An Analysis of the Potential Costs and Consequences of a Hurricane Impacting the Virginia Beach-Norfolk-Newport News Metropolitan Area

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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. 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 about 8 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 wind and water 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 displacement of about 200,000 of the region's 1.7 million residents. Over 16,000 of these displaced individuals would seek public shelter, likely placing significant strains on public and private resources. With over 6,000 residences destroyed during the hurricane, a considerable number of individuals are likely to be permanently displaced outside of Hampton Roads.

Over 175,000 individuals could possibly lose their jobs as the result of a Florence-Katrina type of hurricane striking Hampton Roads. 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 in the first year following the storm. When the estimated physical damages and economic impact are aggregated, the total damage from a Florence-Katrina class hurricane would approach, if not exceed, $40 billion in the first year following the storm.

The Research Collaborative

The Old Dominion University research collaborative has decades of experience with respect to 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.

Old Dominion University (ODU), located in Norfolk, Virginia, is one of the eight colleges and universities in Hampton Roads. ODU 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, including an international student population of 1,408 representing 130 countries, are enrolled.

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* maintains the goal of stimulating thought and discussion that ultimately will 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 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.

Faculty and Research Staff Biographies and Qualifications

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Emily Steinhilber is an Assistant Research Professor in the Office of Research at Old Dominion University (ODU) in Norfolk, Virginia 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. "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 also how a relatively benign storm can still result in significant damages 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. 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.

We must also recognize that the estimated costs do not include numerous volunteer agencies that provided financial assistance, cleanup, and remediation of damaged housing. The Virginia Conference of the United Methodist Church, for example, reported several thousand volunteer hours in support of recovery efforts.[3] Including these efforts would raise the 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 previously months. Monthly retail sales

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[1] Whichard, R. D. (1959). *The History of Lower Tiderwater Virginia*. New York: Lewis Historical Publishing Company, Inc.

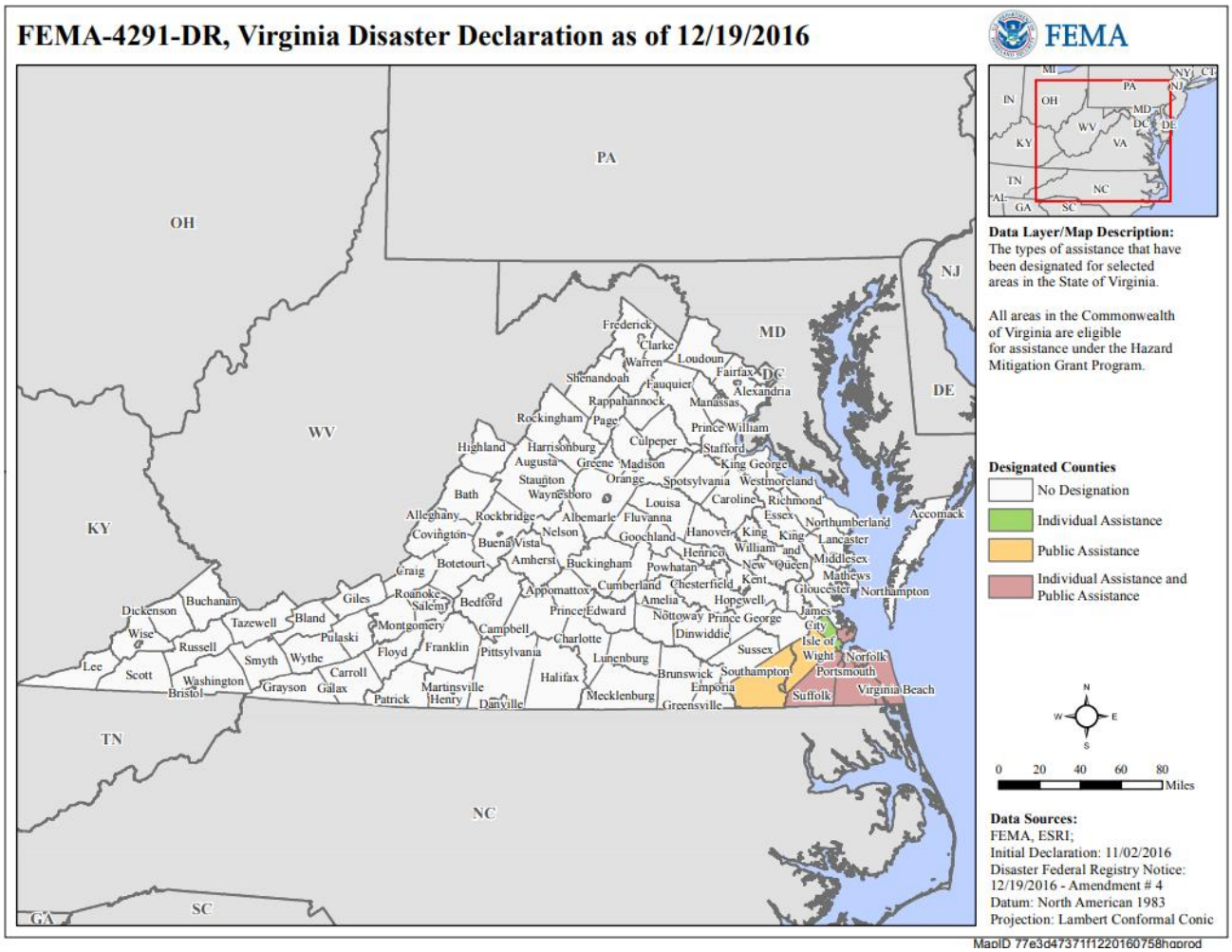
[2] FEMA's Individuals and Households Program (IHP) provides financial and direct services to eligible individuals and households affected by a disaster. For more information, see https://www.fema.gov/media-library-data/1528984381358-6f256cab09bfcbe6747510c215445560/IndividualsHouseholdsPrograms.pdf

[3] 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

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)

However, the monthly data 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.[4] 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,

[4] 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

households will 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 sufficient damage to residential and commercial infrastructure that lowers potential economic activity for months, if not years. The damage inflicted to Puerto Rico is an example of how a major hurricane can destroy residential housing, private businesses, and public infrastructure. Partly as a result, the population of Puerto Rico declined by 4.3 percent from 2017 to 2018 (United States Census Bureau, 2018).

Figure 2

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

Source: The Virginian Pilot (2016).

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. The decision to evacuate portions of Hampton Roads should be informed, in part, by the potential magnitude of damages, including loss of life. Hurricanes, by their very nature, are uncertain events and there is a tradeoff between forecast certainty (the closer to landfall, the more certain the forecast of where landfall will occur) and the time required to safely evacuate residents to shelters (too early and the decision may be costly in hindsight, too late and an insufficient number of people may be able to evacuate). This, as we discuss in this report, is a wicked problem in that it cannot be solved until the storm has actually made landfall.

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) would 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.

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.[5] The damage to the island was undeniably catastrophic, with most of the electrical, sanitation, and communication infrastructure failing in the aftermath of the storm. While estimates of fatalities vary, there is now an emerging consensus that over 3,000 U.S. citizens perished during or as a result of Hurricane Maria.

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.[6] 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.

[5] https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf

[6] 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

Table 1
Damage Estimates from Selected Major Storms and Hurricanes
United States, 1980 – 2018

year	name	category	State	Direct Damages (Millions of 2018 Dollars)	Estimated Fatalities
1980	Allen	5	TX	$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	Chantal	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
1998	Georges	2	FL, MS, AL	$4,259	602
1999	Bret	4	TX	$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	Ivan	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	$138,861	1,200
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	Ike	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, VA, MD	$15,000	60
2018	Florence	4	FL, NC, SC, VA	$17,900	55

Sources: FEMA (2018), Commonwealth of Virginia (2018), NOAA (2018)

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 on August 24th, 1635. In September of 1667, the Chesapeake Bay rose 12 feet and a large number of homes were destroyed in Jamestown. Less than one hundred years later, a hurricane caused the Chesapeake Bay to rise 15 feet and also 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"

Table 2 contains a listing of the major storms and hurricanes from the 1600s to the current day. One should immediately recognize that historical records are incomplete and that the smaller number of recorded storms in the 1600s and 1700s does not necessarily imply there were actually fewer severe weather events. Regardless of the completeness of these records, however, it should be clear that Virginia, and the Hampton Roads area in particular, have 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.

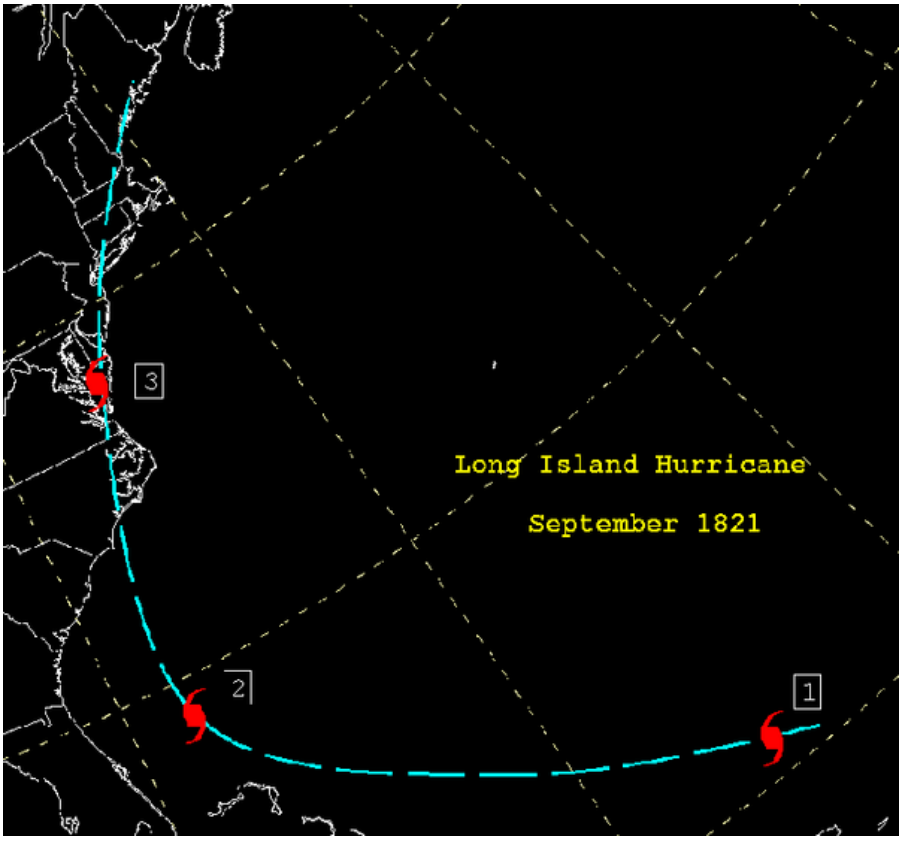
Table 3 illustrates the lives lost and direct damages for a select number of hurricanes in the past one hundred years. Hurricane Isabel tops the list with an estimated 100 lives lost and approximately $2.5 billion in estimated damages. Second is an unnamed hurricane in 1933 (often referred to as the '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.

What should immediately stand out is that Virginia, and Hampton Roads, in particular, have been struck by violent, damaging storms 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 also 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 3rd, 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.[7] 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 also limited and written communication, while slow, did not require fixed infrastructure or electricity.

[7] Linkin, M. (2014). The big one: The East Coast's 100 billion hurricane event.

In a hurricane similar to 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 economic impact would likely exceed $150 billion dollars (Linkin, 2014). Damages for the Commonwealth would be in the billions of dollars if a future hurricane followed a track similar to the 1821 hurricane.

Yet, we should be careful in our thinking with regards to 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.[8] Florence, however, caused extensive damage through a combination of rainfall in an already saturated area, wind, and storm surge. 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-ten 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), and/or Katrina (Gulf Coast, 2005) would likely result in billions of dollars in damages as the result of storm surge and-or flooding. Wind damage would also likely be in the billions of dollars. These, unfortunately, 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.

[8] 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.

Table 3
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
1933	Unnamed Chesapeake-Potomac Hurricane	18	$1.2 billion	--	--	--	--
1969	Hurricane Camille	153	$4.0 billion	--	--	--	--
1972	Tropical Storm Agnes	55	$578 million	--	--	--	--
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 Jeanne	1	$4.6 million	280	12	$3.2 million	--
2006	Tropical Depression Ernesto	7	$144 million	609	--	Denied by FEMA[9]	$44.7 million
2011	Tropical Storm Lee	2	$12.5 million	--	--	Denied by FEMA[10]	$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.

[9] http://www.vaemergency.gov/fema-denies-appeal-for-tropical-depression-ernesto-assistance/
[10] 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

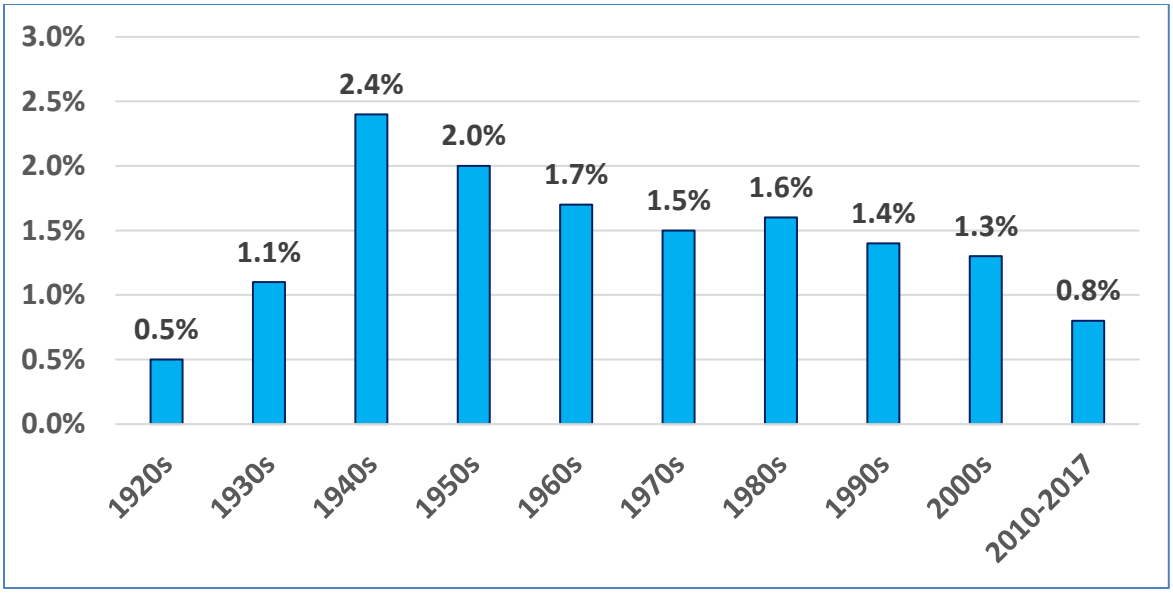
Virginia is currently the 12th most populous state in the nation with a 2017 estimated population of 8,470,020. Virginia's population ranking in the U.S. has waxed and waned, in large part due to economic circumstance. In the 1870 census, Virginia ranked as the 10th most populous state. By 1930, however, 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.

More recently, Virginia has continued to grow, albeit slowly. From 2010 to 2017, the population of Virginia has increased by 475,218 or about 5.9 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 (see 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 eleventh largest state. By 2040, our state will be home to more than 10 million people—making it the tenth largest state.

Figure 4

Annual Population Growth in Virginia

1920-2017



Source: Demographic Research Group, University of Virginia and U.S. Census Estimates of the Components of Resident Population Change, April 1, 2010 to July 1, 2017

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.[11] Forty-nine localities in Virginia grew by 10 percent or more in the 2000s. **This decade, however, 72**

[11] One locality, Newport News, remained essentially unchanged in population from the 2000 to 2010 Census.

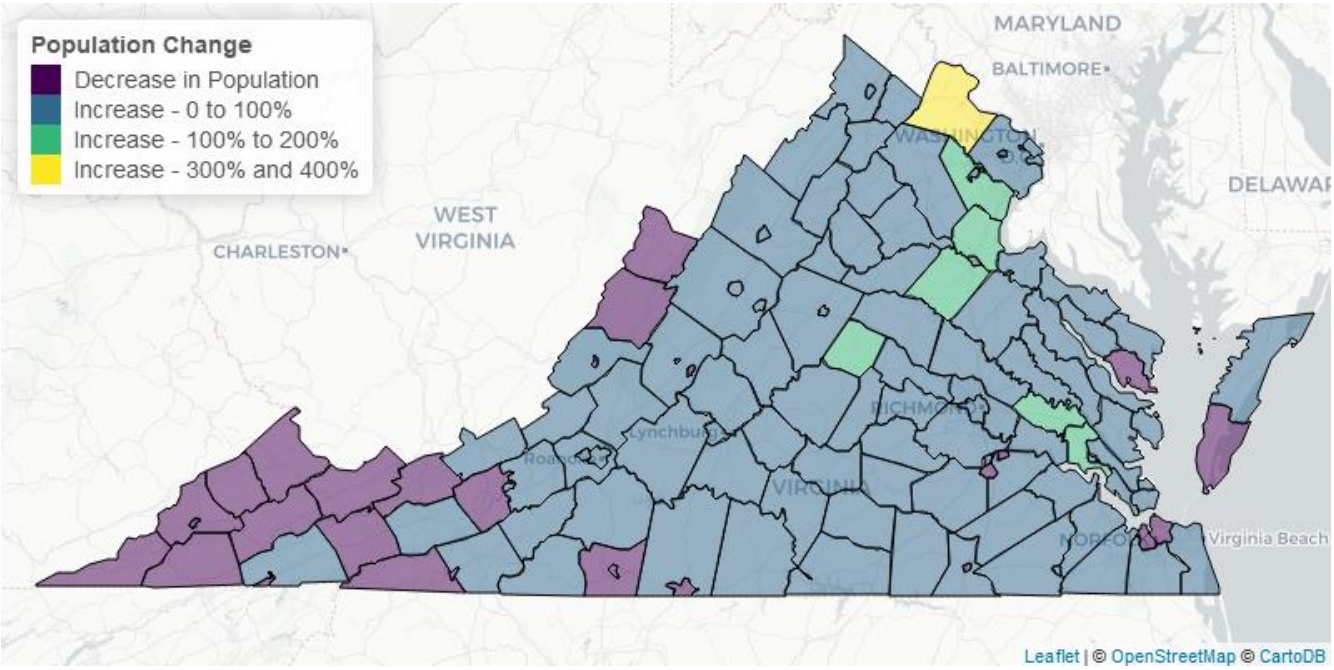
cities and counties have grown while 61 cities and counties have become smaller. Only 13 localities in the Commonwealth have grown by 10 percent or more this decade, a sign of slowing population growth.

Of concern from the perspective of a tropical storm, cyclone, or hurricane striking the Commonwealth is that the geographic center of Virginia's population shifted eastward from the 1940s to the 1970s, but then began a dramatic shift northward. The current population center resides just east of Spotsylvania County.[12] By 2040, the geographic population center of the Commonwealth will be near Fredericksburg. By 2040, one-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.

Figure 5

Population Change in Virginia, 1990-2017



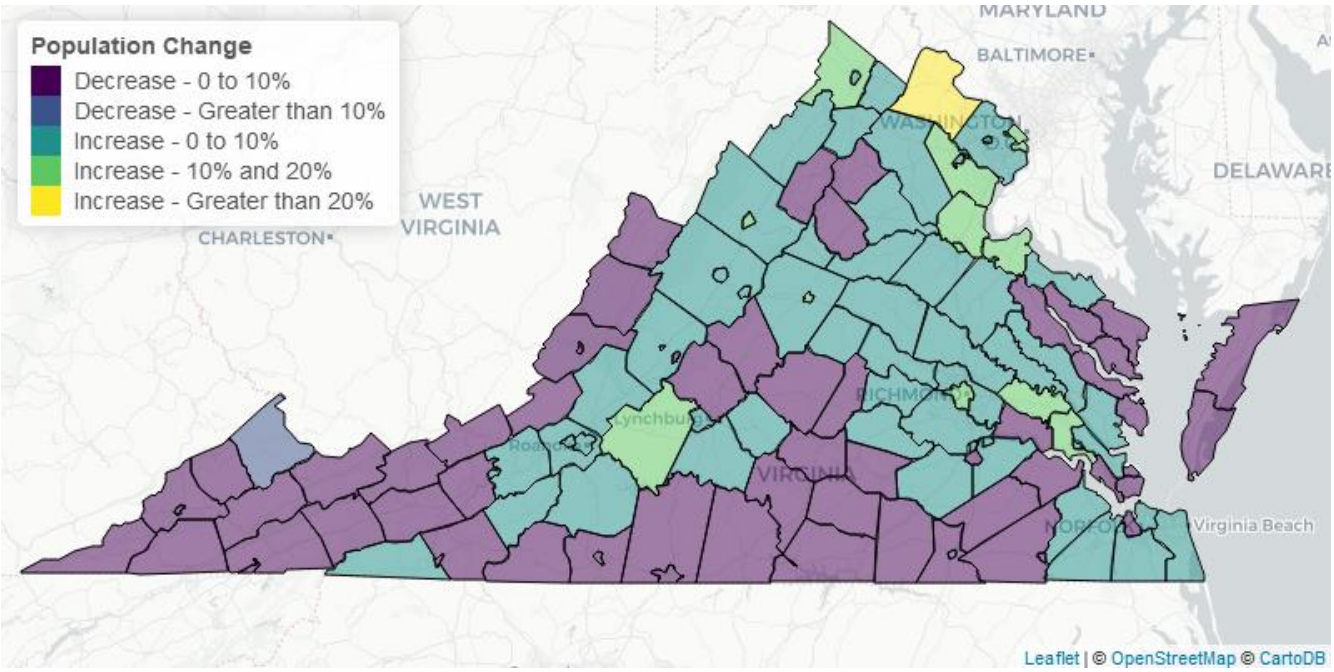
Sources: U.S. Census Bureau, 1990 Decennial Census and 2017 Population Estimates and Dragas Center for Economic Analysis and Policy.

[12] U.S. Census (2018) and University of Virginia Weldon Cooper Center for Public Service, StatCh@t, June 26, 2017.

From 2010 to 2017, however, 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, in that Norfolk, Newport News, Portsmouth, and Poquoson have all lost population this decade. Overall, the Hampton Roads region has gained population this decade, lead, in part, by Chesapeake.

Figure 6

Population Change in Virginia, 2010-2017



Sources: 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 tracts in terms of population in 2017 in Table 4. First, seven of the top ten 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 perspective is that most of the tracts gaining the most population this decade border or are reasonably close to water and would thus likely be impacted by storm surge.

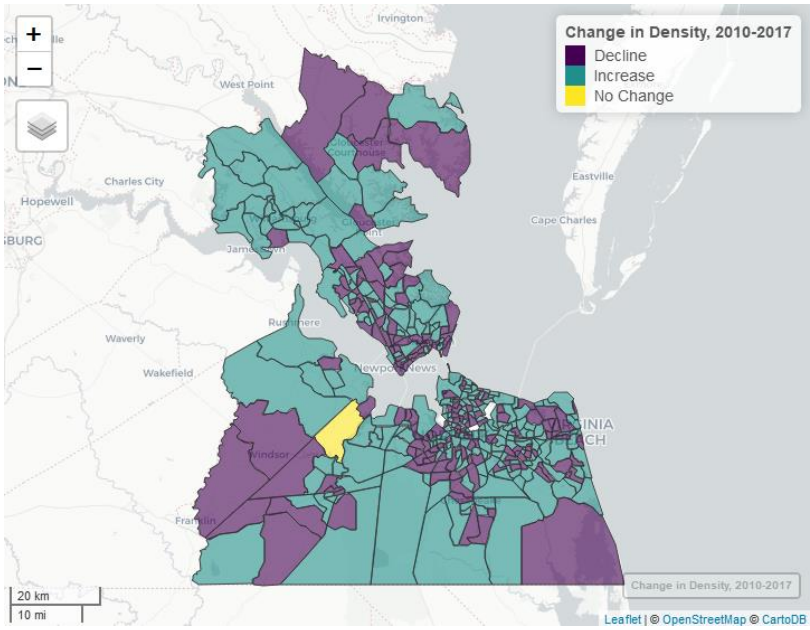
In Figure 7, we illustrate how population density has changed this decade in the Hampton Roads region. Of interest is the increase in density in the census tracts bordering or near water. The increasing density of these tracts provides a rationale for the increasing economic impact of a severe weather 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.

Table 4
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%

Sources: 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



Sources: 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 striking roads is a journey in uncertainty. Every weather event is unique, and the estimates from any model are a product of the underlying assumptions. With this caveat in mind, we briefly review the potential physical damages from a hurricane similar to characteristics 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."[13] 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 Florence-type of hurricane made landfall in Hampton Roads, the HAZUS model estimates that 20,137 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 completely destroyed. Table 6 illustrates the estimated damage by occupancy type.

The wind damage associated with a Florence-type of hurricane will also lead to the generation of 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.

Of note, the destruction of property would displace 1,500 households and require short-term 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.

[13] https://www.fema.gov/hazus

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**	--

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

Table 6
Expected Wind Damage by Occupancy Type
Florence-Type Hurricane Impacting Hampton Roads

Occupancy	Total	No Damage		Minor Damage		Moderate Damage		Severe Damage		Destruction	
	Count	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	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 6 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 is at risk from flooding from a Florence-type of hurricane (Table 7)

Table 7
Building Exposure by Occupancy Type
Water Exposure

Occupancy Type	Exposure (Thousands of Dollars)	Percent of Total
Residential	$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**	**--**

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

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

Table 8
Expected Water Damage by Occupancy Type
Estimated Building Damage in Percent
Florence-Type Hurricane Impacting Hampton Roads

Occupancy	**1-10**		**11-20**		**21-30**		**31-40**		**41-50**		**>50**		**Total Damaged**
	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	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.

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 event. In total, building-related losses are approximately $13.7 billion, with most of these losses ($10.6 billion) being borne by homeowners.

Table 9
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).

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

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 due to wind damage. HAZUS estimates 204,125 people will be displaced in the immediate aftermath due to flooding and that over 15,000 people will 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 Florence-type hurricane striking Hampton Roads. Wind and water damage would approach $18 billion. Approximately 38,000 structures in Hampton Roads would be damaged, with residential housing taking the brunt of damage. 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.

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 and 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 that occur 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 undoubtedly 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	Year 1	Year 2	Year 3	Years 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 significant physical damage, economic activity would not be disrupted for a significant period of time. No significant population displacement would occur. While there was 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 Florence-type event for 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. 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 is 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. Hurricane Katrina struck New Orleans in August 2005. The Bureau of Economic Analysis reports that the New Orleans-Metairie MSA went from a total of 783,035 jobs in 2004, the last full year before the storm, to 648,243 in 2006. This represents a 17% loss in employment. How would the Hampton Roads economy have been impacted if a hurricane like Hurricane Katrina had struck the region?

To estimate the economic impact of Hurricane Katrina striking Hampton Roads, we utilize data from the Bureau of Economic Analysis (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 the equivalent-size hurricane would affect the Hampton Roads economy today. 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 Hurricane Katrina striking Hampton Roads would result in a decline of 94,950 jobs in the first year following the hurricane. 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 declines by 176,028 jobs. The primary and secondary impact on total output would result in a decline of $22.8 billion. 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 Katrina-like event striking Hampton Roads.

Table 11
1-Year Total Estimated Economic Impacts
Katrina-Class Hurricane Striking Hampton Roads

1 Year Total Estimated Economic Impact A Storm Similar to Hurricane Katrina on 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 (in millions)	-$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.

Table 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 almost $23 billion in lost economic activity. Table 14 illustrates the breakdown of the almost $7 billion in lost compensation. These estimates are sobering in that approximately 20% of the Hampton Roads workforce will lose their jobs and economic activity in Hampton Roads will decline by about one-quarter 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
Agriculture, 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.

Table 13
1-Year Total Estimated Sales/Output Impacts
Katrina-Class Hurricane Striking Hampton Roads
(Millions of Dollars)

Industry	Direct	Indirect	Induced	Total
Agriculture, 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**

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.

Table 14
1-Year Total Estimated Compensation Impacts
Katrina-Class Hurricane Striking Hampton Roads
(Millions of Dollars)

Industry	Direct	Indirect	Induced	Total
Agriculture, 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**

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 due to the need 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 initially 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 or Florence, 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, and also 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/

A Florence-Katrina type hurricane making landfall (or closely skirting the coastline) in Hampton Roads would have catastrophic physical and economic impacts. We estimate that the immediate impact will exceed $40 billion, even if there is not a loss of life or physical injury. If there are fatalities, and we employ a Value of Statistical Life (VSL) methodology, the costs could increase by $5 to $15 million per life lost.

What should be clear from Table 15 is that preparation is imperative. Improving building codes, sewage and sanitation infrastructure, and implementing 'no build' zones for extremely hazardous areas of Hampton Roads should be scrutinized. Faced with such an event, public officials would need to seriously consider evacuating a significant portion of Hampton Roads, a decision that is fraught with uncertainty.

Table 15
Summary of Physical and Economic Impacts
Katrina/Florence-Class Hurricane Striking Hampton Roads

	Buildings Affected (Destroyed)	**Estimated Impact**	**Individuals Affected (Requiring Shelter)**
Wind Damage	20,137 (1,114)	>$4 billion	1,500 (800)
Water Damage	18,427 (6,231)	>$13 billion	204,125 (15,000)
Employment Loss	--	--	>170,000
Output Loss (Including Compensation)	--	>$22 billion	--
Total	>38,000 (>7,000)	>$40 billion	>380,000 (>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.

Hurricane Rita: Uncertainty and Anchoring

Major tropical storms and hurricanes are, by their very nature, uncertain events. Only once the storm has passed can we accurately assess damages and decisions. While forecasting and damage prediction has improved considerably over the past fifty years, the core questions of preparation and evacuation must be answered prior to a storm's arrival. There is an inherent tradeoff between certainty and time, that is, the characteristics of the storm become more precise the closer the storm is to landfall. On the other hand, waiting to prepare and, in some cases, evacuate until the storm arrives is clearly not the most appropriate course of action.

The decision to evacuate a major metropolitan area in the projected path of a storm, for example, must be made prior to the storm's arrival. Evacuate too soon, and one may face criticism if the storm does not strike the evacuated area. Evacuate too late (or not at all), and one may face criticism for placing the public at risk. Furthermore, evacuation poses its own risks and costs. A poorly-planned and implemented evacuation can result in more fatalities and costs than the storm itself.

Soon after Hurricane Katrina ravaged New Orleans and the Gulf Coast in 2005, Hurricane Rita formed and approached the Texas coastline. The last forecast discussion by the National Hurricane Center on September 21st, 2005, discussed how Rita continued to strengthen and some forecast models predicted that Rita would strike the Houston-Galveston area (Figure 9). These forecasts suggested that Rita would make landfall as a Category 4 (if not Category 5) storm[14], potentially resulting in billions of dollars in damage from wind and storm surge.[15]

With Katrina in mind, public officials decided that an evacuation was the most appropriate course of action. Officials predicted that 800,000 to 1.2 million would evacuate vulnerable areas, however, an estimated 2.5 million people attempted to evacuate. The evacuation effort did not attempt to stage the evacuation (most vulnerable areas first, followed by areas at lower risk), counterflow the highways, or provide enough emergency services to aid those attempting to evacuate. Some people reported being stuck in traffic for at least an entire day while the temperature soared to 100 degrees.[16] By landfall on September 24, however, Hurricane Rita weakened and shifted towards East Texas. While Rita resulted in about 100 fatalities and an estimated $12 billion in damages, more people likely died in the evacuation attempt.

In retrospect, the decision to evacuate appears to be ill-informed because of the eastward shift of the storm. After Rita had passed, many in the public and media castigated public officials for an apparently ill-informed decision to evacuate and the poorly managed evacuation process. However, we must recognize for all the flaws of the evacuation itself, that the decision to evacuate or not had to be made prior to the storm's arrival. If the evacuation had not suffered from numerous flaws, the officials would have been subject to comparatively mild criticism for evacuating without cause. On the other hand, if the evacuation had been reasonably well-managed and Rita had struck the Houston-Galveston area as a Category 4 or 5 storm, the officials would have been likely lauded for their foresight in ordering an evacuation. The problem was that the "right" answer could not be known until Rita had jogged eastward and spared the Houston-Galveston metropolitan area. Unfortunately, the decision to evacuate often places decision-makers in a "dammed if you do, dammed if you don't" situation.

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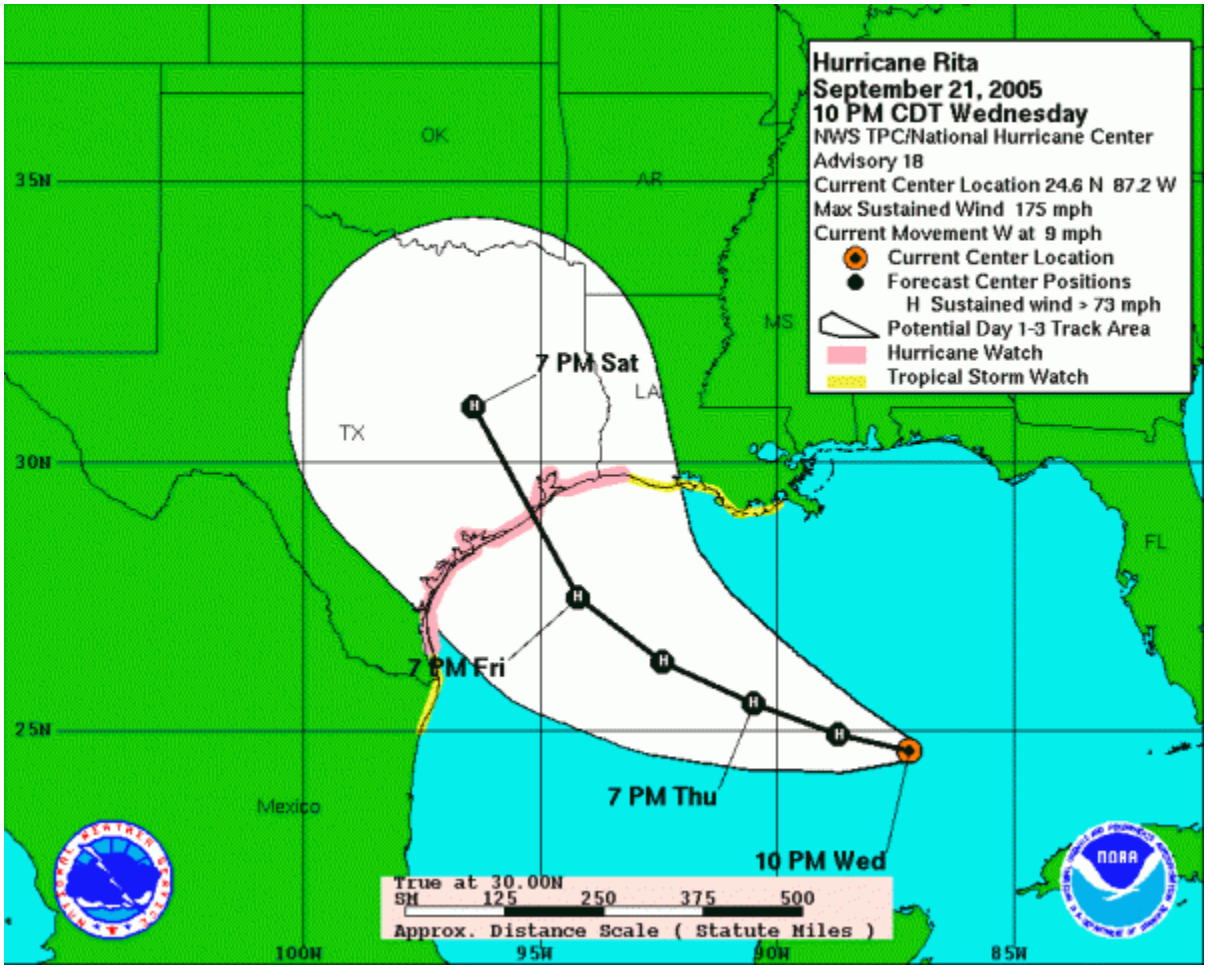
[14] https://www.nhc.noaa.gov/archive/2005/dis/al182005.discus.018.shtml

[15] https://www.chron.com/news/houston-texas/article/Models-show-massive-devastation-in-Houston-1950585.php

[16] https://blog.chron.com/weather/2015/09/ten-years-ago-houston-was-a-living-hell/

Figure 9

Forecast Advisory for Hurricane Rita on September 21st, 2005



Source: National Weather Service, National Hurricane Center, RITA Graphics Archive, Available at: https://www.nhc.noaa.gov/archive/2005/RITA_graphics.shtml

Evacuating Hampton Roads: A Wicked Problem

Virginia is one of a few states to use the Regional Tiered Evacuation System, more commonly known by its interactive tool: "Know Your Zone." This resource, which can be found on the Virginia Department of Emergency Management website[17], serves about 1.25 million residents in Coastal Virginia by providing clarity on whether to evacuate and how to do so. As shown in Figure 10, the map sections the region into zones, A through D, with A being the most vulnerable to hurricanes and other types of severe storms.

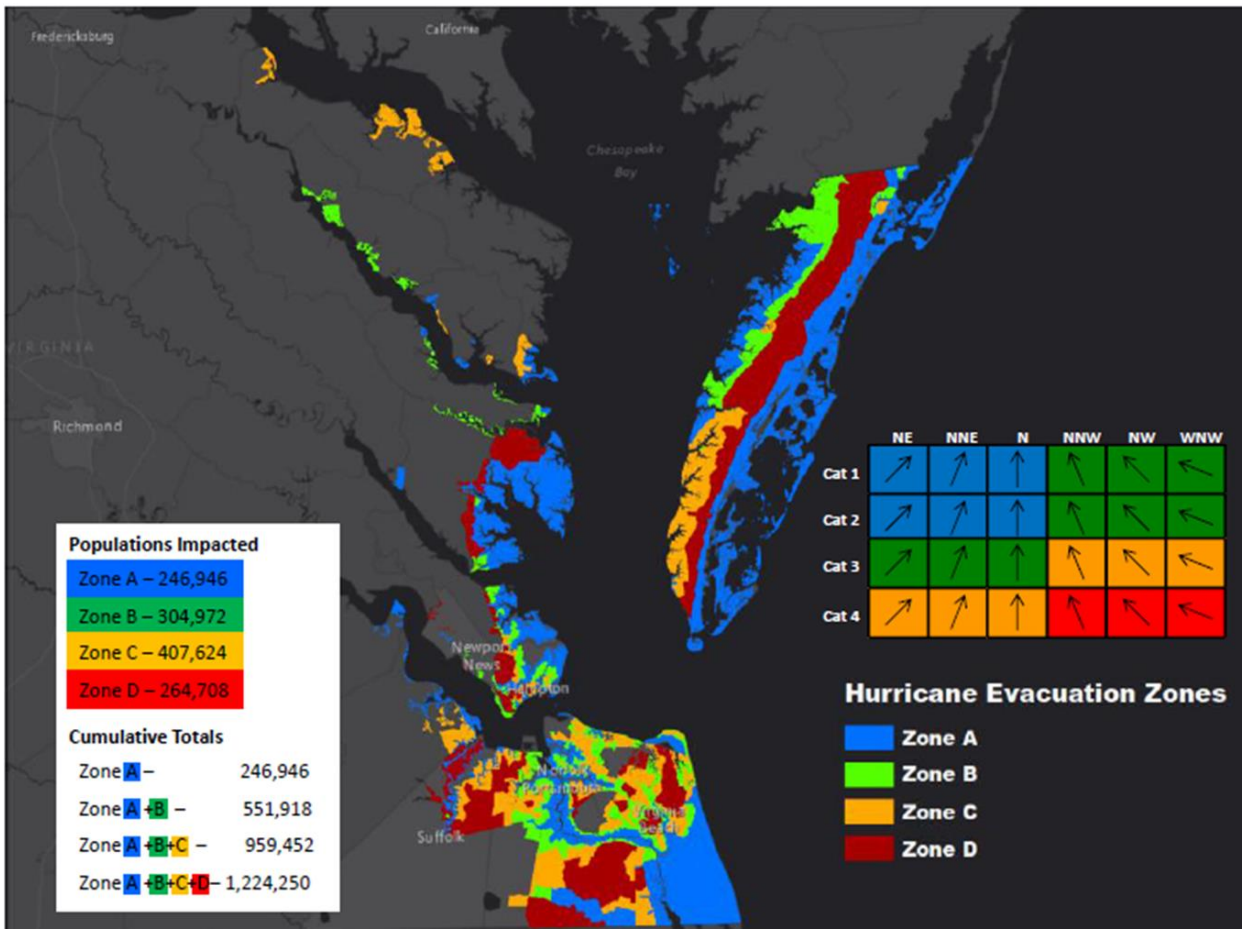
This approach incorporates the lessons learned from evacuations in the past. When a serious storm is expected to affect the Hampton Roads region, state and local emergency agencies are to determine which zones are most at risk and, if necessary, provide evacuation instructions. A severe

[17] http://www.vaemergency.gov/hurricane-evacuation-zone-lookup/

storm, cyclone, or hurricane may result in a call for the evacuation of Zone A, for example, while instructing residents of Zones B through D to shelter in place for the duration of the storm. Unlike a call for evacuation that creates confusion and panic, the zone approach to evacuation may reduce unnecessary travel, traffic congestion, reduce overcrowding at shelters, and unnecessary financial expenditures for those not in an evacuation area.

Figure 10

Evacuation Zones in the Hampton Roads Metropolitan Area



Source: Virginia Department of Emergency Management (2018)

Given that Virginia has prepared itself for an evacuation of the Hampton Roads region, what happened prior to the arrival of Hurricane Florence? To understand why Virginia issued its first mandatory evacuation order using the Regional Tiered Evacuation System, we must first look at the days prior to the potential arrival of Hurricane Florence rather than after Florence made landfall in North Carolina.

The question to evacuate a zone or multiple zones is fraught with uncertainty. This wicked problem is only compounded in Hampton Roads, which is likely to be adversely impacted by a severe weather event as many areas are low-lying and already prone to flooding. Hampton Roads, relative to many other major metropolitan areas, also has limited options in terms of evacuation routes. Furthermore, there are questions of how to evacuate residents who do not have private transportation and where to care for the homebound, disabled, and those with significant medical conditions. A

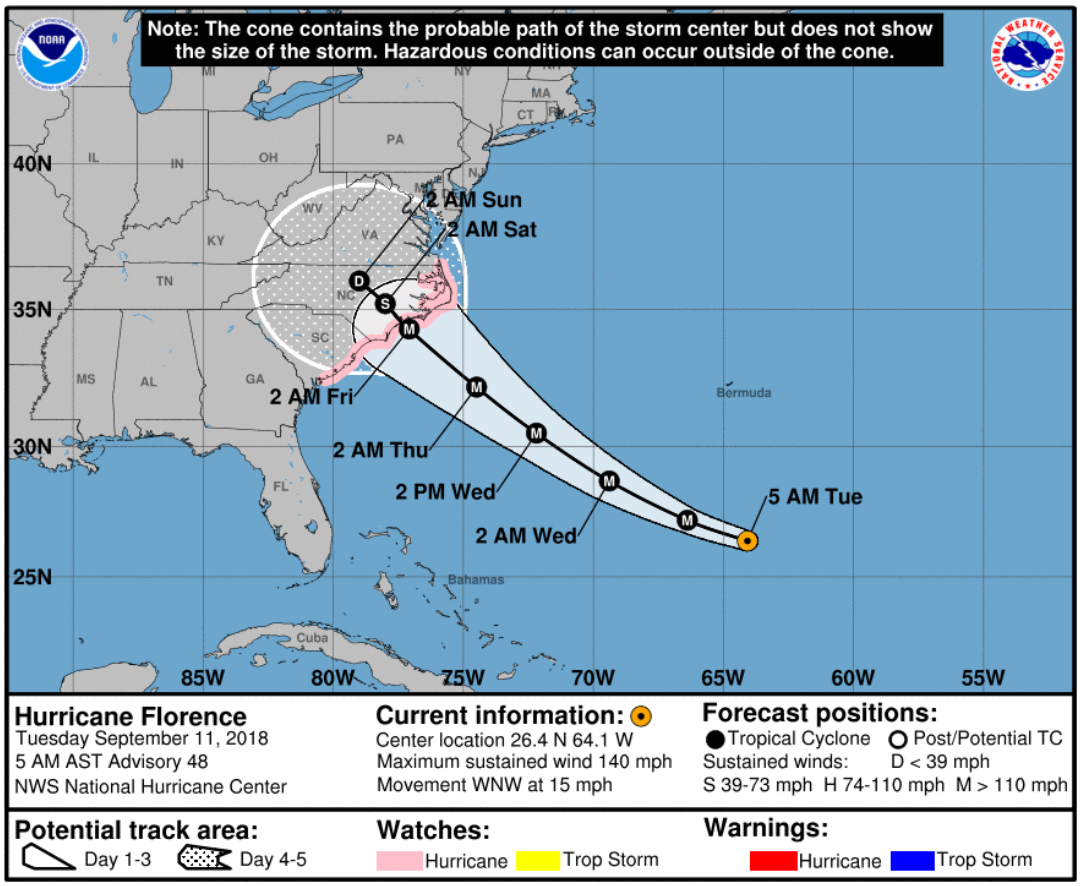
decision to evacuate is understandably not taken lightly given the costs imposed on evacuees, local governments, and the state government.

Furthermore, we must understand that the National Hurricane Center's (NHC) forecast cones are representations of the **probable** track of the center for a tropical cyclone. The forecast cone is a representation of uncertainty and evolves over time. As noted by the NHC, the entire track of a tropical cyclone is expected to remain in the forecast cone *roughly 60 to 70 percent of the time*.[18] We present the 5 am forecast cone on September 11th, 2018 for Hurricane Florence to illustrate the uncertainty associated with Florence's arrival. At this time, there was a significant probability that much of Hampton Roads would be impacted by Florence (Figure 11).

Figure 11

National Hurricane Center, Track Forecast Cone

Hurricane Florence, 0500 AST Update, September 11, 2018



Source: National Hurricane Center, Florence Graphics Archive (2018)

The NHC's discussion of Florence on the morning of September 11th was to the point: "A life-threatening storm surge is likely along portions of the coastlines of South Carolina, North Carolina, and Virginia, and a Storm Surge Watch has been issued for a portion of this area. All interests from South Carolina into the mid-Atlantic region should ensure they have their hurricane plan in place and follow any advice given by local officials."

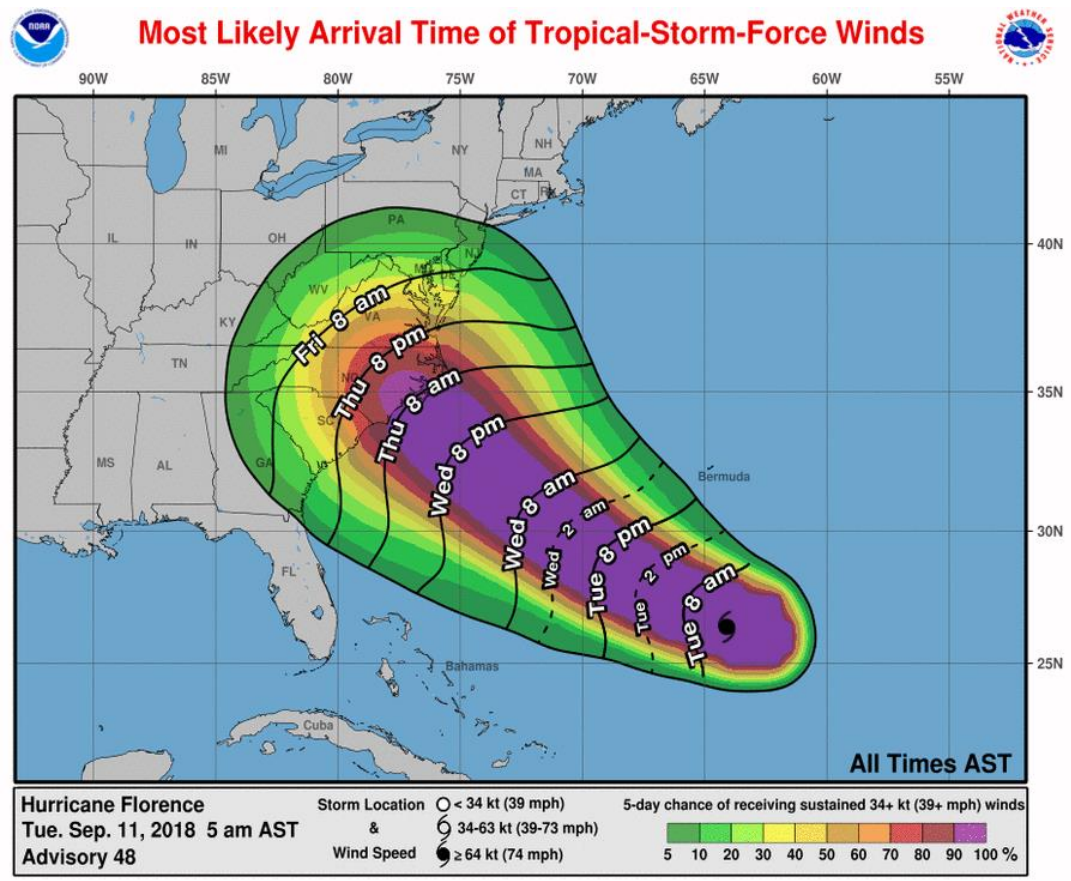
[18] https://www.nhc.noaa.gov/aboutcone.shtml

Even if one believed that Florence would make landfall in North Carolina, the NHC's wind projections on September 11th strongly suggested that much of Hampton Roads would be subject to Tropical Force winds (Figure 12). In other words, the question of what to do had to be made with information that, by its very definition, was uncertain but appeared to be highly probable that much of the Hampton Roads region would be negatively impacted by the approaching storm.

Figure 12

National Hurricane Center, Track Forecast Cone

Hurricane Florence, 0500 AST Update, September 11, 2018



Source: National Hurricane Center, Florence Graphics Archive (2018)

Using the Regional Tiered Evacuation System, the Governor of Virginia ordered the evacuation of Zone A in Hampton Roads. The evacuation order affected approximately 245,000 residents of the region. At the same time, the Commonwealth implemented the 2006 State Managed Shelter program, establishing shelters for 5,775 individuals. The Commonwealth partnered with private sector contractors for the provision of these shelters. The implementation of the 2006 State Managed Shelter Program (CNU, WM, and VCU) and other shelter plans led to over $31 million in costs. These costs, however, were shared between Virginia and FEMA. FEMA paid approximately $23 million while Virginia bore almost $8 million of the total shelter cost.

While it is appropriate to reflect on the evacuation process and ask whether it can be done more efficiently and effectively when the next storm approaches Virginia, we must be careful to avoid facts not in evidence to criticize the decision to evacuate. While Florence's impact on Hampton Roads, in

retrospect, was relatively mild, this information was not available to decision-makers on September 11th, 2018. The nature of the problem prevents a certain solution from being known until the event has passed, at which time it is too late to take preventative action to mitigate the impact of an adverse event. Simply put, you have to decide before all the facts are known, and sometimes the correct decision made with uncertain information will appear to be the wrong one after the fact.

One potential critique is that the Commonwealth 'spent too much for too little' with regards to shelter services. At face value, the relatively high unit cost per potential evacuee seems to lend credence to this argument. We argue, however, that this is the wrong question. The question should be whether the Commonwealth should spend resources building, maintaining, and servicing shelters that, in many years, will go unused? In all likelihood, establishing and funding such a network of shelters would be costlier in the long-run than contracting for shelter services when necessary.

Lastly, we need to recognize that the prevention of the loss of life can be valued and this value can inform our decision making. Using guidelines from the federal government on the Value of a Statistical Life, we estimate that each life saved through an evacuation-sheltering plan is worth approximately $5.5 million (this the lowest of the estimates from the federal government). A simple thought experiment provides insight. For example, if Florence has struck Hampton Roads and the evacuation-sheltering plan had saved 10 lives, the value of the lives saved would itself have outweighed the total cost of the sheltering plan.

Final Thoughts

It's a matter of when, not if.

Our estimates suggest that the cost of a Florence-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 decade following a hurricane.

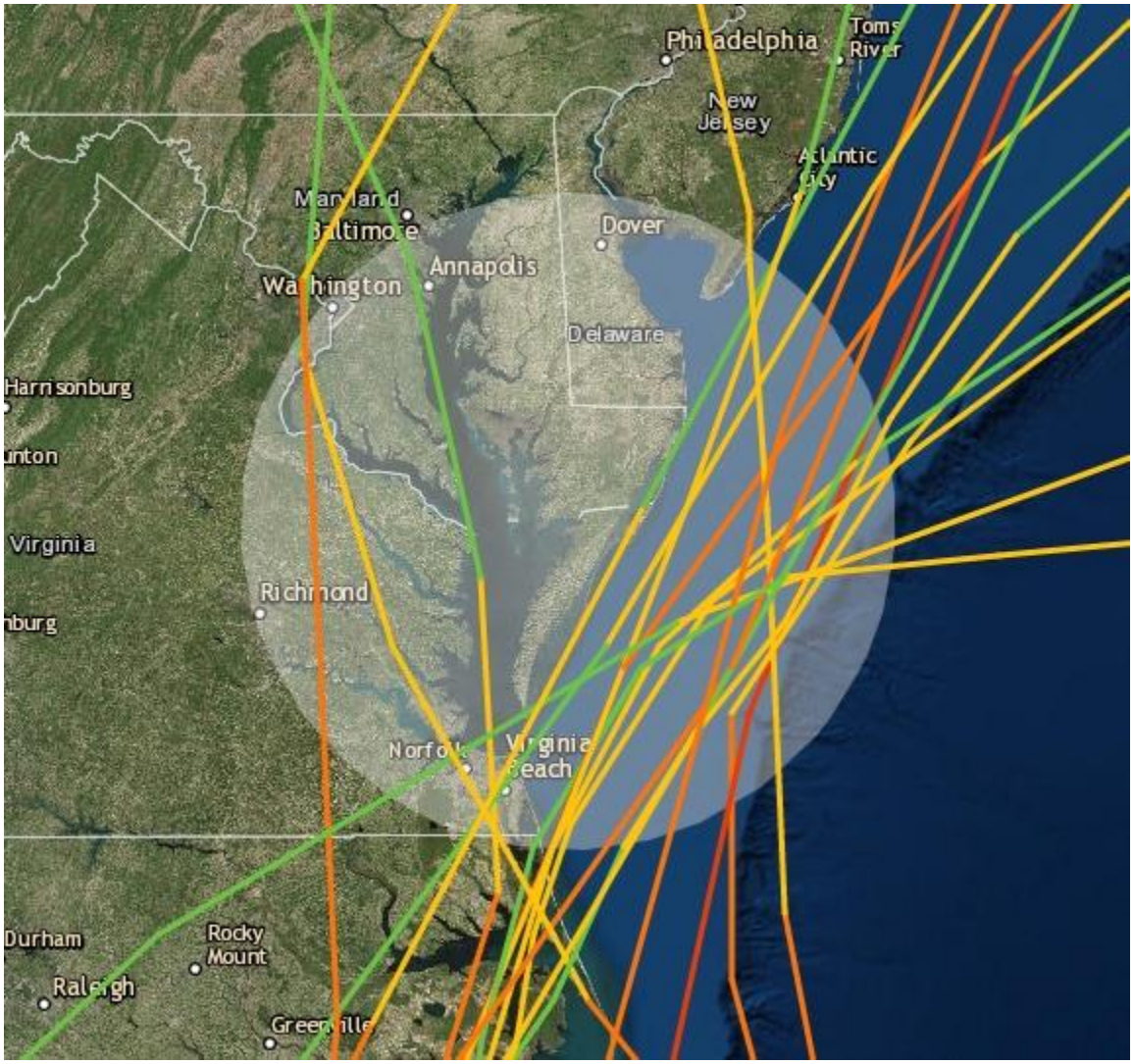
The historical record shows that the Commonwealth, and Hampton Roads in particular, has been struck by hurricanes in the past. While geography may lower the likelihood of a hurricane directly making landfall in Hampton Roads, the well-documented hurricane of 1821 illustrates that at some point, there will be a major weather strike on Hampton Roads. Figure 13 illustrates that the Commonwealth has not been struck by a Category 3 or higher hurricane from 1851-2017. While we cannot know the exact timing, we can be certain that, at some point, Hampton Roads will face the prospect of being in the bullseye of a hurricane.

One possible reaction to such an uncertain event is to dismiss the possibility that it will ever occur. This is obviously not a prudent course of action. Likewise, acting as if Hampton Roads will be struck every year by a hurricane is also imprudent. There are, however, policy issues that we need to work on today that will also reduce the impact of a hurricane.

First, we need, as a region, to continue tackle 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 conservation. 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.

Figure 13

Tropical Storms and Hurricane Tracks – 1851 to 2017



Source: Washington Post (2018). Tropical storms and hurricane tracks through the Mid-Atlantic since 1851. Green indicates tropical storm strength, yellow category one hurricane, orange category two hurricane, and red category three hurricane. https://www.washingtonpost.com/news/capital-weather-gang/wp/2017/07/13/why-a-single-hurricane-has-not-directly-hit-virginia-maryland-or-delaware-since-1851/?utm_term=.633f6356447a. Also available at: https://coast.noaa.gov/digitalcoast/tools/hurricanes

Second, we should seriously consider whether or not 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 lessons of Hurricane Rita and Harvey is that many people may end up better off by sheltering place. Strengthening residences will likely reduce injuries and the loss of life, when sheltering in place is warranted to by the type of storm approaching Hampton Roads. 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, the uncertain nature of hurricanes means the Commonwealth should not invest resources in maintaining a system of shelters. Shelters (and warehousing the goods needed for shelters to operate) are expensive to maintain relative to the uncertain demand for their use. The private sector can more aptly plan for these expenses in many cases. Instead, the Commonwealth could budget for the anticipated costs of a sheltering program and apportion the costs to an emergency fund over time akin to the Revenue Stabilization Fund. Such a fund would also mitigate arguments about the costs of using contractors to operate shelters, which are always easier to make in hindsight.

Given that tens, if not hundreds, of thousands of Virginians would find themselves displaced and out of work following a major hurricane strike on Hampton Roads, it is now time to prepare for this eventuality. As the saying goes, “Time and tide wait for no man.”