The Economic Impact Of A Hurricane On Hampton Roads

THE ECONOMIC IMPACT OF A HURRICANE ON HAMPTON ROADS

When clouds are seen, wise men put on their cloaks;
When great leaves fall, then winter is at hand;
When the sun sets, who doth not look for night?
Untimely storms make men expect a dearth.

– "Richard III," Act 2, Scene 3

The rain began to fall on Norfolk in the early morning of Sept. 2, 1821. Within two hours, winds reached gale force, increasing to hurricane force by 11:30 a.m.[1] When the winds and rain abated that afternoon, residents emerged to a scene of devastation. The Norfolk Herald recorded an account of the hurricane's passage: "From half past 11:00 until half past 12:00, so great the fury of the elements, that they seemed to threaten a general demolition of everything within their reach. During that period the scene was awful. There was the deafening roar of the storm, with the mingled crashing of windows and falling of chimneys, while the rapid rise of the tide threatened to inundate the town."

For the Virginia Beach-Norfolk-Newport News metropolitan statistical area (MSA), also referred to as the Hampton Roads MSA, the question is not if, but when a major tropical storm or hurricane will impact the region again. Even a relatively weak hurricane would likely cause significant damage to property, displace residents and reduce economic activity. Hurricane Matthew, which had weakened to a post-tropical cyclone by the time it skirted the coast of Hampton Roads in October 2016, provided a reminder of the region's vulnerability to a major storm.

Matthew arrived in a region already saturated by rain. In the previous month, rainfall totals approached 50% of the annual average. In just the day prior to Matthew's transit through Hampton Roads, rainfall totals approached 25% of the annual average. Flooding from rainfall, not wind, was the primary cause of damage. Matthew's relative weakness and track fortunately meant there was no appreciable storm surge. Yet, even though Matthew was a relatively weak storm when it passed through Virginia, Jeffrey D. Stern, state coordinator for the Virginia Department of Emergency Management (VDEM), estimated that Matthew caused nearly $500 million in damage.[2]

The damage inflicted by Matthew resulted in 2,661 approved applications to the Federal Emergency Management Agency's (FEMA) Individuals and Households Program (IHP).[3] Of the $10.2 million in approved applications, the majority (about $8.2 million) was for housing assistance. FEMA also provided approximately $15.9 million in public assistance grants. The National Flood Insurance Program (NFIP) paid out more than $10 million in claims. Many damaged residences, however, were not covered by flood insurance. Some houses and public infrastructure remain in a state of disrepair to this day.

1 Gale-force winds equal or exceed 32 miles per hour (mph) and can range up to 63 mph; hurricane-force winds equal or exceed 73 mph (National Weather Service, 2019).

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

3 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.

The estimated costs from Hurricane Matthew do not include the numerous volunteer agencies that 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.

We should consider ourselves fortunate. Aside from the physical damage from rain and wind, Matthew appears to have had a negligible impact on economic activity in Hampton Roads. Seasonally adjusted nonfarm payrolls (jobs) in October 2016 increased by 0.36% year-on-year, in line with increases in previous months. Monthly retail sales also increased year-over-year, suggesting that while some sales may have been displaced during the storm, the storm did not significantly impact sales over the entire month. The median sales price of residential housing in October 2017 was 5.5% higher than October 2016 and sales activity increased year-over-year.

While Hampton Roads has not been struck by a Category 3 or higher hurricane in over 150 years, past may be prologue. The physical and economic damages from a major hurricane making landfall in our region would be catastrophic. We estimate that residential housing would bear the brunt of the approximately $18 billion in wind and water damage. More than 200,000 residents would be displaced in the immediate aftermath of the storm, with almost 16,000 seeking accommodation in public shelters. In the first year after the hurricane, over 150,000 jobs could be lost, and economic activity could decline by over $20 billion. All told, the physical and economic impacts of a Category 3 hurricane making landfall in Hampton Roads could exceed $40 billion in the year following the storm.

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.

Whether a major hurricane will impact Hampton Roads is not a question of if, but when. Understanding the extent of the potential 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 our cities. Improving the economic resiliency of the region to these future storms complements the ongoing efforts to mitigate and adapt to sea level rise.

A Primer On Hurricane Strength

To understand how a major storm (such as Superstorm Sandy in 2012) or hurricane (such as Hurricane Michael in 2018) could affect Hampton Roads, we first need to briefly discuss the categorization of hurricanes. A common measure of hurricane strength is the Saffir-Simpson Hurricane Wind Scale (Table 1), which ranges from Category 1 to Category 5. Hurricanes that reach Category 3 are classified as major hurricanes due to the potential for physical damage and loss of life. **In general, damage rises by a factor of 4 for every category increase; thus, a Category 3 hurricane will, on average, create 16 times the damage as a Category 1 hurricane.**

TABLE 1

SAFFIR-SIMPSON HURRICANE WIND SCALE

CATEGORY	SUSTAINED WINDS	TYPES OF DAMAGE DUE TO HURRICANE WINDS
1	74-95 mph 64-82 kt 119-153 km/h	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph 96-112 kt 178-208 km/h	**Devastating damage will occur:** Well-built frame homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 kt 209-251 km/h	**Catastrophic damage will occur:** Well-built frame homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher	**Catastrophic damage will occur:** A high percentage of frame homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Source: National Hurricane Center (2019), https://www.nhc.noaa.gov/aboutsshws.php

The Most Expensive Storms In U.S. History

Advances in weather forecasting and surveillance have, in most cases, led to dramatic reductions in the loss of life from major storms. In terms of known fatalities, the 1900 Galveston Hurricane had estimated sustained winds greater than 120 mph and a storm surge of approximately 20 feet. The estimated loss of life was between 6,000 and 12,000 people. More recently, Hurricane Maria struck Puerto Rico as a Category 5 hurricane with maximum sustained winds of 175 mph and a reported maximum storm surge of 3 to 5 feet.[6] Damage to the island was undeniably catastrophic, with most of the electrical, sanitation and communication infrastructure failing in the aftermath of the storm. Many of the fatalities associated with Hurricane Maria, however, occurred after the storm.

As the damage to public and private infrastructure increases, the impact of the hurricane may linger, leading to more deaths after it has passed than when it made landfall. The Milken Institute School of Public Health at George Washington University recently 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.[7] Every social and age group experienced increased mortality during this period. Individuals in lower socioeconomic development communities and males 65 or older experienced the highest rates of excess mortality. Partly as a result of the hurricane, the U.S. Census Bureau estimated that Puerto Rico's population declined by 4.3% from 2017 to 2018.

6 https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf.
7 Milken Institute School of Public Health, (2018), "Ascertainment of the Estimated Excess Mortality from Hurricane Maria in Puerto Rico," retrieved from Washington, D.C.: https://prstudy.publichealth.gwu.edu/.

Table 2 illustrates that nine of the 10 most expensive storms in U.S. history have occurred this century. 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-plus 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 to 26 people per square mile in the rest of the continental United States.[8] More people, homes and businesses are now at risk from a major storm.

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 appear to be positively correlated with the global average rise in sea level temperatures.[9] While projections on the number of major storms may be uncertain, the intensity and rainfall associated with these storms are expected to increase in the future. Rising sea levels and temperatures mean that storm surge risk is predicted to increase with future storms.[10]

Hurricane Harvey in 2018 is an 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, the heat stored in the ocean, was the highest on record. After Harvey's passage, ocean heat content fell sharply. Harvey not only was "fueled" by record ocean temperatures, but it also accumulated more moisture, which, in turn, increased rainfall and flooding after landfall.[11] If average ocean temperatures continue to rise, we can reasonably expect that future hurricanes will become "wetter," increasing the odds of flooding relative to historical storms.

8 K. Dapena (Sept. 29, 2018), "The Rising Costs of Hurricanes," *The Wall Street Journal*, retrieved from https://www.wsj.com/articles/the-rising-costs-of-hurricanes-1538222400.
9 F. Estrada, W.W. Botzen and R.S. Tol (2015), "Economic losses from US hurricanes consistent with an influence from climate change," *Nature Geoscience*, 8(11), 880.
10 K.J. Walsh, J.L. McBride, P.J. Klotzbach, S. Balachandran, S.J. Camargo, G. Holland, G. and A. Sobel (2016), "Tropical cyclones and climate change, *Wiley Interdisciplinary Reviews: Climate Change*, 7(1), 65-89.
11 K.E. Trenberth, L. Cheng, P. Jacobs, Y. Zhang and J. Fasullo (2018), "Hurricane Harvey links to ocean heat content and climate change adaptation," *Earth's Future*, 6(5), 730-744.

TABLE 2

TOP 10 HURRICANES IN TERMS OF DIRECT DAMAGES: UNITED STATES, 2000-2018

Rank	Year	Name	Category	State	Estimated Direct Damages (Millions of 2018 Dollars)	Estimated Fatalities
1	2005	Katrina	3	FL, LA, MS	$138,861	1,833
2	2017	Harvey	4	TX, LA	$128,053	107
3	2017	Maria	5	PR	$93,222	3,057
4	2012	Sandy	TS	Eastern Seaboard	$76,560	285
5	2017	Irma	4	FL	$54,294	92
6	1992	Andrew	5	FL, LA	$48,860	65
7	2008	Ike	2	LA, TX	$34,429	103
8	2005	Wilma	3	FL	$27,009	23
9	2004	Ivan	3	AL, FL	$25,017	92
10	2004	Charley	4	FL	$20,089	15

Sources: FEMA (2018), NOAA (2018) and authors' calculations. Tropical Storm Sandy is included, given the magnitude of damages.

Hurricanes In Virginia And Hampton Roads

While historical records may not fully include all the major storms and hurricanes that have made landfall in Virginia, the first recorded hurricane was on Aug. 24, 1635 (Table 3). In September of 1667, records show that the Chesapeake Bay rose 12 feet, destroying many homes in Jamestown. Less than 100 years later, a hurricane caused the Chesapeake Bay to rise a reported 15 feet and destroyed Fort George at Old Point Comfort. Regardless of the incompleteness of early records, it is clear that major storms have struck Virginia in the past. **We should avoid letting the recent past bias our decision making. Major hurricanes have struck Hampton Roads in the past and will do so again.**

TABLE 3

HISTORICAL MAJOR STORMS AND HURRICANES IN THE COMMONWEALTH OF VIRGINIA

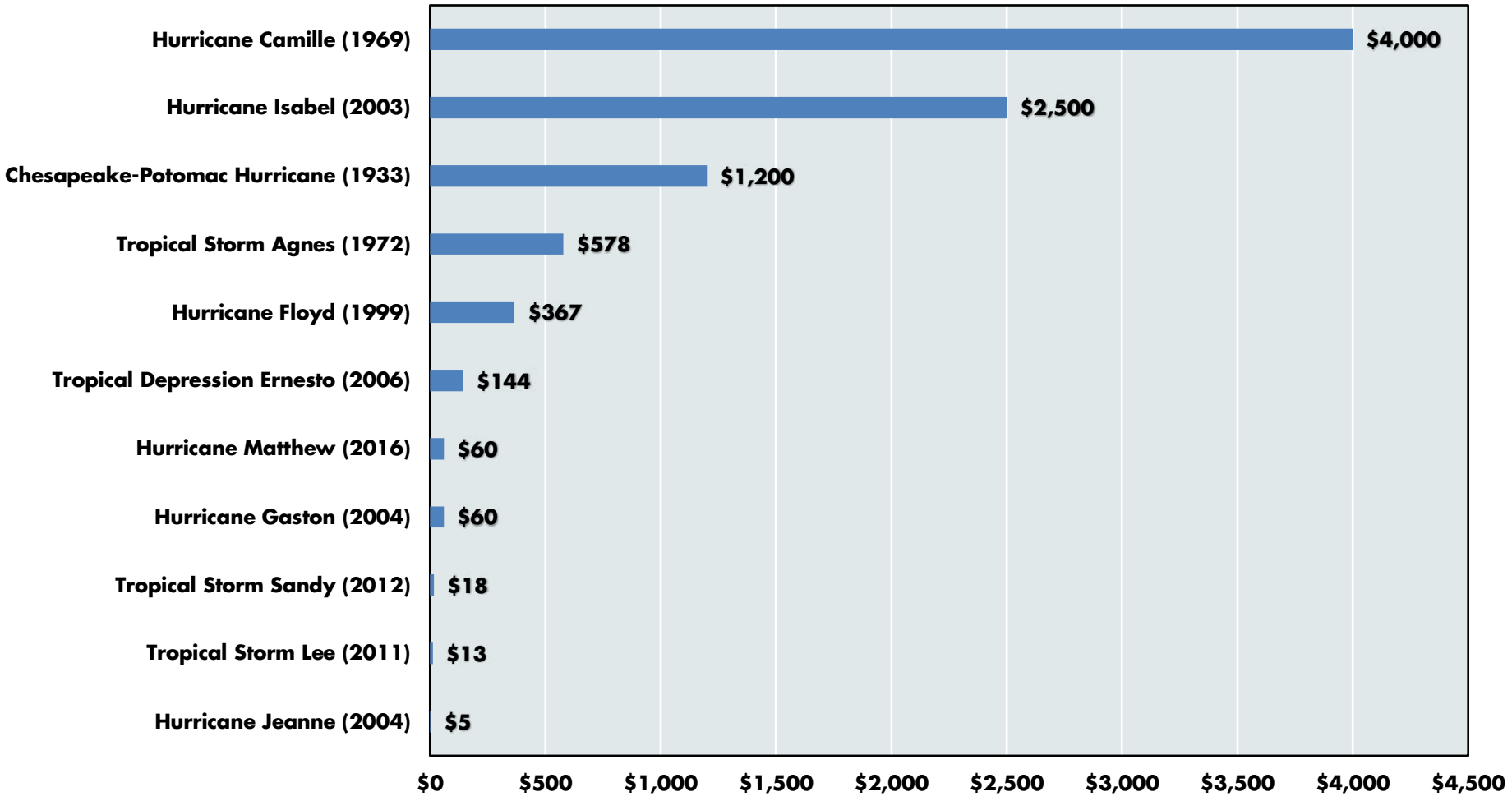
Period	Year of Major Storm or Hurricane
1600s	1635, 1667, 1693
1700s	1749, 1775, 1769, 1785
1800s	1804, 1821, 1846, 1876, 1878, 1879, 1888, 1889, 1893, 1894, 1896 (2), 1897, 1899
1900s	1903, 1924 (2), 1926 (2), 1928, 1932, 1933 (2), 1935, 1936, 1944, 1952, 1953, 1954, 1955, 1959 (2), 1960, 1964, 1969, 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 also recorded severe weather events.

Graph 1 illustrates the physical damages for a select number of hurricanes that have, in some form, passed by or through Virginia in the past century. The damages represent the total impact of the storms on the U.S., not on Virginia. Hurricane Camille in 1969 tops the list with approximately $4 billion in damages in 2018 dollars, followed by Hurricane Isabel in 2003.

GRAPH 1

ESTIMATED PHYSICAL DAMAGE IN MILLIONS OF 2018 DOLLARS, SELECTED STORMS AND HURRICANES AFFECTING THE COMMONWEALTH OF VIRGINIA



Sources: Virginia Department of Emergency Management and the National Hurricane Center. 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.

The Norfolk-Long Island Hurricane Of 1821

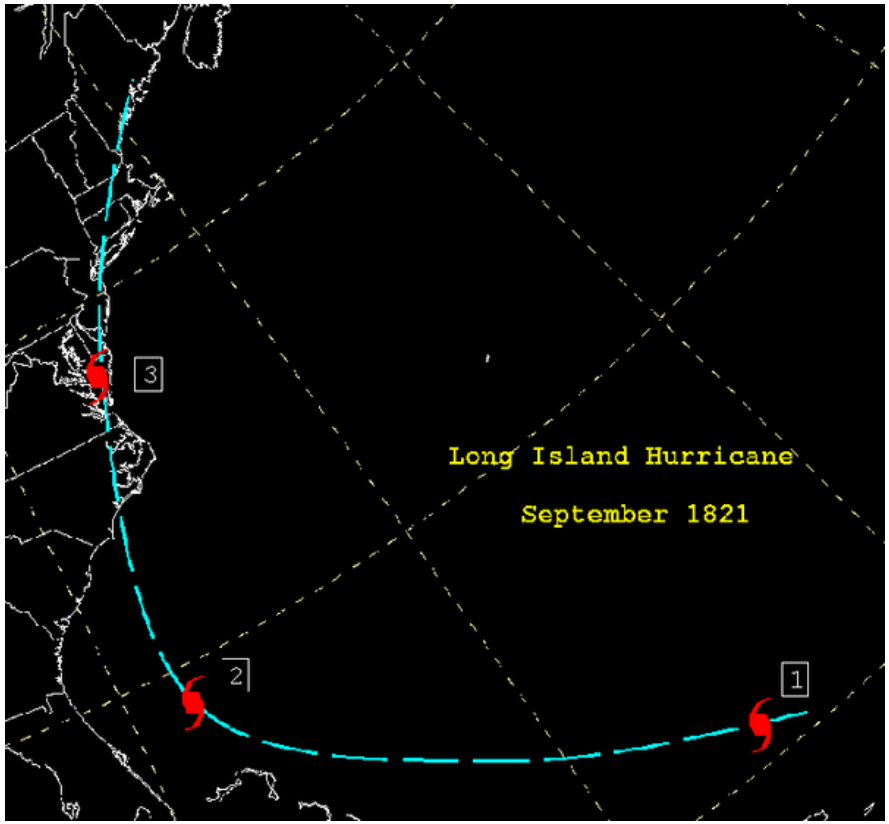
If there is a worst-case scenario for Hampton Roads, it may be similar in intensity to the Norfolk-Long Island Hurricane of 1821. Figure 1 illustrates the estimated track of the 1821 storm, including the passage of the eye of the estimated Category 3 hurricane over Norfolk. Weather observations from the time reported gale-force winds in Norfolk on Sept. 3, 1821, accompanied by at least a 10-foot storm surge. The storm continued north to the New York-New Jersey area without a significant loss of strength, with hurricane-force winds and a reported storm surge up to 20 feet in Atlantic City.[12] While significant in terms of damage, the numbers of people and structures at risk were considerably lower than they would be today. The U.S. Census of 1820 reported that the population of the Commonwealth of Virginia was 1,065,379, of which 15,478 resided in Norfolk County.

In contrast, in 2018, there were 8,517,865 Virginians and 244,076 of those called Norfolk home. In 1820, the combined population of New York City and Washington, D.C., was almost 140,000, compared to approximately 10 million in 2018. A Category 3 hurricane like that of 1821 would place millions of people and tens (if not hundreds) of billions of dollars' worth of public and private assets along the Eastern Seaboard at risk today. A 2014 simulation by Swiss Re, an international reinsurance company, estimated that wind and storm surge damages from a hurricane like that in 1821 would exceed $40 billion and $60 billion, respectively. The total economic impact would likely exceed $150 billion for the United States.[13]

Yet, we should be careful in our thinking with regard to the reported magnitude of a tropical storm or hurricane. Florence in 2018, for example, was only a Category 1 hurricane when it made landfall near Wilmington, North Carolina. 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 came ashore in densely populated areas of the Eastern Seaboard, it resulted in significant damage and continues to rank among the 10 most expensive storms to strike the United States in the last three decades.

FIGURE 1

ESTIMATED TRACK OF THE 1821 NORFOLK-LONG ISLAND HURRICANE



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

12 M. Linkin (2014), "The big one: The East Coast's USD 100 billion hurricane event," Swiss Re.
13 M. Linkin (2014), "The big one: The East Coast's USD 100 billion hurricane event," Swiss Re.

What does this mean for the Commonwealth? Both Northern Virginia and Hampton Roads are relatively densely populated. 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 due to storm surge and flooding. And it is probable that wind damage would be in the billions of dollars. These, unfortunately, are the direct consequences of such a storm. If a future storm damaged infrastructure, housing and businesses, the economic impact could be greater than the direct damages of the storm. Recovery could take years. Simply put, a major storm or hurricane striking Hampton Roads or Northern Virginia could, in the worst case, rank among the costliest storms in U.S. history.

With this in mind, let's examine the impact of a major hurricane making landfall in Hampton Roads.

Estimating The Physical Damage From A Hurricane

Estimating the physical damage from a major storm is a journey in uncertainty. Every weather event is unique, and the estimates from any model are a product of the underlying assumptions. To explore the potential physical damages from a hurricane striking Hampton Roads, we modified the track and strength of Hurricane Florence, where the modified Category 3 storm makes landfall near the Virginia-North Carolina border (Figure 2). The modeled storm surge occurs at the worst possible time and generates the largest possible estimates in terms of damage.[14]

We used the HAZUS model to generate the damage estimates for a Category 3 hurricane making landfall in Hampton Roads. According to FEMA, the HAZUS model is a regional multihazard 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." FEMA developed HAZUS in concert with the National Institute of Building Sciences (NIBS). HAZUS estimates multihazard losses on 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 and earthquakes).

14 According to the National Hurricane Center, the maximum of the Maximum Envelope of Water (MEOW) provides a worst-case snapshot for a particular storm category under "perfect" storm conditions. For more information, see: https://www.nhc.noaa.gov/surge/momOverview.php.

FIGURE 2

MODIFYING FLORENCE TO IMPACT HAMPTON ROADS

Hurricane Florence (actual)

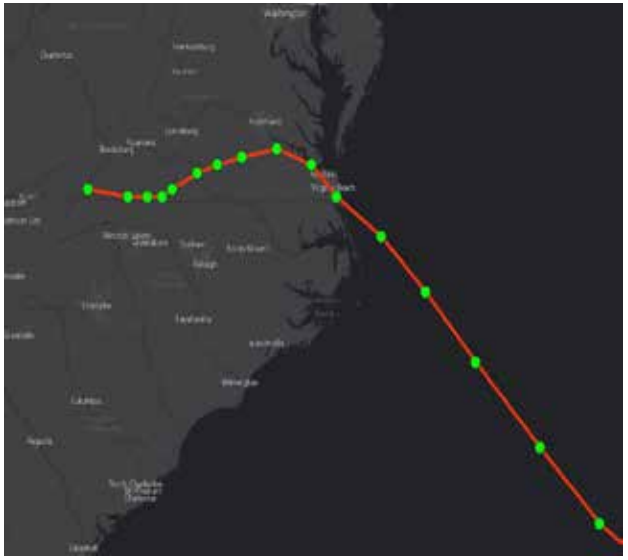
Landfall: Near Wilmington, North Carolina

Storm Surge: 6 feet

Rainfall: 30-plus inches

Speed at Landfall: slow

High Category 1 at landfall



Modified Hurricane Track

Landfall: Virginia-North Carolina Border

Storm Surge: Category 3

Rainfall: 36 inches

Speed at Landfall: slow

High Category 2 at landfall

Sources: NOAA (2018) and HAZUS (2018). Storm surge in the modified track is generated using the Maximum Envelope of Water Category 3 scenario.

Wind Damage

For Hampton Roads, HAZUS estimates that there are 580,120 buildings with an aggregate replacement value of $209.4 billion in 2014 dollars. About 92% of the physical structures are residential, followed by commercial (5.1%) and industrial (1.3%). On a valuation basis, 83% of the value is residential, followed by commercial (11.3%) and industrial (2.4%). All the building stock in Hampton Roads is considered at risk.

We estimate that 3% (20,137) of all the buildings in Hampton Roads would be at least moderately damaged by the winds from the Category 3 hurricane. Approximately 1,388 buildings would be severely damaged, while 1,114 buildings would be destroyed (Table 4). The physical damage and loss of contents would be approximately $4.1 billion for residential property, $197 million for commercial property and $129 million for other types of property. The hurricane would also result in approximately 1.8 million tons of debris, the majority of which is tree debris (63%), followed by brick and wood debris. The destruction of property would displace about 1,500 households and require short-term shelter for around 800 people.

TABLE 4

EXPECTED WIND DAMAGE BY OCCUPANCY TYPE, CATEGORY 3 HURRICANE STRIKING 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. Of the $209.4 billion in building stock in Hampton Roads, approximately $44.2 billion would be at risk from water damage.

Table 5 illustrates that over 33% of the number of buildings exposed to flooding risk would be damaged by the simulated Category 3 hurricane. Of the estimated 19,464 buildings that are damaged, 6,321 are destroyed. All the destroyed buildings in this scenario are residential. Water damage would generate 643,591 tons of debris. Most of the debris comes from 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.

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. More than 200,000 residents would be displaced in the immediate aftermath as a result of flooding. While many of these residents would find shelter with family or friends in the region, over 15,000 people would seek temporary accommodations in public shelters.

Combining the wind and water damage, the total physical damage from a Category 3 hurricane would approach $20 billion. Over half of the losses ($10.6 billion) would be borne by homeowners. Lastly, downed trees and damaged and destroyed structures would create over 2.4 million tons of debris, which would require more than 50,000 25-ton truck trips to landfills.

TABLE 5

EXPECTED WATER DAMAGE BY OCCUPANCY TYPE:
ESTIMATED BUILDING DAMAGE BY PERCENTAGE, CATEGORY 3 HURRICANE STRIKING 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

Sources: Dragas Center for Economic Analysis and Policy, Old Dominion University, and the Commonwealth Center for Recurrent Flooding Resiliency. Percentages are rounded to nearest 10th and may not sum to 100%.

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 storm striking the region would not only damage structures and displace residents, it also would impact economic activity. Damage to infrastructure may limit the ability of many to travel to work, and displaced residents may be far from their place of employment. Damage to businesses may result in reduced hours 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: people unable to work and businesses unable to operate due to storm damage.

Businesses that are directly impacted by the storm do not need as many supplies and reduce their orders accordingly. The decline in orders to suppliers is the indirect economic impact of the storm. As businesses that are directly and indirectly affected by the storm experience a slowdown in business activity, employment and output fall. The declines in employment and output ripple out through the economy. This third-order effect is known as the induced impact. In other words, because of the interconnectedness of the economy, the total economic impact of a hurricane is larger than the direct economic impact.

How Bad Could It Get? A Worst-Case For Hampton Roads

To examine the impact of a major hurricane on the economy of Hampton Roads, we have drawn upon historical data that reflect the direct physical damages discussed previously. Examining recent history, we selected Katrina, which struck New Orleans and the Gulf Coast as a Category 3 hurricane in 2005. While 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 percentage of the population is displaced by a major weather event.

Katrina remains the costliest hurricane to hit the United States. With a total estimated cost of $138 billion and well over 1,000 fatalities, Hurricane Katrina had a devastating impact on the economy of the New Orleans region. 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, a 17% loss in employment.

How would the Hampton Roads economy react if a major hurricane made landfall here? To estimate the economic impact of a Category 3 hurricane striking Hampton Roads, we calculated the annual change in employment from 2004 to 2006 by industry sector in the New Orleans MSA. We then applied these changes to the Hampton Roads workforce of 2018 to estimate the potential economic impact of a Category 3 hurricane on the regional economy.[15]

Table 6 illustrates the estimated economic impacts of a Category 3 hurricane on the Hampton Roads economy. The direct economic impact of the hurricane would be a loss of almost 95,000 jobs and $15 billion in output. When these direct impacts ripple throughout the regional economy, another 81,000 jobs would be lost, and output would decline by

15 We used JobsEQ software developed by Chmura Economics and Analytics. The software is based on regionalized input-output tables and makes estimates based on the relationships between industries.

almost another $8 billion. The overall economic impact would approach (if not exceed) one-quarter of the region's economic activity.

TABLE 6

ONE-YEAR TOTAL ESTIMATED ECONOMIC IMPACTS OF A CATEGORY 3 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 (in millions)	**-$4,152**	**-$901**	**-$1,622**	**-$6,676**

Sources: Quarterly Census of Employment and Wages (2019), Chmura Economics - JobsEQ and the Dragas Center for Economic Analysis and Policy, Old Dominion University. Percentages from the New Orleans MSA 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 7 illustrates the estimated impact on jobs by industry. 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 experience significant declines in employment, output and compensation. The government sector, for example, would shed almost 32,000 jobs. The decline in direct government employment would ripple throughout the regional economy, causing the loss of approximately another 56,000 jobs. In total, the economic impact on the public sector could result in the loss of almost 88,000 jobs.

TABLE 7

ESTIMATED IMPACT ON SELECTED INDUSTRY EMPLOYMENT (JOBS), CATEGORY 3 HURRICANE STRIKING HAMPTON ROADS

	Direct Impact	Indirect and Induced Impact	Total
Public administration	**-31,801**	**-55,839**	**-87,640**
Health care and social assistance	**-15,147**	**-7,028**	**-22,175**
Accommodation and food services	**-12,224**	**-2,228**	**-14,452**
Retail trade	**-9,353**	**-2,620**	**-11,973**
Other services	**-6,581**	**-2,050**	**-8,631**
Finance and insurance	**-4,366**	**-2,927**	**-7,293**
Manufacturing	**-2,693**	**-2,166**	**-4,859**
Administrative and support	**-3,497**	**-1,107**	**-4,604**
Arts, entertainment and recreation	**-3,119**	**-986**	**-4,105**
Professional, scientific and technical services	**-2,490**	**-1,582**	**-4,072**
Information	**-1,688**	**-1,656**	**-3,344**
Wholesale trade	**-1,417**	**-976**	**-2,393**
Transportation and warehousing	**-1,548**	**-824**	**-2,372**
Educational services	**-1,274**	**-351**	**-1,625**
Management of companies and enterprises	**-770**	**-528**	**-1,298**
Real estate and rental and leasing	**58**	**156**	**214**
Construction	**2,960**	**1,634**	**4,594**
Total	**-94,950**	**-81,078**	**-176,028**

Sources: Quarterly Census of Employment and Wages (2019), Chmura Economics - JobsEQ and the Dragas Center for Economic Analysis and Policy, Old Dominion University. Percentages from the New Orleans MSA are applied to 2017 employment and wages in the Hampton Roads MSA. Three sectors – forestry, mining and utilities – are not included due to disclosure requirements for the QCEW.

Summing Up The Estimates

In Table 8, we summarize the estimates of the physical and economic impacts. We estimate that physical damages from a Category 3 hurricane that makes landfall on the Virginia-North Carolina border, with significant storm surge, would exceed $20 billion. Almost all the buildings damaged during the hurricane would be residential. Tens of thousands of residents would be internally displaced within the region and more than 15,000 would need some form of public shelter. Approximately 2.5 million tons of debris would need to be removed from residential and other areas, requiring about 50,000 landfill trips.

The potential economic costs of the hurricane in the first year are just as staggering. More than 170,000 jobs would be lost, and economic output would decline by over $20 billion. These economic costs do not include the fiscal impact to local governments, as property tax revenue would fall due to the number of destroyed residences, and sales tax revenue would decline due to the loss of jobs. The Commonwealth's resources would be rapidly overwhelmed by the magnitude of the disaster and the state budget would also likely take a substantial hit.

TABLE 8

SUMMARY OF PHYSICAL AND ECONOMIC IMPACTS OF A KATRINA-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)**

Sources: Quarterly Census of Employment and Wages (2019), Chmura Economics - JobsEQ and the Dragas Center for Economic Analysis and Policy, Old Dominion University. Percentages from the New Orleans MSA are applied to 2017 employment and wages in the Hampton Roads MSA. HAZUS model estimates use a track similar to Hurricane Florence. Table represents the estimated one-year impact. Some double counting may occur, as some individuals may have residences physically damaged and have employment loss.

Are Military Bases Vulnerable?

Recognizing that climate change poses a threat to national security, the Department of Defense has engaged in a wide range of planning to prepare for current and future climate-driven threats. Among these threats is how a climate-related event would affect key military installations. In January 2019, the DOD highlighted 79 military installations most vulnerable to five climate-related hazards: recurrent flooding, wildfire, drought, desertification and permafrost thaw.[16] In March 2019, the DOD further refined the list to provide the military installations most at risk from climate change. **Four of our region's military installations were on the list (Table 9). One of the main drivers of perceived risk was recurrent flooding – flooding that would undoubtedly be exacerbated by a hurricane.**

In advance of a hurricane, military assets would be sent to sea and flown to other bases inland. Coastal bases, however, would remain at risk from the hurricane. If Naval Support Activity Hampton Roads 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, Marines, civilian employees and contractors. Some might argue that Hurricane Andrew's damage to Homestead Air Force Base in 1992 (near Homestead, Florida) contributed to its selection for closure by the Base Realignment and Closure Commission in the mid-1990s (see photo).

The potential for base closure and the relocation of military assets is not far-fetched. Hurricane Michael damaged nearly every structure on Tyndall Air Force Base, located 12 miles east of Panama City, Florida, in October 2018. With approximately one-third of the structures destroyed and operations impeded by the damage, some of the assets at Tyndall were relocated to Langley Air Force Base in Hampton.

16 Office of the Undersecretary of Defense for Acquisition and Sustainment, Department of Defense (January 2019), report on "Effects of a Changing Climate" to the DOD.

The damage to Tyndall was compounded by an impasse over disaster aid between Congress (and within Congress) and the administration.[17] Current estimates are that it will take billions of dollars and years to fully repair Tyndall Air Force Base. One can easily draw the conclusion that a similar level of destruction in Hampton Roads might spur arguments for the Navy, Air Force or other services to relocate personnel and assets to other locations in the United States.

Homestead Air Force Base, post-Andrew damage, 1992.

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

TABLE 9 DEPARTMENT OF DEFENSE, SELECTED MILITARY INSTALLATIONS AT RISK FROM THE IMPACT OF CLIMATE CHANGE			
Rank	**Installation**	**Service**	**State**
1	Hill Air Force Base (AFB)	USAF	UT
2	Beale Air Force Base (AFB)	USAF	CA
3	Vandenburg Air Force Base (AFB)	USAF	CA
4	Greeley Air National Guard Station (ANGS)	USAF	CO
5	Eglin Air Force Base (AFB)	USAF	FL
6	Patrick Air Force Base (AFB)	USAF	FL
7	Joint Base (JB) Andrews	USAF	MD
8	Malmstrom Air Force Base (AFB)	USAF	MT
9	Tinker Air Force Base (AFB)	USAF	OK
10	Shaw Air Force Base (AFB)	USAF	SC
26	Naval Air Station (NAS) Oceana	USN	VA
27	Naval Station (NS) Norfolk	USN	VA
28	Naval Support Activity (NSA) Hampton Roads	USN	VA
29	Naval Support Activity (NSA) Hampton Roads - Northwest	USN	VA

Source: Office of the Undersecretary of Defense for Acquisition and Sustainment, Department of Defense (March 2019), via communication with U.S. Rep. Jim Langevin.

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,[18] serves about 1.25 million residents in Coastal Virginia by providing clarity on whether to evacuate and how to do so. Figure 3 displays the zones in the region, 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 storm, cyclone or hurricane may result in a call for the evacuation of Zone A, for example, and instructions for 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, overcrowding at shelters and unnecessary financial expenditures for those not in an evacuation area.

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.

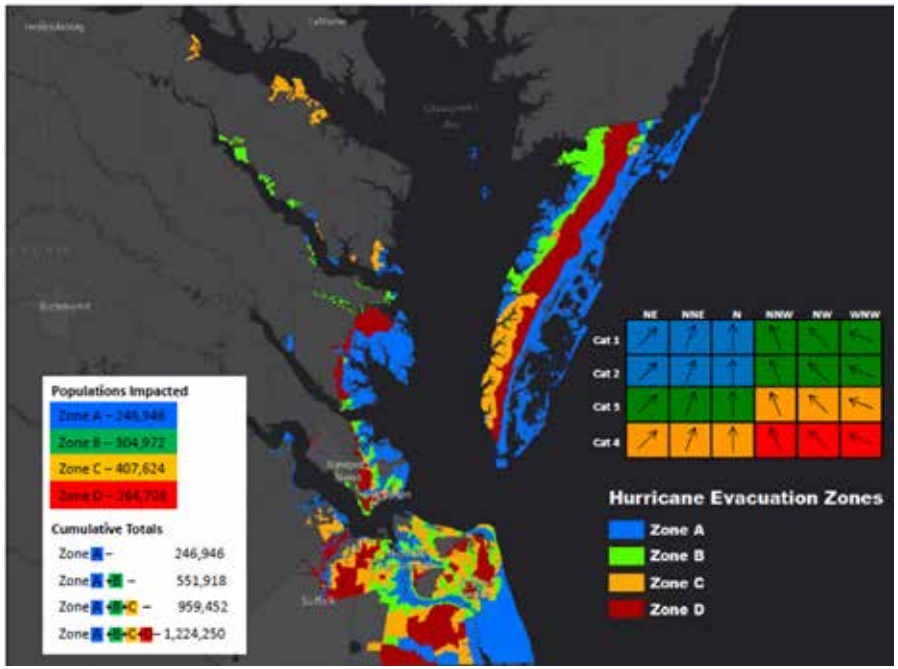
The question of whether to evacuate a zone or multiple zones is fraught with uncertainty. This wicked problem is only compounded in Hampton Roads, which is likely to be adversely impacted by a severe weather event, as many areas are low-lying and already prone to flooding. Relative to many other major metropolitan areas, Hampton Roads 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

18 https://www.vaemergency.gov/hurricane-evacuation-zone-lookup/.

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.

FIGURE 3

EVACUATION ZONES IN THE HAMPTON ROADS METROPOLITAN AREA



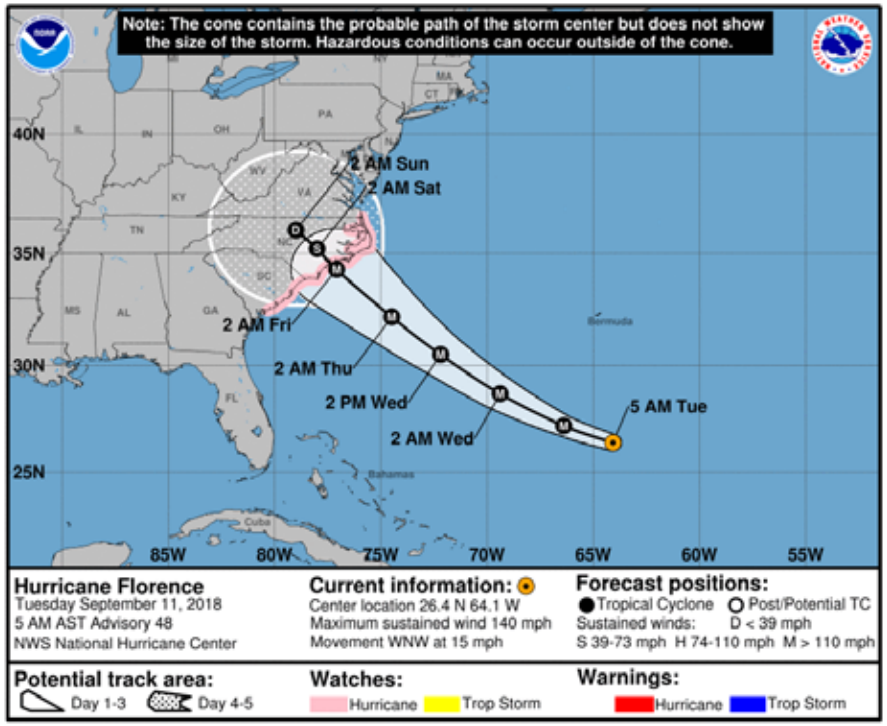
Source: Virginia Department of Emergency Management (2018)

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*.[19] We present the 5 a.m. forecast cone on Sept. 11, 2018, for Hurricane Florence to illustrate the uncertainty associated with the storm's arrival. At the time, there was a significant probability that much of Hampton Roads would be impacted by Florence (Figure 4).

19 https://www.nhc.noaa.gov/aboutcone.shtml.

FIGURE 4

NATIONAL HURRICANE CENTER, TRACK FORECAST CONE: HURRICANE FLORENCE, 0500 AST UPDATE, SEPT. 11, 2018



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

The NHC's discussion of Florence on the morning of Sept. 11 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."

Even if one believed that Florence would make landfall in North Carolina, the NHC's wind projections on Sept. 11 strongly suggested that much of Hampton Roads would be subject to tropical-force winds (Figure 5). 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 5

NATIONAL HURRICANE CENTER, TRACK FORECAST CONE: HURRICANE FLORENCE, 0500 AST UPDATE, SEPT. 11, 2018

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

Using the Regional Tiered Evacuation System, Gov. Ralph Northam 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 people. The Commonwealth partnered with private-sector contractors for the provision of these shelters. The implementation of the 2006 State Managed Shelter Program (involving Christopher Newport University, William & Mary and Virginia Commonwealth University) 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 and Virginia bore almost $8 million of the total shelter costs.

It is certainly appropriate to reflect on the decision to evacuate and the evacuation process, and ask whether these actions could have been done more efficiently and effectively, when the next storm approaches Virginia. We can also ask, given the information available at that time, whether the decision to evacuate was appropriate. Obviously, if the actual track of the storm and its impact on Hampton Roads had been known prior to landfall, then there would have been no need to evacuate. While Florence's impact on Hampton Roads, in retrospect, was relatively mild, this information was not available to decision makers on Sept. 11, 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 preventive 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 might appear to be the wrong one after the fact.

One potential critique is that the Commonwealth "spent too much for too little" with regard 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 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 is the lowest of the estimates from the federal government). A simple thought experiment provides insight: If Florence had struck Hampton Roads and the evacuation-sheltering plan saved 10 lives, the value of the lives saved would itself have outweighed the total cost of the sheltering plan.

Final Thoughts

It's only a matter of time before Hampton Roads is struck by a major hurricane.

On Aug. 27, 1668, a storm lashed the Chesapeake Bay with gale-force winds and rain that, by some accounts, lasted for over 24 hours. When the rain and winds finally abated on Aug. 28, 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."[20]

Our estimates suggest that the cost of a major hurricane striking Hampton Roads would be in the billions, if not tens of billions, of dollars. For a Category 3 hurricane, we estimate that 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 our region. 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 bull's-eye 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 can work on today that will reduce the impact of a hurricane.

First, we need, as a region, to continue to 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 conversation. **We should accelerate efforts to mitigate, where possible, the impact of sea level rise. Where possible, we should also look at development more closely to ensure we are not making flooding worse.**

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 lessons of Hurricanes Rita and Harvey are that many people may end up better off by sheltering in place. Strengthening residences will likely reduce injuries and the loss of life, when sheltering in place is warranted by the type of storm approaching Hampton Roads. The Commonwealth should ensure that essential facilities (such as hospitals, fire stations and police stations) have electrical generation equipment well above ground to avoid the catastrophic events and loss of life that occurred post-Katrina. While some may complain

20 R.D. Whichard (1959), *The History of Lower Tidewater Virginia*, New York: Lewis Historical Publishing Co. Inc.

about spending public funds now, such expenditures will seem trivial if the 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 Virginia's 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 of thousands of residents 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."