion in building stock in Hampton Roads, approximately \$44.2 billion would be at risk from flooding from a Florence-type hurricane (**TABLE 7**).

Over 33 percent of buildings exposed to flooding risk would be damaged in the Florence-type scenario. Of the estimated 19,464 buildings damaged, 6,321 are completely destroyed. All the destroyed buildings in this scenario are residential. **TABLE 8** shows the flooding damage estimates by type of building category.

Not only are a significant number of residential buildings destroyed, a number of essential facilities also incur damage. As illustrated in **TABLE 9**, schools, police and fire stations, and one hospital are expected to be significantly damaged during the hurricane. In total, building-related losses are approximately \$13.7 billion, with most of these losses (\$10.6 billion) borne by homeowners.

Water damage creates debris. The model estimates that 643,591 tons of debris will be generated by the storm. Most of the debris is interior structures and furnishings (62%), followed by structural debris (22%), and foundation debris (15%). Approximately 25,744 25-ton truckloads would be required to remove the debris

Building Exposure by Occupancy Type Water Exposure

| OCCUPANCY TYPE | EXPOSURE (Thousands of Dollars) | PERCENT OF TOTAL | | |
|----------------|------------------------------------|------------------|--|--|
| Reseidential | \$36,680,872 | 83.0% | | |
| Commercial | \$4,404,873 | 10.0% | | |
| Industrial | \$1,223,790 | 2.8% | | |
| Religious | \$685,295 | 1.6% | | |
| Education | \$639,919 | 1.4% | | |
| Government | \$466,619 | 1.1% | | |
| Agricultural | \$75,157 | 0.2% | | |
| Total | \$44,176,525 | | | |

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Source: HAZUS Estimates for Florence-Type storm impacting Hampton Roads (2019). Percentages rounded to nearest tenth and may not sum to 100 percent.

TABLE 8

Expected Water Damage by Occupancy Type Estimated Building Damage in Percent Florence-Type Hurricane Impacting Hampton Roads

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| OCCUPANCY | 1 | -10 | 11 | -20 | 21 | I-30 | 31 | I-40 | 41 | I-50 | ^ | -50 | total Damaged |
|-------------|--------------|---------|--------------|---------|--------------|---------|--------------|---------|--------------|---------|--------------|---------|------------------|
| | <u>Count</u> | Percent | |
| Agriculture | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 |
| Commercial | 41 | 18.0% | 187 | 81.0% | 3 | 1.0% | 1 | 0.0% | 0 | 0.0% | 0 | 0.0% | 232 |
| Education | 5 | 100% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 5 |
| Government | 52 | 66.0% | 27 | 34.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 79 |
| Industrial | 8 | 11.0% | 45 | 60.0% | 19 | 25.0% | 2 | 3.0% | 1 | 1.0% | 0 | 0.0% | 75 |
| Religion | 0 | 0.0% | 9 | 100% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 9 |
| Residence | 931 | 5.0% | 6,157 | 32.0% | 3,127 | 16.0% | 1,603 | 8.0% | 925 | 5.0% | 6,321 | 33.0% | 19,064 |
| Total | 1,037 | | 6,425 | | 3,149 | | 1,606 | | 926 | | 6,321 | | 19,464 |

Source: HAZUS Estimates for Florence-Type Storm Impacting Hampton Roads (2019). Percentages rounded to nearest tenth and may not sum to 100 percent.

Expected Water Damage to Essential Facilities Florence-Type Hurricane Impacting Hampton Roads

| CLASSIFICATION | TOTAL | AT LEAST Moderate | AT LEAST SUBSTANTIAL | LOSS OF USE |
|--------------------------------|-------|----------------------|-------------------------|-------------|
| Emergency Operation Centers | 4 | 1 | 0 | 1 |
| Fire Stations | 63 | 10 | 0 | 10 |
| Hospitals | 26 | 4 | 0 | 1 |
| Police Stations | 63 | 12 | 0 | 12 |
| Schools | 561 | 56 | 0 | 54 |

Source: HAZUS Estimates for Florence-Type Storm Impacting Hampton Roads (2019).

Given the significant amount of residential damage, it should be no surprise that the number of people displaced is significantly higher due to flooding than wind damage. HAZUS estimates 204,125 people will be displaced in the immediate aftermath due to flooding and that over 15,000 people would seek temporary shelter in public shelters. To say that this outflow of residents from Hampton Roads would strain shelters throughout the Commonwealth would be an understatement.

Putting this together, we estimate the total physical damage resulting from a Florencetype hurricane striking Hampton Roads would approach \$18 billion. Approximately 38,000 structures in Hampton Roads would be damaged, with residential housing taking the brunt. Wind and water would combine to create over 2.4 million tons of debris, requiring over 50,000 25-ton truck trips to landfills across and outside the Commonwealth. Over 200,000 people would be immediately displaced in the aftermath of the storm, and almost 16,000 would seek accommodation in a public shelter.

THE ECONOMIC IMPACT OF A HURRICANE STRIKING HAMPTON ROADS

The physical damage from a hurricane is only part of the total impact on the economy. A major tropical storm or hurricane striking the region would not only damage structures and displace residents, it would also impact economic activity. Damage to infrastructure may limit the ability of many to travel to work, and displaced residents may be unable to commute to their place of employment. Damage to businesses may result in their reduction or complete closure. These impacts ripple through the economy.

The direct economic impact creates a decline in employment, sales, and compensation. This, in turn, creates a secondary economic impact that we classify into indirect and induced effects. To estimate the total economic impact of a hurricane making landfall in Hampton Roads, we must explore the direct economic impact and, from that, the indirect and induced economic impacts. One can think of these impacts as an economic chain, where a jolt in one part of the chain is transmitted to each link in the chain, affecting many more people. The direct economic impact is often the most visible, with people unable to work and businesses unable to operate due to the direct damage associated with the storm.

The direct economic impact creates a decline in employment, sales, and compensation. This, in turn, creates a secondary economic impact that we classify into indirect and induced effects. One way to think about this is to assume that Joe's Bakery is destroyed in the hurricane. Joe and his four employees are directly affected by the physical damage from the hurricane, so regional employment declines by five, regional wages decline by the amount that Joe and his employees earned, and so on.

However, Joe's Bakery does not operate in a vacuum. Suppliers to businesses directly impacted

by the hurricane also experience a decline in business activity, producing an additional decline to employment, sales, and compensation. In other words, the suppliers who provide flour, eggs, milk, and other products to Joe's Bakery experience a decline in sales which, in turn, lead to declines in employment and compensation. This is what is known as the indirect economic impact.

The impact continues to ripple throughout the economy. Employees of Joe's Bakery are not spending as much money, deferring everything from grocery shopping to repairing their cars. The decline in income and employment by industry sectors directly and indirectly impacted by the hurricane further ripples through the rest of the local economy. This happens when a decline in employment or compensation in one sector of the local economy leads to less spending by employees in other industry sectors, causing a further decline in employment, sales, and compensation. This third-order effect is known as the induced impact.

In other words, because of the interconnectedness of the economy, the economic impact of a

hurricane is larger than the direct impact. If the indirect effect is 0.5 and the induced effect is 0.2, then a loss of 1,000 jobs would result in the indirect loss of 500 jobs and an induced loss of 200 jobs, for a total loss of 1,700 jobs. The multiplier effect in this case is equal to 1.7, which is (1,000+500+200)/1,000. It is important to note that the size of the multiplier depends upon the extent of the ripple effects inside the region. For example, if the suppliers to businesses directly impacted by the hurricane are located outside of the region, the multiplier would become smaller.

The Best of the Worst: A Hurricane Harvey Event

The destruction left in Hurricane Harvey's wake was significant. Thousands of homes, tens of thousands of vehicles, and numerous public and private enterprises were disrupted during and after Harvey. Harvey's physical damage was in the billions of dollars, yet Harvey may have a net positive economic impact on the economy of Texas.

Why? First, while Harvey disrupted industrial output, many manufacturers were back up and running within a month. In the year following Harvey's landfall, federal, state, and local governments, along with private insurers, injected over \$30 billion of spending into local economies. This spending helped offset the decline in economic activity due to Harvey's physical damage. The State of Texas Comptroller estimates that the recovery from Harvey will stimulate economic activity, producing an estimated \$800 million cumulative gain in Gross Domestic Product in the three years following Harvey (**TABLE 10**).

TABLE 10

Net Economic Impact of Hurricane Harvey on Texas Gross Domestic Product (Billions of Nominal Dollars)

| IMPACT | YEAR1 | YEAR 2 | YEAR 3 | YEAR 1-3 |
|------------------------|---------|--------|--------|----------|
| Estimated Losses | -\$16.8 | -\$2.0 | -\$1.0 | -\$19.8 |
| Estimated Gains | \$13.0 | \$4.1 | \$3.5 | \$20.6 |
| Net Economic Impact | -\$3.8 | \$2.1 | \$2.5 | \$0.8 |

Source: State of Texas Comptroller (2018). Available at: https://comptroller. texas.gov/economy/fiscal-notes/2018/special-edition/impact.php

A Harvey-type scenario would be the best alternative among many bad alternatives for Hampton Roads. Although there would be substantial physical damage, economic activity would not be disrupted for a significant period of time. No major population displacement would occur. Despite physical damage, many structures would remain habitable (though in imperfect condition), and life would quickly return to some semblance of normal.

The injection of reconstruction and remediation funds from the public and private sector would likely boost economic growth in the months and years following the severe weather event. Much of the funding would come from outside Hampton Roads, stimulating the regional economy. There would be significant gains in construction and utilities and no lasting disruption to manufacturing and associated industries. The injection of funds would also provide an opportunity to upgrade or replace aging infrastructure, improving transportation and utility networks and expanding flood mitigation efforts.

Hurricane Katrina: How Bad Could It Get for Hampton Roads?

To examine the impact of a major hurricane on the economy of Hampton Roads, we have drawn upon historical data that reflects the direct physical damages discussed previously in this report. Examining recent history, we selected Hurricane Katrina which struck New Orleans and the Gulf Coast in 2005. While Hurricane Katrina generated significant wind damage across the Gulf Coast, much of the damage was due to storm surge and flooding. Hurricane Katrina also offers an example of what happens to a region when a significant percent of the population is displaced by a major weather event.

Hurricane Katrina was the second costliest hurricane to hit the United States. With a total estimated cost of \$138 billion, Hurricane Katrina had a devastating impact on the New Orleans economy. The Bureau of Economic Analysis (BEA) reported that the New Orleans-Metairie MSA had 783,035 jobs in 2004, the last full year before the storm. By 2006, the number of jobs had declined to 648,243. This represents a 17% loss in employment.

How would the Hampton Roads economy have been impacted if a storm like Hurricane Katrina had struck the region? To estimate the economic impact of Hurricane Katrina striking Hampton Roads, we utilize data from the BEA. We calculate the annual change in employment from 2004 to 2006 by industry sector in New Orleans. We then apply those changes to estimate how an equivalent-size hurricane might affect the Hampton Roads economy. We modeled estimates of indirect and induced economic impacts of Hurricane Katrina using JOBSEQ software developed by Chmura Economics and Analytics. The software is based on regionalized input-output tables and estimates to relationship between industries.

TABLE 11 shows the direct economic impact of a major hurricane striking the Hampton Roads region would be a decline of 94,950 jobs in the following year. Total sales in the region would fall by an estimated \$15 billion. Employee compensation (which is included in the aggregated output estimates) would decline by \$4.1 billion. When we include the indirect and induced impact, employment would decline by 176,028 jobs. The primary and secondary impacts on total output would result in a decline of \$22.8 billion in output. Total compensation would fall by \$6.7 billion over the same period.

In other words, over 175,000 jobs would be lost, and economic activity could fall by almost \$23 billion as the result of a catastrophic hurricane making landfall in Hampton Roads.

TABLE 11

1-Year Total Estimated Economic Impact Katrina-Class Hurricane Striking Hampton Roads

| T-Year Total Estimated Economic Impact Katrina-Class Hurricane Striking Hampton Roads | | | | | |
|--|------------------|--------------------|-------------------|-----------------------------|--|
| | Direct Impact | Indirect Impact | Induced Impact | Total Economic Impact | |
| Employment | -94,950 | -20,844 | -60,234 | -176,028 | |
| Sales/Output (in millions) | -\$15,093 | -\$2,614 | -\$5,119 | -\$22,825.8 | |
| Compensation | -\$4,152 | -\$901 | -\$1,622 | -\$6,676 | |

Source: Quarterly Census of Employment and Wages (2019), Chamura Economics – JobsEq, and Dragas Center for Economic Analysis and Policy. Percentages from the New Orleans Metropolitan Statistical Area are applied to 2017 employment and wages in the Hampton Roads MSA. Note that compensation is included in the sales/output estimates and is broken out for illustrative purposes. **TABLES 12**, **13**, and **14** present the direct, indirect, and induced effects by industry sector. **TABLE 12** provides industry level estimates of the 176,000 lost jobs. **TABLE 13** provides detail on the nearly \$23 billion in lost economic activity. **TABLE 14** illustrates the breakdown of the nearly \$7 billion in lost compensation. These estimates are sobering as approximately 20% of the Hampton Roads workforce will lose their jobs, and economic activity in Hampton Roads will decline by about onequarter in the year after hurricane landfall.

TABLE 12

1-Year Total Estimated Employment Impacts Katrina-Class Hurricane Striking Hampton Roads

| INDUSTRY | DIRECT | INDIRECT | INDUCED | TOTAL |
|---|---------|----------|---------|----------|
| Agricultural, forestry, and fishing* | - | - | - | - |
| Mining, quarrying, and oil and gas extraction* | - | - | - | - |
| Utilities* | - | - | - | - |
| Construction | 2,960 | 679 | 955 | 4,594 |
| Manufacturing | -2,693 | -886 | -1,281 | -4,859 |
| Wholesale trade | -1,417 | -435 | -541 | -2,393 |
| Retail trade | -9,353 | -1,136 | -1,484 | -11,973 |
| Transportation and warehousing | -1,548 | -389 | -435 | -2,372 |
| Information | -1,688 | -858 | -798 | -3,344 |
| Finance and insurance | -4,366 | -1,128 | -1,799 | -7,293 |
| Real estate, rental and leasing | 58 | 115 | 40 | 214 |
| Professional, scientific, and technical services | -2,490 | -526 | -1,056 | -4,072 |
| Management of companies and enterprises | -770 | -205 | -323 | -1,298 |
| Administrative and support and waste management | -3,497 | -443 | -663 | -4,604 |
| Educational services | -1,274 | -108 | -244 | -1,625 |
| Health care and social assistance | -15,147 | -2,794 | -4,234 | -22,175 |
| Arts, entertainment, and recreation | -3,119 | -466 | -519 | -4,105 |
| Accommodation and food services | -12,224 | -932 | -1,296 | -14,452 |
| Other services (except government and government enterprises) | -6,581 | -671 | -1,378 | -8,631 |
| Government | -31,801 | -10,662 | -45,177 | -87,640 |
| Totals | -94,950 | -20,844 | -60,234 | -176,028 |

Note: Data are based on Bureau of Economic Analysis data at the 2 Digit NAICS sector level.

* Denotes sectors with missing data in the Hampton Roads MSA due to disclosure issues.

1-Year Total Estimated Sales/Output Impacts Katrina-Class Hurricane Striking Hampton Roads (Millions of Dollars)

| INDUSTRY | DIRECT | INDIRECT | INDUCED | TOTAL |
|---|--------------|-------------|-------------|--------------|
| Agricultural, forestry, and fishing* | - | - | - | - |
| Mining, quarrying, and oil and gas extraction* | - | - | - | - |
| Utilities* | - | - | - | - |
| Construction | \$518.71 | \$112.07 | \$155.35 | \$786.14 |
| Manufacturing | -\$995.38 | -\$163.07 | -\$194.73 | -\$1,353.19 |
| Wholesale trade | -\$325.38 | -\$72.85 | -\$86.84 | -\$485.07 |
| Retail trade | -\$820.30 | -\$190.74 | -\$230.27 | -\$1,241.30 |
| Transportation and warehousing | -\$201.89 | -\$47.91 | -\$61.33 | -\$311.13 |
| Information | -\$562.93 | -\$135.48 | -\$106.34 | -\$804.75 |
| Finance and insurance | -\$939.85 | -\$180.75 | -\$261.98 | -\$1,382.58 |
| Real estate, rental and leasing | \$37.88 | \$11.47 | \$4.71 | \$54.05 |
| Professional, scientific, and technical services | -\$448.18 | -\$84.01 | -\$169.76 | -\$701.95 |
| Management of companies and enterprises | -\$138.43 | -\$37.42 | -\$52.98 | -\$228.82 |
| Administrative and support and waste management | -\$293.67 | -\$62.14 | -\$102.68 | -\$458.50 |
| Educational services | -\$94.09 | -\$20.70 | -\$39.50 | -\$154.29 |
| Health care and social assistance | -\$1,369.81 | -\$391.58 | -\$527.13 | -\$2,288.51 |
| Arts, entertainment, and recreation | -\$256.84 | -\$71.76 | -\$71.48 | -\$400.09 |
| Accommodation and food services | -\$698.07 | -\$173.28 | -\$206.66 | -\$1,078.00 |
| Other services (except government and government enterprises) | -\$490.20 | -\$119.17 | -\$161.51 | -\$770.87 |
| Government | -\$8,014.51 | -\$986.45 | -\$3,005.91 | -\$12,006.87 |
| Totals | -\$15,092.95 | -\$2,613.76 | -\$5,119.04 | -\$22,825.75 |

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Note: Data are based on Bureau of Economic Analysis data at the 2 Digit NAICS sector level.

* Denotes sectors with missing data in the Hampton Roads MSA due to disclosure issues.

1-Year Total Estimated Compensation Impacts Katrina-Class Hurricane Striking Hampton Roads (Millions of Dollars)

| INDUSTRY | DIRECT | INDIRECT | INDUCED | TOTAL |
|---|-------------|-----------|-------------|-------------|
| Agricultural, forestry, and fishing* | - | - | - | - |
| Mining, quarrying, and oil and gas extraction* | - | - | - | - |
| Utilities* | - | - | - | - |
| Construction | -\$191.14 | -\$57.98 | -\$61.70 | -\$310.83 |
| Manufacturing | -\$100.83 | -\$28.65 | -\$27.51 | -\$156.99 |
| Wholesale trade | -\$299.34 | -\$66.22 | -\$72.96 | -\$438.52 |
| Retail trade | -\$84.94 | -\$18.55 | -\$19.43 | -\$122.92 |
| Transportation and warehousing | -\$82.60 | -\$38.91 | -\$33.69 | -\$155.20 |
| Information | -\$316.67 | -\$65.51 | -\$83.01 | -\$465.19 |
| Finance and insurance | \$2.40 | \$3.60 | \$1.49 | \$7.49 |
| Real estate, rental and leasing | -\$214.09 | -\$30.44 | -\$53.79 | -\$298.33 |
| Professional, scientific, and technical services | -\$88.92 | -\$12.28 | -\$16.79 | -\$117.99 |
| Management of companies and enterprises | -\$135.55 | -\$23.08 | -\$32.53 | -\$191.16 |
| Administrative and support and waste management | -\$81.57 | -\$5.56 | -\$12.52 | -\$99.64 |
| Educational services | -\$736.13 | -\$121.68 | -\$167.02 | -\$1,024.83 |
| Health care and social assistance | -\$87.90 | -\$19.71 | -\$22.65 | -\$130.25 |
| Arts, entertainment, and recreation | -\$281.73 | -\$59.88 | -\$65.48 | -\$407.09 |
| Accommodation and food services | -\$185.49 | -\$32.48 | -\$51.17 | -\$269.14 |
| Other services (except government and government enterprises) | -\$1,460.92 | -\$359.71 | -\$952.41 | -\$2,773.05 |
| Government | -\$191.14 | -\$57.98 | -\$61.70 | -\$310.83 |
| Totals | -\$4,152.73 | -\$901.10 | -\$1,621.94 | -\$6,675.77 |

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Note: Data are based on Bureau of Economic Analysis data at the 2 Digit NAICS sector level.

* Denotes sectors with missing data in the Hampton Roads MSA due to disclosure issues.

There is a sliver of good news in the estimates. Construction employment increases in the aftermath of a hurricane to repair or replace damaged structures. The pillars of the Hampton Roads economy, defense, tourism, and trade, however, would all experience significant declines in employment, output, and compensation. Of particular concern is our estimate that the government sector would shed almost 32,000 jobs, leading to a total employment decline of almost 88,000 jobs. How could this happen? First, a significant hurricane like Katrina would result in direct physical damage that would displace tens (if not hundreds) of thousands of residents. In such an event, significant damage would likely occur to defense bases scattered throughout Hampton Roads. If Naval Support Activity Norfolk or Naval Air Station Oceana, for example, sustained significant damage, the ships and planes could go away, never to return. With the ships and planes go the soldiers, sailors, airmen, and Marines, as well as civilian employees and contractors. Some might argue that Hurricane Andrew's damage to Homestead Air Force Base contributed to its selection for closure by the Base Realignment and Closure Commission in the mid-1990s (FIGURE 8).

FIGURE 8

Homestead Air Force Base, Post-Andrew Damage, 1992



Source: United States Air Force (2012). https://www.homestead.afrc.af.mil/News/Article-Display/Article/701110/ homestead-arb-and-hurricane-andrew-a-look-back-a-look-forward/

The potential for base closure and the relocation of existing military assets is not far-fetched. Hurricane Michael damaged nearly every structure on Tyndall Air Force base in October 2018. With approximately one-third of structures destroyed and operations impeded by the damage, some of the assets at Tyndall were relocated to Langley Air Force Base in Hampton Roads. The damage to Tyndall has been compounded by an impasse over disaster aid within Congress and between Congress and the Administration.¹⁷ One can easily surmise that a similar level of destruction in Hampton Roads might spur the Navy, Air Force, or other services to relocate personnel and assets to other locations in the United States.

In **TABLE 15**, we summarize the estimates of the physical and economic impacts. Faced with a total potential loss of \$40 billion in the first year following a major hurricane, the need for prior planning and preparation becomes paramount. Improving building codes, sewage and sanitation infrastructure, and implementing 'no build' zones for extremely hazardous areas of Hampton Roads are concrete policy actions that can mitigate some of the costs highlighted in **TABLE 15**.

TABLE 15

Summary of Physical and Economic Impacts Katrina-Class Hurricane Striking Hampton Roads

| | BUILDINGS AFFECTED (Destroyed) | ESTIMATED IMPACT | INDIVIDUALS AFFECTED (Requiring Shelter) |
|---|-----------------------------------|------------------|---|
| Wind Damage | 20,137 | >\$4 billion | 1,500 |
| | (1,114) | | (800) |
| Water Damage | 18,427 | >\$13 billion | 204,125 |
| | (6,231) | | (15,000) |
| Employment Loss | | | >170,000 |
| Output Loss (Including Compensation) | | >\$22 billion | |
| Total | >38,000 | >\$40 billion | >380,000 |
| | (>7,000) | | (>15,000) |

Source: Quarterly Census of Employment and Wages (2019), Chamura Economics – JobsEq, and Dragas Center for Economic Analysis and Policy. Percentages from the New Orleans Metropolitan Statistical Area are applied to 2017 employment and wages in the Hampton Roads MSA. HAZUS model estimates using a track similar to Hurricane Florence. Table represented estimated 1-year impact. Some double-counting may occur as some individuals may have residences physically damaged and have employment loss.

^{17.} https://www.wsj.com/articles/hurricane-torn-air-force-bases-recovery-stalls-as-congress-lingers-on-disaster-aid-11556988607

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FINAL THOUGHTS

Our estimates suggest that the cost of a Florence or Katrina-like hurricane striking Hampton Roads would be in the tens of billions of dollars. Direct physical damages would likely approach \$20 billion, and the economic impact could approach \$25 billion. Tens of thousands of residents would be displaced, and more would find themselves out of work. A significant number of displaced residents would likely seek their fortunes elsewhere, additionally depressing economic activity in the years following a hurricane.

While we cannot know the exact timing, we can be certain that, at some point, Hampton Roads will face the bullseye of a hurricane. The Commonwealth has a history of hurricane strikes. While Virginia has not been struck by a Category 3 or higher hurricane from 1851-2017, the well-documented hurricane of 1821 illustrates the need for prior planning and preparation. While we cannot know the exact timing, we can be certain that, at some point, Hampton Roads will face the bullseye of a hurricane.

Given the uncertainties surrounding hurricanes, are there specific policy actions that we can take today to mitigate the potential damage in the future?

First, the region needs to continue tackling the issue of sea level rise. To our credit, we are making progress and working together to improve drainage, elevate buildings, and mitigate recurrent flooding. These efforts are placing Hampton Roads at the forefront of the national policy conversation. We should accelerate efforts to mitigate, where possible, the impact of sea level rise. Where possible, we should look at development more closely to ensure we are not making flooding worse. New developments should not sacrifice long-term resiliency for short-term economic gains. This will require a change for local governments. Second, we should seriously consider whether some structures are too costly to save. Rising tides and the prospect of a significant storm surge may render some low-lying areas as flood-prone. The National Flood Insurance Program may actually incentivize building in flood-prone areas. If we do not want to have to continually repair or rebuild following severe storms, then we should consider restoring some low-lying areas to their natural state. The added benefit is that these areas would possibly alleviate flooding to some extent and mitigate a portion of a hurricane's storm surge.

Third, the Commonwealth should seriously review building codes in Florida and other states, and adopt more stringent codes. The lesson of Hurricanes Rita and Harvey is that many people may end up better off by sheltering in place. Strengthening residences will likely reduce injuries and loss of life, when sheltering in place is warranted. The Commonwealth should ensure that essential facilities (hospitals, fire stations, police stations) have generation capacity well above ground to avoid the catastrophic events and loss of life post-Katrina. While some may complain about spending public funds now, such expenditure will seem trivial if the hospitals, police and fire stations, and other essential services are up and running following a major hurricane.

Fourth, we must recognize the positive spillovers associated with prior planning and preparation. We must plan, prepare, and then test our plans and preparations. The adage 'no plan survives first contact with the enemy' applies here. Hurricanes cannot be swayed or diverted by argument or emotion. We must recognize the risk and build the capacity for response regionally. The good news is that by improving our preparedness for a hurricane, we improve our ability to respond to other events, including terrorism or a large-scale industrial accident.

We should prepare now, while the sun is shining, before the storm clouds gather.



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