Interim Update to the North Carolina General Assembly

UNC Flood Resiliency Study

Submitted by NC Policy Collaboratory
February 2021

https://collaboratory.unc.edu

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FOREWORD

Legislative Charge

In September 2019, the North Carolina General Assembly (NCGA) passed Senate Bill 429, the "Disaster Recovery Act," (Session Law 2019-224) into law. Among its many provisions the bill appropriated $2,000,000 to the North Carolina Policy Collaboratory to conduct research related to flood resiliency in eastern North Carolina. The legislation called for submittal of the final report by December of 2020.

During the 2020 legislative session, in response to challenges faced by university researchers due to the ongoing pandemic, the NCGA passed House bill 308, which delayed the final report date until June 1, 2021. (Session Law 2020-74)

The additional time allotted for the study will allow researchers to develop a more robust data set and conduct further analysis of some of the early findings. **Importantly, the research team believed it was timely to submit this Interim Update to the NCGA to share some initial findings and recommendations that could potentially be acted on during the 2021 legislative session.**

Study Development and Focus

A research team comprised of experts in a wide range of fields was developed to evaluate flood resiliency from a comprehensive perspective. The flood resiliency study is focusing on five specific focal topics:

- Floodplain Buyouts
- Financial Risk
- Natural Systems
- Infrastructure
- Public Health

The study represents a collaboration of many projects and researchers from UNC-Chapel Hill and NC State University as partner universities. The full study is being overseen by Principal Investigator Mike Piehler, the Director of the UNC Institute for the Environment (IE). The various lenses through which inland flood resiliency is analyzed coalesce on the same goals of:

1. Keeping North Carolinian's safety as the first priority
2. Improving the state's responses to flood and storm events

This project spanned research techniques from water sampling to financial analysis and flood modeling. This multi-faceted approach allowed wide engagement and applicability. **While the majority of research pertains to eastern North Carolina, the significance of the key findings of these studies extends to communities beyond the coastal plain region of the state—the implications of flood resiliency research are statewide, not regional.**

Initial Outcomes and Recommendations

Outlined below are a few of the initial research outcomes and in some cases preliminary recommendations developed during the course of the study to this point. ***These recommendations will be expanded and refined in the final report.*** *One overarching recommendation is provided at the outset.*

- Response to flooding following large storm events is managed by a myriad of state and local agencies. These agencies and response organizations provide critical support to residents following events. However, a standing committee at the NC General Assembly specifically focused on this topic, such as a Joint Oversight Committee on Recovery and Resiliency, could provide needed coordination and oversight.

Floodplain Buyouts

- Conducted nationwide census of buyout funding programs for baseline information and to identify best practices.
- Analyzed and mapped data to track where buyout recipients relocated for the purposes of evaluating relative neighborhood quality before and after buyouts.

Financial Risk

- Estimated the risk of mortgage defaults from joint exposure to property value changes and uninsured damages from flood events using publicly available data on single family mortgage originations.
- Developed a predictive modelling approach to estimate community vulnerability and map expected annual uninsured loss at the census tract scale for the entire State of North Carolina.

Natural Systems

- Analyzed the implementation of natural infrastructure and found that:
    - widespread use could provide some flood reduction benefits at the tributary scale; impacts are limited along the mainstem rivers.
    - natural infrastructure cannot alleviate flooding of the 100-yr floodplain; infrastructure in these areas should be target for buyout or relocation to avoid repeat loss.
    - implementation of wetland creation/restoration projects could provide substantial water quality benefits.

Infrastructure

- Evaluated water and wastewater utilities through the lens of resilience and identified potential improvements, such as:
    - operating resilience at the state level through the development of clearer resilience planning guidance for water and wastewater utilities.
    - creating a bridge funding/financing program to help utilities buffer the lag time for FEMA funding.
- Completed a model of the entire NC power grid to evaluate flooding impacts on the grid and are continuing with a geospatial analysis of the extent of flooding associated with hurricanes Dorian, Florence and Michael.
- Studied actions to address the long-term issue of coastal urban flooding and outlined solutions, including:
    - Updating infrastructure to address network inundation (e.g., backflow prevention, pumping, fixing leaky pipes)
    - Decentralized or low impact development practices to manage stormwater (e.g., stormwater harvesting and storage above ground)
    - Landscape-scale planning to incorporate temporary surface storage of flood waters

Public Health

- Collected and analyzed water samples following hurricane events finding that flooding can be associated with increased levels of pathogens and antimicrobial resistance in surface waters, with effects lasting for days or weeks.

Figure 1. Flooding in North Carolina from Hurricane Matthew. Source: ABC News

Study Overview

In recent years, North Carolina has seen powerful hurricanes cause significant damage, including loss of life and devastating economic and environmental impacts across the state. With trends pointing to an increased number of powerful storms, inner-coastal communities and ecosystems will face more damage and longer-lasting flooding. To combat this, scientists are studying resiliency with policy in mind, determining how to enact policies that take a preventative preparedness approach and are fast-acting in order to give flooded communities the resources to bounce back. Given the importance of this study and its large scope across five disciplines, the large award from the legislature was pivotal to making this research a possibility.

The study team is comprised of more than a dozen Primary Investigators with other faculty, research technicians, and graduate and undergraduate students involved as well. The broad and diverse expertise of the study subjects made it so the project could address flooding and resiliency issues in a comprehensive manner.

Study Principles

Though this study took place as a request from the state, the research conducted follows the guidelines of rigorous academic research, as is true of all North Carolina Policy Collaboratory funded projects. The study has the goal of gathering new data and information from research that will assist in informing decisions by the state's policy-makers and state and local government agencies.

Study Activities

In the year and a half dedicated to the project, scientists have worked on a number of scientific and economic research sub-projects. Some of the specific research and project activities undertaken during the course of the study included:

- Assessing operational flooding risks for substations and the wider North Carolina electricity grid
- Evaluating the impact and challenges of stormwater control measures during floods
- Exploring the funding mechanisms available for floodplain buyouts
- Creating a dynamic model of flood damage and property values
- Modeling storm surge on coasts from Hurricane Florence
- GIS analysis of areas to implement natural infrastructure practices
- Storm sampling for pathogen tracing
- Engaging stakeholders throughout eastern North Carolina and state leaders

Figure 2. Research team members sample water for Public Health analysis.

Outreach and Engagement

At the outset of the Study, members of the research team held meetings with the leadership of the NC Division of Emergency Management (DEM) and the NC Office of Recovery and Resiliency (NCORR). These meetings were designed to ensure that the research team was working with the most up-to-date data

and not duplicating efforts underway at the state agency level. The cooperation of the DEM and NCORR were critical to the research plan developed for the study.

Research team members also met with a number of state agencies to solicit their feedback and share information about the study. These agencies included:

- Department of Agriculture and Consumer Services
- Department of Commerce
- Department of Environmental Quality
- Department of Health and Human Services
- Department of Insurance
- Department of Transportation

In addition to the engagement with state agency officials, project leaders also presented information about the Resiliency Study to numerous other parties. This outreach work was intentional in sharing information about the project and listening to key stakeholder input that could inform the research. The input and guidance from local government officials, environmental organizations, and industry had a direct impact on identifying key issues that are being examined as part of the study.

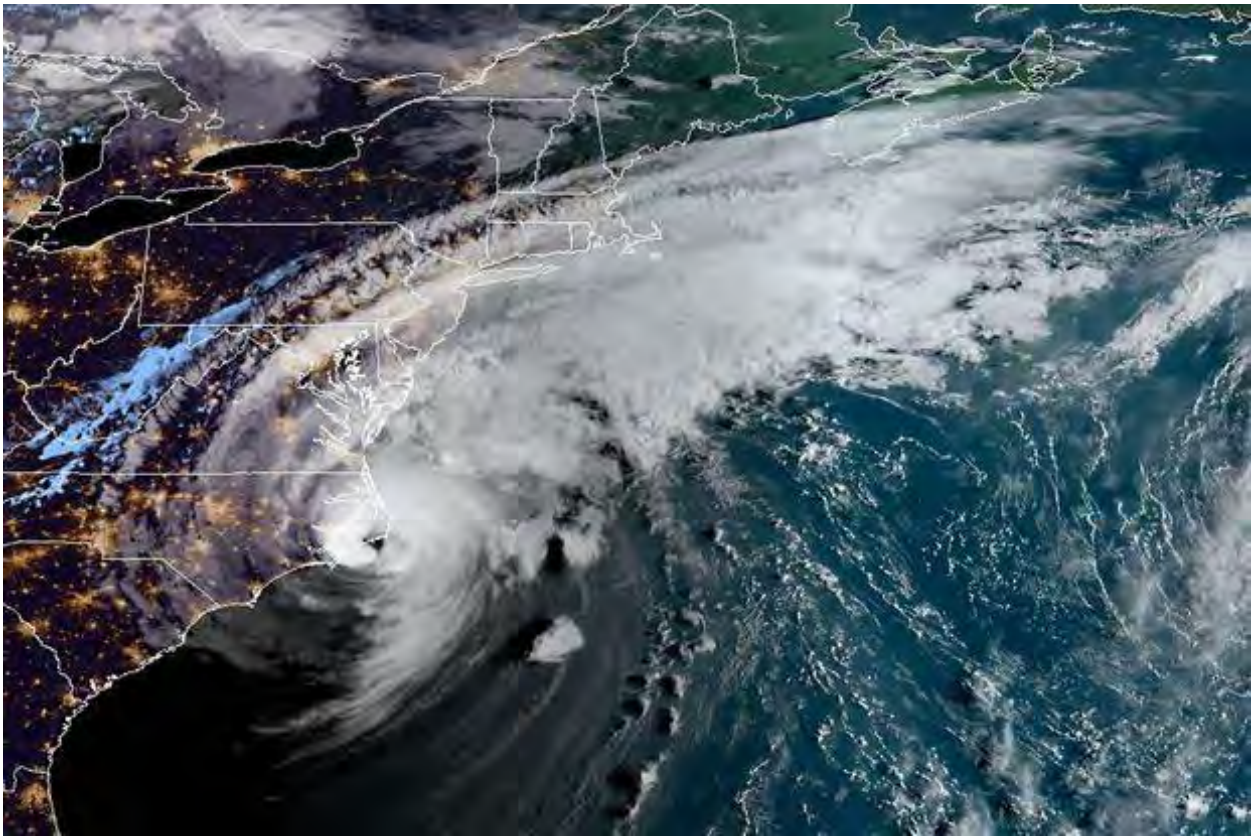
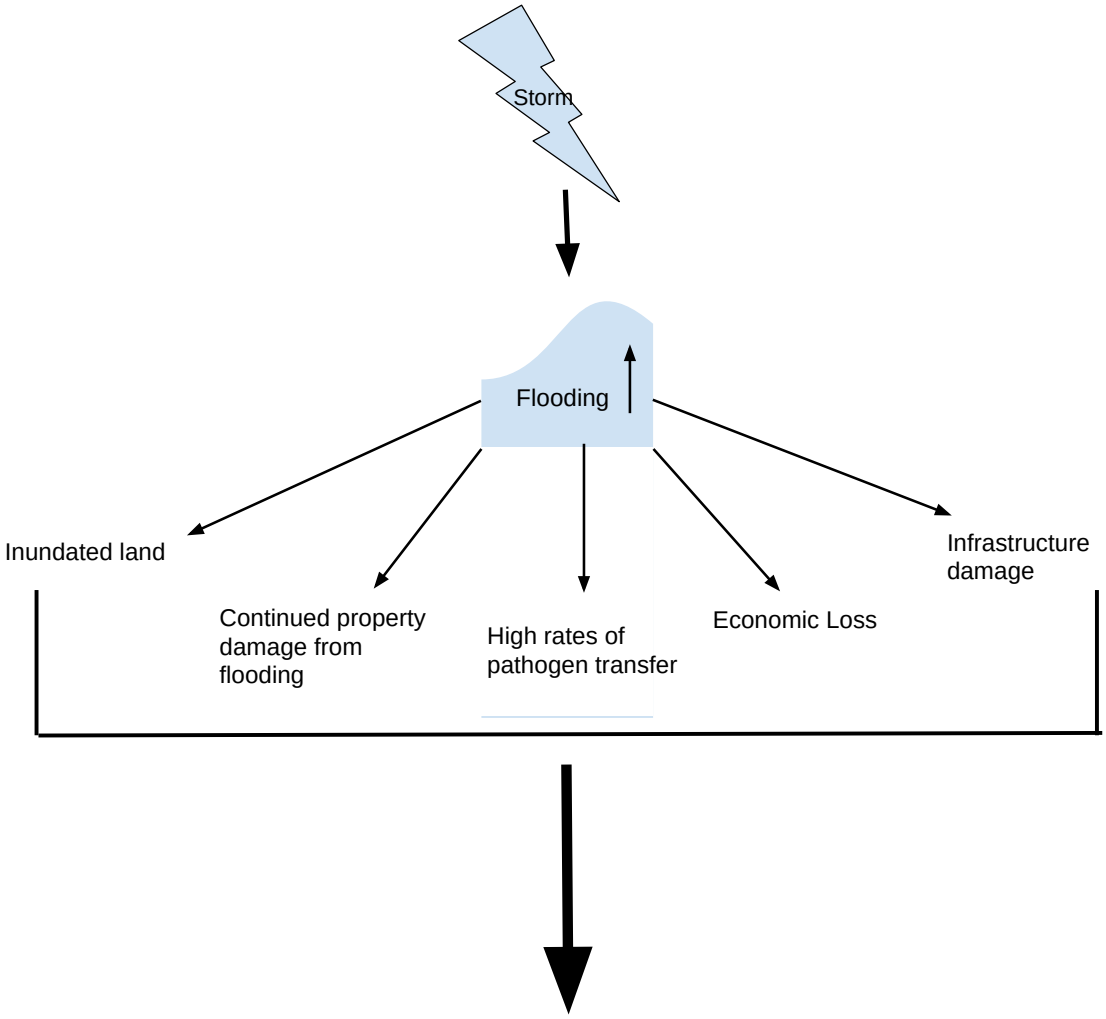


Figure 3. Hurricane Dorian over North Carolina. Source: Wall Street Journal.

Study Outline



Flood Resiliency Study

RESILIENCY MEASURES	Natural Systems	Floodplain Buyouts	Public Health	Financial Risk	Infrastructure
GOALS	Utilizing natural recovery systems more effectively and efficiently	Using most impacted land as a water holding space through paying residents to move.	Limiting pathogen spread from flooded waters	Reducing economic loss	Natural recovery measures for water holding

BACKGROUND

In North Carolina, like many coastal states, hurricane season from June-November each year can be nerve-wracking. Storms are destined to appear on the radar, but one never knows how powerful they will be or how much damage they will cause. Large amounts of money go into the preparation and protection from hurricane events as well as clean-up efforts once they have hit. The 2020 hurricane season was particularly active, with most of the impacts affecting the Gulf Coast states.

For both coastal and inland areas, one of the largest concerns is flooding. Diseases are more prominent in flood waters, electrical lines are torn down by high winds and cause outages in the grid for weeks, and full recovery often takes months and millions of dollars.

Figure 4. Flooding caused by Hurricane Florence. Source: ABC News.

In the past few years, North Carolina has had especially bad luck with these storms, experiencing "once-in-a-hundred-year-storms" multiple times. In 2016, Hurricane Matthew caused catastrophic flooding and killed 28 people. The flooding didn't go down for months afterward. In 2018, Hurricane Florence battered the southern shores of North Carolina, evacuating students at UNC-Wilmington for months. In 2019, Hurricane Dorian nearly leveled the Bahamas and made its way slowly up the coast, wreaking havoc on Ocracoke Island, among other treasured locations in the state and across the southeastern United States.

These more frequent, intense storms put stress on the people and land involved and impose economic strain. The compounding mental health burdens and financial distress for families can be extremely detrimental, especially if they are dealing with the loss of life or property due to the hurricane.

Figure 5. Flooding from Hurricane Matthew. Source: Vox.

The Flood Resiliency Study was established and funded after Hurricane Dorian. The study focuses on methods to mitigate and control for inland flooding, and will be utilized when large storms hit North Carolina in the future. The project was set up to develop a set of policy recommendations making the communication between the university system and state legislature seamless and quick. Five subprojects are incorporated to address flooding and its risks from several perspectives. Methods such as floodplain buyouts to increase land used for water absorption and natural infrastructure measures to effectively use undeveloped land as a safety measure are included.

RESEARCH STUDY

In this section, we summarize methods and findings from the five different subsections of the study. While research teams have been working independently on their specific topics, the researchers are continuously sharing information and providing feedback to each other.

Floodplain Buyouts

Floodplain Buyouts

Todd BenDor and Jonas Monast, et al.

Objective

This floodplain buyout initiative is focused on analyzing the current processes by which buyouts are carried out, determining the financial cost and net change in aggregate risks of administering these buyouts in a particular community, and working with relevant consultants and government officials with experience in organizing buyouts.

To complete the analysis of the buyout process and its costs, a review of current funding and literature analysis must be finalized and submitted for publication. Surveys of consultants and government officials must also be completed and added to the report. To complete the assessment of risks, the team will finish data archiving and curation and finalize the buyout database designed to highlight floodplain buyout locations and corresponding municipal land use and stormwater policies in North Carolina.

Research Methods and Initial Outcomes

- The team is working to compile a manuscript of research regarding existing funding mechanisms for floodplain buyouts throughout the country, as well as an additional manuscript covering specific techniques used to determine the real costs of buyouts.
- Efforts are also being made to clean and merge several datasets of buyouts in North Carolina to produce a single, comprehensive dataset.
- Research is being performed to determine relationships between new development sites and areas marked for buyouts, as well as to gather information regarding the potential impact these new developments may have in enhancing the susceptibility of an area to flood damage.
- The team is working to finalize NCDEM's state-wide parcel data by combining this existing data with datasets detailing floodplain data and real estate data.
- Regarding efforts to understand the floodplain buyouts process, the team has successfully completed a nationwide database of all US buyouts—the first database of its kind—to aid in future research on the spatial distribution of buyouts, the aggregate risk associated with flooding in buyout communities, and the economic impact of buyouts on a given community. Researchers also effectively measured data (2001 to present) of new development and housing in floodplains throughout the state.
- Detailed analyses and subsequent report of federal, state, and local floodplain buyout mechanisms was completed and submitted to a peer-reviewed journal during the fall of 2020.
- The team has completed analysis of literature regarding the financial costs of implementing buyouts as well as local budgets of communities with buyouts; evaluation of these communities' budgets show that most budgets do not factor in the financial cost of buyouts.

- An online survey regarding buyout costs will be completed and distributed to state hazard mitigation officers, local officials, and federal agencies (FEMA and HUD).

Figure 6. The checker-board pattern of floodplain buyouts in Greenville, NC.

Financial Risk

Greg Characklis, et al.

Objective

This project aims to determine the communities most financially vulnerable during flood events, as well as the factors (geographic, socio-demographic) attributed to greater loss in property value, the factors that expedite recovery, and the financial impact of flood damage on property owners, financial institutions, and local governments. Spatial relationships were derived between quantified flood damages and market data of property values in counties comprising the Neuse Watershed of eastern North Carolina. A hedonic model and corresponding map of estimated 2016 property values in rural and urban areas of Wayne County has been developed, and future actions of this project will focus on completing such analyses of other counties using point-level flood damage and insurance data.

Research Methods and Initial Outcomes

- Preliminary results of this project are displayed via spatial interpolation based on the hedonic model for Wayne County in 2016, illustrating estimated real estate values derived from the hedonic model contained within urban and rural areas. This spatial interpolation is shown in *Figure 7* from the *Characklis, et al.* report:

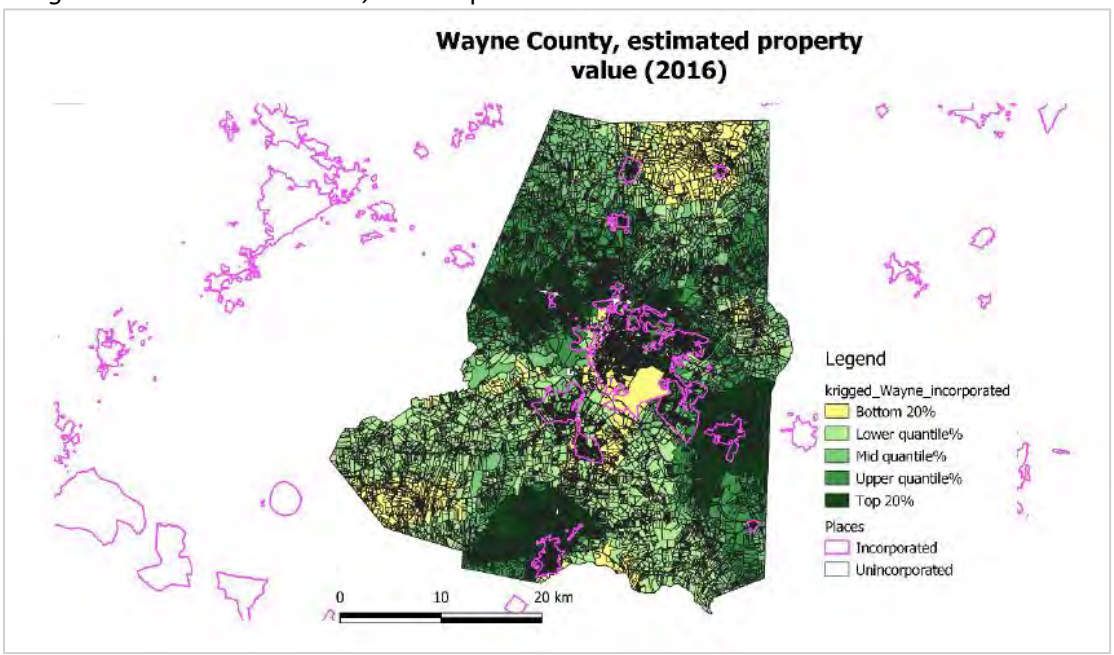


Figure 7. Result of the hedonic model for Wayne County in 2016.

Natural Systems

Improving North Carolina's Resilience to Coastal Riverine Flooding

Barbara Doll, et al.

Objective

The primary goal of this project is to represent the impact of natural infrastructure projects on flood mitigation and water quality enhancement efforts in the Neuse River Basin, specifically focusing on three sub-basins: Nahunta Swamp, Bear Creek, and Little River. GIS-based analysis has determined locations within the Neuse River Basin in which strategic natural infrastructure efforts could reduce flooding and improve water quality and natural habitats. Hydrologic models for the three sub-basins are being developed to assess the effectiveness of mitigation practices and estimate water storage potential within these regions. An advisory board was created to survey farmers and landowners in Wayne County in order to collect data on existing water management efforts, flooding conditions, previous property damages, and other factors.

Research Methods and Initial Outcomes

- Seven natural infrastructure practices pertaining to agriculture, ecological restoration, and engineered practices have been evaluated for their potential to mitigate flooding.
- Researchers from the NCSU Dept. of Biological and Agricultural Engineering (BAE) developed hydrologic models for the three sub-basins studied in this project (Little River, Nahunta Swamp, and Bear Creek) and are working to model mitigation strategies.
- BAE researchers have developed SWAT models for Nahunta Swamp and Little River. NCSU College of Design's Coastal Dynamics Design Lab completed geospatial analyses to locate specific areas within the Neuse River Basin with the greatest potential to reduce flooding and improve habitats and water quality. These analyses identified potential locations for reforestation, water farming, and wetland creation within the middle Neuse River Basin.
- Results from hydrological modeling of Bear Creek and Nahunta Swamp reveal that:
    - For Bear Creek, peak flow during Hurricane Floyd (1999) would have been reduced by 21.8% had the watershed incorporated 5% water farming, 10.6% reforestation, and 21% routing via constructed wetlands into the watershed's natural infrastructure
    - For Nahunta Swamp, peak flow during Hurricane Matthew (2016) would have been reduced by 13.6% had the watershed incorporated 5% water farming, 1.8% reforestation, and 12% routing via constructed wetlands into the watershed's natural infrastructure
- Preliminary results from geospatial analysis and modeling of various sub-basins in the middle Neuse River Basin reveal significantly less water flow reductions in the Neuse River Basin because the region's steep slopes and existing development.
- The team constructed a survey for Wayne, Craven, Greene, Lenoir, Jones, and Wilson counties for potential landowner agreement options.
- Print and online products designed to share project results with eastern North Carolina stakeholders are currently under construction.

Compound Flood Modeling

Rick Luettich and Antonia Sebastian, et al.

Objective

The purpose of this project is to assess eastern North Carolina's modeling systems for compound flooding (the combined effects of precipitation and coastal storm surge flooding). In addition to analyzing NOAA's National Water Model and the models currently used by the NC Division of Floodplain Management, this team is working to locate areas in eastern North Carolina that are most susceptible to compound flooding and improve existing coastal surge and flood modeling systems based on analysis of Hurricane Florence. The team will finalize the New River watershed's flood model, which will serve as the pilot test case for the flood modeling of all coastal watersheds in the state. The team's modeling efforts will concentrate primarily on the Neuse River and may include the Cape Fear basins.

Research Methods and Initial Outcomes

- Modeling of the coastal storm surge from Hurricane Florence has exhibited minimal compound flooding north of Cape Lookout. These results are supported by ADCRIC model predictions, though results for areas south of Cape Lookout may be less accurate, possibly due to errors in meteorological data or water level observations.
- Surge components in the region south of Cape Lookout have been deemed as essential to understand and represent accurately because of the area's strong indications of compound flooding components.
- Analyses of existing flood models provided by the NC Flood Risk Information System (NCFRIS) website and discussions with the NC Department of Environmental Management (NCDEM) have revealed that there are no existing hydrologic models for large river basins such as the Neuse River Basin, and that the availability of hydraulic models depends on the tributary within the basin.
- Many existing hydraulic models are outdated and lack georeferenced data; future endeavors from this team will include analyzing the ADCRIC coastal model's ability to incorporate coastal riverine hydraulics, as well as constructing new inland hydrologic models.
- Small coastal watersheds were found to be disproportionately more susceptible to compound flooding due to the short time of concentration in the event of hurricane precipitation.

Infrastructure

Stormwater Control Measure Resiliency

Bill Hunt, et al.

Objective

This two-pronged project focuses on transferring information collected through interviews from maintenance professionals into resiliency-based guidelines for design and maintenance strategies for Stormwater Control Measure (SCM) infrastructure in coastal North Carolina. From this information, four SCM resiliency fundamentals were developed and used to evaluate the resiliency of existing systems. These active SCMs were evaluated and the most resilient practice types were identified (e.g., SCMs that utilized vegetation in their infrastructure tended to fare better with high water flow, temporary inundation, and lack of maintenance). Specific SCM design features that may impact resiliency were also identified, such as proximity to surface water, use of forebays to reduce erosion, and the effectiveness of emergency spillways. The final component of this project will be to draft a report on SCM resiliency and assess resiliency-based SCM infrastructures carried out in two urban watersheds in eastern NC: Jacksonville and Wilmington.

Research Methods and Initial Outcomes

- Interviews of maintenance professionals with experience in Storm Control Measure (SCM) infrastructure allowed the researchers to determine four key "SCM Resiliency Fundamentals": Appropriately situated, well-designed, specifically constructed, reliably maintained SCMs are comparatively more resilient; most existing SCMs fail to satisfy one or more of these conditions.
- SCM strategies that incorporate vegetation fare better when faced with high water flows, inundation, and lack of maintenance, with constructed stormwater wetlands performing the best. Vegetated infiltration basins and wet detention ponds are more resilient than average SCMs.
- Due to low installment of bioretention cells in coastal regions, which would normally be expected to perform better than infiltration basins and wet detention ponds in terms of resiliency, the research team refrained from recommending this method.
- Forebays are reservoirs built as flood buffers, and they reduce systems' internal erosion caused by opposite-direction flow from downstream. Emergency spillways in existing SCM infrastructure do not withstand high flow rates effectively, which can result in embankment failure.

Financing Strategies for Resilient Infrastructure

Erin Riggs and Austin Thompson

Objective

Researchers at UNC's Environmental Finance Center are compiling a dataset of existing sources of funding for flood-resilient infrastructure and performing case studies on eastern North Carolina communities whose infrastructure was impacted by the floods induced by Hurricanes Matthew, Florence, and Dorian. The group updated previous datasets of funding resources and presented write-ups of innovative financing strategies for resilient infrastructure. They gathered financial data and information about water and stormwater infrastructure from nine communities in three river basins and performed case studies with Cape Fear Public Utility Authority (CFPUA) and Whiteville to gain better insight on flood resiliency efforts. Next steps will involve case studies of more communities in eastern North Carolina and the development of a larger, more comprehensive report on flood resiliency progress in the region.

Research Methods and Initial Outcomes

- The research team developed a free tool designed for utilities to use as a way to judge their "financial resilience," or their ability to quickly cover shortfalls in revenue.
- The research team at the EFC compiled a table of existing funding resources designated for supporting more resilient infrastructure and presented this table at an EPA workshop on flood resiliency for utilities.
- A comprehensive write-up, followed by supplementary write-ups for further analysis of each of the main document's key components, was constructed to analyze innovative funding mechanisms for resilient infrastructure, specifically highlighting environmental impact bonds, resilience bonds, parametric insurance, and the community rating system.
- Case study analysis helped the EFC team inventory past water infrastructure projects, costs and levels of governmental project supervision, and target communities' financial data. The collected data was used to create a survey for six communities (Kinston, New Bern, CFPUA, Fayetteville, Lumberton, Whiteville) that gauged preparedness for floods and flood resiliency.
- Cape Fear Public Utility Authority's (CFPUA) environmental and public policy department will utilize its resources to produce long-term infrastructure plans that embody resiliency and sustainability. Whiteville, though smaller and with access to fewer resources compared to CFPUA, will focus on financial resilience, specifically by building the utility fund balance for future service interruptions and continuing to use the stormwater utility the town created in 2019.

Assessing Operational Flooding Risks for Substations and the Wider North Carolina Power Grid

Jordan Kern and Luis Prieto Miranda

Objective

The goal of this project is to assess the vulnerability of the electric grid to flooding in parts of eastern North Carolina. Researchers discussed coastal and inland flood concerns with North Carolina Electric Membership Corporation (EMC), a major supplier for much of eastern NC's bulk power system. The consultation prompted the team to conduct a preliminary geospatial flood risk assessment for the region using energy generation asset data (renewable and nonrenewable). This analysis identified which power grid assets were located within flood inundation zones. The research team investigated which portions of the eastern North Carolina power grid were most susceptible to long-term outages induced by flooding and developed a holistic model of the state's power grid infrastructure. The model drew from each individual substation and assessed the grid's response in the event of partial outages.

Research Methods and Initial Outcomes

- According to NC State researchers' geospatial analysis of flood risk and recent hurricanes, many sub-stations and generation resources are vulnerable to flood damage because they lie in the paths of flood waters.
- The study highlighted the tendency for risk-based maps (such as 1-in-100-year storm projections) to underestimate the risks posed by recent storms.
- The researchers determined that further research—e.g., developing a relevant database—regarding how specific design features and assets impact the vulnerability of power grids to flood damage is essential.
- An open-source, highly-detailed model of the state's power grid was constructed as a tool to effectively demonstrate the disruption caused by widespread power outages and pre-emptive storm de-energization.

Stormwater Infrastructure and Water Level

Mike Piehler, et al.

Objective

Addressing the growing need to upgrade the outdated "curb and gutter" drainage systems that most cities in the southeastern United States rely on for stormwater management, **this team is focusing its efforts on analyzing the impact of rising sea levels on coastal North Carolina's stormwater infrastructure.** Research involves surveying stormwater networks in Wilmington, Beaufort, Nags Head, and other municipal partners and utilizing NOAA sea level maps and elevation data. The team will also develop flood risk maps and relevant statistics to illustrate stormwater infrastructure inundation from rising sea levels.

Research Methods and Initial Outcomes

- 65 NC municipalities had estimated road area impacted by high tide flooding (HTF) and over a third of them observed impact on at least 1% of road area.
- Smaller municipalities were more likely to have higher relative amounts of HTF on roads
- Modeling results and water level measurements suggested that extensive inundation of underground stormwater infrastructure frequently occurs during typical water levels.
- Of the four modeled municipalities, the two with the most extensive stormwater infrastructure inundation (Beaufort and Nags Head) had approximately 1% of their total road area impacted by HTF.
- Model results show that stormwater infrastructure can sometimes act as a conduit for elevated receiving waters to flood low-lying inland areas that would otherwise be disconnected.
- Stormwater infrastructure inundation is common and likely increases the occurrence of urban flooding in coastal NC by reducing the capacity of drainage networks
- Stormwater infrastructure inundation is often underground under current conditions, making it difficult to observe.
- Issues with stormwater network survey data quality and availability make it difficult to directly characterize and model the extent of the issue.
- The issue of stormwater infrastructure inundation will rapidly increase with sea level rise.
- Many low-lying coastal areas will need to adapt quickly to mitigate stormwater network inundation and excessive stormwater runoff due to the effects of climate change

Public Health

Hurricane Florence Response

Jill Stewart and Rachel Noble

Objective

Flooding from extreme weather events poses public health risks from the spread of pathogens, antimicrobial resistant bacteria, and other microbial hazards. **To understand and mitigate these risks, the project team is evaluating microbial hazards associated with flooding versus background levels of contaminants in water systems.** The researching laboratories have collected and analyzed water samples from before and after Hurricane Florence, built capacity in molecular pathogen analysis, and coordinated large-scale sampling events to evaluate trends in water quality and effects of flooding.

Research currently includes regulatory targets such as total coliforms, fecal coliforms, and *E. coli*, as well as other targets of public health concern including antibiotic resistant bacteria, HF183 human fecal marker, *Vibrio* sp., somatic and male-specific coliphages, *Campylobacter* sp., *Salmonella* sp. and respiratory and gastrointestinal viral pathogens. Samples were collected from selected locations in the Lumber, Cape Fear, and Neuse river basins (Figure 2). An estimated 1.4 million residents depend on onsite septic systems for wastewater management. Samples were analyzed using standard membrane filter techniques and/or standard IDEXX enzymatic substrate techniques.

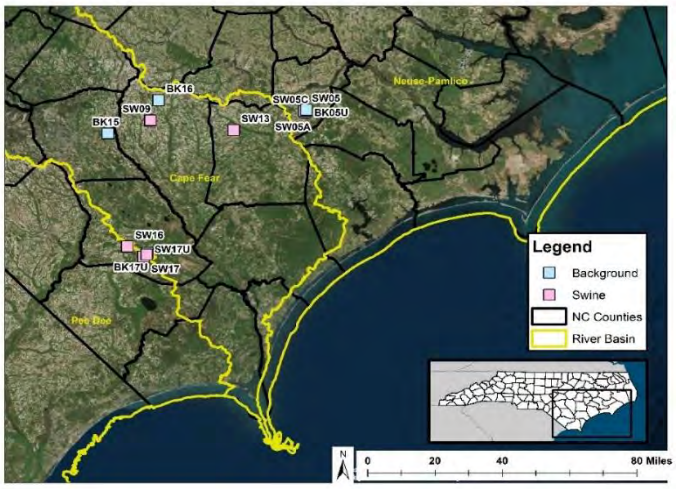


Figure 8. Sampling locations for post-Florence sampling events.

Next steps in this project include analyzing water samples for SARS-CoV-2 in the event of an extreme weather event using new COVID-19 surveillance methods and improving the ability to respond to extreme events through well sampling and the collection of fecal indicators. This project team will also determine the most effective methods of accurately quantifying pathogens and genes in water sources that potentially threaten human health, and to work with stakeholders to communicate the importance of molecular diagnostics in assessing water quality when extreme weather events occur. Septic, package treatment plant, and low resource sewage infrastructure and their potential impacts on human health will also be further reviewed.

Recent Findings and Initial Outcomes

- Precipitation-related effects on concentrations of fecal indicator bacteria like *E. coli* are not limited to large hurricane events but can occur across a range of precipitation events, particularly when there has been antecedent rainfall with water-saturated soils or impervious landcovers.
- Direct measures for pathogens and antimicrobial resistance can supplement fecal indicator analysis to identify locations with pathogen hazards and to better characterize health risks.

- Flooding can be associated with increased levels of pathogens and antimicrobial resistance in surface waters, with effects lasting for days or weeks.
- Risks from microbial hazards are higher in locations proximal to human and animal wastewaters (i.e., areas with food animal production that use waste lagoon systems).
- Both laboratories have now invested in molecular analysis equipment that permits real-time, fully quantitative analysis for viral pathogens important to public health concerns, including SARS-CoV-2 and related variants. The application of this technology will permit NC to lead an advanced set of studies on the impacts of flooding and extreme events.
- Over 250 samples have been collected and analyzed in response to extreme events for microbial contaminants. The project team is building a database for selection of pathogen response variables that will allow the development of a new monitoring system.

APPENDIX I

Legislative Text of Session Law 2019-224, Section 2.1 (8)

$10,160,000 to The University of North Carolina Board of Governors to be used as follows:

a) *$160,000 to the North Carolina Policy Collaboratory (Collaboratory) for the ModMon program.*

b) *$2,000,000 to the Collaboratory to study flooding and resiliency against future storms in Eastern North Carolina and to develop an implementation plan with recommendations. The Collaboratory shall report the flooding and resiliency implementation plan to the Joint Legislative Emergency Management Oversight Committee no later than December 1, 2020. Notwithstanding Section 3.1(c) of S.L. 2018-134, funds allocated to the Collaboratory as provided in this sub-subdivision shall revert on December 30, 2020. The University of North Carolina shall not charge indirect facilities and administrative costs against the funding provided for the Collaboratory from the Hurricane Florence Disaster Recovery Fund.*

c) *$8,000,000 to the University of North Carolina Wilmington (UNC-W) for repairs and renovations to the Dobo Hall science building, which was damaged by Hurricane Florence.*

Legislative Text of Session Law 2020-74, Section (8)(b)

Section 2.1 of S.L. 2019-224, reads as rewritten:

The Collaboratory shall report the flooding and resiliency implementation plan to the Joint Legislative Emergency Management Oversight Committee no later than ~~December 1, 2020~~ June 1, 2021. Notwithstanding Section 3.1(c) of S.L. 2018-134, funds allocated to the Collaboratory as provided in this sub-subdivision shall revert on ~~December 30, 2020~~ June 30, 2021.

APPENDIX II: Study Team Roster

Floodplain Buyouts

Floodplain Buyouts Project

Project Team:

Todd BenDor ..... Odom Institute; UNC Dept. of City and Regional Planning
David Salvesen ..... UNC Institute for the Environment
Miyuki Hino ..... UNC Dept. of City and Regional Planning
Nikhil Kaza ..... UNC Dept. of City and Regional Planning
Antonia Sebastian ..... UNC Dept. of Geological Sciences
Jonas Monast ..... UNC School of Law
Rebecca Kihslinger ..... Environmental Law Institute (ELI)

Graduate students:

Jordan Branham ..... UNC Dept. of City and Regional Planning
Nora Schwaller ..... UNC Dept. of City and Regional Planning
Shane Sweeney ..... UNC Dept. of City and Regional Planning
Hallee Haygood ..... UNC Dept. of City and Regional Planning
William Curran-Groome ..... UNC Dept. of City and Regional Planning

Undergraduates:

Emily Apadula ..... UNC Institute for the Environment
Kels Peterson ..... UNC Institute for the Environment

Financial Risk

Assessing Financial Impact of Flood Events

Project Team:

Greg Characklis ..... Center on Financial Risk in Environmental Systems; UNC Dept. of Environmental Sciences and Engineering
Simona Denaro ..... UNC Dept. of Environmental Sciences and Engineering
Harrison B. (H.B.) Zeff ..... UNC Dept. of Environmental Sciences and Engineering

Graduate students:

Benjamin Foster ..... UNC Dept. of Environmental Sciences and Engineering
Joy Hill ..... UNC Dept. of Environmental Sciences and Engineering

Natural Systems

Improving North Carolina's Resilience to Coastal Riverine Flooding

Project Team:

Barbara Doll ..... NC Sea Grant
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