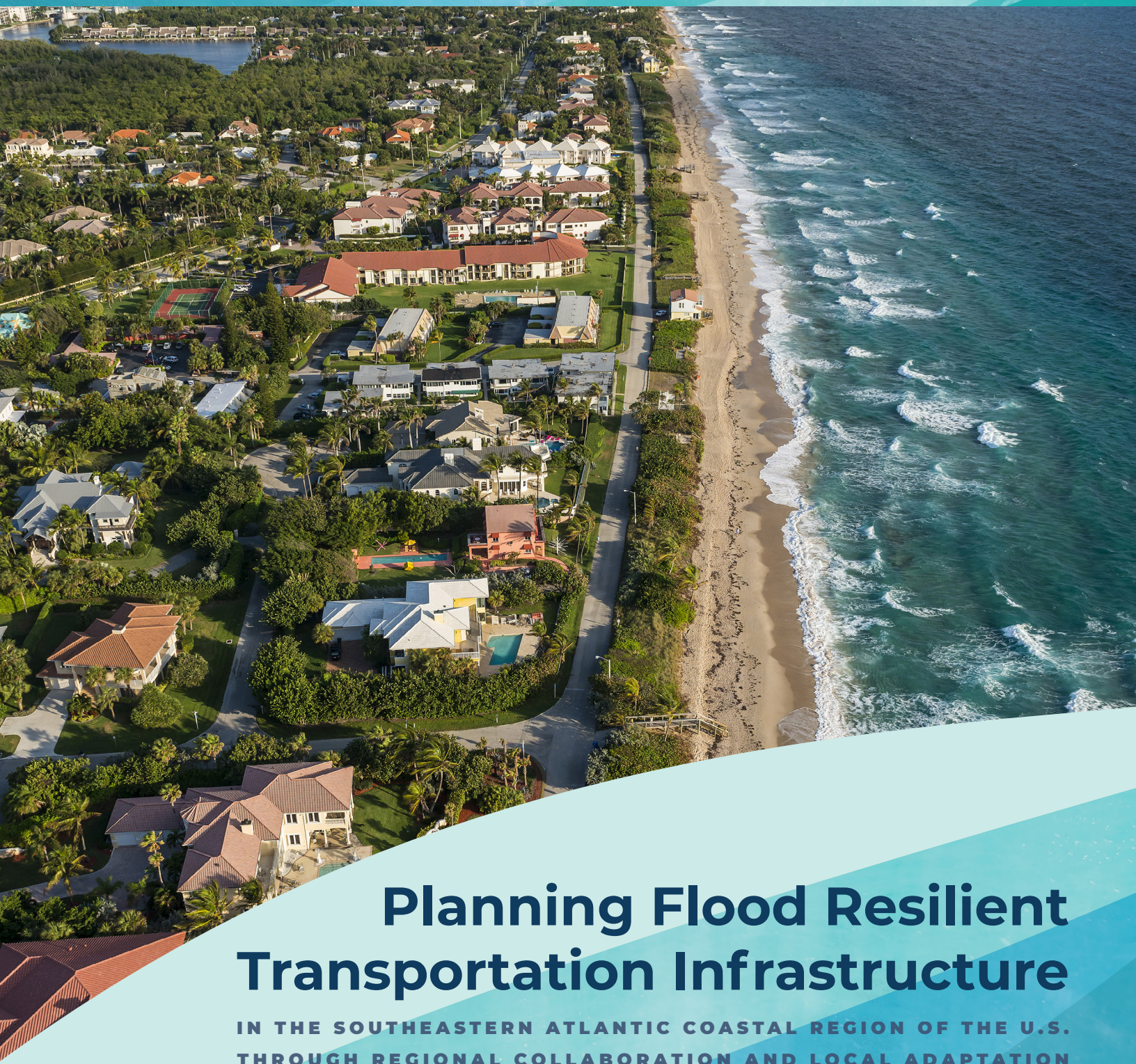

Planning Flood Resilient Transportation Infrastructure

IN THE SOUTHEASTERN ATLANTIC COASTAL REGION OF THE U.S. THROUGH REGIONAL COLLABORATION AND LOCAL ADAPTATION

December 2023

Sea Grant

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

Editor: Dr. Charles Sidman | **Designer:** Donielle Nardi

"The city of Cape Canaveral benefitted from the collaboration of regionally-based investigators with local consulting environmental engineers to design nature-based solutions to address chronic nuisance flooding. In addition, the regional team implemented a desk-top tool for identifying public lands suitable for green stormwater infrastructure projects near several major roads prone to flooding in Chatham County and the city of Savannah. Regional teamwork strengthened the impact of local adaptation measures and results."

— Dr. Jason M. Evans,
Project Principal Investigator, Stetson University

PROJECT BACKGROUND

Storms and other natural processes common to our ocean and coastal environments can induce widespread and prolonged flooding. This can be particularly impactful to private and public infrastructure, which underpins the quality of life of inhabitants and the economy of coastal communities. The type, location, and economic effects of flooding can vary among coastal communities, driving unique sets of priorities for planning and implementing appropriate interventions to promote resilience by safeguarding people and public investments. A community's public transportation infrastructure is common to the organization and function of all coastal municipalities, representing a vital and highly prioritized component of maintaining and strengthening resilience.

The application of measures to promote coastal community resilience can be as varied as the physical settings, the public institutions, and the culture of the people who inhabit these dynamic environments. This diversity, however, is supported by a common transportation infrastructure that can be compromised by natural disturbances, disrupting life and economic prosperity. These considerations presented a unique opportunity to explore several types of green infrastructure options such as permeable surfaces that absorb water, or landscaping that reduces runoff into storm drains (bioretention systems, stormwater wetlands), geospatial and economic methodologies, and planning practices to address transportation infrastructure vulnerabilities, applied in local contexts, with regional synthesis.

This project started in 2020 in the South Atlantic region of the United States through a partnership among the NOAA Office for Coastal Management and the Sea Grant programs of Florida, Georgia, South Carolina, and North Carolina (Figure 1). The multi-state project implementation team represented a collaboration among investigators affiliated with Stetson University, the University of Georgia, Clemson University, and the University North Carolina-Wilmington. Each state-based investigative team implemented a set of evaluative and planning initiatives tailored to the needs of partnering municipalities and county governments, which included Cape Canaveral, FL; Chatham County, GA; Georgetown County, SC; New Hanover County, NC; and New Bern, SC. Regional project coordination among investigative teams and their partnering communities was provided by the Florida-based team from Stetson University, working in cooperation with the East Central Florida Regional Planning Council.

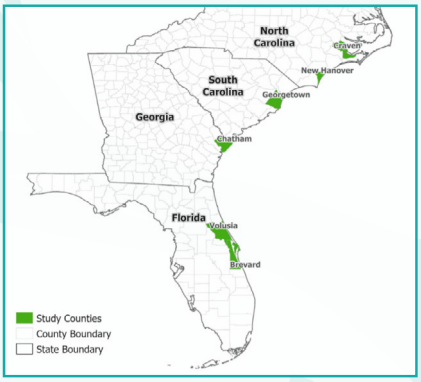

Figure 1. South Atlantic region and study locations

GUIDING QUESTIONS

Each investigative team tailored a set of activities to the needs of partnering communities within which they worked. Four guiding actions directed project activities.

1. **Assess** short and long-term flooding vulnerability to transportation corridors within partnering communities.
2. **Predict** the economic loss associated with transportation infrastructure flooding vulnerabilities.
3. **Analyze** legal and policy frameworks that can facilitate or inhibit the planning and implementation of resilient transportation infrastructure options.
4. **Identify** local opportunities for integrating green infrastructure (i.e., Nature Based Solutions – NBS) options into transportation system upgrades that include long-term flood resilience as a primary engineering design criterion.


Photo Credit: Jason Evans

REGIONAL COLLABORATION

Investigative teams were assembled for their capabilities for working semi-independently with respect to outreach and collaboration with their partnering communities. Teams also possessed complementary skill sets allowing for broader disciplinary scope and capabilities for providing unique skills to support the activities of partnering teams working with communities in their respective states. For example:

Scott Pippin J.D. and Shana Jones J.D. at the University of Georgia, as licensed attorneys, provided legal and policy expertise regarding ambiguous ownership of legacy drainage infrastructure within the city of Cape Canaveral.

Dr. Jason M. Evans at Stetson University worked with Chatham County, city of Savannah, and consulting environmental engineers to implement a desk-top tool for identifying public lands suitable for green stormwater infrastructure projects near several major roads prone to flooding.

Dr. Robert T. Carey at Clemson University implemented economic damage assessments of tidal flooding impacts to property, businesses, and transportation infrastructure for the city of Cape Canaveral, for Georgetown County, New Hanover County, city of New Bern, and Chatham County.

Dr. Narcisa G. Pricope at UNC-Wilmington adapted a green stormwater infrastructure suitability model into a general desktop tool that was successfully implemented in partnering communities across all four southeastern Atlantic region states.

In addition, Dr. Evans oversaw the cross-disciplinary, cross-institutional, and cross-state collaborations of the investigative teams, which fostered regional synergies and added capacity and value to the locally implemented projects. The role of faculty at academic institutions unified science and community outreach successfully bridging student education, research, and Extension functions, which align with the mission of the National Sea Grant College program.

BENEFITS OF GREEN INFRASTRUCTURE

"The landscape is changing and infrastructure is failing. The physical landscape, however, can be designed to prepare for disturbance and stress. These challenges present opportunities to address both resilience and environmental goals while at the same time providing social and economic value."

— **Dr. Narcisa G. Pricope,**
Geographer,
UNC-Wilmington

The project also fulfilled a priority of the NOAA Office for Coastal Management to promote coastal resilience, and document successes from applying a regional investigative framework to strengthen local community resilience. This was accomplished through a suite of case studies that integrated mapping, community engagement, legal and economic analysis, and design that integrated green or nature-based options at a variety of scales to address flooding on vulnerable transportation infrastructure (Figure 2).

Figure 2. Nature-based solutions to improve resilience

Conventional infrastructure conveys stormwater from roadways into waterways using structures such as curbs and gutters that can allow contaminants such as fertilizers, auto fluids, and waste to run-off into surrounding water bodies. Lower impact NBS mimic and restore the natural water cycle by filtering out contaminants. Nature-based design also offers co-benefits including improved water and air quality and the provision of habitat for wildlife.

LOCAL ADAPTATION

Evaluating Economic Impacts due to Storm-based and Tidal Flooding in the Coastal Southeastern U.S.

Georgetown County is located on the coast of South Carolina north of Charleston. Portions of the county are low-lying and vulnerable to flooding, including loss of access through major transportation corridors. These conditions prompted Georgetown County officials to request that project

investigators conduct an economic assessment that future flooding, exacerbated by sea level rise, could have on the county. A Regional Economic Model (REMI) was applied to conduct economic damage assessments, which predicted that $3.8 billion in property and $214.2 million in total sales activity within Georgetown County are at risk of being lost due to coastal flooding over the next five decades. At current tax rates, this would translate to an approximately $9.6 million annual loss in commercial and non-primary residential property tax receipts and $3.8 million annual loss in primary residential property tax receipts. Flooding impacts would also be associated with a loss of approximately 1,268 jobs.

The flood-impact model developed for Georgetown County was applied to other partnering communities to examine the economic impact of flooding (periodic 'nuisance' flooding, and long-term flooding from sea-level-rise). The analysis considered the impact of flooding on infrastructure and its associated effect on residential property values and property tax revenues, its effects on long-term population loss, and lost business sales (e.g., tourism and local business). Outputs included graphs and charts illustrating lost sales, which would affect partnering communities according to a variety of industry sectors, including manufacturing, wholesale, real estate, construction, and arts and entertainment (Figure 3).

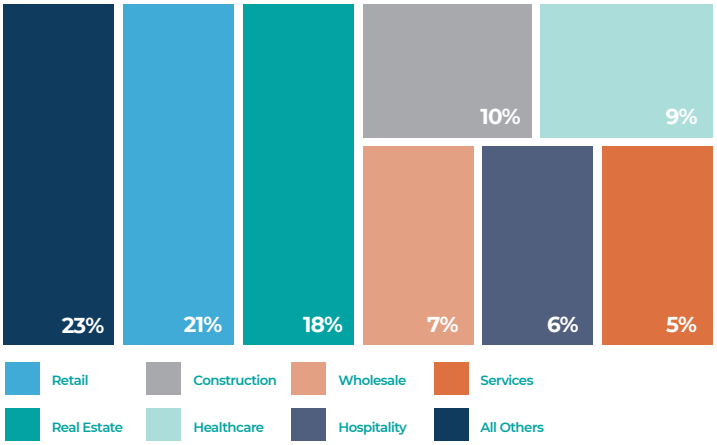

Figure 3. Example of predicted lost sales by industry sector caused by flooding

Leveraging the Power of Earth Observation Data to Design Nature-based Solutions that Mitigate the effects of Coastal and Inland Flooding

A community engagement process conducted for New Hanover County and the city of New Bern prioritized the need for an environmental flooding assessment (Figure 4). In response, the team from the University of North Carolina Wilmington conducted a wetland vulnerability analysis using geo-spatial tools and remotely sensed environmental data to identify locations amenable to nature-based solutions. The analysis used NOAA

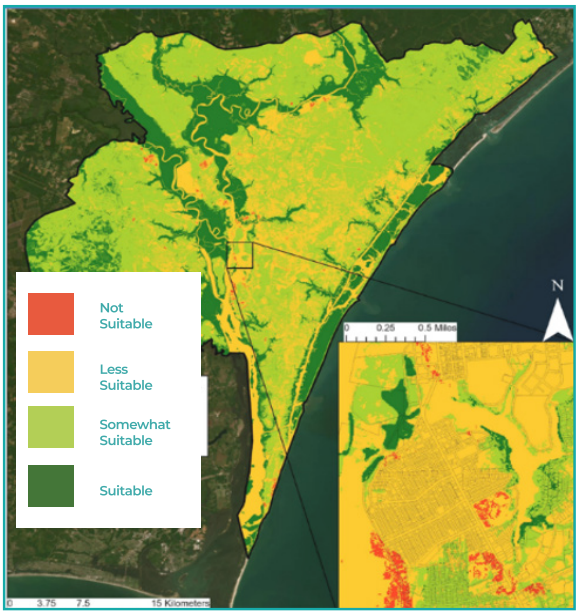

Figure 4. Mapping green infrastructure suitability

"The Regional Sea Grant project provided invaluable insights into assessing community member concerns regarding both current and future urban flooding within the city of Cape Canaveral. As a hub of socio-economic activity at the crossroads of ongoing space exploration activities and Central Florida tourism, the city of Cape Canaveral is utilizing the project's findings to ensure long-term resilience of local transportation systems and restorative vitality within the built and natural environments."

— Zachary Eichholz,
Chief Resilience Manager,
City of Cape Canaveral, FL

high tide flooding, sea level rise predictions and FEMA 100 and 500-year flood areas, and Landsat imagery time series to evaluate 'exposure' and 'sensitivity' of wetland locations to flooding based on vegetation type and condition. This supported community planning aimed at protecting critical public lands and infrastructure through green infrastructure investments. The results identified several government-owned parcels containing highly vulnerable wetland areas that were prioritized for potential NBS implementation. Suitable wetland types include brackish and freshwater marshes and riverine swamp forests, underscoring the importance of conserving or restoring marshes and swamp forests to mitigate coastal flooding.

Resilient Cape Canaveral

The city of Cape Canaveral experiences frequent nuisance flooding along transportation corridors due to poor soils, increasing water tables associated with sea level rise, high amounts of impervious cover, and antiquated drainage infrastructure (Figure 5). To address this issue, the city partnered with the team from Stetson University to implement technologies to gauge and degree and map the extent of persistent flooding in particularly vulnerable areas. This information supported a public engagement process attended by 50 locals and development of a plan that currently is guiding construction of a new rain garden and stormwater infiltration system that will help to address drainage concerns. The conceptual design for the park is illustrated in Figure 6. Additionally, the city of Cape Canaveral received the Resilient Florida grant of $250,000 and a $467,500 FDEP grant to fund the construction of a pump and tide gate to alleviate flooding.

Figure 5. Nuisance flooding in Cape Canaveral, Florida. Photo Credit: Jason Evans.

Figure 6. Conceptual nature-based "rain garden" design for improved water drainage in Cape Canaveral, Florida. Photo Credit: Kimley Horn

Identifying Green Infrastructure Sites in Chatham County and the city of Savannah Georgia

The city of Savannah, Georgia, is located on the northern end of Georgia's coast, along the Savannah River. Newer development has encroached into low lying areas vulnerable to flooding, which is being exacerbated by sea level rise, threatening these localities with permanent inundation. Sea level rise vulnerability modelling and economic impact assessments were augmented by a comparative legal analysis of local government options to implement green infrastructure solutions for a suite of sites identified though a geospatial vulnerability analysis (Figure 7). This information was applied to ameliorate potential threats from recurrent flooding in eight areas of interest within Chatham County. The aim was to secure access to and maintain connectivity of key transportation corridors and military bases. Several smaller projects are planning the construction of bioswales for stormwater retention. Several smaller projects are planning the construction of bioswales for stormwater retention. One is being funded by the Chatham County Savannah Metropolitan Planning Commission, which serves as the regional transportation planning body. Another is planned by the Department of Defense, building on data and analyses conducted by this project to motivate larger-scale resilience.

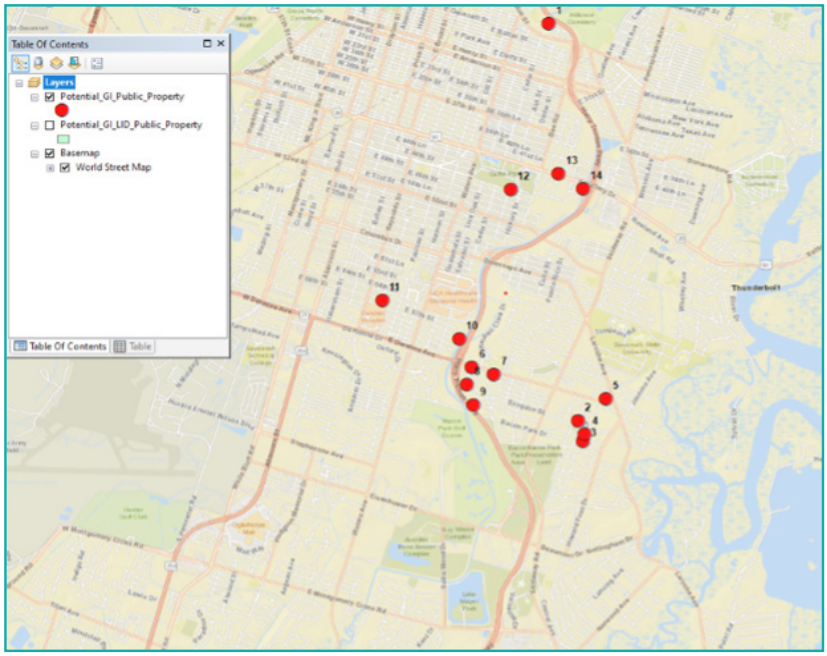

Figure 7. Potential green infrastructure sites owned by Chatham County or the city of Savannah

PUBLICATIONS & PRODUCTS

Dedication

This project was conceived and implemented in memory of **Dr. Karl Havens**, Florida Sea Grant's director from 2007-2019. Karl, who passed in 2019, lived for many years in coastal southeast Florida, experiencing first-hand the effects of rising seas and storms on his canal-front property. Karl was a keen observer of the environment, devoting his career to helping us better understand our role and collective capacity to make our water resources and communities healthier and more resilient. Karl would be proud of the outcomes of this project.

To learn more about Karl and his legacy, please scan the QR code below.

JOURNAL ARTICLES

Evans, J.M., J. Mainali, E. Niederman*, **D. Hitchcock, T. McCue,** P. Hines*, and **N. Pricope.** In preparation. Landscape suitability model for green stormwater infrastructure implementation in the southeast U.S. Coastal Zone. Target journal: *Landscape and Urban Planning*

Pricope, N.G. and Shivers, G.* 2022. Wetland vulnerability metrics as a rapid indicator in identifying nature-based solutions to mitigate coastal flooding. *Hydrology* 2022, 9(12), 218: https://doi.org/10.3390/hydrology9120218

Pricope, N.G., Hidalgo, C.*, **Pippin, J.S., and Evans, J.M.** 2022. Shifting landscapes of risk: quantifying pluvial flood vulnerability beyond the regulated floodplain. *Journal of Environmental Management 304 (2022) 114221*: https://doi.org/10.1016/j.jenvman.2021.114221

Mapes, K.L.* and **Pricope, N.G.** 2020. Evaluating SWAT model performance for runoff, percolation, and sediment loss estimation in low-gradient watersheds of the Atlantic Coastal Plain. *Hydrology* 2020, 7(2), 21; https://doi.org/10.3390/hydrology7020021

THESES

Shivers, G.* 2022. Assessing the Vulnerability of Wetlands to Identify Locations for Nature-Based Solutions to Mitigate Coastal Flooding. Master of Geosciences Program, thesis option (chair). University of North Carolina Wilmington. Grant RA.

Scopa, J.* 2022. Using Thermal Imaging with Unmanned Aerial Vehicles to Visualize and Quantify Non-Source Point Discharge into Tidal Creeks. Master of Geosciences Program, thesis option (chair). UNC Wilmington.

Dalton, E.* 2022. Comparing Metrics of Wetland vegetation Structure Derived from UAS LiDAR and Photogrammetric Collections (honors thesis chair). UNC Wilmington.

*Indicates a student author, though not necessarily a student who received financial support from the project.

Photo Credit (above): Rendering by Kimley Horn

TECHNICAL REPORTS

EAST CENTRAL FLORIDA REGIONAL PLANNING COUNCIL. 2023. The Economic Impact of Sea Level Rise in Cape Canaveral.

Carey, R.T., Nieves-Ruiz, L., and **Mainali, J.,** 2023. Estimated Economic Impact of Flooding Associated with Sea Level Rise, Georgetown County, SC.

Carey, R.T., Nieves-Ruiz, L., and **Mainali, J.,** 2023. Estimated Economic Impact of Flooding Associated with Sea Level Rise, Chatham County, GA.

Carey, R.T., Nieves-Ruiz, L., and **Mainali, J.,** 2023. Estimated Economic Impact of Flooding Associated with Sea Level Rise, Craven County, NC.

Carey, R.T., Nieves-Ruiz, L., and **Mainali, J.,** 2023. Estimated Economic Impact of Flooding Associated with Sea Level Rise, New Hanover County, NC.

CONFERENCE PROCEEDINGS

Williams, B.J.*, **B.S. Song,** T.M. Williams*, and **D. Hitchcock.** 2022. Use of a standalone virtual reality headset in hurricane river flooding. Proceedings of the 13th Southern Forestry and Natural Resource Management GIS Conference, Athens, GA USA K. Merry, P. Bettinger, C. Cieszewski, M. Crosby, A.R.G. Garzon, J. Siry, B.Song, Z. U car, and J. Uzu, eds. Pages 31-40.

ARCGIS STORYMAP

Evans, J., N. Pricope, D. Hitchcock, R. Carey, J. Mainali, T. McCue, L. Nievez-Ruiz, E. Niederman*, G. Shivers*, B. Williams*, and P. Hines*. 2023. Sea Level Rise Impact in US Southeast: Exploring Climate Change Impacts and Planning for Resilience through Regional Collaboration in Southeast United States. https://storymaps.arcgis.com/stories/a4086f877f414674b046d866e813f11f.

POSTER SUMMARIES

Pricope, N.G. 2023. Understanding localized and cross-site infrastructure, build and natural environment vulnerabilities to sea-level-rise across coastal communities in four states.

Evans, J., A. Joesoef, **J. Mainali, C. de Bodisco, T. McCue, L. Nieves-Ruiz,** B. Defoe-Surprenant, Z. Eichholz, A. Miller, **H. Abeels.** 2023. Costs, Benefits, and Connectivity: Assessing Options for Flood Resilient Transportation Upgrades in Four Southeastern Coastal Communities.

BLOG POST

Pricope, N.G. Balancing Green and Gray Infrastructure Solutions to Mitigate Coastal Flooding, NC Sea Grant Currents Magazine (May 18, 2021). https://ncseagrant.ncsu.edu/currents/2021/05/balancing-green-and-gray-infrastructure-solutions-to-mitigate-coastal-flooding/

THURM BLVD BIOSWALE

Photo Credit: Rendering by Kelsey Broich, University of Georgia

PARTNERS:

CAPTURED RUNOFF: max depth 9 inches | **MEDIA:** 18 inches | **GRAVEL:** 8 inches | **PIPE:** 6 inches

THE INSTITUTE FOR WATER AND ENVIRONMENTAL RESILIENCE
STETSON UNIVERSITY

CLEMSON UNIVERSITY SOUTH CAROLINA 1889

College of Environment + Design
UNIVERSITY OF GEORGIA

UNIVERSITY OF GEORGIA
Marine Extension and Georgia Sea Grant
Carl Vinson Institute of Government

Sea Grant

NOTABLE OUTCOMES

"The Cape Fear Public Utility Authority is currently identifying areas to implement nature-based solutions for stormwater management. Obviously, your research would greatly benefit us in identifying the region we now own, areas adjacent to our property, and potential areas of interest. I'm really excited about your work and thankful to have this project being conducted in our region."

— **Kat Pohlman,**
Assistant Director or Environmental Management and Sustainability, Cape Fear Public Utility Authority


Photo Credit: Jason Evans

1. **Comprehensive flood footprint flood vulnerability analysis** (including property, roads, and business activity), with economic damages estimated through 2070 using the REMI model, in all partner communities.

2. **Identification and assessment of candidate sites** for potential green stormwater infrastructure (GSI) interventions in Cape Canaveral, Chatham County, New Hanover County, and New Bern.

3. **National Science Foundation The Civic Innovation Challenge Stage 1 award** for Stetson University and Florida Sea Grant to continue and expand upon the work, further supporting a close partnership with the city of Cape Canaveral, other local governments in the Brevard Space Coast region, and numerous private non-profit and business entities.

4. **National Science Foundation CIVIC Stage 2 proposal** for Stetson, Florida Sea Grant, and other partners to construct and monitor a GSI intervention in Cape Canaveral was recommended for funding on July 19, 2023.

5. **NASA Research Opportunities in Space and Earth Sciences (ROSES) Equity and Environmental Justice grant** awarded to UNC-Wilmington to continue developing the GSI modeling framework.

6. **Graduate student Greer Shivers** from UNC-Wilmington graduated with an M.S. degree. A peer-reviewed article from her thesis was published, and she is now employed with the Wilmington Area Metropolitan Planning Organization.

7. **Post-doctoral researcher,** Dr. Janardan Mainali, leveraged his experience through this project at Stetson University to land a position as lead Geospatial Analyst with Streamline Technologies, Inc., lead developers of the ICPR4 stormwater model used extensively throughout Florida and the Southeast U.S..

8. **Three undergraduate students** at Stetson University, Carson Bockoven, Mollie James, and Ryan Clifton, worked as interns at East Central Florida Regional Planning Council and contributed significantly to work developed through this project.

9. **Leveraging relationships developed through this project,** utilized private grant funds (Arthur Vining Davis Foundations) to install three long-term water level gauges (two in the Banana River and one in a central stormwater drainage ditch) and one water quality sensor (at the stormwater drainage ditch site) in the city of Cape Canaveral.

10 **A GIS-based assessment of flood-based access pinch points** or hot spots during tidal events using county data, GDOT data, and a digital elevation model in Chatham County, GA.

11 **Georgia Sea Grant Legal Fellow Scott Luis conducted law and policy research** regarding how explicit or implied public ownership translates into public responsibility and liability for infrastructure maintenance and failure.

12 **A Story Map showcasing outcomes** from all four states and five associated partner communities.

LEVERAGED FUNDS

Project PI's and CO-PI's have aquired substantial additional funding for the grant and have submitted additional proposals to build on the work.

Table 1. Additional funding generated by this grant

AMOUNT	SOURCE
$49,817	National Science Foundation Civic Innovation Challenge Stage 1
$50,000	Georgia Department of Natural Resources, NOAA Coastal Zone Management Program
$150,000	NASA Research Opportunities in Space and Earth Sciences Equity and Environmental Justice
$150,000	Chatham County-Savannah Metropolitan Planning Commission
$1,000,000	National Science Foundation Civic Innovation Challenge Stage 2

The project team is hopeful to secure additional funding through the following sources:

$800,000	**U.S. Department of Defense Office of Local Defense Community Cooperation.**
$2,000,000	**National Oceanic and Atmospheric Administration Climate Resilience Regional Challenges.**
$3,898,525	**Regional Oceanic and Atmospheric Administration Transformational Habitat Restoration and Coastal Resilience Grants under the IIJA Program.**
$24,295	**North Carolina Sea Grant Community Collaborative Research Grant.**

"This project allowed me to learn more about how local governments operate and research issues that are not covered in law school classes that can help improve the ways local governments plan ahead and enable coastal communities to be more empowered and prepared to face future challenges caused by climate change."

— Scott Luis,
Funded Student,
UNC-Wilmington

STUDENTS FINANCIALLY SUPPORTED

The following students were finiancially supported through this project grant.

Carson Bockoven
B.S. in Environmental Science,
Stetson University

Mollie Sioux James
B.S. in Environmental Science,
Stetson University

Ryan Clifton
B.A. in Political Science & Economics,
Stetson University

Greer Shivers
M.S. in Geosciences,
UNC-Wilmington

Ifeanyi Ogbekene
Ph.D. in Political Science,
ClemsonUniversity

Scott Luis
J.D. in Law,
University of Georgia

INVESTIGATIVE TEAM

This project benefitted from a collaboration among Sea Grant programs in the South Atlantic, universities in Florida, Georgia, South Carolina, and North Carolina, NOAA's Office for Coastal Management, and the Eastern Central Florida Regional Planning Council.

Dr. Jason Evans
Principal Investigator & Landscape Ecologist,
Stetson University

Dr. Chris de Bodisco
Environmental Economist,
Stetson University

Dr. Janardan Mainali
Geographer,
Stetson University

Dr. Narcisa Pricope
Geographer,
UNC-Wilmington

Dr. Daniel Hitchcock
Water Resources Engineer,
Clemson University

Dr. Robert Carey
Regional Economist,
Clemson University

Dr. Bo Song
Landscape Ecologist,
Clemson University

Dr. Marzieh Motallebi
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Clemson University

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Katie Hill, Esq.
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Frank Lopez
Extension Director,
North Carolina Sea Grant

Dr. Jessica Brown
Stormwater Specialist,
Georgia Sea Grant

Brooke Saari
Coastal Environmental Quality
Program Specialist,
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Tara McCue
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East Central Florida
Regional Planning Council

Luis Nieves-Ruiz
Economic Development Manager,
East Central Florida
Regional Planning Council

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Florida Sea Grant. 2023. *Planning Flood Resilient Transportation Infrastructure in the Southeastern Atlantic Coastal Region of the U.S. Through Regional Collaboration and Local Adaptation.* Charles Sidman and Donielle Nardi (eds.). Gainesville: University of Florida, Florida Sea Grant College Program. 14 pp.