Annual and Final Progress Report Template

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Project Goal(s)

The overall goals for this project are threefold:

1. To examine and determine on a parcel-level scale the capacity of critical infrastructure in the Charleston region to effectively absorb impacts of flooding events, both in the short-term and long-term, and enhance the region's response to immediate water hazard impacts and support its adaptive capacity ("resilience") to future hazards events;
2. To produce detailed information and analyses that will assist multiple stakeholders and organizations as they move from resiliency planning to implementation; and
3. To foster a unified strategy and provide a forum to share science-based information, educate stakeholders and enhance long-term planning decisions that result in resilience.

Geographical Location of Study

Charleston, S.C. metropolitan region, with targeted engagement areas within (see details below)

Partners

The Charleston Resilience Network (CRN) (250 organizational and individual partners, led by a Steering Group comprised of the following organizations:

- City of Charleston
- Charleston County
- Berkeley-Charleston-Dorchester Council of Governments
- Charleston Water System
- SCANA Corporation
- S.C. Department of Health and Environmental Control
- South Carolina Sea Grant Consortium
- Carolinas Integrated Sciences and Assessments
- College of Charleston
- Department of Homeland Security, Office of Infrastructure Protection*
- National Oceanic and Atmospheric Administration*

**federal agencies advise the Steering Group, providing technical expertise and publicly available information or resources regarding matters of mutual interest*

Accomplishments

The above stated goals for the project are to be met through addressing the following three objectives. The objectives are broken out below, highlighting the progress and accomplishments made on each one during the six-month reporting period.

1. LOCALIZED PLACE-BASED MODELING AND MAPPING

By partnering with climate, hazard, and modeling experts and engineers from College of Charleston, The Citadel, University of South Carolina, NOAA National Weather Service and NOAA Office for Coastal Management, the project is leveraging existing and generating new data to create localized flooding models for the Charleston region which incorporate tides, meteorological events, wind, surge, rainfall runoff, and infrastructure features such as tunnels, drains and pumps. This critical type of modeling will provide parcel-level vulnerability assessments which are now lacking, information critical when planning and implementing place-based strategies to increase resilience. Also, this project is localizing social vulnerability models to better understand the cascading impacts of failing critical infrastructure on our most vulnerable populations.

Component 1: High Resolution Flood Modeling
Co-Lead Technical PI Norman Levine, College of Charleston, Lowcountry Hazards Center (LHC), with assistance of Landon Knapp, S.C. Sea Grant Consortium and LHC

Modeling/Mapping
The low-elevation, low-relief topography of the Charleston, S.C. area presents challenges for modeling the movement of flood waters across the landscape as compared to higher elevation areas many traditional models are designed to describe. One of the primary obstacles has been the low resolution of the data inputs used to drive hydrological models in the region, which tend to obscure the small-scale changes in the built and natural environment occurring between model nodes. Most available data at the time of project implementation were at a thirty-meter (30-m) scale, which was determined as much too coarse for the needs of the study region. In order to overcome such limitations from prior studies, investigators chose a resolution of one-meter (1-m) for all data layers used as inputs to the flood models, resulting in a corresponding 1-m resolution for all flood maps produced for the area. This required the creation of new data sets describing the landscape utilizing a range of geospatial analysis techniques.

LiDAR point cloud data in LAZ format were obtained covering the entirety of Charleston County for the multi-year collection spanning 2006-2009[1], which were the most recent comprehensive data collections at the time of project implementation. LAZ's were converted to LAS files and a LAS dataset for each year was generated covering the land and marsh area of Charleston County. Tiles were created for parallel processing of point cloud data with marginal overlap between tile areas. Digital elevation models (DEMs) were interpolated for each tile using inverse distance weighted (IDW) interpolation on classified ground points with 1-m cell size. All DEM tiles were mosaicked to a new raster using the Blend operator to diminish tiling errors at overlapping boundaries. Hydro-flattening was performed by using Zonal Statistics where grid cells underlying a network of aquatic area polygons were set to their average elevation and all tidal areas set to an elevation of -2. This process resulted in a single 1-m resolution DEM for Charleston County created using the most recent data available to researchers at the time of this project. The methods were repeated using all return LiDAR points to produce a 1-m resolution digital surface model (DSM) of the county.

A mean higher high water (MHHW) surface was created for Charleston County using a combination of point and raster data obtained from the National Oceanic and Atmospheric Administration (NOAA)'s VDatum tool. The Inundation Mapping Tidal Surface – Mean Higher High Water raster surface was obtained from NOAA's Office for Coastal Management (OCM)

[1] See Data Sets list below. Cited data sets are referenced to there.

and converted to points at the centroid of each 100-m raster cell (see Data Set 2). These data were then merged into a single file alongside point data output from the online VDatum tool (see Data Set 3) Points were interpolated using IDW with a cell size of 50-m which resulted in a MHHW surface across all of Charleston County referenced to NAVD88.

Raster calculator was used to generate raster surfaces of elevated MHHW height where the elevation of each grid cell from the original MHHW surface was increased in 0.5-ft increments up to a maximum of 6-ft. The DEM created for the county was then subtracted from each of the elevated MHHW surfaces using raster calculator resulting in tidal flood depth rasters over land for all of Charleston County. NOAA defines MHHW as "[t]he average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch" (NOAA, n.d., p. 1). By modeling the flooding conditions resulting from an average higher high tide, the resultant elevated flood layers serve as a representation of high tide flooding under sea level rise conditions.

Precipitation Modeling

The curve number (CN) runoff method was utilized on four subsections of Charleston County covering a total of 20.7 sqmi. The four study areas (Fig. 1) receiving precipitation modeling were: 1) the Remleys Point area in Mount Pleasant, SC; 2) North Charleston neighborhoods near Filbin Creek; 3) the Peninsula of Charleston, SC; and 4) the Dupont-Wappo (DuWap) portion of West Ashley in Charleston, SC (see Figure 1). The CN method was used to calculate the amount of water that would result in surface runoff versus the amount that would infiltrate through the soils of the study area under various rainfall conditions. In order to estimate runoff at the finest scale possible for the study areas, individual urban watersheds were created across the study surface. Researchers accomplished this by utilizing the Hydrology toolset in ArcGIS (see Esri, 2016 & Esri, n.d. for details on using these tools). The DEM created through the steps above was first run through the Fill tool to remove sinks and then hydrologically conditioned to reflect known drainage patterns and infrastructure across the study area. To accomplish the latter, researchers obtained stormwater infrastructure data (e.g. pipes, culverts, outfalls) which were used to "burn" streams and subsurface drainage features into the DEM to establish an accurate direction of water flow during modeling. Finally, the DEM was clipped to the edge of the MHHW extent to eliminate areas of overlap. This was done to simulate the effects of rainfall accumulation during a high tide event.

That output was fed into the Flow Direction tool, and the resulting raster from that tool used to power the Flow Accumulation tool. Before using the output raster from the Flow Accumulation tool for subsequent steps it was edited to remove cells not reaching a significant threshold of accumulation, so they would not inaccurately represent stream networks not actually present in the study area (see Tarboton, et al., 1991 for rationale). There is no set standard for selecting a threshold value, as each case is unique and dependent on the attributes of the study area. Researchers used a threshold value equivalent to 10 acres of accumulation to represent both known and anticipated stream channels for the study area.

The Stream Link tool was then run using the stream raster from the previous steps as its input. Results from that tool run were used to power the Stream Order tool, which had its output converted to a feature class via the Stream to Feature tool. Pour points were generated using the newly created feature class as input to the Feature Vertices to Points tool in the Features toolset of the Data Management Tools toolbox, using only the end vertices of each stream part. Those pour points were then fed into the Snap Pour Point tool. The snapped pour points along with the flow direction raster created from the steps above were used as inputs for the

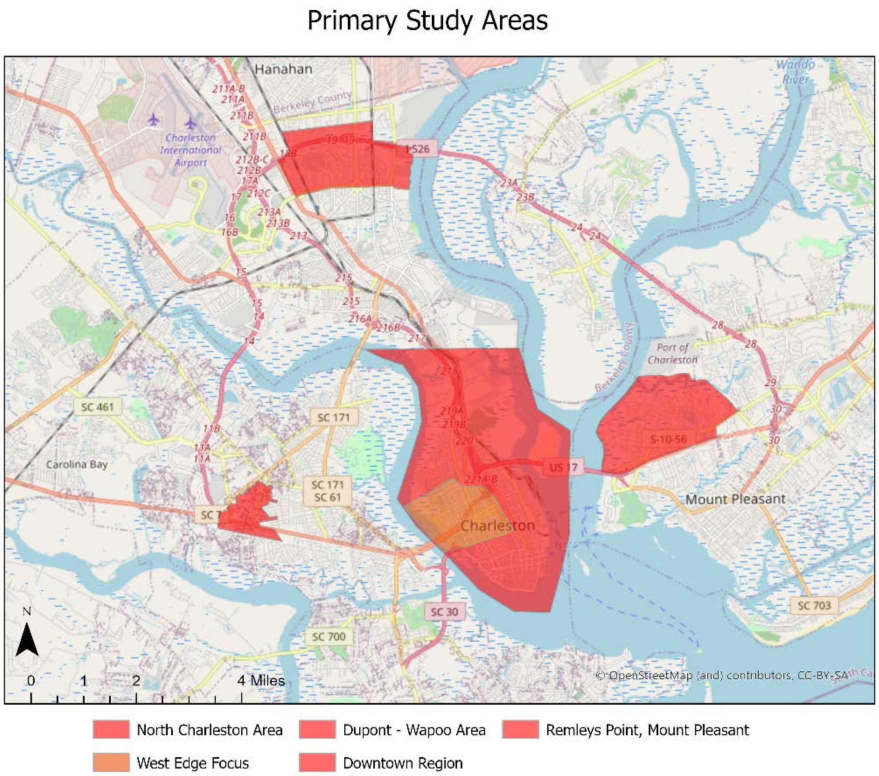

Figure 1: Map of Study Areas

Watershed tool, which generated the localized urban watersheds used for this study. A geometric network was created by connecting the watersheds by the pour points, which represents the flow of water between watersheds across the entire drainage basin. The proportion of water converted from precipitation to stormwater runoff in a given event was then determined via the CN method for each watershed in each drainage basin (USDA SCS, 1986).

Calculation of the individual CN's for each modeled watershed required knowledge of the impervious surfaces and soil types across the study area. Impervious surfaces were initially developed using a LiDAR multispectral fusion routine run on the DuWap study area as a test case for the remaining study areas. That approach required significant manual editing and confirmation for the small suburban site, but yielded a high level of accuracy. However, when those methods were extrapolated to the much larger and more complex Peninsula of Charleston, the manual work load and spatial heterogeneity made those previous methods unfeasible. The greatest obstacle to land cover classification on the Peninsula was the dense tree canopy overhanging and shadowing impervious surfaces, which are vital to fully capture in the flood model. To overcome this, researchers obtained street center line positions from the City of Charleston and created a tool whereby the width of each street was calculated. By measuring representative streets with a diversity of attributes (e.g. speed limit, number of lanes, etc.), investigators developed an equation for automating the width of all streets in the study area and generating polygons covering those extents. That roads data set was used as training data for imagery classification in addition to several other generated layers including the DEM/DSM, building footprints, a vegetation index, and a custom water features layer generated using the Hillshade tool. Final classification was performed via Unsupervised Iterative Self-Organizing Cluster Classification (ISO Cluster) processing of 2017 USDA NAIP 1-m 4-band DOQQ aerial imagery (see Data Set 4). Imagery data were divided into ground-level and above-ground data sets prior to classification using Raster Calculator and mosaicked to a single final raster. The process yielded a 1-m resolution land cover data set identifying areas of impervious cover across the study area (Figure 2). Soil types were obtained from the United States Department of Agriculture's (USDA) Soil Survey Geographic Database (SSURGO) in shapefile format (see Data Set 5). CN's were then calculated for each 1-m grid cell across the study area using the USDA Soil Conservation Service (SCS) TR-55 methodology based on their identified land cover class and underlying hydrologic soil group (USDA SCS, 1986). Mean CNs were then calculated for each watershed using Zonal Statistics, where the higher CNs represent watersheds that will confer higher volumes of stormwater runoff during precipitation events.

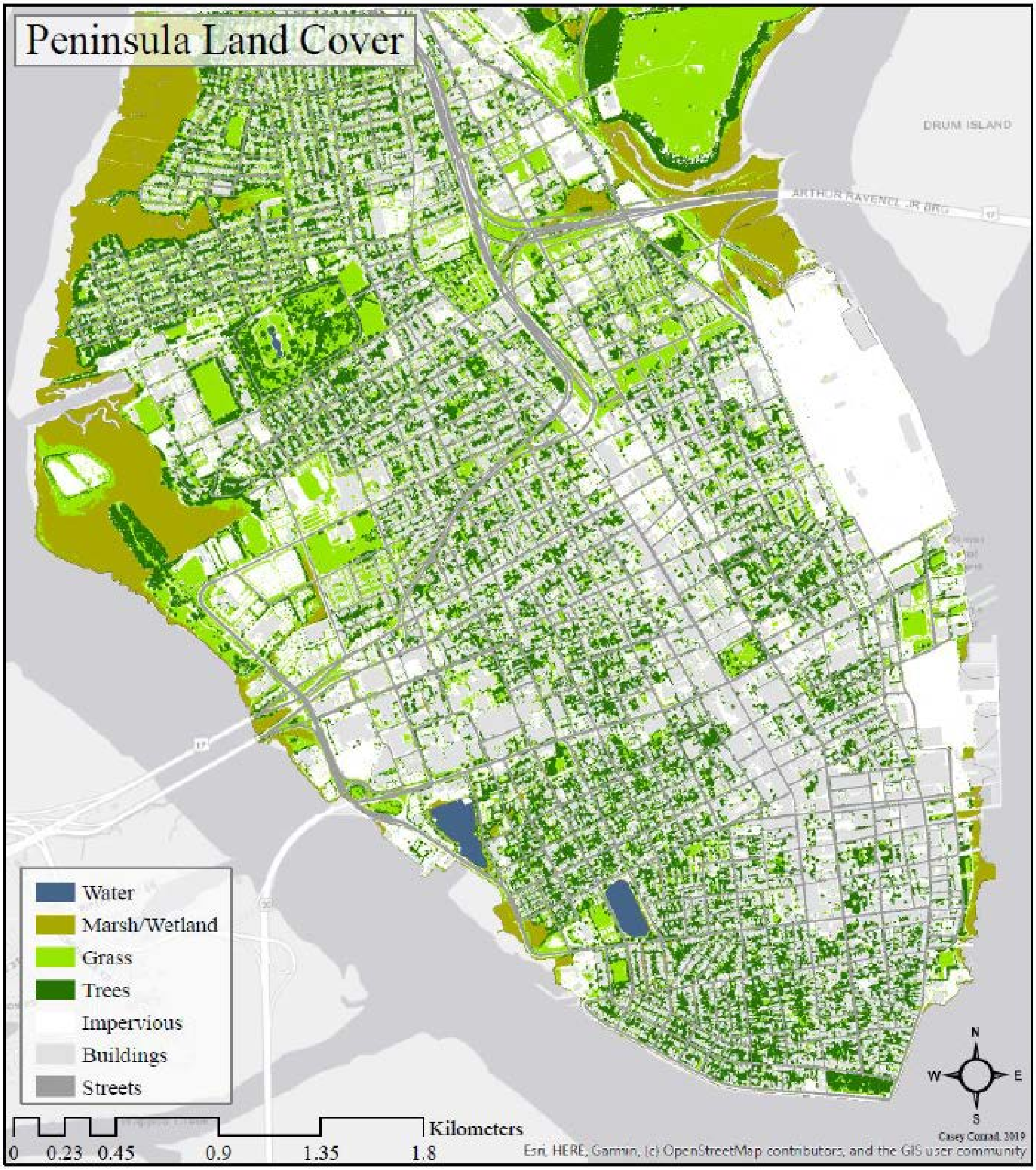

Figure 2: Land Cover Map of Peninsula of Charleston (Conrad, 2019)

Depth of runoff was then calculated for each watershed for 1-inch interval rainfall events via Equation 1:

$$Q_d = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where Q_d equals depth of runoff and P equals depth of rainfall, with depths spread evenly over the watershed surface area; I_a, initial abstraction, is rainfall lost to interception, surface depressions, and infiltration before runoff occurs; and S equals the potential maximum retention after runoff begins" (Blair et al., 2014, p. 561). S is calculated using the CN for each watershed input into Equation 2:

$$S = \frac{1000}{CN - 10}$$

Q_d values for each watershed were assigned to their corresponding outlet points (pour points) and cumulative depths calculated for downstream pour points via the watershed routing discussed above. Stormwater depths at each pour point were added to the surface elevation at each point. These depths were then interpolated across the surface of the study area resulting in precipitation flood depth rasters. The process was iterated through for rainfall depths from 1-6 inches at 1-inch intervals. These flood layers represent the modeled flood conditions resulting from an "instantaneous" rainfall event, or "rain bomb" during high tide. For that reason, the models do not include subsurface removal via stormwater systems and therefore should be viewed as a worst-case scenario for planning purposes.

Results

The tidal and precipitation flood modeling resulted in flood inundation maps for each flood driver spanning from 1-6 ft above MHHW for the former and 1-6 in of rainfall for the latter; produced for each of the four study areas (see Figure 1). The quantity of mapping products resulting from this study prohibits their comprehensive inclusion in a static report of this nature. In order to display the products created by this initiative, an ArcGIS Hub was created on the Santee Cooper GIS and Remote Sensing Laboratory site to allow navigation and display of the web applications created (https://charleston-resilience-network-initiative-na16nos4730012-scgis.hub.arcgis.com/). These maps were used for engagement events held in each of the study areas as a tool to communicate flood risk to residents. While these products were developed for that purpose, an example of results from an analysis conducted using these flood layers can be found in "[t]he use of an L-THIA based modified curve runoff model for flood hazard mapping in Charleston, SC" (Conrad, 2019).

Added Value

In addition to the products created for the four study areas included in the project design, this project resulted in a reproducible methodology for modeling flood inundation in other areas. First, the study area boundaries initially selected by researchers (Figure 1) were expanded in certain areas to capture a much larger coverage than initially planned. The Eastside and West Edge focus areas were expanded to cover the majority of the Peninsula of Charleston and the DuWap area was expanded to cover the majority of the West Ashley area. Those expansions increased those study area footprints to approximately 8 and 42 square miles respectively (Figure 3), which created additional challenges, but strengthened the transferability of methods to other study areas/regions.

Figure 3: Expanded Peninsula and West Ashley Study Areas (Conrad, 2019)

The methodology created in this study was also applied to several other communities outside of this project's scope at little or no cost, which resulted in the extension of flood modeling products and engagement to the Town of Folly Beach, Town of Edisto Beach, Town of Kiawah, and City of Beaufort, S.C. In combination, these additional efforts have increased the project coverage to parts of three coastal counties in South Carolina (Beaufort, Charleston, and Colleton). Tidal flood inundation layers were generated for the Town of Folly Beach and Town of Edisto Beach, S.C. for use in engagement with residents on the islands. As a part of his thesis work, Lucas Hernandez developed precipitation and tidal flood products for Kiawah Island, S.C. using the methods developed in this grant project. Mr. Hernandez was hired by the Kiawah Island Community Association in a new role for the organization, Resilience Specialist, with a significant portion of his time dedicated to continuing development of these products and utilizing them in town planning and project implementation.

Three Masters theses were written on aspects of this project. In total, seven graduate students were trained by this project with an additional 5 undergraduate students though the course of the project. Of the supported graduate students, all now have positions across the region; two now work for NOAA (Federal), two work for State Agencies, two work for municipalities in the region, and 1 student works for Rural Water South Carolina (Not for Profit).

In April, 2019, the City of Beaufort, S.C. contacted the S.C. Sea Grant Consortium (Consortium) for assistance with beginning the process of assessing and mitigating the flooding issues the city was experiencing as well as those projected in future conditions. PI's utilized the methods developed in this project to develop flood inundation maps for the city and conduct a vulnerability assessment of municipal infrastructure and businesses operating in the area. Vulnerabilities were further analyzed independently in 10 separate areas of the city to allow prioritization of future projects using the city's limited resources. Minor funding of $14,639 was provided by the City of Beaufort to fund the entire project, which was allocated entirely to student salary and fringes at the College of Charleston (College) for executing the methods. PI's expanded the tidal inundation models to the full Beaufort County to expand the footprint of the products. The city agreed to share those data with the county, which has used these products for an ongoing sea level rise adaptation plan and has further strengthened the collaboration between the two agencies on addressing climate change challenges. Without the previously-established pathway for completing the work and the in-kind contributions from PI's of this project, the work for the City of Beaufort would not have been possible and especially not on the accelerated timeline the city needed of approximately 5 months from receipt of funding to delivery of final products. The full project report can be found hosted on the City of Beaufort's website (http://www.cityofbeaufort.org/494/November-2019-Flood-Vulnerability-Assess), with PI's of this project having presented results to City Council and the public on January 28, 2020. Blake Waring, the primary student performing analyses on this project, was hired by NOAA's Office for Coastal Management (NOAA OCM) during the course of the project and was initially performing similar functions in that role to what he was tasked with on this project.

The flood modeling efforts in Beaufort, S.C. led to an additional extension of project outcomes, with the formation of a collaboration between the Consortium, the College, and NOAA's Coastal Change Analysis Program (C-CAP). With the flood modeling requiring the development of high-resolution land cover data, the PI's worked with C-CAP staff to develop 1-m resolution land cover products for Beaufort, S.C. This initial work resulted in the formation of a collaborative project in which C-CAP delivers an automated land cover product to the College where technicians then adapt scripts first developed by C-CAP to edit and clean the data. The College's Division of Information Technology invested $22,000 in this project to obtain the necessary licensing for the eCognition software suite, with the Lowcountry Hazards Center investing an additional $3,330 in renewal fees. As a result of those investments, that software program, which is heavily utilized by NOAA OCM staff, is now being used in teaching and training at the College to equip students with the skills they will need in the workforce post-graduation.

Preliminary 1-m resolution land cover products have been completed for Beaufort and Charleston counties. Six of the eight coastal counties have been targeted for complete C-CAP coverage via this new initiative, with the final data serving as the official C-CAP product served out of NOAA's Digital Coast. The impact of this new data product on research and management in South Carolina is expected to be seen from the community level with land use planning and FEMA's Community Ratings System to statewide research spanning a wide range of environmental and socioeconomic foci. These new data will serve as the new standard in the state and will be disseminated by the Consortium staff to ensure their widespread utilization.

Additionally, PIs of this project applied for and received an award as part of the Consortium's FY20-21 Biennial Sea Grant funding opportunity totaling $133,396. The grant project is aimed at developing a real-time map application of flood conditions in Charleston County with forecasts of conditions in the near future. The goal is for this application to aid residents and visitors to the area, as well as businesses, in adaptive behavioral changes to cope with the chronic flooding impacts the area has and will continue to experience. The project design was made possible by the understanding of the hydrological dynamics of the area gained during this regional resilience grant. Products that have been created from this grant will also be used to power the base data needs for the realization of the real-time flood application.

Data Sets

1) 2009 SCDNR Charleston County Lidar

2) Inundation Mapping Tidal Surface – Mean Higher High Water

3) VDatum: Vertical Datum Transformation

4) 2017 Coastal South Carolina NAIP 4-Band 8 Bit Imagery

5) USDA Soil Survey Geographic (SSURGO)

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Component 2: Analysis of Transportation Resilience

Co-PI Jeff Davis, PhD., The Citadel

Overview of Research Methods

Across the U.S., and beyond, as coastal communities work to create effective strategies to adapt to sea level rise and coastal flooding, adverse impacts on transportation network viability are a crucial concern to ensure mobility is preserved for essential movement of people, goods and services. National organizations, such as Federal Highway Administration and American Association of State Highway and Transportation Officials are beginning to investigate how to best address roadway network resiliency issues, however, to date focus of these efforts has been limited to establishing planning frameworks or initiating pilot projects (FHWA, AASHTO). Geographic Information Systems (GIS) analysis methods were used to evaluate roadway network resilience for four (4) Charleston area case student locations by combining data to create an integrated database including the following primary sources:

S.C. Department of Transportation	traffic volumes, road classification, travel lanes, speed limit, lane width, traffic control devices, roadway nodes and segment lengths, etc.

Dr. Norm Levine, Geology & Environmental Geosciences, College of Charleston	sea level rise & flood modeling scenarios, in 0.5 ft. increments (low:0-ft, medium:3-ft, high:6-ft)

Transportation resilience comprises a broad range of technical areas including damage assessment, security, risk analysis, emergency management, network planning, facility design, and traffic operations. Methods for this research focused specifically on assessing traffic operations network impedance resulting from flooding in which metrics to quantify capacity reduction of roadway network and constrained community mobility were explored. Sea level rise and flood model scenarios were represented as polygon areas and superimposed onto Charleston area case study locations roadway network locations to identified portions of the roadway network that would be removed from service in flood prone areas evaluated for low, medium, and high levels of flood inundation model scenarios. Table 1 shows list of steps used to construct an integrated database and determine findings using GIS methods.

Summary of Results and Findings

Results for each of the four selected neighborhood case study locations produced an anticipated range of results quantifying how flooding adversely impacts network mobility. Results are summarized in Table 2, with maps of each case study location shown in Figure 2.

1. Obtained flood scenario modeling polygons from the College of Charleston
2. Obtained transportation network data from S.C. Dept. Transportation Roadway Information Management System (RIMS), including average annual daily traffic (AADT)
3. Adjusted base AADT volumes (2010) to reflect analysis year (2017)
4. Delineated polygons in ArcGIS desired for four neighborhood boundaries
5. Intersected flooding data with four neighborhood boundary polygons
6. Intersected street data with four neighborhood boundary polygons
7. Determined impacted street network segment lengths intersecting flooding polygon scenarios using ArcGIS - Select by Location tool.
8. Calculated Vehicle Miles Traveled (VMT) using equation: VMT = AADT * length of street
9. Determined adverse impact on traffic operations based on VMT by intersecting flooding polygon scenarios using ArcGIS - Select by Location tool
10. Tabulated street segments inundated by low, medium, and high flooding scenarios
11. Tabulated network street traffic operations impedance based on VMT of all street segments inundated by low, medium, and high flooding scenarios
12. Compared street and VMT impedance for four neighborhood areas to evaluate results

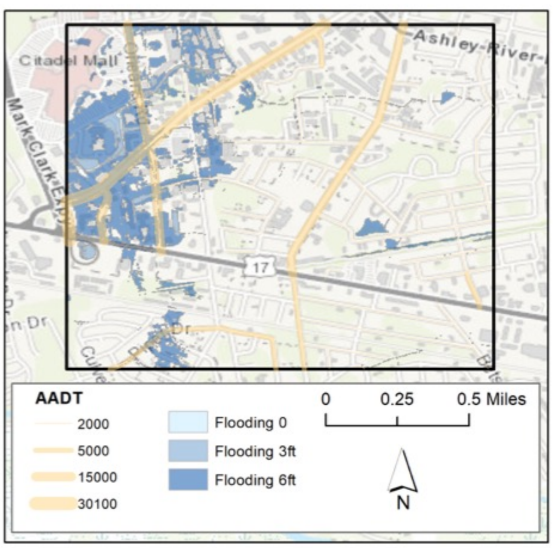
Table 1, Transportation Resilience Modeling, Summary of Data Analysis Procedures

Case Study Neighborhood Locations (representative of Charleston area)	Street Network (mi)	Street Impedance (mi)	% Street Impedance	% VMT Impedance
N. Charleston: Park Circle, Filbin Creek	37.5	-6.5	-17.2%	-28.4%
Charleston: Dupont, Wappo	13.6	-4.0	-29.7%	-67.9%
Charleston: West Edge, Westside	31.0	-24.8	-80.0%	-81.8%
Mt. Pleasant: Hobcaw, Remleys Point	14.2	-3.5	-24.9%	-27.6%

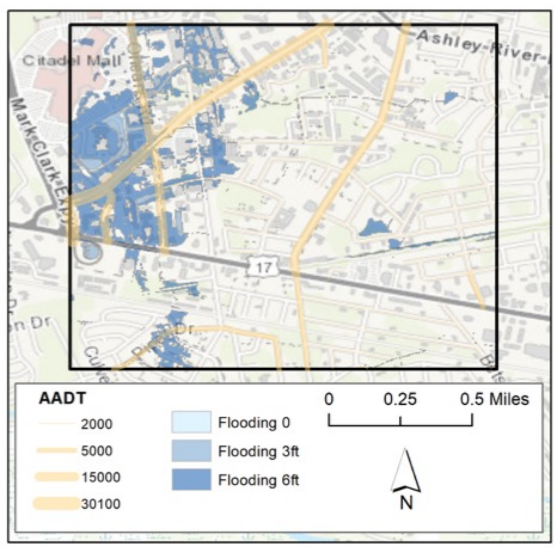
Table 2, Transportation Network Impedance for Case Study Neighborhoods (High, Flooding 6-ft.)

All four neighborhood case study locations are summarized in Figure 2 showing flood scenarios polygons for low (0-ft.), medium (3-ft.), and high (6-ft.), along with road/street networks and daily traffic volume indicated by line width in accordance with map legends provided. These locations were strategically selected as representative of neighborhoods across the Charleston region. GIS results shown in Table 2 for the highest flood inundation modeling scenario (Flooding 6-ft.), indicate there is a considerable difference in levels of mobility impedance between the four case study neighborhoods, with downtown peninsular Charleston: West Edge, Westside, experiencing the worst (80%) reduction in network capacity, essentially resulting in gridlock, while more upland locations in N. Charleston and Mt. Pleasant would experience less adverse impacts, with reductions of 28-30%. Additionally, modest differences are noted between the two metrics for evaluating mobility, street network miles, and street network Vehicles miles traveled (VMT). This valuation was investigated to account for the fact that all road segments are not of equal importance. It was assumed the amount of traffic would provide a useful indication of network importance and loss of the operational functionality of these roadway during a flooding event would cause a much larger adverse impact to network mobility. In reviewing results from the four case study neighborhood locations, only Charleston, West Ashley, Dupont, Wappoo, indicated a sizable difference (67.9-29.7=38.2%) in percent reduction of street miles versus VMT. This value was calculated to provide an insightful indication of how important roadways and streets are in terms traffic carrying dependence for the larger transportation network, in the event these facilities become inoperable due to inundating flood conditions. For the other three neighborhood case study locations, differences between these two network values were much lower, averaging only 5%. The desired mobility importance measurement for this useful variable may need to be determined through inclusion of additional variables (roadway functional classification, number of lanes, speed limit, etc.) and/or weighting factors.

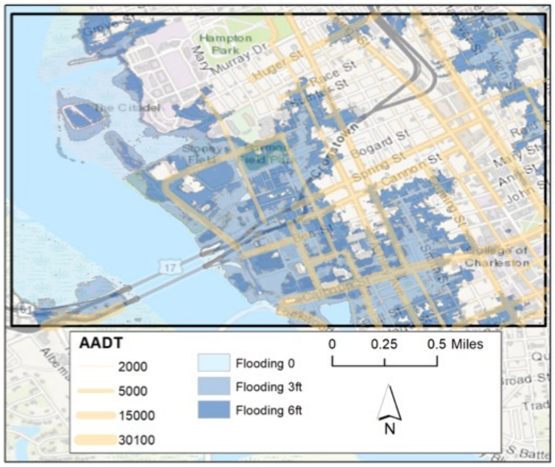
Figure 1. Four Charleston area Neighborhood Case Study Locations



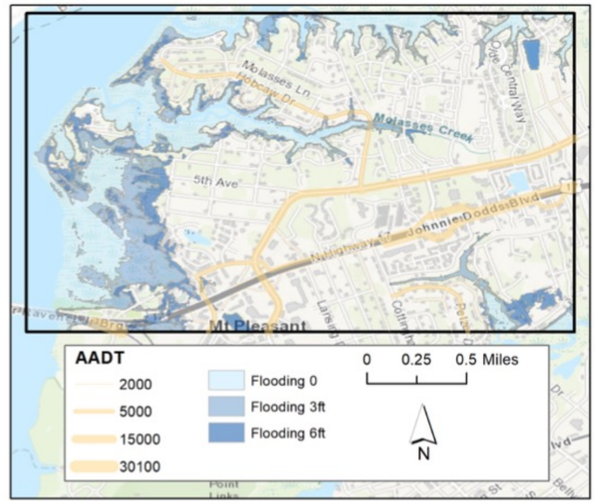
City of N. Charleston: Park Circle, Filbin Creek



City of Charleston: Wappo, Dupont, Citadel Mall



City of Charleston: West Edge, Westside



Town of Mount Pleasant: Hobcaw, Remleys Point

Integration of Findings within Research Project

Developing approaches to understand and quantify the adverse impacts sea level rise and flooding on community mobility and the transportation network has been an overall objection of this larger research initiative. Transportation network resilience is of great interest to the community in understanding how to adapt travel patterns to best use remaining functioning roadway during periods of flood inundation.   Additionally, emergency management officials of local jurisdictions are keenly interested as the viability of road and street networks is a crucial consideration in managing events and orchestrating rescue and recovery efforts. Though community engagements affiliated with this research projects, a great deal of dialog with governments and community leaders has centered on issues related to transportation network resilience, mobility of the public during events, traffic impedance and travel reliability.

In addition to evaluation of network traffic operational impacts, there are obviously many other technical issues interconnected within transportation resilience that need to be considered including damage assessment, security, risk analysis, emergency management, network planning, and facility design. All of these technical emphasis areas each constitute the need for further research and necessitate individual research treads specifically tailored to investigate and evaluate analytical relationships required to create a comprehensive approach to transportation resilience for the Charleston region.

Application of Analytical Approach to other Regions

Determination of quantifiable measures that can analytically derived and communicated with the public to provide communities with an understandable indication of adverse impacts to mobility caused by flooding of the road and street network will be a very useful tool in emergency management. Database construction and GIS methods delineated in the research effort would be transferable to other coastal regions, however, need procedural improvements should be developed and incorporated into the computational process.

Emergence of Additional Research Threads

In addition to evaluation of network traffic operational impacts, there are obviously many other technical issues interconnected within transportation resilience that need to be considered including damage assessment, security, risk analysis, emergency management, network planning, and facility design. All of these technical emphasis areas each constitute the need for further research and necessitate individual research treads specifically tailored to investigate and evaluate analytical relationships required to create a comprehensive approach to transportation resilience for the Charleston region. Furthermore, based on work performed for this project additional research opportunities have emerged and are being pursued including: 1.) activities with Regional Transportation Systems Management and Operations Resilience Subcommittee, AHB10(8), National Academies of Science; 2.) submittal of a National Science Foundation proposal, Real-Time Intelligent Flood Monitoring and Detection System for Informed Emergency Management, 2019; and 3.) participation in Charleston Dutch Dialog programs, 2019; and engagement with emergency management officials, South Carolina Earthquake Risks to Infrastructure and Transportation, 2016.

Future Research (new questions/methods)
Continuation to the technical quest to develop meaningful measures of network mobility impedance resulting from flood inundation that can be effectively communicated to the public to facilitate ongoing citizen adaptation plans for improved safety, security and well-being.

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Component 3. The Effects of Nuisance Flooding and Sea Level Rise on Liquefaction Potential and Other Geotechnical Considerations

Co-PI Simon Ghanat, Ph.D., The Citadel.

Implications of Climate Change on Geotechnical Properties
Climate change in the Lowcountry is expected to lead to drying of soils during dry period, which lowers the strength and the modulus of elasticity of soils. This also influences the stability of lining system of waste containment. As this occurs, soil erosion is expected to increase and the moisture suction capacity is expected to decrease. This can cause flooding during heavy rain events because the soil is not able to absorb water efficiently during the first rains following a dry period. As a result, this leads to an overall loss of soil strength, which can damage building foundations, over-stresses piling, causes scouring in places, and also increases the leaching of pollutants and spreads toxic contaminants. Sea level rise can lead to an increase in soil pore pressure in areas that are subject to a rising groundwater table

Geotechnical Implications of Climate-driven Groundwater Table Rise
As the groundwater table rises, there is a reduction in effective stress as a consequence of increased pore water pressure, which results in reduction of shear strength of soils. There also is a reduction in the bearing capacity because of reduction in shear strength. As a result, there is increased lateral pressure on basement walls because of increased hydrostatic pressure. This can lead to development of uplift pressure and building settlement.

Implications of Ground Subsidence
In the Charleston region, ground and soil subsidence is prevalent in certain areas. This can lead to loss of wetlands, affect the stability of buildings and functionality of infrastructure that supports it, and increase risk of flooding. Subsidence also gas, electric, storm sewers, sewage, and water supplies, affects the surface runoff patterns, causes differential settlement, and increases local relative sea level rise.

Implications of Increase in Relative Sea Level Rise
The implications of an increase in local relative sea level rise is that it put critical infrastructure at risk. It causes groundwater levels to increase, causes groundwater near the coast to become more saline, increases coastal flooding occurrences in low-lying, flood-prone coastal areas, and reduces the effectiveness of storm water drainage systems.

Effects on Earthquake Liquefaction Zones due to Increases in Local Relative Sea Level Rise
A study was performed to determine the effects of climate-driven sea level rise and earthquake ground motion on liquefaction vulnerability for sites in Charleston Peninsula and Mount Pleasant, South Carolina. The analysis was performed using the projected values of sea level rise corresponding with 7, 12, 32, 57 and 92 years (i.e., 0.5’, 0.75’, 2’, 3’, and 5’ of sea level rise). The results indicated significant changes in vulnerability to liquefaction in the next 92 years.

To assess the liquefaction potential, the study investigated two earthquake scenarios (a large magnitude event, M6.9, and a moderate magnitude, M5.8). A magnitude 6.9 is the low end of estimates for the 1886 Charleston event and a magnitude 5.8 is the moderate size event that occurred in the Eastern United State (Mineral, VA) in 2011. The study employed the best available in-situ shear wave velocity data (Fairbanks et al. (2004), Mohanan et al. (2006), and other consulting projects) from ground surface to top of Marl and Chapman et al. 2006 model from Marl to top of bedrock at each site. The water table depth data at each site was taken from Fairbanks et al. (2004), Mohanan et al. (2006). The study used the soil dynamic material properties model of Chapman et al. (2006) and unit weight model of Zhang et al., (2005) and (2008) to perform site response calculations. Furthermore, the study employed the Ishibashi and Zhang (1993) modulus-reduction and damping curves for shallow sands and clays, Chapman et al. (2006) shear modulus reduction and damping curves for Cooper Marl, and Assimaki et al. (2000) shear-modulus reduction and damping values for depths between 100m and the top of the bedrock. In addition, the study used three strong ground motions at rock site stations LPCC and MQZ from 2010 M 7.1 Christchurch, New Zealand events at epicentral distances of approximately 30 km.

Several studies have found the relative depth of groundwater rises along with the sea. Building off those past works, this study examined how extensive liquefaction could get in Charleston during an earthquake. For purposes of this study, it was assumed that the increases in elevation of groundwater table to mimic increases in sea level in the areas near rivers, with decreasing influence further inland. It was also assumed that decreases in depth-to-groundwater equals to the magnitude of projected sea level rise. The increases in ground water depths of 0.5’, 0.75’, 2’, 3’, and 5’ were directly applied to each known groundwater depth or to the median depth groundwater of 1.5 m as reported in literature. Liquefaction potential index (LPI) were computed at each site and the ArcGIS Software was used to develop LPI maps for the Charleston Peninsula and Mount Pleasant.

The results show that the highest risk of liquefaction is in areas covered with artificial fill and the younger natural sediments. For M6.9, the corresponding rise in groundwater level would result in a small increase in liquefaction vulnerability in middle of peninsula, but a more significant increase in liquefaction vulnerability along the Ashley and Cooper Rivers. For M5.8, the corresponding rise in groundwater level would only result in a significant increase in liquefaction vulnerability along both Ashley and Cooper Rivers in Charleston. This is due to the fact that the rising groundwater table increases the extent of profile susceptible to liquefaction and the cyclic stress ratio throughout profile via the ratio of total vertical stress to vertical effective stress and thus reducing the factor of safety.

For prevention and mitigation against liquefaction, it is essential to consider the regional variations of groundwater level caused by global climate change. Best preparations include retrofitting existing infrastructure to a higher seismic standard and ground improvement. Various ground improvement techniques can be used to improve the foundations of existing structures.

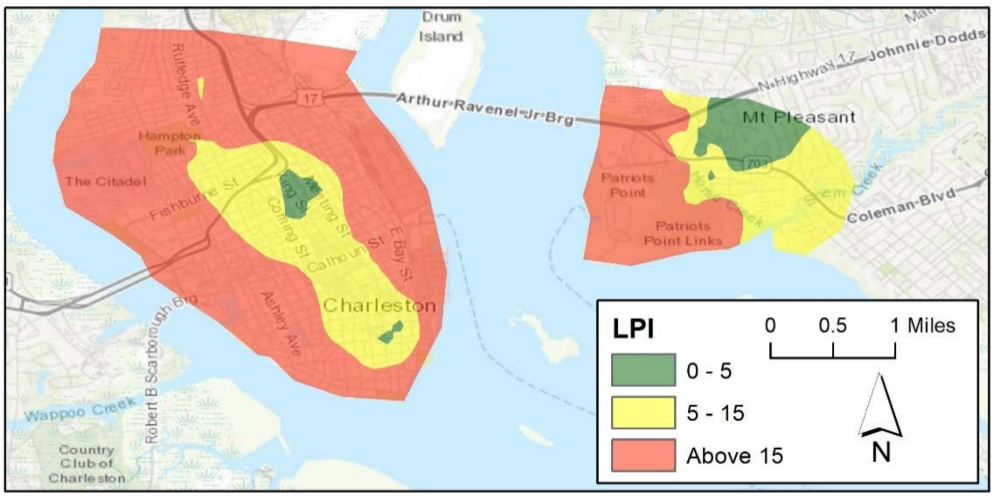

Figure 1. Liquefaction potential index map in year 2018 (M 6.9)

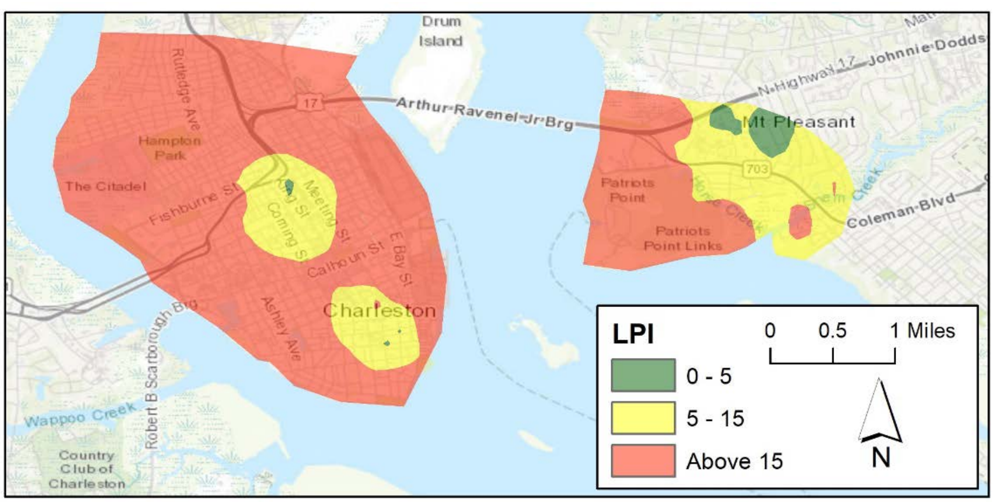

Figure 2. Liquefaction potential index map in year 2100 (M 6.9)

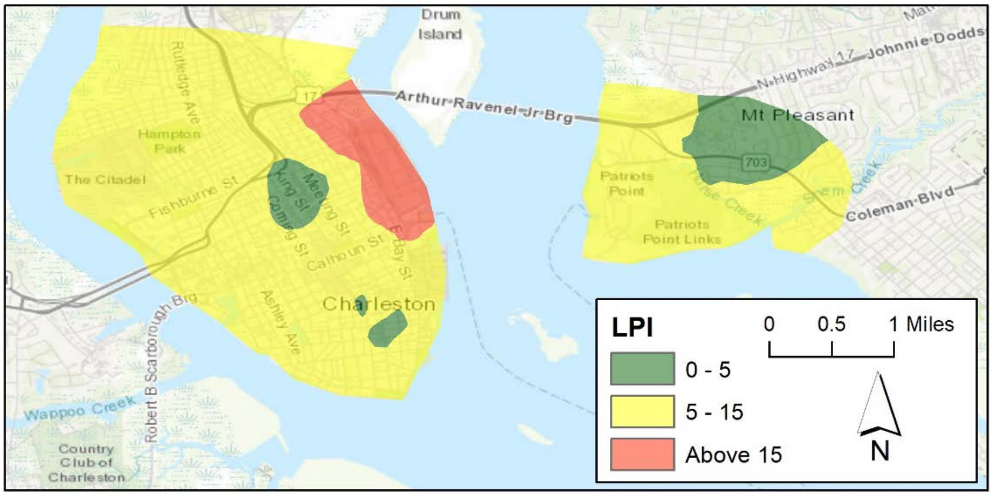

Figure 3. Liquefaction potential index map in year 2018 (M 5.8)

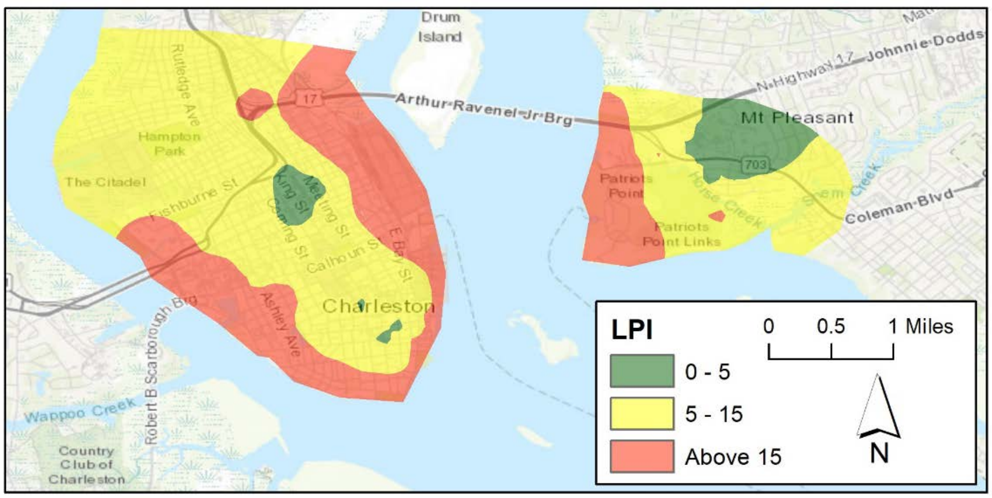

Figure 4. Liquefaction potential index map in year 2100 (M 5.8)

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Component 4. Downscaled climate model precipitation analyses for Charleston County

Co-PI Greg Carbone, Ph.D., University of South Carolina - Carolinas Integrated Sciences and Assessments

Objectives and Nature of the Work

The CISA team create precipitation surfaces for Charleston County during the historic period, and made precipitation projections for mid- and late-twentieth century based on dynamically-downscaled output from general circulation models. These data sets were used as part of a broader study to understand the precipitation intensity that has created historic flooding in Charleston neighborhoods, and to project future scenarios for such flooding. The city regularly experiences nuisance flooding as a function of tide cycles and precipitation events. Such flooding impacts transportation and causes loss of property, and in extreme cases threatens lives.

Overview of Methods

Precipitation scenarios were based on dynamically-downscaled precipitation data from the CORDEX-North America project, an international effort linking multiple general circulation models to multiple regional models for climate scenario development. We specifically examined historic (1971-2000) annual precipitation maxima – a commonly-used metric for precipitation intensity. The first task in the historical analysis was to evaluate the performance of the models relative to observed annual precipitation maxima. This involved calculation of annual precipitation maxima from observed data sets, followed by mirrored analysis using CORDEX-simulated precipitation. The second task was to compare annual precipitation maxima simulated for the historic period against such values calculated from mid-21st century (2041-2070) precipitation projections.

Findings/Results

Our results show that the CORDEX-NA dynamically downscaled precipitation output realistically simulates precipitation intensity during the historic period. Simulations of both annual total precipitation and annual 24-hour maximum precipitation for coastal South Carolina are very close to those observed. Performance among the various combinations of general circulation and regional model output varied. Two of the four combinations produced superior results. Combinations of the UK's Hadley general circulation model and the Giorgi RegCM model (Had_RegCM), and NOAA's Geophysical Dynamics Lab GCM with the Weather Research and Forecasting model (GFDL_WRF) best replicate precipitation intensity during the historic period. The Had_RegCM and GFDL_WRF also produced the most plausible spatial variability in the future scenarios.

Integration with other Aspects of the Project

Precipitation surfaces for 1% annual probability ("100-year" event), and 0.2% annual probability ("500-year" event) were delivered to the hydrology and GIS teams for flood analysis.

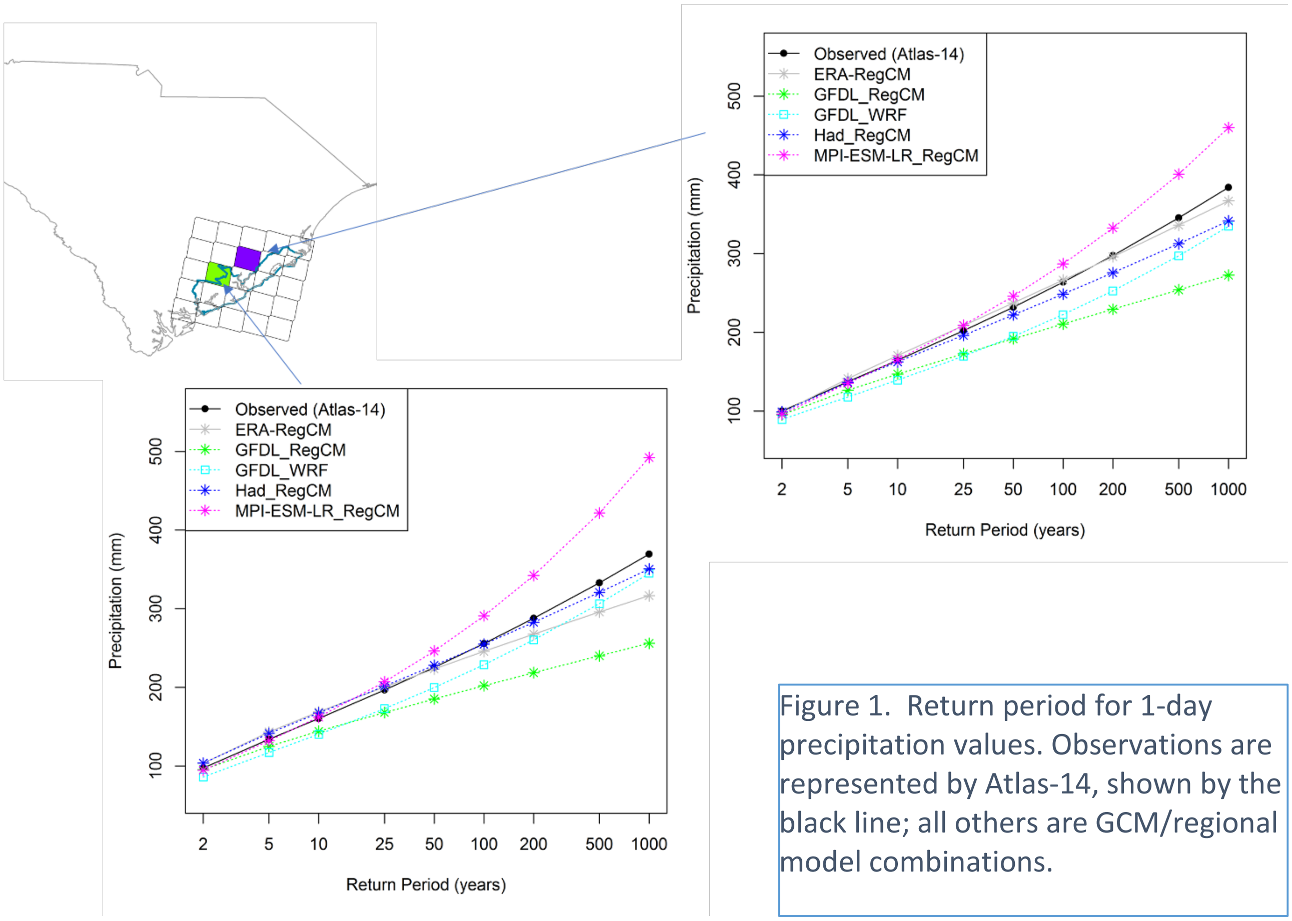


Figure 1. Return period for 1-day precipitation values. Observations are represented by Atlas-14, shown by the black line; all others are GCM/regional model combinations.

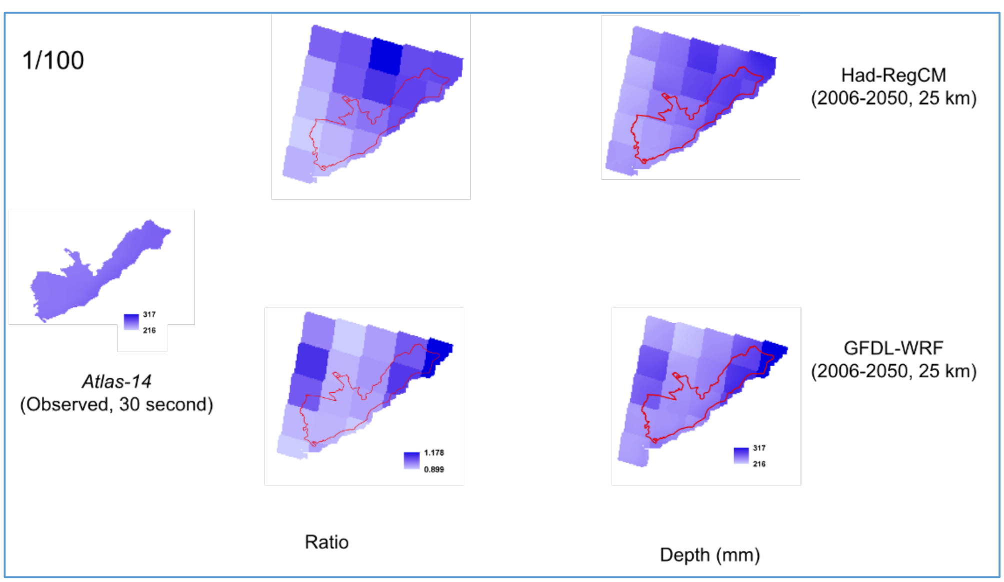


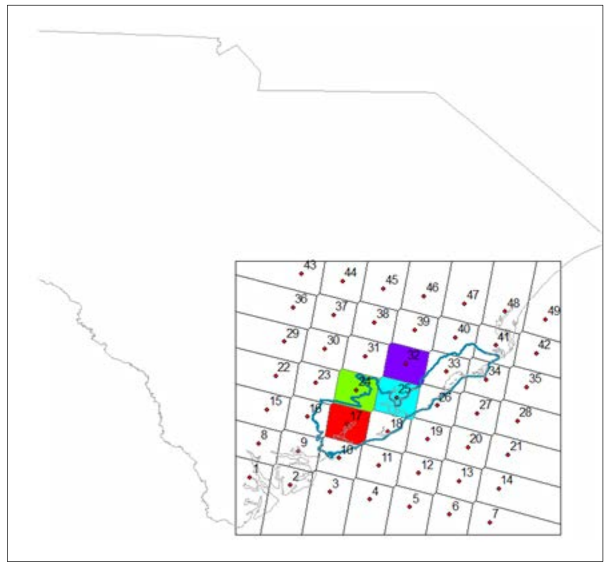
Figure 2. Left panel is observed 100-year 1-day precipitation totals. Middle panels represent the precipitation ratio of future vs control period simulations. This ratio imposed on Atlas 14 to project future values (right panels).

Data Management

We have collected precipitation data from the CORDEX-North America database for coastal South Carolina. These data, as well as historic annual precipitation maxima from them are stored on a hard drive maintained by Greg Carbone. Questions should be directed to Greg Carbone at carbone@mailbox.sc.edu or 803.777.0682.

Application Potential to other Regions

We used an analysis intensive approach to presenting future scenarios of precipitation intensity that can be applied virtually anywhere that has regional-scale model output. For CORDEX, that represents most land areas on Earth.

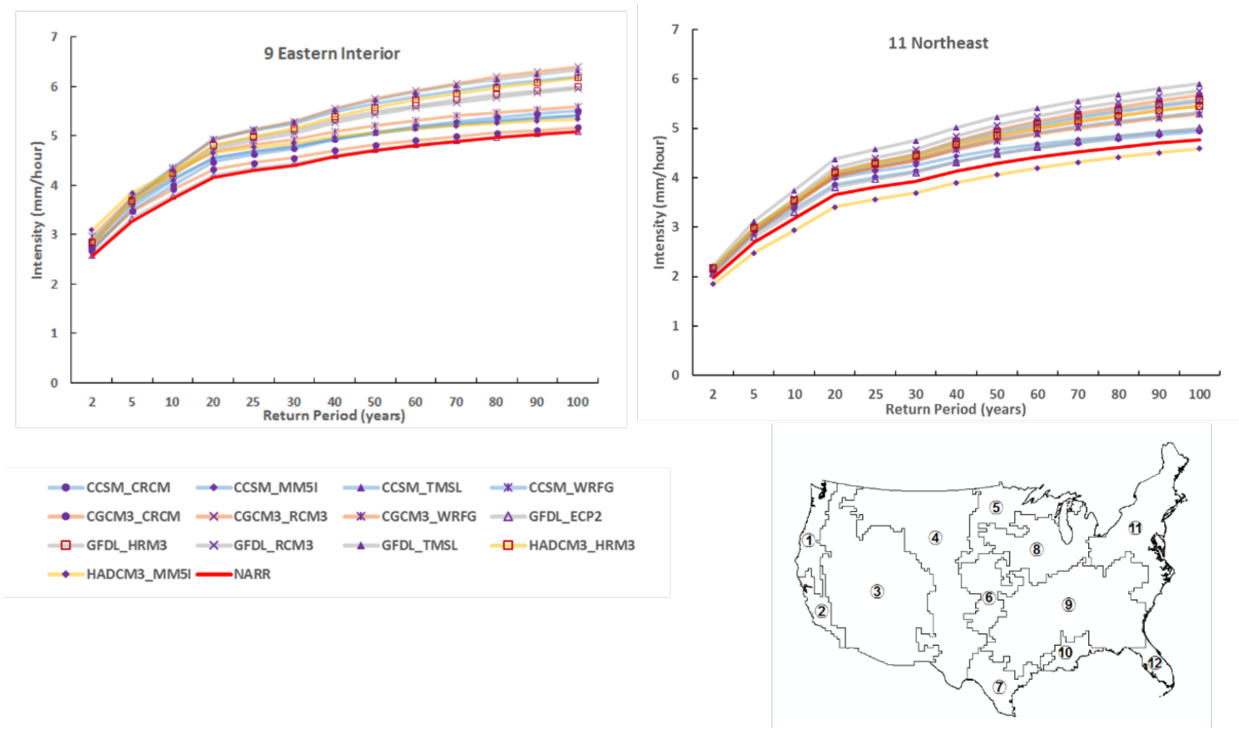


In our analysis at the local level, we stumbled upon something that surprised us as well as some in the community of scholars working closely with model output. We found distinct differences in precipitation output between 50-km grid cells that were just inland from the coast versus those adjacent, but on the coast proper. In the inland cells, the model overestimates total annual precipitation. Meanwhile, the model simulates annual total precipitation very well in those cells right along the coast that include both land and ocean. Our interaction with more experienced modelers taught us that the NA-CORDEX RegCM4 simulations use different convective schemes over water and land points -- the Grell scheme with a Fritsch-Chappell type closure over land, and the Emanuel scheme over oceans. This strategy is a commonly-used option in RegCM because it improves simulations at the continental scale inherent in CORDEX experiments. The modelers were not aware of the implications of the convection-scheme option at the local scale where we applied model output. For us, and others using model output from dynamically-downscaled models, this is a warning that their use at local scales demands close examination of output variability across neighboring grid cells.

Leveraging into Additional Research

The analysis required to deliver future scenarios of precipitation intensity for this project, was applicable for other projects in South Carolina and nationally. Four publications benefitted from the process of data downloading and analysis (listed in the section on publications).

An example of this work applied nationally is shown below, where a broad suite of climate model output is used to compare future scenarios of precipitation intensity against observed values. In the two East Coast regions depicted, nearly every GCM/regional model combination shows higher precipitation intensity in the future.



New Questions/Methods for Future Exploration

There are many other opportunities to explore precipitation intensity in the Charleston area. One was proposed in 2018 for a NOAA SARP call to examine spatial patterns of rainfall intensity using the recently expanded precipitation gauge network (CoCoRaHS) with hourly, coop, and radar data. Integration of these data would exploit the collective benefits of high spatial resolution (CoCoRaHS and radar), high temporal resolution ((ASOS), and longevity (USHCN), allowing exploration of spatial precipitation intensity patterns and identification of trends in heavy precipitation.

2. <u>COMMUNITY AWARENESS AND ENGAGEMENT</u>

An important goal of the Charleston Resilience Network (CRN) and manifested in this project is fostering a common language and community understanding of water-related hazards and impacts, both short-term and long-term. We will conduct participatory workshops to engage a localized and diverse group of sectors to discuss these issues, come to a common understanding, and initiate the means by which local interests can implement place-based resiliency activities.

<u>Component 1</u>: Engaging Charleston area neighborhoods on flood vulnerability and improving household level resilience to current and future risks
Co-Lead PI Sarah Watson, S.C. Sea Grant Consortium and Carolinas Integrated Sciences and Assessments

The initial engagement goal for this project was to conduct a series of down-scaled adaptation planning meetings at the neighborhood level using the Vulnerability Consequences and Adaptation Planning Scenarios (VCAPS) method. VCAPS is a process that requires substantial local government involvement and is intended to inform decision-making at the municipality level. A primary goal of the engagements with this project was to use that opportunity to ground-truth the flood modeling with residents in identified neighborhoods. As planning for engagement began, our partner communities requested that the engagement processes shift to a model that was beneficial to their communication goals and a process that was more appropriate to the scale of participation.

The resulting design was a solutions-focused expo type event that allowed for flood risk education, model verification and ground-truthing with residents, and gave each community the opportunity to highlight existing programs and plans related to flood resilience. Each event had similarities and substantial differences to reflect the needs and goals of each neighborhood. However, each event focused on three core areas: risk education, risk reduction, and relationship-building. Each event required substantial planning in close coordination with municipal partners so they shared a sense of ownership and we could help advance some of their communication and outreach goals. Each community, in return, also received planning protocols so they could replicate the event's design on their own.

North Charleston

The City of North Charleston requested a high-profile event that brought together city staff from multiple departments, multiple smaller neighborhoods, and regional experts. Through discussions with the city, we developed an expo-type event with a design that would take attendees through multiple discussions about the flood risks and then what residents could do personally to reduce their home's risk. A key overall goal for the event was to demonstrate to residents that the city was taking flooding complaints seriously, and to bring together city staff and help begin breaking down internal silos. The event had more than 50 city and partner staff assisting, with nearly 70 residents attending in addition to about 20 attendees that came from outside of the neighborhood and city.

The outreach methods consisted of working with a graduate assistant at Sea Grant to hand-deliver flyers and connect with a local boy scout troop to also assist with delivering flyers in highly targeted neighborhoods. The City posted large construction signs near the community center where the event was held and posted information on its social media page.
Using printed out maps that delineated the flood layers using the newly developed Flood Disruption Scale, residents were able to successfully provide input to the mapping team and also highlight hot-spots that the city did not yet know about. The city went on to name resilience as a key focus in the 2019 state of the city.

Mount Pleasant

Following the North Charleston Event, the Town of Mount Pleasant requested a compact event design that they could easily replicate internally without assistance from the project team. We developed a scaled down approach that provided a simpler view of the risks, again with printed out maps. The Town requested time for individual presentations, which were well-attended. The town did not spend as much time assisting with planning as North Charleston, instead preferring to allow the research team to make most of the recommendations.

The event was initially scheduled for early October, 2019, but was postponed due to Hurricane Florence. Had the event gone as originally scheduled, it would have needed to be canceled or postponed due to Tropical Storm Michael passing nearby on that date. The event was rescheduled for two days after Election Day, something the research team suspects lead to the depressed turn-out as many residents had spent more than an hour in the event site two days prior waiting to vote.

The outreach methods primarily consisted of using United States Postal Service direct mail to deliver flyers to all households in the study area two weeks before the event. There was a discrepancy in the delineation of the study area and a portion of the residents that should have received flyers were inadvertently excluded. The night of the event, a local TV station did a three-hour live-shot from the event, which drew about 10 additional attendees.

Folly Beach

The S.C. Sea Grant Consortium and the Carolinas Integrated Sciences Assessments have been assisting the City of Folly Beach in resilience efforts since 2016. When the City learned of engagement efforts elsewhere in the region, it asked whether we could provide a hybrid type event that could help connect residents with flood modeling and education that typically did not attend city council meetings or other formal public engagement events. The team decided to bring a micro-scale version of the expo style event to an existing family fun night at the Folly River Park. The event had more than 100 residents, primarily parents and children under the age of 10. The team provided flood mapping exercises and conversation with residents, children's activities to allow parents time to focus on the flood information, and tables connecting residents with county and city flood resilience efforts. The team connected on a deep level with about 15 residents, several of whom had been seeking detailed flood risk information and could not find it at the level they needed.

City of Charleston

The City of Charleston was initially slated for two events, one on the peninsula and one in the DuWap section of West Ashely. The City requested that the event on the peninsula would be first and selected the Eastside neighborhood because it had not been engaged. The selection was made in February 2019 with planning expected to last several months as it would take time to understand the challenges and make sure we were including the right people and presenters. City staff worked closely with the project team and as a group decided to hold the event in late July to coincide with the end of the Dutch Dialogues week-long charrette that also would include neighborhood representatives. The event was well-planned and executed, but the timing of another event that was hosted by another researcher connected with the College of Charleston confused residents. As a result, only 6 Eastside residents attended. Those residents that did attend said they felt the neighborhood had been over-engaged on the topics and were not interested in further education until officials would speak about plans for flood reduction.
As a result of the outcomes from Eastside as well as other discussions, the City requested that we not implement the engagement event planned for the DuWap section of West Ashley as they did not think we would have enough attendance to justify city participation because that neighborhood also has had extensive flood-related engagement over the past three years. Given the hybrid engagement event that was done in Folly, and ongoing efforts to ground-truth the model elsewhere, the team felt that it has accomplished its engagement goals with the events which have been held.

Lessons Learned from Engagements

When this project was proposed, the Charleston region's residents had little experience or education involving flooding related to sea level rise, climate change, or extreme weather. However, two things changed over the course of this project: Residents now have been through multiple severe weather events of varying types that have resulted in substantial experience related to tidal flooding, highly localized extreme rainfalls, hurricanes and tropical cyclones, and a combination of the flooding types. Residents also have been increasingly engaged about the issues, with some neighborhoods and areas receiving the bulk of this education and engagement, and many others receiving none at all. Multiple outside groups have highlighted Charleston as a sea level rise hot spot and used the city's flooding problems on the Peninsula as case studies to examine flood risk and adaptation potential. Media outlets, both national and local, have highlighted multiple examples of flooding for stories. The local newspaper, The Post and Courier, has assigned a reporter to the coastal climate and resilience beat. Flood advocacy groups have formed and developed strong alliances with local officials. However, much of this engagement and communication primarily focuses on the problem. The common refrain when asked why don't residents seem to understand, is "we know, we just want to know what you're going to do about it."

As a result, developing engagement events in the region requires deeply answering several questions: Why this group of people, what do you want people to do with this information, and what are you bringing that's different. There still haven't been wholesale discussions about what residents want government to do about flooding, and residents still are not necessarily part of the conversations that are occurring. Most engagement is one-way. We tried to make engagements multi-way, and we had success initially. However, as the conversation and tone changed in the region, we increasingly were playing in a much more crowded field and our role in this project was not to facilitate the conversation about the solutions. As the conversation progresses, we hope that we are able to help facilitate that conversation if the municipalities request our assistance.

We were in the process of developing a guidebook on designing comprehensive engagement events when the COVID-19 pandemic forced a full re-configuring of the entire engagement and outreach landscape, with reverberations and effects likely to last well beyond when social distancing ends. As such, we are putting this aspect of an added-value project on hold to see how the engagement landscape evolves so we can develop a guide that reflects new realities.

<u>Component 2</u>: Assessing existing resident adaptation actions in Charleston area neighborhoods.
Co-PI Kirstin Dow, Ph.D., University of South Carolina; Carolinas Integrated Sciences and Assessments.

Introduction
This project was designed to engage multiple communities in the Charleston area dealing with flooding threats. Initially, the work proposed involved using the Vulnerability and Consequences Adaptation Planning Scenarios (VCAPS) process to bring together community staff and community members in a deliberative discussion of the risks of climate related tidal, fluvial, and severe storm flooding. I was to have been involved in organizing, facilitating, and reporting on a series of these VCAPs engagements. Following the funding of the proposal, there were more detailed and updated conversations with communities about their interests in engagement. We learned that those interests had evolved to some degree and that there was greater interest in supporting a different style of community engagement – a Flood Resilience Expo - that created opportunities for community members to have one-on-one dialogues with municipal staff and representatives from other organizations that could provide information on flood resilience (e.g., the Red Cross, insurance agents, emergency preparedness).

With this new orientation on engagement, my role in the project needed to evolve to better mesh with the emerging approach. While participating in multiple meetings with community staff representatives, I heard frequent comments indicating tension with the sense that residents were asking local government to take much more action towards reducing flood impacts. Although local governments had a variety of tools at their disposal, local staff also realized the limitations of their capabilities and the need for residents to also take actions on their properties.

In further reviewing published research on this tension between public and private action for flood risk reduction, it became clear that there is a limited amount of information on what individual residents, either homeowners or renters, were doing to reduce flood risk at their residences. I proposed conduct surveys of participants at the community flood resilience events. The surveys were designed to understand what actions residents were taking to support flood risk reduction as well as interests and barriers to taking further action.

Methodology

I developed a brief survey of 18 questions arranged into three sections: past experience with flooding, actions taken to increase flood resilience, and interest and barriers to undertaking additional flood mitigation actions. This study was reviewed and approved by the Institutional Revie w Board of the University of South Carolina. Each of these engagements was customized for the community with meeting location and meeting time determined in consultation with community representatives. The survey was administered at three community flood resilience events. These included engagements at North Charleston, Mount Pleasant, and the Eastside neighborhood of Charleston. The Town of Folly Beach requested that a reduced flood Expo event be held in conjunction with a community picnic and music event. The basic structure of the survey remained the same for all events. The only modification to questions made was to collect more detailed information on specific flood mitigation activities undertaken in the last three expo events. The survey was administered on tablets in the North Charleston event and, on paper at other events where Wi-Fi was not available.

Participation varied among these events. The number of completed surveys was less than the total number of participants because only one member of the household was surveyed (Table 1).

Event	**Completed survey responses**
North Charleston	32
Mount Pleasant	8
Folly Beach	6
Eastside neighborhood	1

Table 1: Number of completed survey responses

Confidence in these findings is limited due to the small number of survey participants relative to the population. While the North Charleston flood Expo had good participation, for variety of reasons attendance was lower at the other events and fewer of those attendees took the survey. Therefore, the data collected are not sufficient to inform a peer-reviewed article. The survey results from North Charleston, the largest sample obtained, were shared with Butch Barfield, Emergency Preparedness Coordinator for North Charleston. The other samples were deemed too small to offer much reliable insight to local staff.

Future Research

Further research into the capacity and willingness of homeowners to invest in flood mitigation strategies for their property could prove useful in designing community adaptation strategies and increasing resilience. As Brody et al. observe (2017) while households bear increasing responsibility for reducing flood risks to their property, there is little information on the factors influencing the adoption of flood hazard adjustments. This work has offered a small contribution towards understanding the role of experience in investing in flood mitigation and barriers to further private action and some indication of the degree of private action already underway.

Still, the more general questions of what motivates and impedes private actions for flood mitigation merits further attention. For example, recent research calculates that homeowners in large portions of Europe are not able to afford one-time investments in flood adaptation measures and suggest that the potential of loans can reduce the level of unaffordability (Hudson 2020). In Massachusetts, Millman et al. (2017) focus on landowner perspectives towards Integrated Flood Risk Management finding that beyond pest impacts, landowner worldviews understandings of riverine flood processes and interpretations of relationship between government and private property influence attitudes and support. Wilson et al. (2020) argue that much behavioral adaptation research assumes that individuals will adapt with the right information to inform the risk perception and the likely personal benefits of taking action; while the interconnected nature of flood risk suggests more attention to factors motivating behavior that is pursued for purely collective benefit.

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3. INTEGRATIVE AND COLLABORATIVE CAPACITY BUILDING

The Charleston Resilience Network (CRN) is expanding its internal capacity and forge additional partnerships, such that the results derived from the project's modeling and stakeholder engagement efforts will be given a longevity and an "after-the-project-ends" utility in implementing resilience strategies throughout the Charleston region.

Since 2016, when this project began, the Charleston Resilience Network has developed as an organization, building integrative and collaborative capacity through partnerships across all sectors and leadership by its chair and committee members. The CRN has been instrumental in this project to engage stakeholders, share science-based information, enhance long-term planning decisions, and sustain working groups to increase the impact of project outcomes and enhance long-term utilization. Through the process, CRN has gained organizational capacity and expanded its influence as a convener of experts and stakeholders committed to enhancing the resilience of the region. The following summary identifies the many events, partnerships, and projects that CRN initiated over the course of the last few years since receiving the NOAA award and identifies what efforts are currently underway to build on this foundation to foster safe, resilient communities for the Charleston region and beyond.

Component 1: CRN Collaborative Partnerships and Initiatives
Co-PIs M. Richard DeVoe, S.C. Sea Grant Consortium, and Daniel Burger, SCDHEC-OCRM, along with CRN Committee members

Key Activities

In the first year of this project, CRN became engaged with the S.C. Sea Grant Consortium to help increase the utilization of the South Carolina Coastal Information Network (SCCIN; https://www.sccoastalinfo.org/), a web-based application that tracks educational events and outreach opportunities hosted by area organizations dealing with coastal community resilience efforts. CRN led a workshop to train organizations publishing their events through the SCCIN. Use of the SCCIN has allowed organizations to keep up with other pertinent outreach events working with communities to avoid stakeholder fatigue of overlapping community and stakeholder engagement initiatives.

In the spring of 2017, CRN held the first "Rendezvous for Resilience," which brought dozens of organizational leaders together to discuss regional resilience priorities and engage these organizations with CRN to increase opportunities for partnership. The year 2017 also saw the initiation of bi-monthly "Coffee Hours" to gather members for candid conversation about regional resilience issues, offering a platform to share science-based information, as well as to network with professionals and experts working in the region. Presenters have included both CRN members and outside experts with topics ranging from local issues and initiatives to broad implications of natural hazards and climate change. CRN hit a milestone of 200 members in 2017 and that membership has more than doubled since, in large part thanks to the opportunity provided by the Coffee Hours for area professionals to meet and collaborate.

In June of 2017, the CRN hosted the Hampton Roads & Charleston Coastal Resilience Knowledge Exchange, convening professionals from a wide array of backgrounds to discuss parallels between the Hampton Roads community in Virginia and the Charleston region. Participants discussed key takeaways from the Hampton Roads project outcomes to inform long-term planning decisions pertinent to the resilient adaptation of the Charleston region.

The Department of Homeland Security contracted CRN (through the S.C. Sea Grant Consortium) in 2018 to develop a publicly accessible flood tool, with an Initial focus on water-related issues but with the potential to expand to other environmental hazards. CRN engaged businesses and community members to inform the development of the web-based *ChuckTownFloods* application – a centralized navigation portal – that can be used proactively to understand flood hazards and provide resources to plan proactively for coastal flooding. This information is critical when planning and implementing place-based strategies to increase resilience. CRN coordinated with a working group of developers, the Knee-Deep Team that helped get *ChuckTownFloods* online by providing documentation and resources to ensure the successful data management of this web application for long-term utilization. Based on feedback from stakeholder focus groups and a detailed evaluation of existing vulnerability assessment applications, this tool has been designed to empower Charleston's neighborhoods, businesses, and municipalities to make informed, proactive decisions to mitigate the impact of frequent coastal floods. *ChuckTownFloods* is currently hosted by the College of Charleston's Lowcountry Hazards Center, where it is available at https://chucktownfloods.cofc.edu/.

When Hurricane Dorian hit in 2019, CRN partnered with the Riley Center for Livable Communities to assess the economic impacts of the storm for affected businesses. The Chamber of Commerce provided a venue to gather business leaders and community members to discuss strategies for future collaboration in the face of natural disasters. The conversation provided insightful takeaways that will help Charleston businesses adapt to mitigate the economic impacts of coastal storm events. CRN, along with the Riley Center, published a report of the economic analysis and insights from engagement to inform future resilience planning.

The former chair of the CRN Organizing Committee, Dan Burger, assisted with setting up the Dutch Dialogues in the City of Charleston (see https://www.charleston-sc.gov/1974/Dutch-Dialogues) with international experts sponsored through the Royal Kingdom of the Netherlands, the Water Institute of the Gulf and Waggonner & Ball Architects. This effort engaged and elevated the collective experience and expertise of Charleston to create a compelling new vision for the City's future and an opportunity to redefine its relationship with water. Although this effort focused on the City of Charleston, the lessons learned through this process have been found to be transferable throughout the region. Most notably, this effort highlighted the capacity to work together, innovate, and transcend traditional boundaries. CRN worked alongside leadership provided by the City of Charleston, Historic Charleston Foundation, The Nature Conservancy, Charleston Water System, Medical University of South Carolina, and the Clemson Design Center, in addition to the invaluable contribution of time and expertise among hundreds of participants.

Last year, in 2019, CRN convened a panel for the "Living with Water" conference hosted by Clemson University's Master of Resilient Urban Design (MRUD) program, featuring members from the Dutch Dialogues team that crafted a long-term planning document for the Charleston region as it adapts to rising floodwaters. At the "Living with Water" presentation, students of the MRUD program sat alongside municipal and state government officials and professionals engaged with water-related issues in the region to hear panelists discuss resilient strategies that can help Charleston regain its relationship with water as an asset, instead of a burden.

Moving Forward

Through all of the initiatives led and partnerships formed over the course of the last five years, CRN has grown its role as a convener and to provide a forum to share science-based information to educate stakeholders to enhance long-term planning that results in resilience for the region. This year (2020), CRN's partnership with the Riley Center has allowed CRN to develop a strategic framework and vision for CRN's future, the Resilience Framework. CRN has adapted its convening approach to bring Coffee Hours online in a virtual environment, and is hosting the first *virtual* gathering of the Coffee Hours in November. There is a great need for collaboration across municipal boundaries and CRN has been making headway in establishing partnerships and sharing knowledge in neighboring counties and coastal communities to adapt lessons learned in Charleston for the benefit of a broader region of South Carolina communities facing regional resilience challenges.

Component 2: CRN Organizational Capacity Building

Co-PIs M. Richard DeVoe and Daniel Burger, with the assistance of Andrea Sassard, Syl Foster, Ian Rossiter, and Rebecca Fanning

Key Activities

With the support of the S.C. Sea Grant Consortium (https://www.scseagrant.org) and the Carolinas Integrated Sciences and Assessments (CISA) program (https://www.cisa.sc.edu/) based at the University of South Carolina, CRN was able to employ its first full-time Program Coordinator in 2017. Alongside members of the CRN Organizing Committee, the Program Coordinator attended public outreach and stakeholder engagement events associated with the NOAA RCRG award to provide project continuity and promote CRN at area events. The Organizing Committee began to meet monthly in 2017 for quality assurance and quality control of all program efforts to ensure good stewardship of funding and to leverage longevity of project outcomes. Each month, with help from the Program Coordinator, the committee would review modelling results and community engagement activities and provide feedback to further strengthen programmatic efforts.

The CRN website (http://www.charlestonresilience.net/) was reorganized in 2017 to serve as a clearinghouse for information regarding key takeaways of educational programming and community engagement events. Additionally, a regional events calendar was included in this update to include events hosted by other organizations that would be of interest to network members. The bi-monthly Coffee Hours continued to bring in new members to the network, and to increase organizational capacity, in 2019, presenters became hosts of the events, bringing the audience into their offices and promoting the events broadly.

One of the co-founders of CRN, Dan Burger, launched the formation of a Steering Committee in 2018 to research alternatives to governance structures that could build the programmatic capacity of CRN. The Rendezvous for Resilience, held in the previous spring of 2017 had made connections within the leadership of area organizations and provided a basis for the formation of this committee. In late 2018, Burger presented alternative governance structures to the Steering Committee to inform decision-making for the future organizational and programmatic reach of CRN.

The Riley Center for Livable Communities (https://riley.cofc.edu/) was identified as a potential partnering organization committed to science-based discussions of regional resilience issues, and in the spring of 2019, the two organizations signed a Memorandum of Understanding to partner and develop collaborative programming efforts to increase the impact of CRN and provide a forum to facilitate discussion resulting in regional resilience initiatives. The Riley Center is an interdisciplinary initiative of the College of Charleston with the mission to leverage the intellectual and administrative resources of the College to support the economic and cultural vibrancy of the City of Charleston and other communities throughout South Carolina, the United States, and around the world. A steering committee has engaged in a facilitated dialogue with the Riley Center to recast the geographic scope, vision, and strategic framework that will guide a sustained network-based approach to enhance the Charleston metropolitan region's resilience capacity and ability to effectively cope with and adapt to acute disasters and chronic environmental and climate disruptions.

In the aftermath of Hurricane Dorian, the Riley Center and CRN collaborated to present an economic analysis of natural disaster impacts to area businesses at the Chamber of Commerce and reported on key takeaways from that discussion to inform regional resilience strategies moving forward. By partaking in this program, the Riley Center was able to offer CRN guidance towards establishing a Resilience Framework to inform the mission and future programming activities of CRN. This framework was presented in February 2020 at the Leadership Roundtable Session, gathering dozens of professionals across all sectors to discuss the future of CRN and provide feedback regarding what the community requires to further resilience efforts and initiatives.

The Leadership Roundtable gathered over 40 leaders and representatives of dozens of organizations across all sectors, and discussions provided insight into the next steps for the CRN, clarifying benefits and pitfalls of alternative governance structures and outlining regional resilience priorities. CRN continues to work closely with members of the Riley Center to move forward as an organization that can facilitate and inform discussions forwarding regional resilience for Charleston and beyond. Through partnerships among climate, hazard, and modeling experts, engineers, and specialists from the College of Charleston Lowcountry Hazards Center, The Citadel, University of South Carolina, the S.C. Sea Grant Consortium, and

NOAA, CRN is leveraging existing and generating new data to create localized flooding models that can expand across the Charleston region, as well as neighboring counties and coastal communities.

Moving Forward

CRN offers a platform to enable effective, long-term preparedness and resilience planning that can sustain and enhance the Charleston region's ability to absorb and recover from episodic natural disasters and chronic coastal hazards. As an organization, CRN is currently engaging the expertise of its members to establish two working groups that will sustain and enhance the capacity of CRN to address regional resilience challenges in coastal communities, establish partnerships across jurisdictional and sectoral boundaries, and share science-based information to enhance long-term planning efforts. The Governance Committee will develop alternative structures CRN can use to expand its efforts sustainably, and the Outreach & Resilience Committee has been established to further identify regional resilience priorities and guide programming efforts to address them.

List of completed, peer and non-peer reviewed publications, white papers, or reports (with internet links if possible) -

Braud, Alexander, and Norman S. Levine. 2019. "Economic Value of Beach and Dunes Systems in Storm Protection, Isle of Palms, South Carolina." In Abstracts with Programs - Geological Society of America, 3rd ed., 51:22–21. Abstracts with Programs - Geological Society of America. https://search-proquest.com.nuncio.cofc.edu/georef/docview/2267396194/abstract/88E5E917BAC3453APQ/1?accountid=9959

Conrad, Casey Douglas. "The use of an L-Thia Based Modified Curve Number Runoff Model for Flood Hazard Mapping in Charleston, South Carolina." Order No. 27671994 College of Charleston, 2019. Ann Arbor: ProQuest. Web. 26 Oct. 2020.

Gao, P., G.J. Carbone, J. Lu, and D. Guo. 2017. An Area-Based Approach for Estimating Extreme Precipitation Probability. Geographical Analysis doi:10.1111/gean.12148

Gao, P., G.J. Carbone, and J. Lu. 2018. Flood simulation in South Carolina watersheds using different precipitation inputs. Advances in Meteorology. Article ID 4085463.

Hernandez, Jon Lucas. "Understanding Coastal Resilience and Natural Disaster Preparedness through Raster-Based Flood Modeling: Kiawah Island, S.C." Order No. 13863546 College of Charleston, 2019. Ann Arbor: ProQuest. Web. 23 Oct. 2019. http://nuncio.cofc.edu/login?url=https://search.proquest.com/docview/2240081531?accountid=9959

Hernadez, Lucas, and Norman S. Levine. 2019. "Coastal Resilience Through Raster Based Flood Mapping and Modeling; Kiawah Island, South Carolina." In Abstracts with Programs - Geological Society of America, 3rd ed., 51:23–25. Abstracts with Programs - Geological Society of America. https://search-proquest.com.nuncio.cofc.edu/georef/docview/2267396232/abstract/ABBD356BA06249E0PQ/1?accountid=9959

Knapp, L., Dow, K., Harris, M., Braud, A., Levine, N., & Watson, S. (2019). Flood Vulnerability Assessment: City of Beaufort, S.C. Report prepared for the City of Beaufort, S.C. at the South Carolina Sea Grant Consortium.

Hung, C.-L., L.A. James, and G.J. Carbone. 2018. Impacts of urbanization on stormflow magnitudes in small catchments in the Sandhills of South Carolina, USA. Anthropocene 23: 17–28.

Hung, C.-L. J., L. A. James, G. J. Carbone, and J. M. Williams. 2020. Impacts of Combined Land-use and Climate Change on Streamflow in Two Nested Catchments in the Southeastern United States. Ecological Engineering, 143, 105665. https://doi.org/10.1016/j.ecoleng.2019.105665.

Rubin, Nicholas D. "Developing Flood Maps for Coastal Resilience in Charleston County and in North Charleston Neighborhoods." Order No. 10844335 College of Charleston, 2018. Ann Arbor: ProQuest. Web. 26 Oct. 2020.

List website addresses relevant to the project for further information -

- Charleston Resilience Network Initiative NA16NOS4730012 https://charleston-resilience-network-initiative-na16nos4730012-scgis.hub.arcgis.com/
- Charleston Resilience Network www.charlestonresilience.net
- South Carolina Coastal Information Network www.sccoastalinfo.org
- The Joseph P Riley Center for Livable Communities http://riley.cofc.edu/
- S.C. Sea Grant Consortium https://www.scseagrant.org/
- Low Country Hazards Center https://hazards.cofc.edu/

List of presentations/seminars, photos, or other visuals related to project -

Burger, Dan, Invited Speaker, "Blue Planet Forum: Coastal Resilience," Chesapeake Bay Foundation. Norfolk, Virginia. April 2017
Audience: ~350 residents of the Norfolk/Hampton Roads region

Burger, Dan, Invited Moderator, "The Case for Resilience: Planning, Design and Building for Charleston's Future," Urban Land Institute and American Institute of Architects. Charleston, South Carolina. August 2017
Audience: ~80 professionals from the design/build community

Burger, Dan, Speaker, “Resources and Considerations for Resilience Planning,” Town of Kiawah Island Environmental Committee. Kiawah Island, S.C., April 2018.
Audience: ~ 12 Town of Kiawah Island Council Members and Staff.

Burger, Dan, Speaker, “Leading Resilience Communities: Case Studies on Regional Resiliency,” Leading Resilient Communities Conference, Government Finance Officers Association, Joseph P. Riley Center for Livable Communities, College of Charleston, Charleston, S.C., June, 2018.
Audience: ~ 50 state, county and municipal leaders

Burger, Dan, Speaker, “Public-Private Partnerships for Disaster Recovery and Resilience,” Southeast Disaster Recovery Partnership Annual Meeting, St. Petersburg, FL, June 2018.
Audience: ~ 40 emergency managers, consultants, non-governmental and governmental practitioners

Burger, Dan, Speaker, “Collaborative Networks for Accelerating Regional Resilience,” National Academy of Sciences Resilient America Roundtable, Washington, D.C., February 2019.

Burger, Dan, Speaker, “Introduction to Coastal Hazards and the Charleston Resilience Network,” Spring Meeting of the Ft. Sullivan Chapter of the Daughters of the American Revolution (DAR). Charleston, S.C. March 2019.

Burger, Daniel J., Speaker, “Keynote Panel: Disaster Resiliency - To Insurance and Beyond!” National Association of Insurance Commissioners, 2019 NAIC Summit. Kansas City, MO, June 2019

Burger, Daniel J., Speaker, “Zurich Flood Resilience Alliance: A Prototype for Multisector Collaboration,” 2019 Natural Hazards Research and Applications Summit, Boulder, CO, July 2019

Burger, Daniel J., Speaker, “Resilience Planning in the Charleston Metropolitan Region,” 2020 EERI Annual Meeting and Federal Alliance for Safe Homes Conference, San Diego, CA. March 5, 2020

DeVoe, M.R., Invited Keynote Speaker, “Communicating Science: Enhancing Relevance and Importance,” Annual Membership Banquet of Sigma Xi-Charleston Chapter, Charleston, S.C., April 20, 2017
Audience: ~70 professionals from the broader Charleston, S.C. scientific community

DeVoe, M.R., Invited Speaker, “Resilience and South Carolina: The Message and the Method,” Southern Association of Marine Laboratories Annual Meeting, Wilmington, NC, May 22, 2017.
Audience: ~25 laboratory directors and associated from the southeastern United States

DeVoe, M.R., Invited Plenary Panel Speaker, “Lowcountry Lessons in Resiliency,” Annual Conference of the National Marine Educators Association, Charleston, S.C., June 25-29, 2017
Audience: ~300 professionals from the marine education community

DeVoe, M. Richard, Panel Convenor, “Important Tools and Resources for Community Resiliency: Risk Communication Planning, Localized Mapping and Educational Resources,” Featuring panelists from the S.C. Sea Grant Consortium, NOAA, and the Extension Disaster Education Network, Leading Resilient Communities Conference, Government Finance Officers Association, Joseph P. Riley Center for Livable Communities, College of Charleston, Charleston, S.C., June 28-29, 2018.
Audience: 72 attendees, local community leaders and local government fiscal officers from across South Carolina and the southeastern United States as well as the rest of the country

DeVoe, M. Richard, Speaker, "Resilience of the Charleston, S.C. Area," Learning in the Field Exercise, NOAA Southeast and Caribbean Regional Team, Charleston Harbor, S.C., July 25, 2018.

DeVoe, M. Richard, Plenary Panel Convener, "Preparing for Change: Addressing Regional and Local Coastal Resilience Challenges," Oceans18 Charleston Conference and Exposition, Charleston, S.C., October 24, 2018.

DeVoe, M. Richard, Panel Convener and Moderator, "Public-Private Partnerships for Disaster Recovery," Southeast and Caribbean Disaster Recovery Workshop 2019, Savannah, GA, January 23-24, 2019.

DeVoe, M. Richard, Speaker, "Introduction to the S.C. Sea Grant Consortium and Its Resilience Activities," Coastal Business Disaster Recovery Workshop, South Carolina Emergency Management Division and City of Myrtle Beach, S.C., Myrtle Beach, S.C., January 30, 2019.

DeVoe, M.R., "Development of Multi-Hazard Coastal Resiliency Tools for the Charleston, S.C. Region," National Adaptation Forum, Madison, WI, April 24, 2019

DeVoe, M.R., Invited Plenary Panelist, "Supporting Communities Facing Serious Challenges: Flooding, Storms, Development, Oh My!" 2019 NERRS-NERRA Annual Meeting, Charleston, S.C., November 18, 2019

Johnston, David, Speaker, "Sea Level Rise & Security in South Carolina: Implications for Military and Civilian Communities," Center for Climate and Security, Charleston, S.C., August 2018.
Audience: ~ 100 Government, military, private and non-profit organizational leadership

Johnston, David, Speaker, "Promoting Regional Resilience through the Charleston Resilience Network," *Securing Prosperity in the Coastal Zone,* Virginia Academy of Sciences, Engineering and Medicine, Richmond, VA, November 2018.

Knapp, Landon, Speaker, "Building Community Resilience to Water-Related Hazards in the Charleston S.C. Region: A Charleston Resilience Network Initiative," South Carolina Association of Hazard Mitigation, Hilton Head, S.C., March, 2019

Knapp, Landon, Speaker, "Building Community Resilience to Water-Related Hazards in the Charleston S.C. Region: A Charleston Resilience Network Initiative," South Carolina Association of Environmental Professionals, Columbia, S.C., March, 2019

Knapp, L., & Levine N., "Developing High-Resolution Data and Neighborhood-Scale Flood Modeling in Charleston County, SC," Oral presentation delivered at the 17th Annual Climate Prediction Applications Science Workshop, Charleston, S.C., June 13, 2019

Levine, N., N. Rubin, and T. Callahan. "High Resolution Flood Modeling for Planning, Mitigation, and Response, Charleston, S.C." Presentation at the 2017 Geological Society of America Southeastern Section Meeting, March 30-31, 2017, Richmond, VA.

Levine, Norman S, Speaker, “Lessons from the Lowcountry Hazards Center: Communicating Natural Hazard Risk to Diverse Populations,” Presented at the GSA Annual Meeting in Indianapolis, Indiana, USA, November 2018
Retrieved from https://gsa.confex.com/gsa/2018AM/webprogram/Paper324371.html
Audience: ~ 40 scientific, technical, and outreach professionals from throughout the U.S

Levine, N., “Drilling Down to Local Levels: A Climate Change Informed View of Connectivity Across the Lowcountry,” Oral presentation delivered at the Lowcountry Land Conservation Symposium: Conservation in the Face of a Changing Climate, Charleston, SC, May 14, 2019

Levine, N., “The Physical System, Charleston and Water,” Oral presentation delivered at the Dutch Dialogues Colloquium, Charleston, S.C., May 1, 2019

Levine, N. S., Knapp, L. C., Braud, A., & Conrad, C., “Communicating Climate Change Induced Flooding and Sea Level Rise Risk in One of America’s Most Vulnerable Regions, Charleston County, S.C.,” GSA Annual Meeting in Phoenix, AZ, September 25, 2019, Retrieved from https://gsa.confex.com/gsa/2019AM/meetingapp.cgi/Paper/339760

Watson, Sarah, Speaker, “Coastal Science Serving South Carolina,” S.C. Association of Hazard Mitigation, Hilton Head, S.C., March 2018
Audience: ~ 100 S.C. hazard mitigation professionals

Watson, Sarah, Speaker, “Building Community Resilience to Water-Related Hazards in the Charleston S.C. Region: A Charleston Resilience Network Initiative,” South Atlantic Sea Grant Regional Meeting, Cedar Key, FL, July 2018
Audience: ~ 40 Sea Grant extension specialists and managers from the South Atlantic region

Watson, Sarah, Davis, Jeff, Ghanat, Simon, Dow, Kirstin, Speakers, “Building Community Resilience to Water-Related Hazards in the Charleston S.C. Region: A Charleston Resilience Network Initiative,” Carolinas Climate Resilience Conference, Columbia, S.C., October, 2018.

Watson, Sarah, Session Organizer, “Building Effective Resilience Networks,” Carolinas Climate Resilience Conference, Columbia, S.C., October, 2018.

Watson, Sarah, Speaker, “Applying Risk Communication Practices to Community Engagement,” Restore America’s Estuaries Summit, Long Beach, CA, December, 2018.

Watson, Sarah, Speaker, “Building Community Resilience to Water-Related Hazards in the Charleston S.C. Region: A Charleston Resilience Network Initiative,” S.C. Beach Preservation Association Annual Conference, Isle of Palms, S.C., February, 2019.

Watson, S, Knapp, L., Davis, W.J., Ghanat, S., Dow, K., Speakers, “Science and engagement co-production around compounding climate risks and impacts in the Charleston, S.C. region,” National Adaptation Forum, Madison, WI, April 24, 2019

Watson, Sarah, Speaker, “Engaging the Over-Engaged: Tell us something we don’t already know.” Social Coast Forum, Charleston S.C. February 5, 2020

List of Media Coverage - Please share, if possible any media coverage

***Announcement of NOAA Regional Coastal Resilience Grant Award*:**
(Where links to media are no longer available, a summary is provided of additional sources that announced the grant award.)

Television broadcasting:

Charleston, S.C.

ABC News 4 (2016, March 4). "Grant will help Charleston area plan for sea level rise". Retrieved from: http://abcnews4.com/news/local/grant-will-help-charleston-area-plan-for-sealevel-rise

NBSC News 2 (2016, June 6). "Charleston area group receives grant for flooding study". Retrieved from: http://counton2.com/2016/06/06/charleston-area-group-receives-grant-forflooding-study/

Columbia, S.C.

WACH Fox 57 (2016, March 10). "Grant will help Charleston area plan for sea level rise". Retrieved from: http://wach.com/news/local/grant-will-help-charleston-area-plan-for-sea-level-rise-03-10-2016

Additional television broadcasting stations that announced the grant award, but where links are no longer available online include:

WCSC Live 5 News of Charleston, S.C. "Grant will help Charleston area plan for sea level rise"
WLTX CBS of Columbia, S.C. "Grant will help Charleston area plan for sea level rise"
WIS TV MSNBC of Columbia, S.C. "Grant will help Charleston area plan for sea level rise"
WRDW MSNBC of Augusta, GA "Grant will help Charleston area plan for sea level rise"
WSCOC TV of Charlotte, NC "Grant will help Charleston area plan for sea level rise"
WECT TV of Wilmington, NC "Grant will help Charleston area plan for sea level rise"

Newspapers Articles:

Links are no longer available online for articles that appeared in the following newspapers:

In South Carolina

The Post & Courier of Charleston, S.C.: (2016, March 16). "Mapping the floods and source…"
The State of Columbia, S.C.
The Sun News of Myrtle Beach, S.C.
The Georgetown Times of S.C.
The Rock Hill Herald of S.C.
The Times & Democrat of Orangeburg, S.C.
The Aiken Standard of S.C.
Spartanburg Herald-Journal of S.C.
Florence Morning News of S.C .
The Charleston Regional Business Journal of S.C.
The Moultrie News of Charleston, S.C.

Around the country:

Raleigh News and Observer of N.C.
The Roanoke Times of VA
The News & Advance of Lynchburg, VA
The Bowling Green Daily News of KY
The Star Herald of Scotts Bluff, AR
The Republic of Columbus, IN
The Daily Journal of Franklin, IN
The Greenfield Reporter of IN
The Pendleton Times Post of IN
The Opelika Auburn News of AL
Odessa American of TX
The Baytown Sun of TX
The Eagle of College Station, TX

Articles Related to this Project

SC Sea Grant Consortium:
https://seagrant.noaa.gov/ProgramLocations/SC/ArtMID/1022/ArticleID/547

Freedman, A. (2019, September 4). Hurricane Dorian is on track to bring historic coastal flooding to the Carolinas. *Washington Post*. Retrieved from https://www.washingtonpost.com/weather/2019/09/04/hurricane-dorian-is-track-bring-historic-storm-surge-flooding-carolinas/

Charleston Resilience Network. June, 2017. Virginia coastal communities share coastal flooding experience with Charleston at Knowledge Exchange event. Last retrieved from: http://www.charlestonresilience.net/events/links/hampton-roads-charleston-coastal-resilience-knowledge-exchange/

Developments in disaster-prone areas means big bucks for builders, but can leave communities at risk. (2019, August 13). Retrieved August 14, 2019, from State of Emergency | News21 website: https://stateofemergency.news21.com/developments-in-disaster-prone-areas-means-big-bucks-for-builders-but-can-leave-communities-at-risk/

Bartelme, T. February 11, 2018. *The Post and Courier*. Slowly but surely, South Carolina's incredibly complex shoreline is losing ground. Last retrieved from: https://www.postandcourier.com/news/slowly-but-surely-south-carolina-s-incredibly-complex-shoreline-is/article_46e18626-cde8-11e6-be82-6393ed1dbe62.html

Editorial: Charleston must learn to love and live with its water. (2019, May 1). Retrieved August 5, 2019, from Post and Courier website: https://www.postandcourier.com/opinion/editorials/editorial-charleston-must-learn-to-love-and-live-with-its/article_2af75278-6c52-11e9-ae6a-03da063a382c.html

Media Clip: New study shows Charleston businesses' frustrations over yearly hurricane disruptions: https://www.postandcourier.com/business/new-study-shows-charleston-businesses-frustrations-over-yearly-hurricane-disruptions/article_9455a7ce-15e9-11ea-a214-db9aa6e1348f.html

For Final Report please include - *Powerpoint slide summarizing project and major accomplishments (should be in .pptx format)*