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Tropical cyclones (TCs) pose a persistent threat to North Carolina. The state's coastal plain and outer banks lie between 78 and 75 degrees W, farther east than any other southeastern state. In the last 150 years there have been more than 400 tropical and subtropical cyclones that have affected the state. This project seeks to examine what has become a recurring problem. The storms come, they flood, and the most vulnerable members of society lose everything. Major research questions include: 1) How do the geographic extent of the individual floods compare to the 100-year floodplain and its margins? 2) How many buildings fell within the flooded area? 3) How do the individual floods compare to one another, and what factors explain their differences? The methodology for this study used NASA Landsat 5 and NOAA aerial imagery to examine the extent of the flooded area. Supervised and unsupervised land cover classifications were created to compare the floods on a pixel-by-pixel level. Key results from this study included the number of total buildings in the study area that had been flooded in any one or all of the TCs, the observation that TC Matthew was by far the most disastrous of the three TCs studied, and that both TCs Matthew and Florence met or exceeded the defined 100-year floodplain in the area of study. Although this study is limited in scope, it may provide a stepping stone to further examination of how best to deal with the new reality of 100-year floods every decade in a socially vulnerable urban landscape.

EXAMINING NORTH CAROLINA'S RECENT TROPICAL CYCLONE HISTORY:

TWENTY YEARS ON THE NEUSE RIVER

by

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

Background

Tropical cyclones (TCs) are inevitable in North Carolina. Data from the North Carolina Climate Office (NCMO) show that, since 1851, 83 tropical cyclones have made direct landfall in North Carolina, seen in Figure 1 (NOAA).

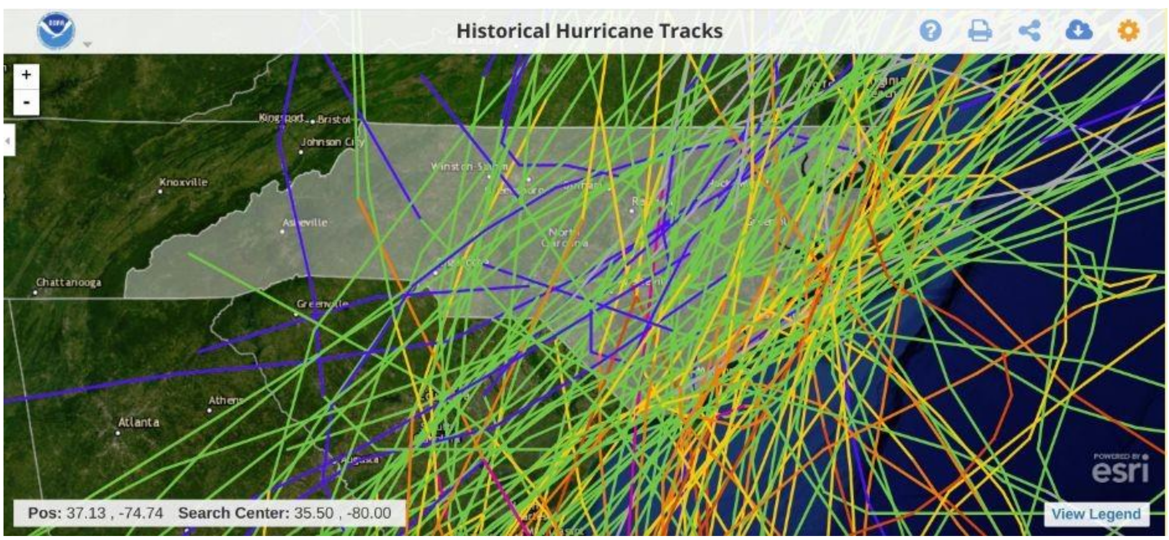


Figure 1.1. All Category 1-5 Landfalling TCs in North Carolina, 1851-2018. Source. NOAA https://coast.noaa.gov/hurricanes/.

The average return interval is 2.02 years, and in any given year there is a 49% chance of a TC making direct landfall in North Carolina (NCMO, 2018). Flooding problems have been magnified by nearly exponential population growth and the extent of impermeable land cover. From 1975-2018, the population of North Carolina doubled from 5.2 million to 10.5 million. Private residences, urban areas, and commercial and industrial locations also grew rapidly during the period. The final exacerbating factor is climate change. In the last 45 years, the amount of CO_2 in the atmosphere has increased from 332 parts per million (ppm) to 411 ppm, in the process increasing the average global temperature by 0.6° Celsius (Lindsey, 2018). A one-degree Celsius increase in temperature is enough to create a 7% increase in the amount of water vapor saturated air can hold (Coumou and Rahmstorf, 2012).

Figure 1.2. North Carolina River Basins. Source. https://www.ncpedia.org/anchor/mapping-rainfall-and)

The Neuse River is one of North Carolina’s longest rivers. Its 442-km course reaches from just north of Raleigh to the Pamlico Sound, where it joins the Tar and Pamlico Rivers. According to the U.S. Census Bureau, the greatest amount of population growth within the Neuse River Basin occurred in Wake County, where the population grew from 265,000 to 1.1 million from 1975-2018 (Census Bureau, 2018). Another additional factor is the flat terrain of the coastal plain and Neuse River Basin, which leads to floods that reach miles away from the river channel. In September and October 1999, three TCs tracked through eastern North Carolina. The total precipitation from the three storms ranged from 550-660 mm in the central Neuse River basin. Flooding lasted for several weeks in eastern North Carolina. At the height of flooding, the USGS recorded peak flood stages at Goldsboro of 8.79 m and discharge of 1,090 m^3/sec and at Kinston of 8.45 m with discharge of 1,028 m^3/sec. The flooding around Goldsboro was classified as a 50-year recurrence interval, while Kinston's flooding was marked at a 50- to 100-year recurrence interval. Seventeen years later, TC Matthew tested North Carolina's ability to handle massive flooding. NOAA estimated rainfall for Goldsboro of 367 mm and Kinston of 419 mm during the October 8-9 event. The USGS peak flood stage at Goldsboro of 9 m was 0.6 m higher than during the 1999 storms and created a measured discharge of >1,538 m^3/sec for more than 12 hours on October 12, 2016. USGS markers recorded new highs for Kinston also, with 8.6 m and 1,081 m^3/sec. In mid-September 2018, TC Florence claimed 51 lives along its path (of which 39 were in North Carolina), and broke 28 flood records in North and South Carolina in September 2018. The storm made landfall at Wrightsville Beach, North Carolina, and slowed its forward movement to 3-5 km/hr as it moved in a general westerly direction. More than 1.8 million Duke Energy customers in the Carolinas lost power during the event. Initial property damage estimates exceed $22 billion, including the loss of 3.4 million poultry and 5,500 hogs (National Grain and Feed Association). The slow movement allowed the storm to accumulate record rainfall totals. More than 914 mm of rainfall was measured just to the west of Wilmington. USGS stream gages recorded nine locations between 100- to 500-

year recurrence interval flood levels, three of which were designated at the 500-year level. The greatest rainfall was to the south of the Neuse River, but much of it was still within its basin. Goldsboro recorded 365 mm of rainfall. Although flooding was less severe than during TC Matthew, USGS station 02089000 recorded a peak streamflow of 1,039 m^3/sec and a peak height of 8.4 m. Just 48 km downstream at the USGS station at Kinston, where 479.5 mm of rainfall was recorded, Gage 02089500 recorded peak streamflow exceeding 850 m^3/sec for more than 36 hours, and a peak height of 7.9 m was measured (USGS, *Preliminary Data*, 2018).

Purpose of Study

This study seeks to examine the scope and financial impact of these flooding events using GIS-based flood-inundation datasets and NOAA aerial images and other remote-sensing products; floodplain hazard and building-footprint shapefiles; and other data. In particular, this study focuses on the area of the Neuse River between Goldsboro and Kinston to examine and map the geographic extent of the floods with respect to the 100-year flood zone and its margins. The study also examines the number of buildings within the flooded area, including the dozens of CAFOs (Concentrated Animal Feeding Operations) that fall within the floodplain, such as the Bob Ivey facility just north of Goldsboro on Howell's Branch Creek, which flooded and caused large-scale pollution during TC Matthew. The American Rivers organization estimates Matthew "partially submerged 10 industrial hog facilities...with 14 open-air pits holding millions of gallons of liquid hog manure...directly into rivers" (AmericanRivers.org). The organization successfully lobbied for the removal of CAFOs from the 100-year floodplain following

TC Floyd (1999) and is seeking to remove more of these facilities from the current floodplain. Finally, this study seeks to analyze the effectiveness of flood policy in the affected areas, and to determine if changes in policy have helped residents and businesses in and along the 100-year flood-zone borders.

CHAPTER II

LITERATURE REVIEW

The literature review for this study will focus on the history of inland flooding from TCs in eastern North Carolina; the extent and causes of loss of life, damage, and water pollution from these TCs; social and temporal vulnerability as a result of limited public awareness due to language barriers or forms of communication; FEMA floodplain determination and policy; and potential effects from climate change.

TCs in Eastern North Carolina

Data from the North Carolina Climate Office (NCMO) shows that, since 1851, 83 tropical cyclones have made direct landfall in North Carolina. The average return interval is 2.02 years, and in any given year there is a 49% chance of a TC or tropical storm making direct landfall in North Carolina. The most severe of these have brought storm surge in excess of 5.5 m (Hazel, October 15, 1954), winds in excess of 185 km/hr (Hazel, 1954, and Fran, 1996), and extreme precipitation of 1016 mm (Florence, September 12-15, 2018). This resulted in hundreds of deaths and billions of dollars of economic and property loss, and turned the floodplains and rivers of North Carolina into an anoxic toxic habitat that killed millions of riverine organisms. Several scholarly sources document the extent of North Carolina's TC history. Hippensteel and Garcia (2014) attempted to recreate the paleohistory of North Carolina's TCs by examining the marine transgression layers in the backwaters of Onslow Bay. Their study found significant layers of stormdeposited marine foraminifera dating back hundreds of years; however, they were unable to recreate a structured history of tropical cyclone (TC) storm surge because of the degree of recent bioturbation. Peter Robinson's (2003) study of North Carolina flooding history determined the most frequent threat to North Carolina was not TCs, but rather slow-moving systems whose duration and plodding forward progress were major factors in their flooding. However, this also explains the floods generated by the 1999 TCs and the slow-moving TC Florence in 2018. The key factor in almost every major flooding event was that the major flood was always preceded by precipitation events that saturated the ground. While Robinson did not conclude that global warming would automatically lead to greater flooding from TCs, he acknowledged that the increase in temperature and the ability of the atmosphere to hold more moisture would lead to greater rainfall events. "Hurricanes in North Carolina" (2006, State Climate Office of North Carolina) provides background information, including frequency by season and by decade for 164 TCs that made landfall or passed through the state, whereas Barnes' popular history of North Carolina TCs, *North Carolina's Hurricane History 4th ed.* (2013), provides details from primary-source interviews with survivors, as well as insight from modern climatologists. Often overlooked, primary-source interviews help provide details of the dynamic and often localized effects during TCs, which could help direct the efforts of researchers to recreate a storm's history with greater specificity.

There is a wealth of scholarship and government publications which examine individual TCs in North Carolina. For the purposes of this study, the major floods of 1999, 2016, and 2018 are the focus. Two months of flooding in eastern North Carolina

(Bales et. al, 2000) examines the prolonged inundation created by TCs Dennis, Floyd, and Irene in fall of 1999. Their work examines changes in water quality and coastal geomorphology, as well as the inland flooding extent of these storms. Stewart's study of TC Matthew for the National Hurricane Center (2016) and Merryman's *Hurricane Matthew in North Carolina: Precipitation and Flood Analysis Along the Neuse River* (2016) detail the greatest flooding event in eastern North Carolina to that date. Stewart analyzes the loss of life in Haiti, where 500 died in flooding and mudslides, and in the United States, where an additional 34 people died. This includes 25 in North Carolina. He found that the loss of life in Haiti was most attributable to social vulnerability and lack of infrastructure and proper warning. In North Carolina, however, the greatest loss of life resulted from people driving or walking around barricades and attempting to cross rapidly moving flood waters. Merriman's work maps NOAA daily rainfall totals in conjunction with the Soil Survey Geographic Database (SSURGO) soil available water storage data to analyze storm runoff during TC Matthew, "using Thiessen polygon and spline interpolations of 7-day cumulative precipitation station data", to potentially predict soil saturation and runoff for future TCs in the Neuse River Basin (Merriman, 2016,14).

Most recently, TC Florence's slow march through southeastern North Carolina broke numerous flood-stage records. It is best documented in *Hurricane Florence Preliminary Peak Stage and Streamflow Data Report* (2018, USGS), as well as *Brief Communication: Analysis of the Fatalities and Socio-Economic Impacts Caused by Hurricane Florence* (Paul et al., 2019). Paul et al. (2019) examine how, when, and where people died during and after TC Florence, as well as who these people were. The authors found most deaths occurred in the poorest and most socially vulnerable North Carolina counties. The average victim was a white man over the age of fifty, who died in his vehicle well after the storm had made landfall. This suggests many of them either did not heed, or did not hear early warnings, and only chose to leave after flooding had cut off most of their potential routes of escape.

TC Flooding and Water Quality

The health of rivers and estuaries in the aftermath of landfalling TCs is always of concern. The flotilla of hog carcasses, sewage, coal ash, and chemical runoff creates a witch's brew that threatens the health of humans and riverine biota. However, rivers seem remarkably resilient. The Burkholder et al. (2004) study of post-TC flooding on the Neuse River and Pamlico Sound reveals that short-term disruption in the form of contaminants, lower dissolved oxygen, and reduced salinity resulted in the deaths of millions of organisms within the system. However, the health of the rivers and estuaries usually rebounds within a year. They also point out that the degree of contamination is worse in mid-level floods that lack the ability to dilute the concentration of contaminants. Likewise, Malin et al. (2002) examined the effects of multiple TCs on the Cape Fear River basin. They found that the threat posed by each TC depended upon its track and characteristics. Like Burkholder et al. (2004), they found that the greatest threat from heavy precipitation events was flooding and contamination. However, they also noted that wind events which knock out power frequently shut down sewage-treatment facilities and lead to tens of millions of liters of untreated or partially treated human waste being released into nearby rivers. The Peierls et al. (2002) study of post-TC water quality and phytoplankton in the Pamlico Sound found that there were disastrous short-term effects on water quality and estuarine biota but, like previous studies, they found that the water quality and health of the estuary recovered with time. One interesting side note of their study was the pendulous nature of recovery. There were seasonal reversals in estuarine health each summer but, over the course of nearly three years, the overall balance returned to its pre-flood levels.

Social Vulnerability

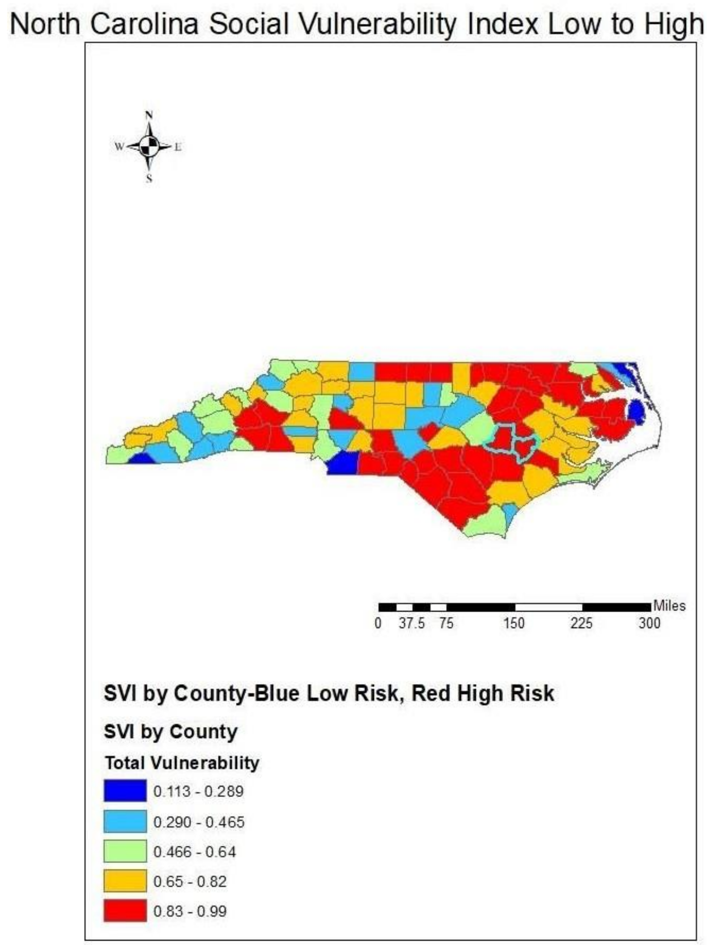


Figure 2.1. SVI of Most Endangered NC Counties includes Wayne and Lenoir Outlined in Light Blue. Source. (Data) Center for Disease Control https://svi.cdc.gov/, ArcMap-Brackett

There are numerous studies that examine social vulnerability to natural hazards. Figure 3 shows the relative social vulnerability of North Carolina's counties. The area of focus for this project is in Lenoir and Wayne Counties (highlighted in the map). Fifteen vulnerability variables that create the data from the CDC's Social Vulnerability Index (SVI) are used to create four group themes. The four major group themes; 1) Socio-economic status, 2) Household composition/disability, 3) Minority status and language, and 4) Housing/Transportation status. The combined SVI from themes 1-4 are totaled into the RPL Themes category which is an overall composite of SVI. Each of these themes are composed of multiple census variables and averaged into an overall ranking (0 for no risk and 1 for high risk). For example, a cumulative SVI of 0.95 would indicate the area is in the 95th percentile of vulnerability to disaster or hazard. In 2016 Wayne County had an SVI of 0.96 and Lenoir County's SVI was 0.98.

North Carolina's most dangerous floodplains are also the nexus for its poorest people, and the agricultural fields where many of them work, and the harvest and TC seasons coincide. Burke et al. (2012) assessed the vulnerability and preparedness of North Carolina's Latino farmworkers when faced with TC-generated flooding. The authors interviewed Latino farmworkers and found that they were increasingly vulnerable due to their mistrust of the government and the failure of official Spanish-language warnings. Many, especially those who had not been through a natural disaster before, were unprepared. The workers and authors concluded that a more concerted effort to provide Spanish-language broadcasts and small public forums would reduce their risk exposure. De Vries (2011) examined the temporal vulnerability of residents along the Neuse River. The author found that misinformation about the frequency and likelihood of major flooding was reaching the level of "cultural mythology" (De Vries, 160). Local government officials, media, and public memory defined TC Floyd as a 500-year flood when it was somewhere between a 75- to 100-year event, with localized flooding in some areas approaching the 500-year recurrence interval. Because of the perception that this was such a rare event, officials were less likely to change policy, and residents less likely to move. Without a change in behavior, people living along the Neuse are more at risk than ever, as they have since found in 2016 (Matthew) and 2018 (Florence).

People often stay with their property during natural disasters to protect it. They cannot protect it from wind nor water, any more than they can elicit sympathy from their insurers. O'Connor (2018) points out that, although there was $20 billion worth of damage from TC Florence, and that 90% of that damage was to residential homes, little will be paid to homeowners. A staggering 80% of private homeowners whose homes were damaged or destroyed had no flood insurance. They would have been protected from the winds of TC Matthew a month later, but the rain and flooding from Florence was not covered under their policies. That leaves billions of dollars of uninsured losses among the public. 93% of the nearly 45,000 buildings that were damaged or destroyed were residential. More than 50,000 claims were filed in North Carolina alone in the first two weeks after Florence made landfall. However, more than 80% of those claims will not be paid out by the insurers. Some of this amount will be absorbed by the National Flood Insurance Policy (NFIP), although NFIP insures only 134,000 homeowners in all of North Carolina. This study makes the vulnerability of homeowners glaringly clear. Most will be dependent upon federal relief, which could be a long time in coming. The federal payments to North Carolina residents from TC Matthew (2016) were only received in late summer of 2018.

FEMA and Floodplain Policy

The Federal Emergency Management Agency (FEMA) defines Special Flood Hazard Areas (SFHA) as "the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year" (https://www.fema.gov/flood-zones). That 1-percent chance is based upon historical rainfall and flooding data, hydrologic studies of floodwater depth and changes to geomorphology, floodplain width and depth, as well as new construction and population growth. In short, determining the exact lines of the 100-year floodplain is akin to firing at a moving object from a moving object. To more accurately assess areas at the greatest risk, FEMA works with local communities to identify where mapping changes have occurred. However, processing this data for the 3,007 counties and more than 20,000 communities of the United States takes time, and with the time lag come additional changes. FEMA also works with 177 flood-zone determination companies. These companies include insurance, engineering, water resources, research, financial and credit, data analysis, and legal and consulting firms (https://www.fema.gov/flood-zone-determination-companies). To update the existing Flood Insurance Rate Map (FIRM) and 100/500-year floodplain designations, FEMA uses three methods of revision. Due to limited federal resources for the project, each year FEMA chooses specific communities that they deem at greatest risk, because of urban growth/development and outdated maps, and studies the potential flood hazard for these communities. FEMA employs a cost/benefit analysis as a sort of litmus test to determine the most vulnerable communities. They also depend upon two different forms of "community-initiated map revisions."

The first of these is Community-Initiated Map Revisions through part 65 of the National Flood Insurance Program (NFIP) regulations. Within this designation, requests for map revisions are categorized for immediate or future revision, based on whether the map changes fall within the SFHA. Communities that believe their SFHA should be altered can fill out the online application/certification forms. The second type of local-initiated change is the Community-Initiated Map Revisions through the Cooperating Technical Partners (CTP) Initiative. This program is a partnership between FEMA and regional, state, and local NFIP communities. The most important contributions local partners make is updating hydrologic modeling and mapping, as well as refining floodplain boundaries based on new construction or other significant changes. Occasionally, this amounts to moving the boundary of floodplain designation to placate major financial benefactors. The H.F. Lee power plant flooded in all three TCs in this study, and spilled coal ash into the flood water. However, when the 100-year floodplain lines were redrawn in 2015, the H.F. Lee plant was no longer considered to be in the flood zone. The normal process for making revisions involves local businesses and stakeholders, who are encouraged to share their digital database and topographic mapping (https://www.fema.gov/flood-map-revision-processes#1). After local revisions are submitted, FEMA begins the review process, which can be protracted due to FEMA's reduced budget and massive workload. Most recently, this included a $10 million cut in

2018, which was reallocated by the Department of Homeland Security to fund U.S. Immigration and Customs Enforcement (ICE). The greater threat to FEMA is not the reallocation of its existing funds; it is the increasing occurrence of billion-dollar disasters they face.

FEMA's 2018 budget of $18 billion paled in comparison to the cost of natural disasters across the United States during that year. There were 14 separate events that caused more than $1 billion in damage. The damage from these 14 events alone exceeded $90 billion (https://www.ncdc.noaa.gov/billions/events/US/1980-2018). A February 2019 study by the National Oceanic and Atmospheric Administration (NOAA) counted no less than 241 billion-dollar disasters during the last 38 years. They estimated total costs to exceed $1.6 trillion. That provides an average of $42 billion in natural-disaster damage per year. The data also clearly show the number of billion-dollar events per year has increased over time. The four most devastating years have occurred since 2011 (https://www.climate.gov/news-features/blogs/beyond-data/2018s-billion-dollar-disasters-context). Shortfalls are left to regional, state, and local governments. NOAA estimates that TC Matthew caused at least $1.5 billion in damages in eastern North Carolina, while the state's request for $900 million was initially met with a federal recovery response of $6.1 million -- less than 1% of North Carolina's request. Additional lobbying and recovery requests from multiple sources met with greater success during 2018. By the fall of 2018, North Carolina had received a total of $1.4 billion in aid, just in time for TCs Florence and Michael, which destroyed several billion dollars' worth of real estate in North Carolina alone. Some regional agencies are attempting to protect themselves.

The Neuse River Basin Regional Hazard Mitigation Plan (2015) highlights the local thought process behind flood mitigation for Wayne and Lenoir counties, as well as the surrounding area within the Neuse River Basin. They found that local social vulnerability is increasing. Demographic information concerning Lenoir County shows that, although the total county population has grown by 3.9% from 1990 to 2010 (57,274 to 59,495), the population of its largest city, Kinston, has dropped by 14.4% during that same period (25,295 to 21,677). The greatest amount of population growth, 20.1%, has occurred in unincorporated areas (US Census Bureau). 43.7% of Kinston's population lives in rental units. Lenoir County had an unemployment rate of 13.8% in 2010 (Mitigation Plan 2015, pp.39-45). In forming an economic picture of the county, examining the per-capita income is useful. Lenoir County's per capita income of $19,017 is 23.1% below the state average of $24,745. The same analysis of Wayne County reveals countywide population growth of 17.2% from 1990-2010; however, Goldsboro's population has dropped by 10.5% during the same period (40,709 to 36,437). Like Lenoir County, unincorporated areas have seen the largest growth, 40.2% in Wayne County. 47.1% of Goldsboro's residents live in rental units.

While the data for Lenoir County shows poor economic conditions, Wayne County's economic status could best be described as dire. In 2010, 47.6% of Wayne County residents were unemployed, including a rate of 20.6% in Goldsboro. Yet Wayne County's per-capita income is higher than Lenoir County ($20,446 to $19,017). This is largely due to the wealthy residents of Seven Springs and Walnut Creek townships, whose incomes are well above the state average (*Hazard Mitigation 2015*, 87-65). Environmental inequality can vary greatly within a localized landscape. Purifoy (2019) provides an examination of how place and race intersect to create localized environmental inequality. The Hazard Mitigation study also contains case studies of 8 TCs that affected the local area from 1996-2005 (including TC Floyd). Floyd destroyed 7,000 homes, left 17,000 uninhabitable, and damaged an additional 56,000 in North Carolina (Hazard Mitigation 2015, p 3.5). The Mitigation Plan also maps the 100-year (Zone A) and 500-year (Zone X) floodplains. The predicted hazard impact within the Neuse River Basin lists hurricanes and flooding atop the list with likely (>10% chance in the next year) occurrence, severe impact, and critical potential impact (affecting 25-50% of the area, shutting down critical facilities for 1-2 weeks, and severely damaging >10% of all property) (*Hazard Mitigation 2015*, pp. 89-90). Finally, the mitigation plan examines the vulnerability of each county based on previous events and current assessments.

Climate Change

The future effects of climate change are not entirely understood. The pace, extent and effects of anthropomorphic climate change are not definitively predictable. However, it is certain that, as the atmosphere warms, heat waves and heavy precipitation events will likely occur more frequently. According to the Intergovernmental Panel on Climate Change (IPCC), human activities have caused 1 degree Celsius of global warming above pre-industrial levels and is likely to cause an additional 0.5-degree Celsius increase within the next 10-25 years (IPCC 2019, p.6). Coumou and Rahmstorf (2012) argue that there are certain categories of events, such as heat waves and floods, that are more likely to be the direct result of anthropogenic climate change. 2001-2011 was a decade of superlatives---the wettest, hottest, strongest seasons on record from around the globe. The authors focus on the prolonged heat waves and precipitation events. They analyzed the 2003 heatwave in Europe, the hottest summer in the last 500 years. The overall 2.4-degree Celsius temperature increase in Switzerland was 5.4 standard deviations from the norm. However, this was a global increase due in part to the climbing average of night temperatures. Rainfall extremes are more difficult to quantify since they are often local. Despite this, the authors found extreme precipitation events (beyond the 98th percentile) have increased by 33% in the United States during the last century. The increased CO_2 content in the atmosphere and subsequent warming allow for greater retention of moisture, thus the potential for larger precipitation events. The authors conclude that statistical analysis of observed data and climate modeling “strongly indicate…heatwaves and precipitation extremes, will greatly increase in a warming climate and have already done so” (Coumou and Rahstorf, 495).

Additional links to human activity and climate change are found in Keelings and Hernandez-Ayala (2019), whose examination of TC Maria links extreme rainfall to climate variability and change. Patricola and Wehner (2018) also found links between major TC events and anthropogenic influences. In particular, the authors discovered no link between TC intensity and human influence, but they did cite an enhancement in both average and extreme rainfall related to TCs, while Risser and Wehner (2017) found an attributable link between the magnitude of precipitation during TC Harvey and anthropogenic influences. One of the most likely human influences is the rise in the amount of CO_2 in the atmosphere. Van Dam et al. (2018) suggest that scientists may have been missing one mechanism of CO_2 creation: CO_2 release in the wake of TC flooding into estuaries. The estuaries act as a repository for a concoction of inorganic nutrients and dissolved organic carbon (DOC) that "shift the metabolism" of estuaries. In the process, they release anywhere from one-third to 40% of an estuary's yearly CO_2 flux. One factor which increases the likelihood of additional TC-derived inland flooding is the potential extension of the Atlantic TC season in the southeastern United States. Stone and Cohen (2017) argue that not only will TC precipitation likely intensify up to 20%, but also the extension of the Atlantic TC season may encroach upon the time of year when many rivers are in their high discharge season. Their study focused on the Neches (Texas), Pearl (Louisiana), Mobile (Alabama), and Roanoke (North Carolina) rivers, which are usually in low flood stage during the June-November TC season. The authors calculate that global warming could extend the Atlantic TC season up to 28 days on both ends. In the process, this May-December season would overlap with the traditional high-discharge season. Of the rivers studied, the Roanoke seemed to be the most at risk by an extension of the TC season. The authors found that, during the 1998-2014 period of study, the Roanoke had 50 days at risk of flooding; they calculated the extended season could add up to 34 additional days at risk. This is a 68% increase in the total days at risk and would result in 2.02% of all days in the May-December season being at risk of flooding along the Roanoke River (Stone and Cohen, 445). The effects on the Neuse River basin have yet to be calculated for an extension of the Atlantic TC season, although the North Carolina Department of Transportation stated that the benefits derived from the Flood Control Act of 1965, namely the construction of the Falls Lake Dam in Wake Forest, North Carolina, would be compromised by two consecutive heavy rainfall events (NCDOT, 2018, vi). An extension of the Atlantic TC season would make this chain of events increasingly likely.

CHAPTER III

METHODOLOGY

Area of Study and Research Question 1

How does the geographic extent of the individual floods compare to the 100-year floodplain and its margins?

This question was answered by examining data from aerial imagery taken of the three major flooding events in question. Landsat images from Floyd, and NOAA's airborne images for Matthew, and Florence, (https://storms.ngs.noaa.gov/) which show the extent of flooding during each event, were examined and compared to the 100-year and 500-year flood maps from the North Carolina Flood Risk Information System (FRIS) (https://fris.nc.gov/fris/?ST=NC). Flood-zone classification maps for the study areas of Goldsboro and Kinston were generated in ArcMap using the FRIS flood zone and supervised land cover classification of flood extent.

TC Floyd

The near-IR band allowed for a Normalized Difference Water Index (NDWI) to be created using the following formula: $NDWI=(X_{green}-X_{nir})/(X_{green}+X_{nir})$ (McFeeters, 1996). Since water has low radiation and high absorption, the index uses the near-IR and green bands to enhance the visibility of water bodies. The NDWI formula can be created using the spatial analyst tool raster calculator, as follows: Float ("Band 3.TIF"- "Band 5.TIF")/Float ("Band 3.TIF + "Band 5.TIF"). The resulting output raster NDWI.tif has a high value of 1 (light-colored) and a low value of -1 (dark-colored). Values >0.3 are then displayed as water. According to McFeeters (2013), NDWI values >0.3 indicate detectable water surfaces. All no-data values are removed in symbology layer properties within the stretched field, and zero background values are displayed as no color. This effectively removes the black collar that surrounds the image.

The Landsat 5 image of flooding created in the wake of TC Floyd was then analyzed by creating supervised and unsupervised land-cover classifications. The timing of the imagery was problematic, since it was taken after peak flooding. Peak flooding in Goldsboro was on September 20 and in Kinston the Neuse reached its peak stage on September 22. Yet, due to continuous cloud cover during the period, no clear images were available until October 13, just five days before the arrival of TC Irene, a Category 1 storm that skirted the North Carolina coast. TC Irene dumped an additional 125-250 mm of rain in a broad band throughout eastern North Carolina with a maximum precipitation band of 375 mm in Bayboro, NC (NOAA, *TC Report Irene*, 2011). At the time of the Landsat 5 image, the Neuse streamflow at the Goldsboro, NC, station (02089000) was measured at 212 cubic meters/sec, which was still nearly three times its median measured streamflow from 1983-2000, of 75.85 cubic meters/sec. However, during peak flooding on September 20, 1999, the Goldsboro station recorded a peak streamflow of 1,090 cubic meters/sec.

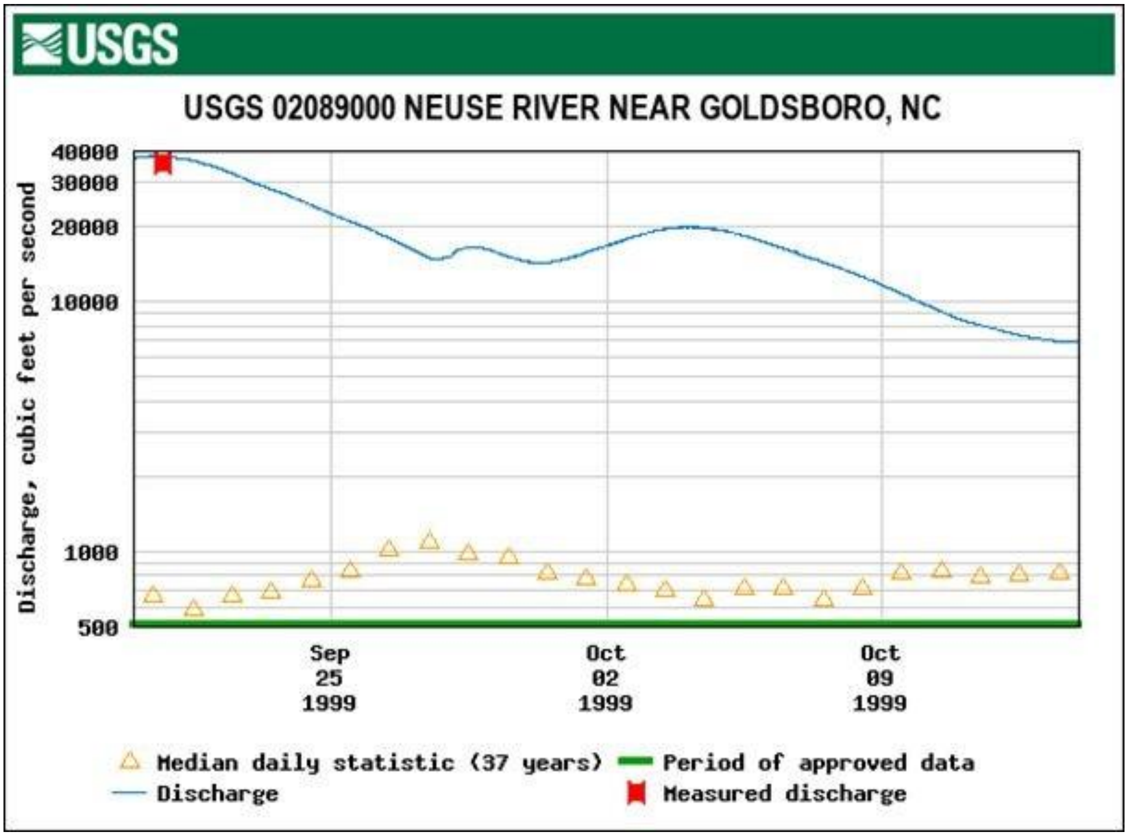


Figure 3.1. USGS Neuse River Streamflow at Goldsboro Sept. 20-Oct. 13, 1999. Source. USGS water data- https://waterdata.usgs.gov/nc/nwis/uv?site_no=02089000

The supervised land-cover classification for TC Floyd was created using three parent classes: Class 1 (urban/built up), class 2 (forest) class 3 (open field), and class 4 (water). After the creation of 120 training areas (30 for each parent class), the maximum-likelihood classification was generated using the original Landsat 5 mosaic and the .gsg signature file was created from the training areas. Then randomly selected accuracy-assessment points were generated and ground-truthed in order to prepare the confusion matrix and assess the classification’s accuracy. The ground truthing step involved comparing the computer identified location; urban, forest, open field, and water, with the actual location from the Landsat 5 images. Were the locations the same? If not, then the image class was changed to show the correct location. Finally, the confusion matrix was created based on the ground-truthed accuracy assessment points.

The unsupervised land-cover classification of TC Floyd was generated using the Landsat 5 mosaic image. The Iso cluster unsupervised-classification tool was used to create the classification. The original classification contained 30 bands, which were eventually combined into 6 parent land-cover categories through a process of trial-and-error color matching. Ultimately, these categories were water, light forest, heavy forest, open fields, urban-built up area, and dense vegetated areas. Random accuracy-assessment points were generated and ground-truthed. The unsupervised classification was compared to the original Landsat 5 mosaic.

TCs Matthew and Florence

An examination of inundation created by TC Matthew was based on NOAA imagery downloaded as .tar files from https://geodesy.noaa.gov/storm_archive/storms/matthew/index.html for October 13 and October 15, 2016. Two different days were chosen to highlight the difference in peak flooding between Wayne and Lenoir counties. The aerial images were resampled to 30 m to match the Landsat 5 images. The NOAA imagery for TC Florence was also downloaded as .tar files from https://storms.ngs.noaa.gov/storms/florence/index.html#7/35.360/-77.820 for September 19, 2018.

The 30-m cell size mosaic .tif was then analyzed by creating a supervised land-cover classification. The first step involved creating 30 training samples each for water, urban/built up, open fields, and forested areas. Initially, each sample was selected to exemplify the variety of colors within each category. For example, the urban built-up area included shingled and tar roofs, concrete, asphalt, landing strips, and all possible varieties of urban impervious surfaces. The individual training samples were then combined into single training areas representing their combined characteristics. Step two involved the use of the maximum-likelihood classification data-analysis tool, in which the mosaic .tif was added as the input raster band and the classified training samples .gsg file was entered as the input signature file. The resulting raster was then altered to conform to the area of study by using the clip raster data management tool.

After this process, the *create accuracy assessment points* data-analyst tool was used. In this process, the newly created clipped image mosaic was entered as the input raster and a file of accuracy-assessment points was entered as the output. The target field was listed as classified and 200 random points were selected to be created. Finally, the *stratified_random sampling* strategy was chosen. Once the new accuracy assessment points were created, the editing tool was used to examine the ground truthing box in the attribute table. Once necessary corrections were made for misidentified classifications, a confusion matrix was created. To create the table the *compute confusion matrix* data-analyst tool was opened and the now edited (ground-truthed) accuracy-assessment points were entered as the input, and the output became the new confusion matrix with a .dbf extension.

The unsupervised classification for TCs Matthew and Florence proved to be slightly less accurate than the supervised classification. However, both were created by using the Iso cluster unsupervised-classification tool. The 30 created classes were then combined using a slow system of trial and error to determine what made the most accurate classification. Once each of the 30 bands were identified and a color was chosen to represent their parent class (water, urban, open field, or forest), they were combined into their 6 overarching classes using the reclassify tool, within the reclass subsection of the spatial-analyst tools. The same reclassification process that was used in all unsupervised land cover classifications.

Research Question 2

TC Floyd

How many buildings were within the flooded area?

To show the number of structures within the flooded area for each event, the Wayne County building footprints shapefile from NC OneMap and flood extent from the supervised classification were overlain. Each image of the building footprints is from the same 2019 NC OneMap shapefile. They do not reflect the exact building footprints for each event. This means that each examination is an estimation of the numbers of structures that were potentially flooded during each event. However, due to the drop in streamflow and peak gage height, the image was not useful for analyzing the number of buildings that were within the flooded area during TC Floyd. Since the peak flow and peak gage heights from TC Floyd and Florence were very similar (Floyd was 0.38 m higher and 50.98 m^3/sec greater than Florence), the extent of flooding during TC Floyd can be approximated by examining the imagery and supervised land-cover classification from TC Florence.

TCs Matthew and Florence

For TCs Matthew and Florence, it is fairly easy to see the number of buildings within the flooded area, both in the original mosaic and in the supervised land-cover classification, although it is still difficult to get a definitive count. However, by examining the physical location of the building footprints from the NC OneMap shapefile, an exact total of the buildings in Wayne County that reside in the 100-year and 500-year floodplains can be assessed. Of the 11,660 existing building footprints listed in the Wayne County shapefile, exactly 386 buildings fall within the 500-year floodplain and 1401 structures are within the 100-year floodplain. This can be clearly seen in the composite map that was created by using the original mosaic as the base map and adding the building footprints and supervised land-cover classification maps as additional layers.

Research Question 3

TCs Floyd, Matthew, Florence

How do the individual floods compare to one another, and what factors explain their differences?

To answer this question, inundation maps from each storm were overlain. Areas that were flooded by only one event were delineated from those that were flooded in two events. Those areas flooded in two events were delineated from those that flooded in all three. This helped account for differences in the flood extent for each TC, while the creation of once-, twice-, and thrice-flooded areas over the 20-year period of study provided an indication of how well local residents have been served by flood policy. Perhaps the best method to examine the extent of flooding for each event is the USGS stream-gage data for each event. In order of magnitude from lowest to highest, TC Florence produced peak-stage flooding that was 2.92 m above flood stage, while TC Floyd had peak-stage flooding 3.3 m above flood stage, while for TC Matthew it was 3.58m above flood stage. An examination of peak streamflow may be the best means of assessing the relative floods. The peak streamflow from TC Florence was 1350% of the annual median streamflow of 75.85 cubic meters/sec 1983-2000 for the Neuse River gage at Goldsboro (02089000), TC Floyd was 1420% the base streamflow, and TC Matthew was 2000% the base streamflow.

Table 3.1. Peak Gage Height Associated with TCs Floyd, Matthew, Florence, Including Flood Elevation. Source. https://waterdata.usgs.gov/nc/nwis/uv?site_no=02089000

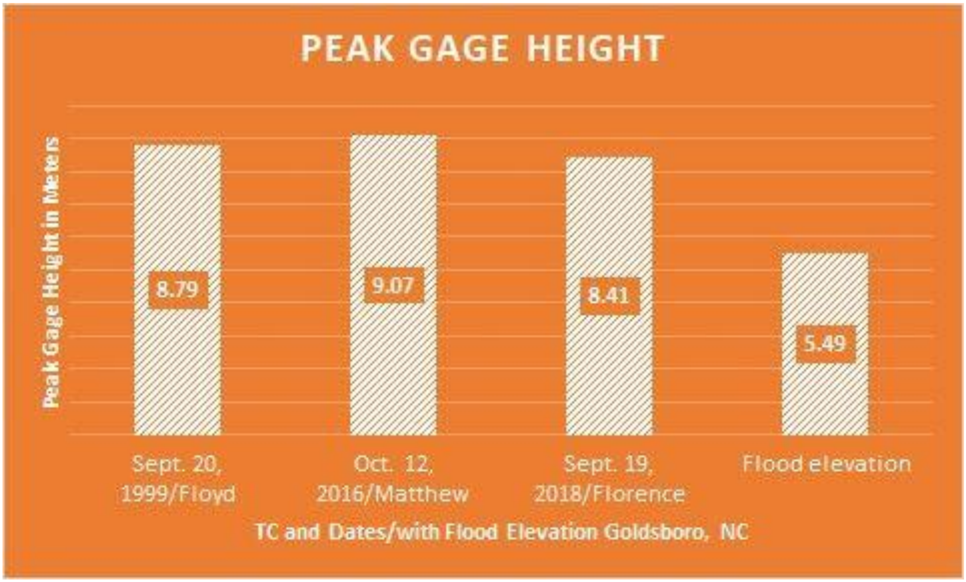
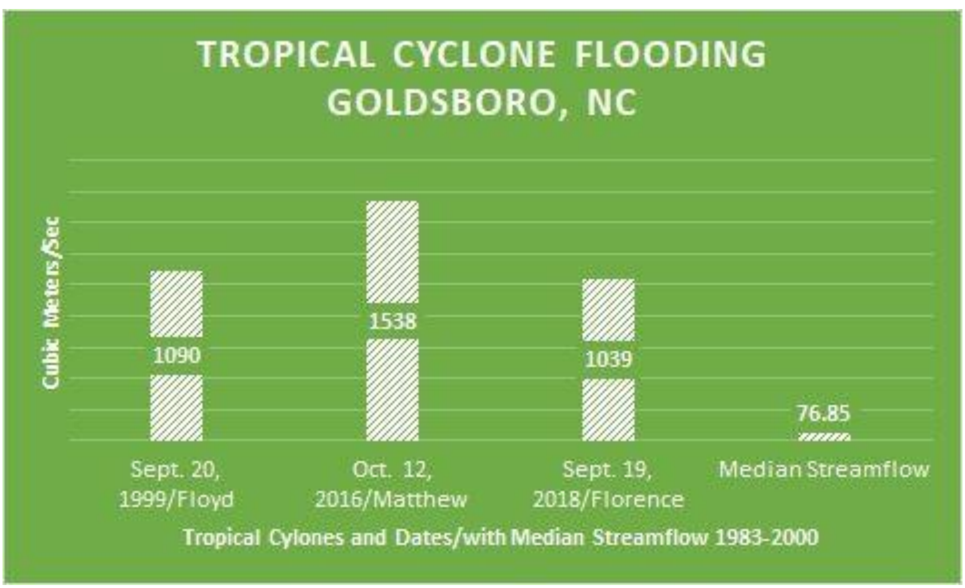


Table 3.2. Comparison of Peak Streamflow Associated with TC Precipitation. Goldsboro, NC. Source. https://waterdata.usgs.gov/nc/nwis/uv?site_no=02089000



CHAPTER IV

RESULTS

Research Question 1

Floyd

The confusion matrix for the NDWI of TC Floyd in Wayne and Lenoir counties shows the values ≥ 0.3 as water. Water values are white in the NDWI, and values in the 0-0.2 range are light grey and reflect urban/built-up areas. The negative display values for open fields are darker grey and grow increasingly dark towards black. The values scaling towards -1.0 are most likely forested or thickly vegetated areas. The NDWI image conforms to the pre-flood image from Google Earth Pro. High-value areas are white (water) and follow the location of the Neuse, nearby lakes and ponds, and any area that is flooded. The kappa value in the confusion matrix is 0.85, which falls within the 0.8-1.0 range of preferred accuracy.

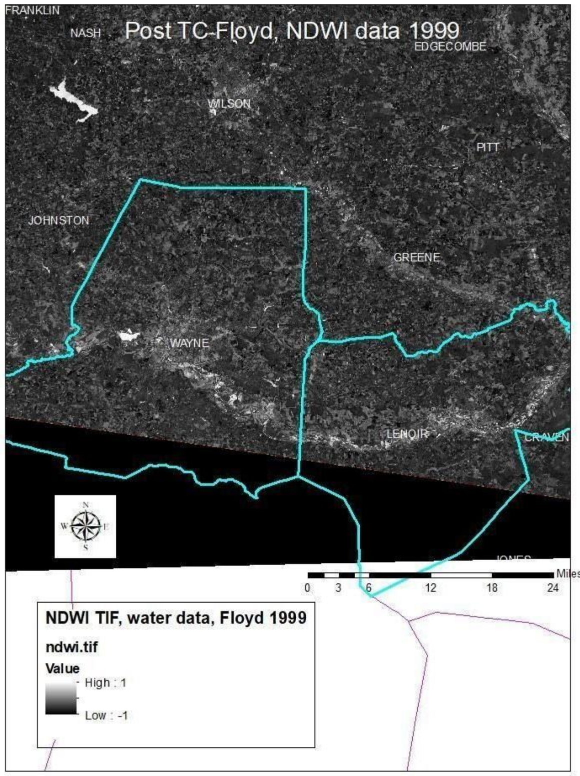


Figure 4.1. Landsat Imagery of Neuse River Oct. 13, 1999. NDWI Map. Source. (Data) Landsat 5 NASA, NDWI ArcMap, Brackett

Table 4.1. Confusion Matrix for TC Floyd NDWI, OID Stands for Object ID in this Table. Source. (Data) from Landsat 5 (NASA) and ArcMap NDWI, Brackett

OID	Class Value	Land	Water	Total	User Accuracy	Kappa Value
0	Land	95	3	98	0.9694	0
1	Water	0	10	10	1	0
2	Total	95	13	108	0	0
3	P_Accuracy	1	0.7692	0	0.9722	0
4	Kappa Value	0	0	0	0	0.8543

The TC Floyd supervised-classification assessment points were then used to create the confusion matrix. The matrix shows a user's accuracy of 86.5% and a kappa value of 0.797.

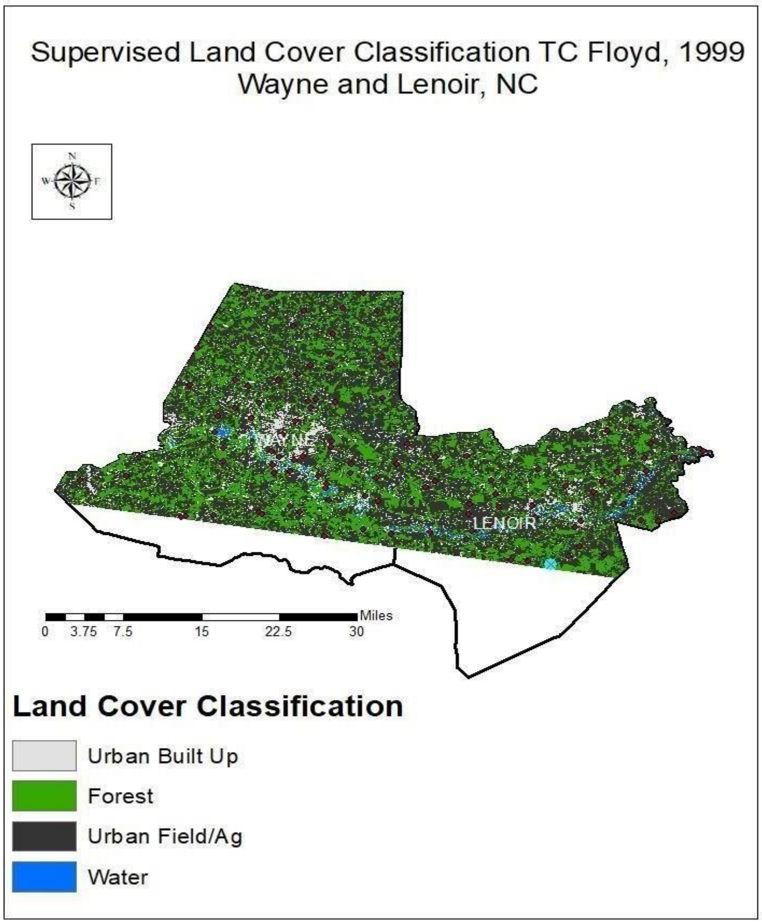


Figure 4.2. Supervised Land-Cover Classification for TC Floyd. Source. (Data) Landsat 5 NASA, Supervised Land Cover Classification Map ArcMap, Brackett

Table 4.2. Confusion Matrix for Supervised Classification of TC Floyd. Source. (Data) from Landsat 5 (NASA) and ArcMap, Brackett

OID	Class Value	C_1	C_21	C_42	C_63	Total	U_Accuracy	Kappa
0	C_1	8	0	0	2	10	.8	0
1	C_21	0	32	1	0	33	.9697	0
2	C_42	8	1	46	3	58	.7931	0
3	C_63	0	0	0	10	10	1	0
4	Total	16	33	47	15	111	0	0
5	U_Accuracy	.5	.9697	.9787	.6667	0	.8649	0
6	Kappa	0	0	0	0	0	0	.7969

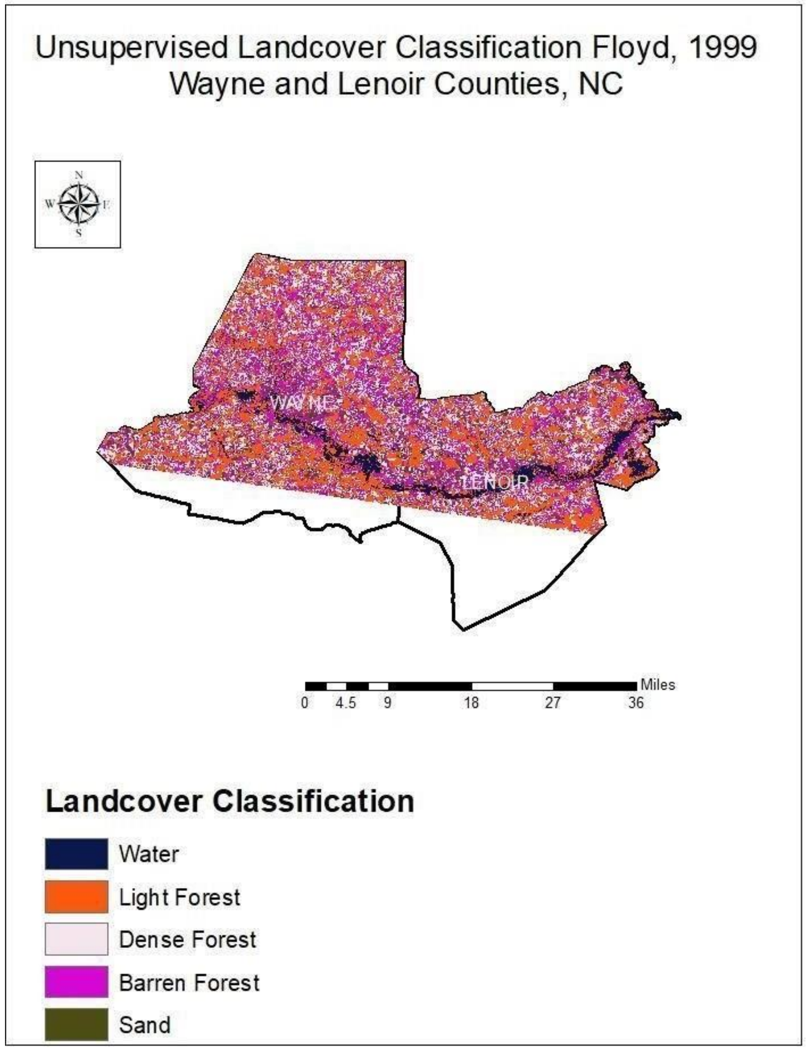


Figure 4.3. Unsupervised Land-Cover Classification of TC Floyd. Source. (Data) Landsat 5 (NASA) and ArcMap, Brackett

Finally, the confusion matrix .dbf was created from the ground-truthed accuracy assessment points. The P_Accuracy or producer's accuracy rating was 84.6% and the kappa value was 0.814.

Table 4.3. Confusion Matrix of Unsupervised Land-Cover Classification TC Floyd. Source. (Data) from Landsat 5 (NASA) and ArcMap, Brackett

OID	Class Value	C_1	C_2	C_3	C_4	C_5	C_6	Total	P_Acc	Kappa
0	C_1	10	0	0	0	0	0	10	1	0
1	C_2	0	6	3	0	0	1	10	.6	0
2	C_3	0	0	13	2	0	0	15	.87	0
3	C_4	0	0	0	8	1	1	20	.8	0
4	C_5	0	0	0	0	10	0	20	1	0
5	C_6	0	0	0	0	2	8	20	.8	0
6	Total	10	6	16	10	13	10	65	0	0
7	P_Acc	1	1	.81	.8	.77	.8	0	.85	0
8	Kappa	0	0	0	0	0	0	0	0	.81

Matthew

The matrix revealed a user accuracy of 84% and a kappa value of 0.76. It also revealed a significantly greater amount of flooded land than in TC Floyd.

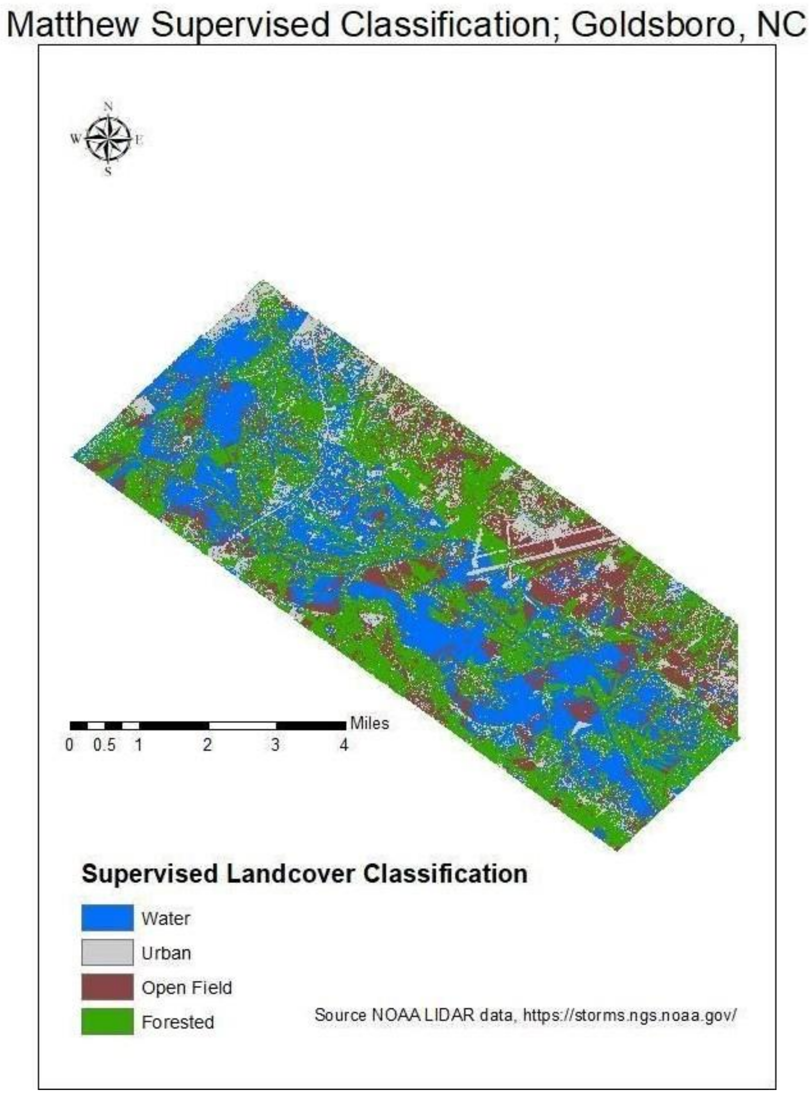


Figure 4.4. Supervised Land-Cover Classification of TC Matthew. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ , and ArcMap, Brackett.

Table 4.4. Confusion Matrix of Supervised Land-Cover Classification of TC Matthew. Source. NOAA aerial data ArcMap, Brackett.

OID	Class Value	C_1	C_26	C_46	C_71	Total	U_Accur	Kappa Value
0	C_1	27	0	2	4	33	.8182	0
1	C_26	1	6	1	0	8	.75	0
2	C_46	3	0	11	3	17	.65	0
3	C_71	1	0	1	40	42	.95	0
4	Total	32	6	15	47	100	0	0
5	P_Accur	.84	1	.73	.84	0	.84	0
6	Kappa	0	0	0	0	0	0	.76

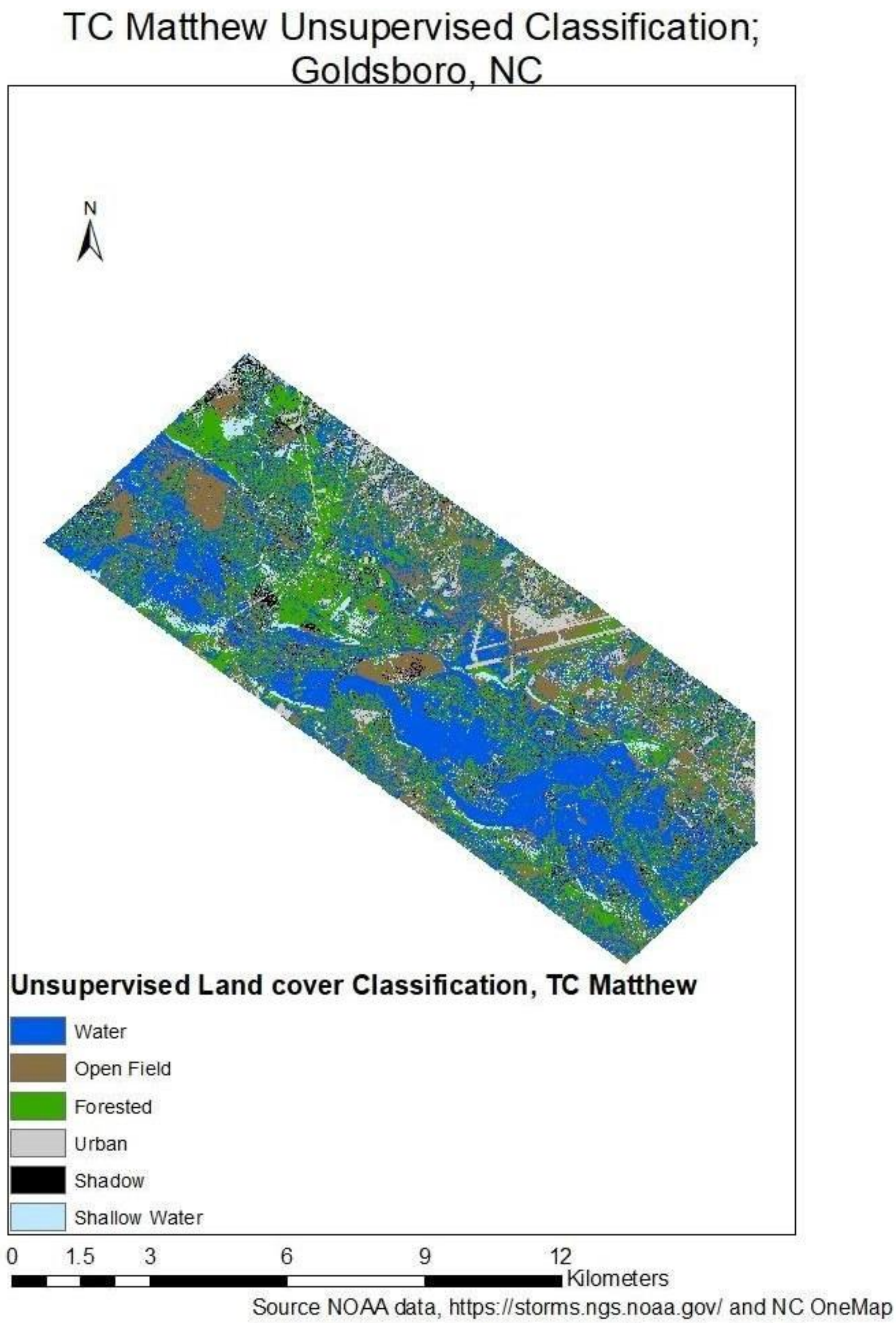


Figure 4.5. Unsupervised Land-Cover Classification, TC Matthew. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and ArcMap, Brackett.

The matrix showed a user accuracy of 89% and a kappa value of 0.85. In this case, the unsupervised image was 6% more accurate than the supervised land cover classification.

Table 4.5. Confusion Matrix of Unsupervised Land-Cover Classification, TC Matthew. Source. NOAA aerial data, and ArcMap, Brackett

OID	Class Value	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Acc	Kappa
0	C_1	37	0	1	0	0	4	42	.88	0
1	C_2	1	16	0	0	1	0	18	.89	0
2	C_3	0	0	21	0	3	0	24	.88	0
3	C_4	0	0	0	8	0	0	8	1	0
4	C_5	0	0	1	0	3	0	4	.75	0
5	C_6	0	0	0	0	0	4	4	1	0
6	Total	38	16	23	8	7	8	100	0	0
7	P_Acc	.97	1	.91	1	.43	.5	0	.89	0
8	Kappa	0	0	0	0	0	0	0	0	.85

Florence

The classification of Florence was the most difficult in the study. Initial efforts ranged from 0.3-0.6 kappa value; however, reducing the size of the training samples led to a more accurate assessment. The increase in accuracy was largely due to confining the training samples to a narrower range of pixel colors. Early efforts included a wide variety of pixel colors within each training area, while the latter efforts were tightly focused on creating training samples that were homogenous in color. This helped clearly define the parent classes and caused less confusion for ArcMap when the accuracy assessments points were created. Overall, the unsupervised land cover classification was nearly 10% more accurate than the supervised land cover classification. The final confusion matrix for the unsupervised land-cover classification for TC Florence was 0.69. While the final confusion matrix for the supervised land-cover classification for TC Florence was 0.67. This is a slight difference, but it is consistent that the unsupervised classifications were better for all three TCs.

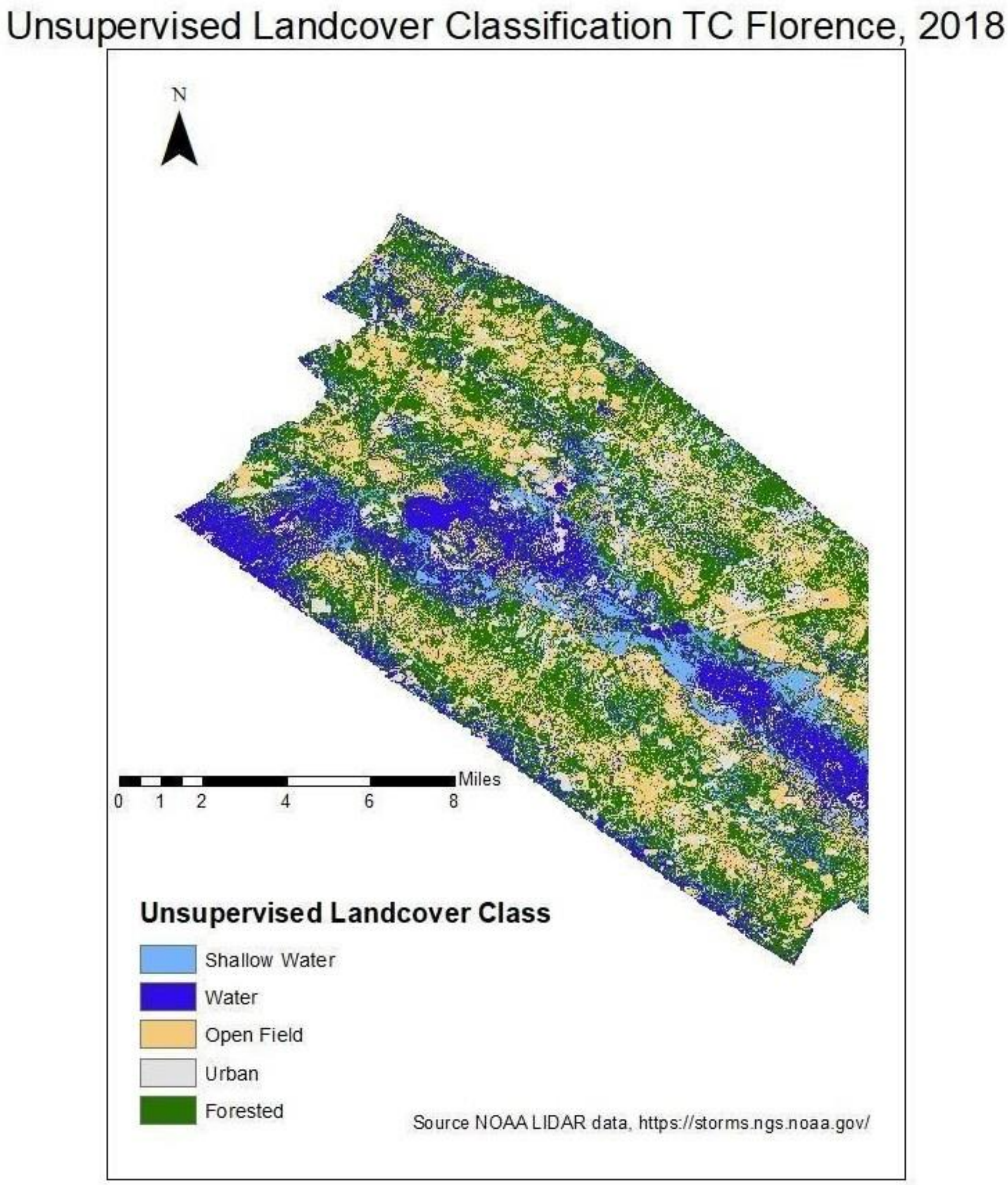


Figure 4.6. Unsupervised Land-Cover Classification, TC Florence. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and ArcMap, Brackett.

Table 4.6. Unsupervised Land-Cover Classification, TC Florence. Source. NOAA aerial data, and ArcMap, Brackett

OID	Class Value	C_1	C_21	C_42	C_63	C_85	Total	U_ACC	Kappa
0	C_1	12	0	1	0	1	14	0.86	0
1	C_21	0	15	1	1	7	24	0.63	0
2	C_42	0	0	38	0	6	44	0.86	0
3	C_63	0	0	2	16	2	20	0.8	0
4	C_85	0	0	16	1	51	68	0.75	0
5	Total	12	15	58	18	67	170	0	0
6	P_ACC	1	1	0.66	0.89	0.76	0	0.78	0
7	Kappa	0	0	0	0	0	0	0	0.69

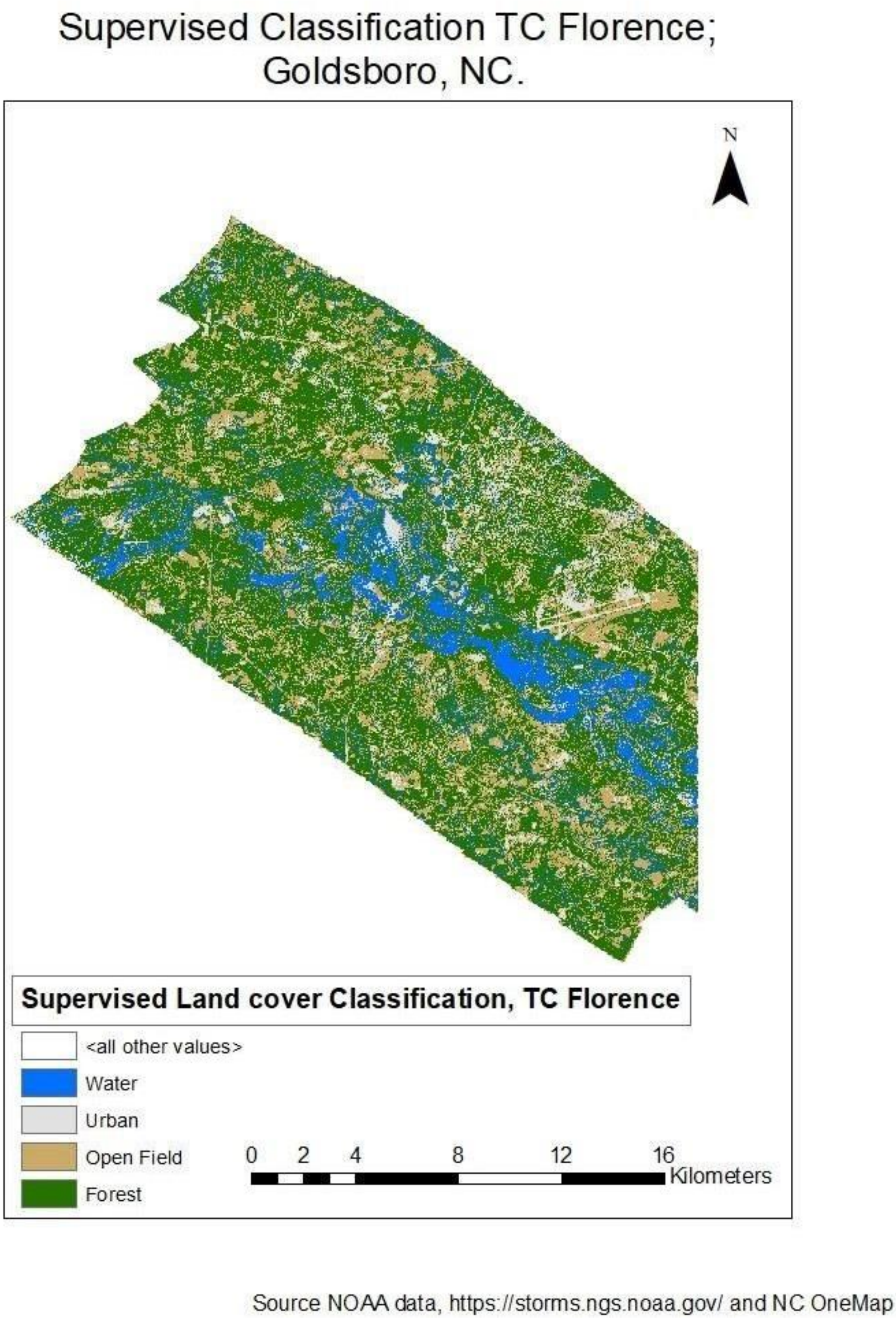


Figure 4.7. Unsupervised Land-Cover classification, TC Florence. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and ArcMap, Brackett.

Table 4.7. Supervised Land-Cover Classification, TC Florence. Source. NOAA aerial data, and ArcMap, Brackett

OID	Class Value	C_1	C_21	C_41	C_62	Total	U_ACC	Kappa
0	C_1	4	0	1	0	5	0.8	0
1	C_21	1	8	0	0	9	0.89	0
2	C_41	0	1	16	5	22	0.73	0
3	C_62	0	0	9	40	49	0.82	0
4	Total	5	9	26	45	85	0	0
5	P_ACC	0.8	0.89	0.62	.89	0	0.8	0
6	Kappa	0	0	0	0	0	0	.67

Research Question 2

Floyd

It is not possible to provide an exact total for the number of buildings that were in the flood zone from TC Floyd because the aerial imagery is so far after the peak streamgage date. However, given the fact that both the peak streamflow and peak stream gage heights for TC Floyd were greater than those for TC Florence, it is possible to get an estimate of the total buildings within the flood zone. We do know that of the 11660 building footprints from the Wayne County NC OneMap shapefile, that 1787 were in the flood zone. 1401 in the 100-year and 386 in the 500-year flood zone. Considering that TC Florence created floodwaters that surrounded 30% of all building footprints within the flood zone, the total number flooded in TC Floyd would likely be between the 30% total flooded in TC Florence and 34.8% flooded in TC Matthew, but most likely closer to 30-31%.

Matthew

Since the close up map of TC Matthew's flooding and building footprints was created using the same NC OneMap shapefile, and the zoomed in image is of the same area, then the total number of buildings in the 100-year and 500-year floodplain is the same. Of the 290 total building footprints in the image 101 were within the unsupervised water classification area. 87 of the 248 (35.1%) building footprints within the 100-year flood zone were located within the water classification. An additional 33% (14 of 42) of the buildings within the 500-year flood zone were located within the water classification. This means 34.8% of all buildings' footprints within the close-up image were within the flooded area.

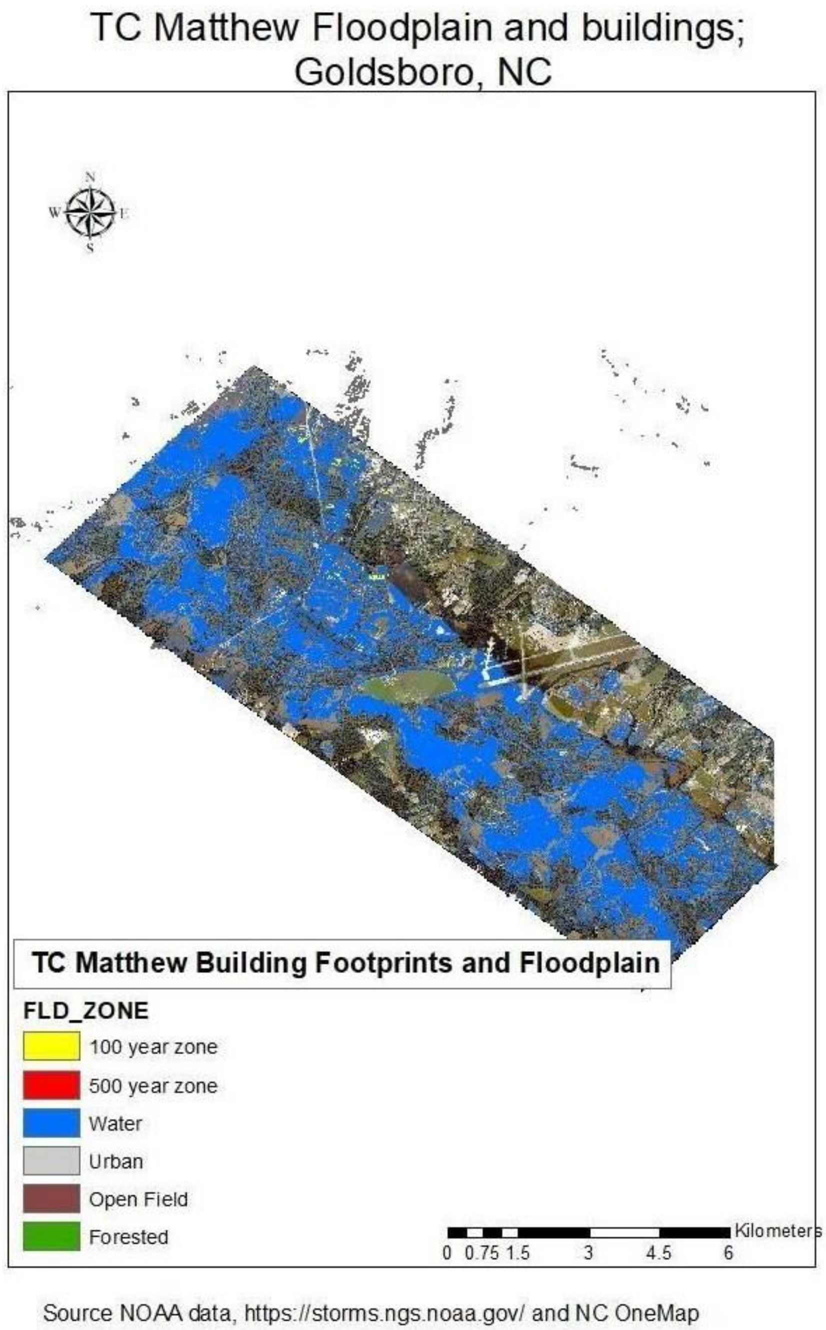


Figure 4.8. Composite Map of Land-Cover Classification (water), Buildings, and Mosaic for TC Matthew. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and , NC OneMap, FRIS and ArcMap, Brackett.

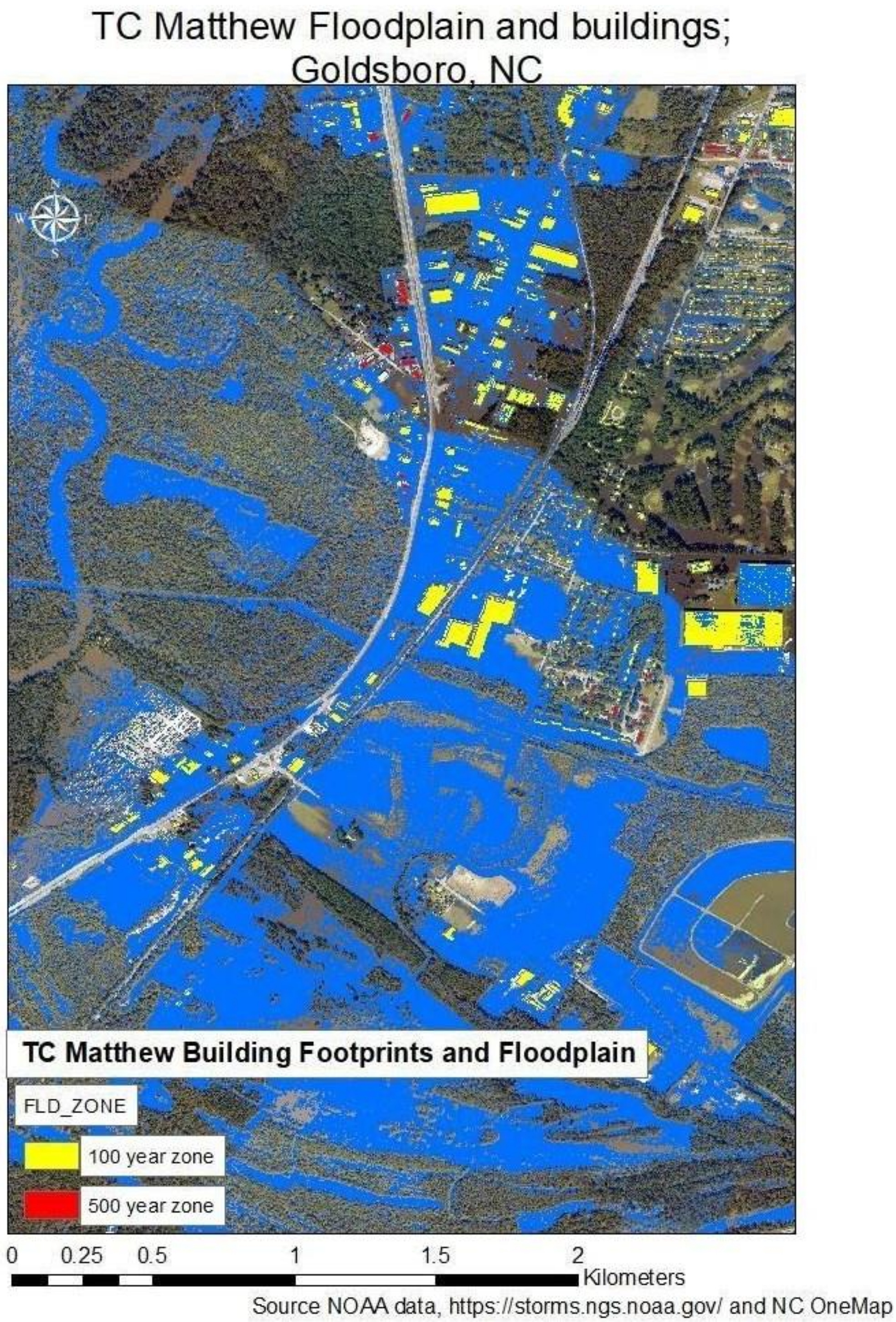


Figure 4.9 Composite Map of Land-Cover Classification (water), Buildings, and Mosaic for TC Matthew. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and , NC OneMap, FRIS and ArcMap, Brackett.

Florence

The close-up image from TC Florence contains 290 total building footprints in the flood zone. 248 of these building footprints are within the 100-year flood zone, of which 74 (29.4%) are located within the flood waters as determined by the Unsupervised land cover classification for TC Florence. There are an additional 42 building footprints within the 500-year flood zone, of which 13 (30.9%) are located within unsupervised water classification.

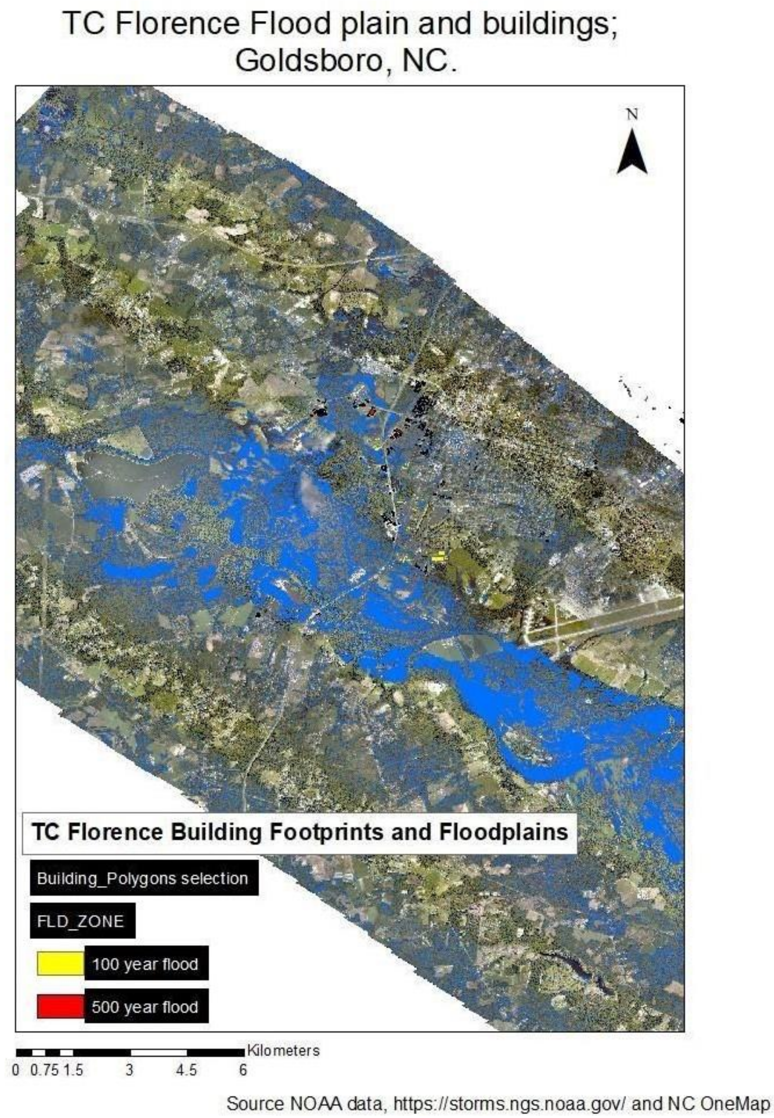


Figure 4.10. Composite Map of Land-Cover Classification (water), Buildings, and Mosaic for TC Florence. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and , NC OneMap, FRIS and ArcMap, Brackett.

Figure 4.11. Composite Close-up of Land-Cover Classification (water), Buildings, and Mosaic for TC Florence. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and , NC OneMap, FRIS and ArcMap, Brackett.

Flood Comparison

The light green areas in the composite image Figure 13, represent flooding from TC Floyd. The Blue areas show the flooding from TC Matthew, the largest of the three floods only. While the areas that flooded in all three events are is a mainly reddish brown color, RGB value (138,128,92) #81805c (https://color-hex.org/color/8a805c). The greenish area from TC Floyd is primarily confined to the river channel and low-lying areas that remained flooded well after the peak storm gage flooding. The #81805c flooded areas were likely flooded in all three events. It is certain they flooded in both TC Florence and TC Matthew. This covers a much broader area. While there are numerous pockets throughout the image that contain the blue color symbol associated with TC Matthew. This area provides the greatest insight into which areas flooded only in TC Matthew and not in the other TCs. The blue areas associate with TC Matthew usually are found along the periphery of the #81805c and in some cases in slightly elevated areas to the left and right of the center road that bisects the image, U.S. Highway 117, Dr. Martin Luther King Jr. Expressway. This area is locally known as the Big Ditch, and is even labeled that as such on zoning maps and in Google Earth Pro. All of the area, except for businesses that have built up the land under their location, falls within the 100-year flood zone. The areas that are most threatened by the flooding are those that fall within the #81805c flooded area. They correspond to the flooding from TCs Floyd and Florence. Since TC Florence had the lowest percentage of building footprints within the flooded area, it is safe to say that approximately 30% of all building footprints within the flood zone flooded in all three events.

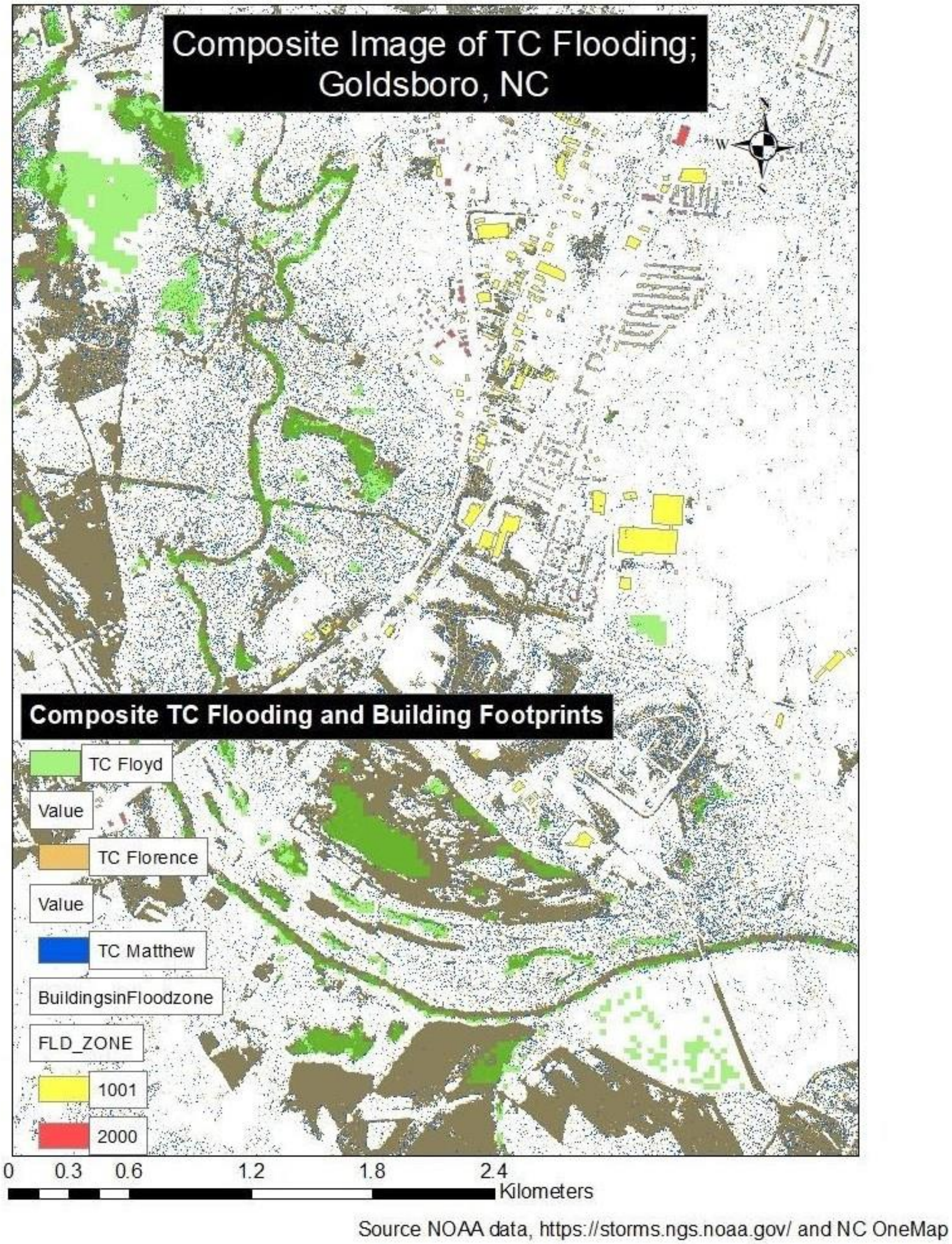


Figure 4.12. Composite Map of TC Flooding and Building Footprints, Goldsboro, NC. Source. NOAA aerial data, https://storms.ngs.noaa.gov/ and , NC OneMap, FRIS and ArcMap, Brackett.

Why was TC Matthew flooding so extreme? Difference in rainfall totals alone is not a sufficient explanation. Comparing the precipitation total maps for TCs Floyd, Matthew, and Florence reveals that the localized effects along the Neuse River were much greater during TC Matthew. The primary factor is where the precipitation fell. Even though the total rainfall for Matthew was nowhere near the totals from Florence, it was much greater in the Upper Neuse River basin. Although the precipitation totals from TC Matthew of 367 mm and Florence of 366 mm in Goldsboro are nearly identical, in Kinston the total precipitation from TC Florence of 480 mm far exceeded that of TC Matthew of 419 mm. Yet the flooding was far greater during TC Matthew. Why? One potential answer may lie with the precipitation and flooding from the Little River and Stoney Creek, which flow into the Neuse in Wayne County. The Little River flooding was calculated to have a 0.2% annual recurrence interval. More investigation will be required to definitively answer this question, however, early examination of the data points towards greater streamflow contribution from the Wayne County tributaries of the Neuse River.

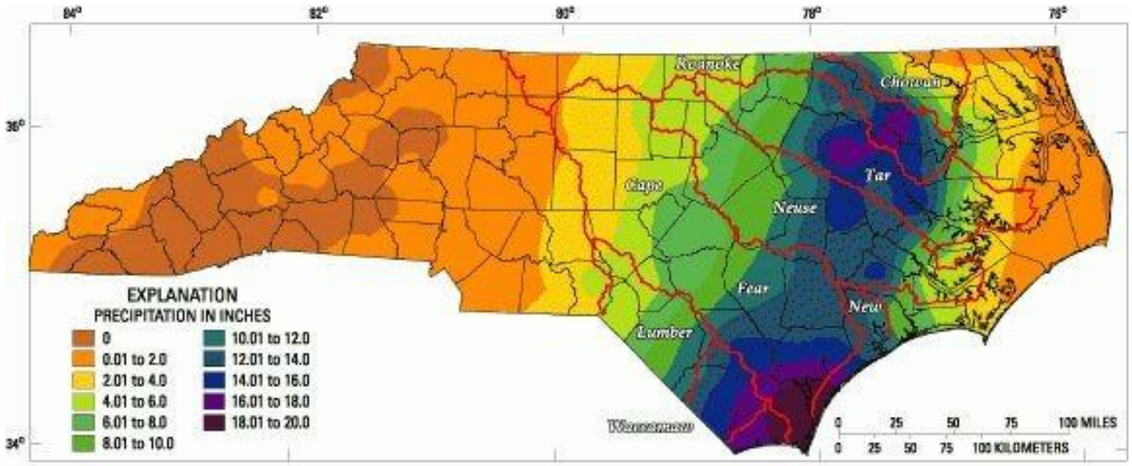


Figure 4.13. TC Floyd Rainfall. Source. https://www.ncpedia.org/media/hurricane-floyd-rainfall-map)

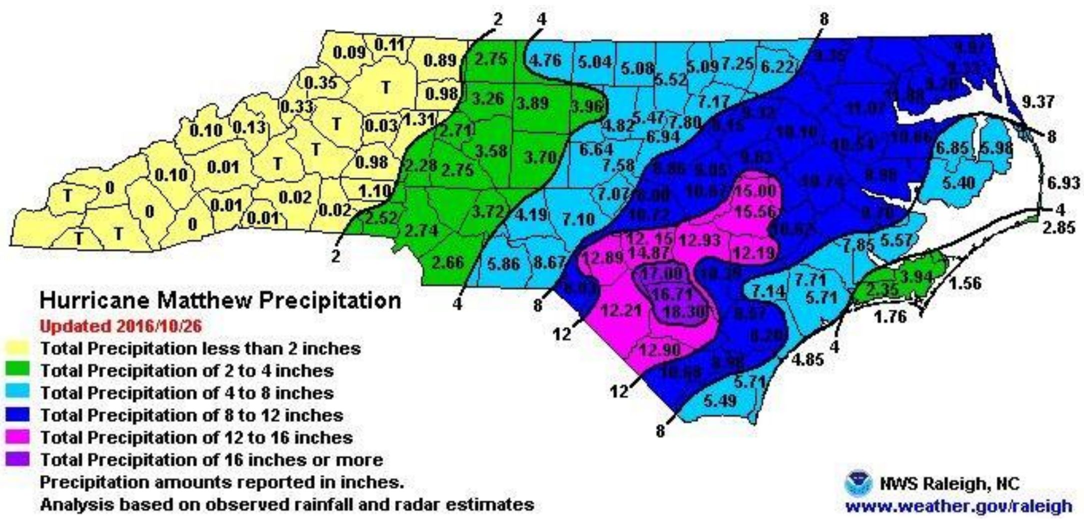


Figure 4.14. TC Matthew Rainfall. Source.
https://projects.ncsu.edu/atmos_collaboration/nwsfo/storage/cases/20161008/precip.20161008.png)

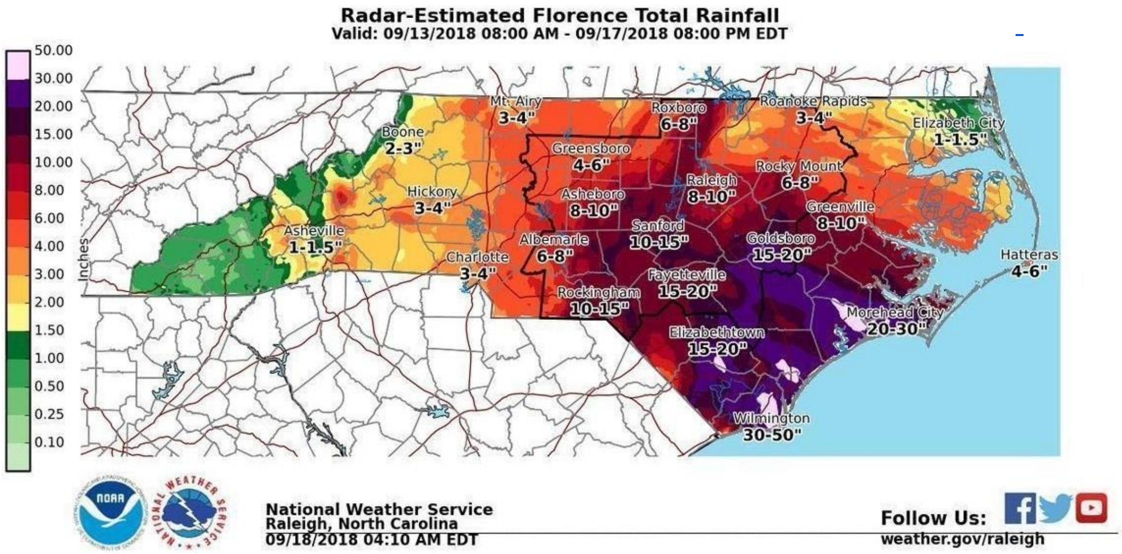


Figure 4.15. Hurricane Florence Rainfall Totals. Source. https://twitter.com/nwsraleigh/status/1042003250881482752)

The rainfall totals for all three TCs are similar. Precipitation totals alone are not enough to explain the difference in flooding between the storms. One primary factor is the rate at which the precipitation fell. NOAA's historical hurricane tracking data https://coast.noaa.gov/hurricanes/ provides imagery for the duration and track of all three TCs. The precipitation total and 6-hour incremental positions of each TC, allows for a total rainfall per each interval.

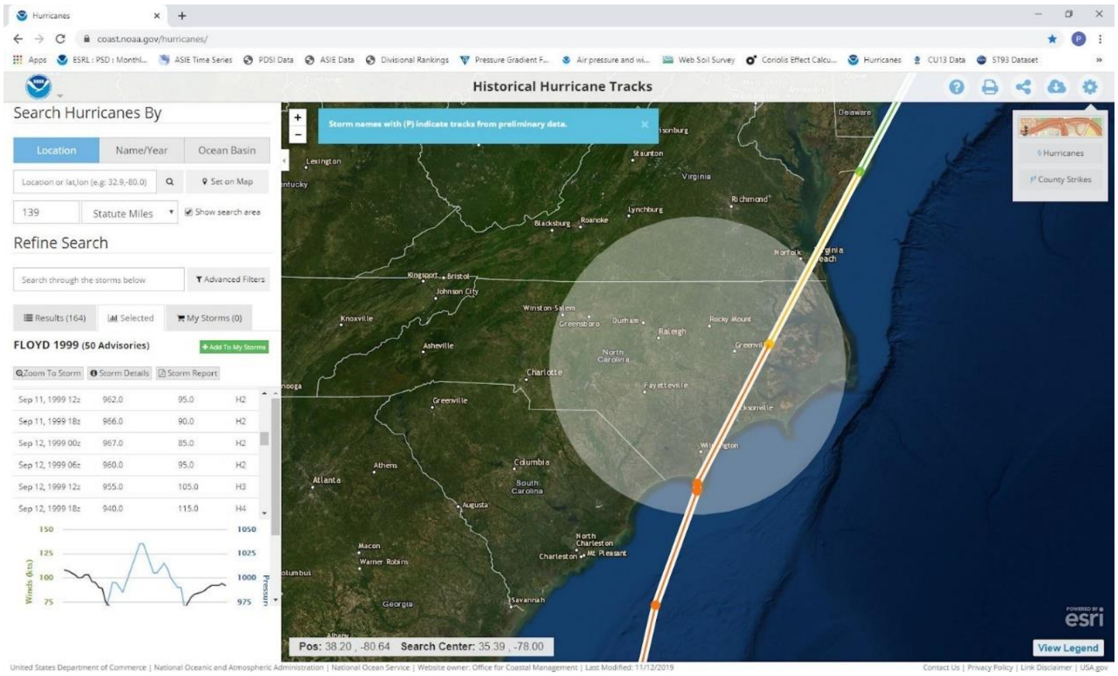


Figure 4.16. Track of TC Floyd and its 12-Hour Path through Eastern North Carolina. Source. https://coast.noaa.gov/hurricanes/

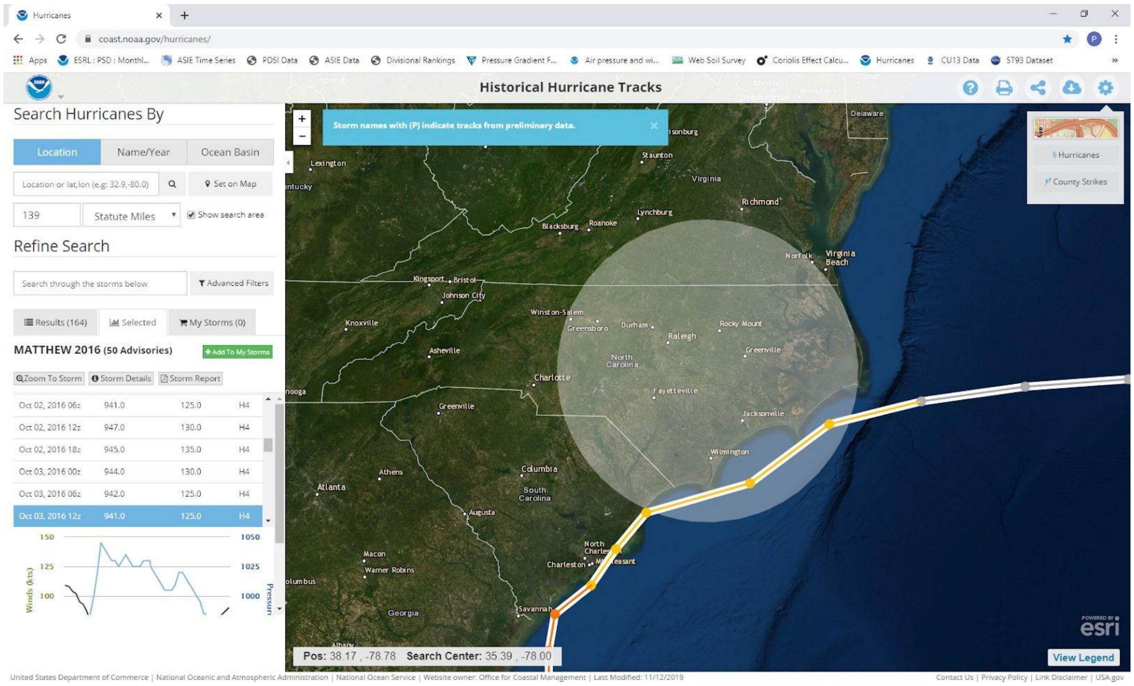


Figure 4.17. Track of TC Matthew and its 18-Hour Path through Eastern North Carolina. Source. https://coast.noaa.gov/hurricanes/

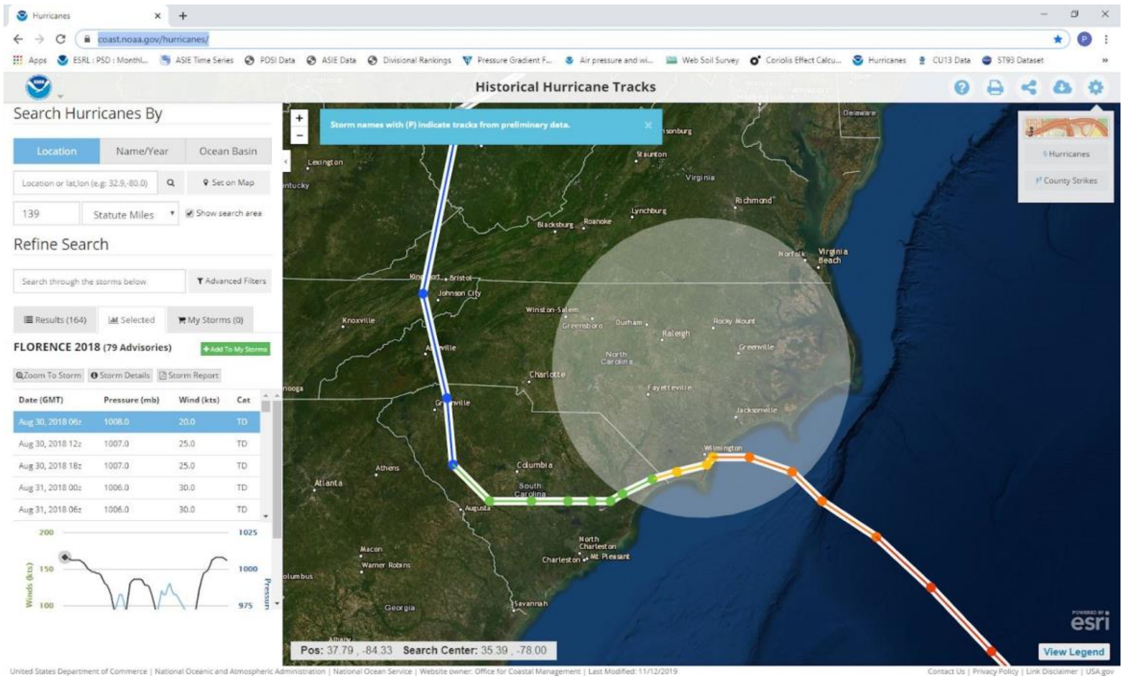


Figure 4.18. Track of TC Florence and its 36-Hour Path through Eastern North Carolina. Source. https://coast.noaa.gov/hurricanes/

CHAPTER V

DISCUSSION

Assessment of Flood Policies

To determine how effective changes in floodplain policies have been, this study examined the 100-year floodplain designation during the last 20 years and the extent of flooding, as well as the number of buildings within that zone. The assessment of floodplain policy was partly determined by examining the flood-inundation maps for each event, used in Research Question 1, to define the total number of structures potentially flooded during each event. This information was used to determine which areas show the greatest risk of flooding and what can be done to reduce the vulnerability of flood victims. Additional assessments were made by examining the effectiveness of emergency warning systems and actual evacuation, based on local and federal government studies, such as the *Neuse River Basin Flood Analysis and Mitigation Strategies Study* (2018), as well as future federal, state, and local plans to purchase property that lies in the most dangerous areas.

One additional component of interest is examining how local residents reacted to the floods, including when and exactly how public announcements were made, how many people in the inundation area remained behind with their property, when local residents left, whether experiencing flooding made local residents more likely to evacuate when warned, and whether residents were more likely to leave for Matthew (2016) and Florence (2108) than they were for Floyd (1999). Both Burke et al. (2012) and de Vries (2011) contain interviews with local residents to assess their attitudes following TC Floyd. Both Lenoir and Wayne counties produced a *Hurricane Matthew Resilient Redevelopment Plan* (2017), which examined resident attitudes and emergency response evacuations of citizens who stayed with their property after the warning, while Paul et al. (2019) contains information about rescues and deaths in the affected area during and after TC Florence.

The composite maps of TCs Florence and Matthew are the best images for showing both the extent of flooding and the buildings that sit in both the 100-year and 500-year floodplain that flooded during these events. Fully 75% of the land in the study zone that lies west of the Seymour Johnson Airforce is inside either the 100-year or 500-year floodplain. Given the limited resources of Wayne County, FRIS, and FEMA it is my estimation that the involved parties have done a great deal of good over the last 20 years. They have purchased and continue to purchase land and homes that lie within the flood zone. They have tried to educate and warn the local residents about the hazards they may face in the near future. However, the greatest resistance has come from local, state, and federal politicians who have placed greater emphasis on short term gain than on the unsustainability of living along the Neuse River and hoping that these flooding events will not continue to happen. They will.

Limitations

There were problems classifying TC Florence and TC Matthew in ArcMap. Color, especially the nuances of color at the 0.25-m resolution, seems to have been the primary impediment to achieving a satisfactory land-cover classification. The color of floodwaters throughout the mosaics varied greatly. From the cream color produced by highly agitated soils, to the mint green of sewage treatment spills, to the urban grey coal ash-coated waters around theH.F. Lee power plant, to the greyish tones of shallow water ov er parking lots, to the dark brown and nearly black coloration of water-soaked fields and tree-shaded river water---it was more than ArcMap was frequently capable of delineating. I made 11 attempts at creating a supervised land-cover classification for TC Florence alone. None of these classifications produced a kappa value of greater than 0.79 in the confusion matrix. I tried creating training areas that were completely distinct and dissimilar from one another with little success. Conversely, when I tried choosing training areas that had more complex color schemes the results were no better. I created supervised land-cover classifications with the 30-m cell size mosaic and with the 0.25-m original aerial mosaic. There appeared to be no discernible pattern to creating an accurate supervised classification. It may be that floodwaters blend colors in ways that ArcMap finds difficult to classify. Ultimately, reducing the size of the training sample to closely control what colors were being represented resulted in a 10% increase in the kappa value.

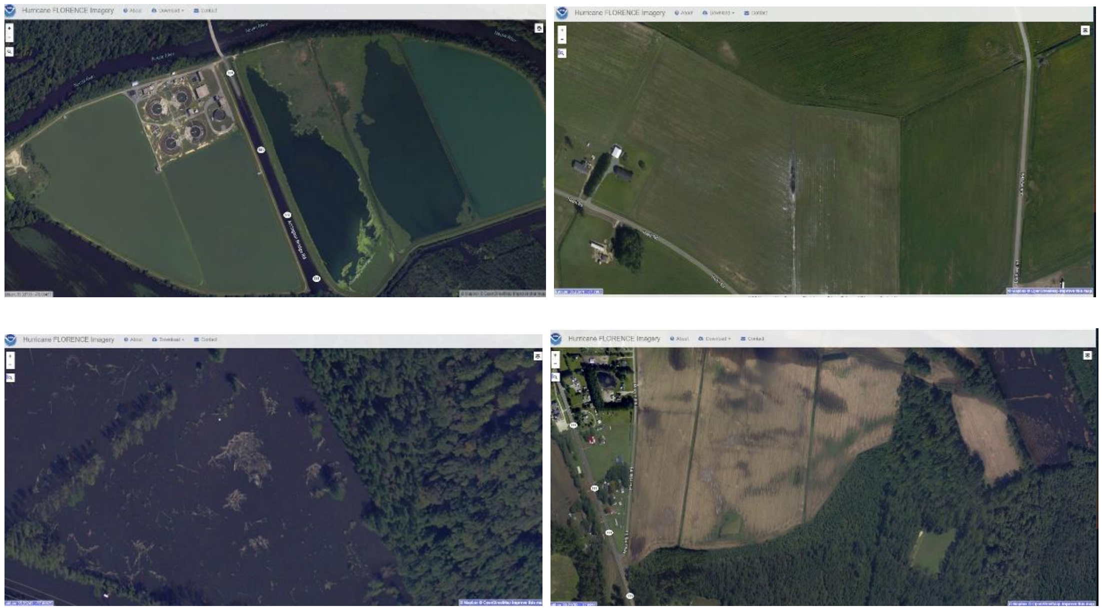


Figure 5.1. Aerial Images TC Florence. (starting upper left moving clockwise) Goldsboro sewage treatment plant and new growth in agricultural field, open field with color ranging from urban to water, and large woody debris raft in Neuse River. Source. aerial imagery of TC Florence, NOAA. https://storms.ngs.noaa.gov/

Additionally, the classifications and images for Floyd are far from perfect. The length of time between the peak streamflow and gage height on September 20 at USGS station 02089000 had been 23 days, and the streamflow had dropped from 1,090 m^3/sec to 212 m^3/sec, and the gage height had fallen from 8.79 m to 6.6 m. This was still nearly three times the annual median streamflow, 1983-2000, and more than half a meter above the flood stage elevation of 5.49 m. However, it does not reflect the extent of flooding in Goldsboro three weeks before the first clear Landsat 5 image was available.

Future Plans

The NDCOT's 2018 study of hazard reduction and flood mitigation was developed by North Carolina Emergency Management (NCEM), who proposed twelve strategies for flood mitigation. The five most viable strategies according to "location, cost and benefits" proposed local changes in elevation, reduction in impervious-surface cover through open-space planning, low-impact construction, additional water-detention facilities, relocation of individuals and structures, and the acquisition of the most threatened land. Mitigation scenario 12 was considered to have the best benefit/cost ratio of all proposed scenarios. Scenario 12 was also considered to have the "highest losses avoided and shortest implementation timeframe" (NCDOT, 2018, 108). The projected cost of $78,728,929 over a 3-year period was determined to potentially avoid more than $193 million in direct losses from flooding. The primary focus of the scenario was elevation, acquisition, and relocation, and the planned implementation time was from 3 to 5 years. According to the study, more than 1,500 buildings would be removed from the 100-year floodplain throughout the Neuse River Basin. Following TC Matthew, FEMA and the State of North Carolina agreed to use $7.8 million to acquire and demolish 75 residences in the flood-hazard area within Wayne County alone.

CHAPTER VI

CONCLUSION

This study shows that even though 75 residences that lie within the 100-year flood zone in Wayne County have been purchased and demolished, there are still 1700 other buildings that remain at risk in either the 100-year or 500-year zone. Both Goldsboro and Kinston have faced and will continue to face floods the size of TC Floyd and TC Florence at least once a decade. Although, these floods were classified in the 50-75-year recurrence interval, they have been met or exceeded 3 times in 20 years.

The land unsupervised land cover classification proved to be nearly 10% more accurate within this study. This may be due to the malleability of the Iso cluster unsupervised classification process. The process that is, of trial and error. Much of land cover classification seems more art than science, and the repeated reclassification of the 30 odd classes into smaller and smaller classes allowed for a slow honing in on a more accurate demarcation of what was water, open field, urban or forested areas.

Perhaps the most useful research question was counting the building footprints that were within the flooded area for each TC. But this too had its limitations. It was easy to acquire a count of buildings within the 100-year and 500-year flood zone; however, the shapefile was from 2019 and did not completely reflect the buildings that were flooded in

1999 and 2016. Therefore, this research question was an approximation, albeit aninsightful one, which clearly showed 290 structures residing in the flooded area.

The final research question hoped to analyze the floods created by each TC in comparison to one another. The USGS peak streamflow and gauge height data revealed that TC Floyd and Florence were very similar, and that TC Matthew's peak gauge height was a full half meter higher than either of the other TC. It also showed that the peak streamflow from TC Matthew was 50% greater than either of Floyd or Florence. The composite map showed a great deal of overlap between the three TCs. Structures within this overlap area would have flooded during all three events. Although, it was not possible to get an absolute count, due to the limited imagery from TC Floyd and the fact that the building footprints were from 2019. However, the blue areas on the map from TC Matthews flooding in conjunction with the close-up map of Goldsboro provided a clearer image of the buildings in the 500-year flood plain that were threatened or flooded during the 2016 event.

This study is a preliminary examination of the past damage and future hazards faced by those in Wayne and Lenoir counties who live along or near the Neuse River. Future flooding will occur largely due to the geographical location and geomorphology of the Neuse River Basin. Although, the county populations of these areas are not growing by leaps and bounds, those who still live there are vulnerable to additional flooding and loss of life. While the Neuse River Basin remains at risk, it is only one of six major basins that course through the poorest areas of eastern North Carolina. One cannot count on the Federal or local governments to purchase all the homes and businesses that remain at risk, if for no other reason, than the financial downturn created by Covid-19 threatens to undermine even the weak safety net that has been cast. Let us hope the fall of 2020 is TC free, because this year the TC season is likely to coincide with the fall resurgence of the Coronavirus, and in eastern North Carolina that combination of events could be disastrous.

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